STUDIES ON SHRIMP AQUACULTURE IN KERALA

SAHADEVAN P.

THESIS

Submitted in partial fulfilment of the requirement for the degree of

Doctor of Philosophy

in

AQUACULTURE

UNIVERSITY OF CALICUT

DEPARTMENT OF AQUACULTURE AND FISHERY MICROBIOLOGY

MES PONNANI COLLEGE, PONNANI

Malappuram

2022

STUDIES ON SHRIMP AQUACULTURE IN KERALA

SAHADEVAN P.

THESIS

Submitted in partial fulfilment of the requirement for the degree of

Doctor of Philosophy

in

AQUACULTURE

UNIVERSITY OF CALICUT

DEPARTMENT OF AQUACULTURE AND FISHERY MICROBIOLOGY

MES PONNANI COLLEGE, PONNANI

Malappuram

2022

DECLARATION

I hereby declare that the work presented in this thesis entitled **"STUDIES ON SHRIMP AQUACULTURE IN KERALA"** is based on the original research work done by me under the guidance of (Dr) S Suresh Kumar, Professor of Biological Oceanography and Dean, Faculty of Ocean Sciences and Technology, Kerala University of Fisheries and Ocean Studies, Panangad, 682 506, Kochi, Kerala, India (formerly Associate Professor, Department of Aquaculture and Fishery Microbiology, MES Ponnani College, Ponnani, Malappuram 679 586) and that no part of this work has previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title or recognition.

Ponnani
18-02-2022 **SAHADEVAN P**.

CERTIFICATE

This is to certify that the research work presented in this thesis entitled **"STUDIES ON SHRIMP AQUACULTURE IN KERALA"** is based on the original work done by Mr Sahadevan P under my guidance at the Department of Aquaculture and Fishery Microbiology, MES Ponnani College, Ponnani, 679 586, Malappuram District, Kerala, India, in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy and that no part of this work has previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title or recognition.

Ponnani
18-02-2022

Dr S Suresh Kumar
Professor of Biological Oceanography
Dean, Faculty of Ocean Sciences and Technology
Kerala University of Fisheries and Ocean Studies
Panangad
Ernakulam
Kerala, India
Pin: 682 506

Dedicated to my parents, wife and children

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to Prof. (Dr) S Suresh Kumar, Professor of Biological Oceanography and Dean, Faculty of Ocean Sciences and Technology, Kerala University of Fisheries and Ocean Studies (KUFOS), Panangad, Kochi, Kerala, (formerly of Department of Aquaculture and Fishery Microbiology, MES Ponnani College, Ponnani, Malappuram, Kerala) for his valuable guidance and constant encouragement during the study and in the preparation of the thesis. He steered me in the right direction while researching and preparing the thesis. I am ever indebted to him for his wise counselling, guidance, encouragement and unfailing support.

I am immensely grateful to Dr Ajims P. Mahammed, Principal MES Ponnani College, Ponnani, Malappuram, for providing me with facilities for conducting the study and preparing the thesis. I am also thankful to Dr TP Abbas, Former Principal, MES Ponnani College, Ponnani, Malappuram, for providing me with facilities for conducting the study.

I am indebted to Dr Zubair AA, Head of the Department of Aquaculture and Fishery Microbiology, MES Ponnani College, Ponnani, Malappuram, for his valuable advice and providing facilities for the conduct of the study. I am also indebted to Dr Razia Beevi M, former Head of the Department of Aquaculture and Fishery Microbiology, MES Ponnani College, Ponnani, Malappuram, for the encouragement and for providing facilities for the conduct of the study.

I am grateful to Dr Rajool Shanis CP and Dr Mujeeb Rahiman KM, Assistant Professors, Department of Aquaculture and Fishery Microbiology, MES Ponnani College, for extending help and support during my research. I am also thankful to Dr PV Jyothi, Head, Department of Botany, MES Ponnani College, for her guidance in preparing the thesis.

I express my deep sense of gratitude to the subject expert Dr Manogem EM Assistant Professor, Department of Zoology, the University of Calicut, for her encouragement and suggestions during the study.

I am also thankful to the Government of Kerala for permitting me to register for the PhD programme. I am profoundly indebted to Sri James Varghese IAS, Former Additional Chief Secretary (Fisheries and Ports), Government of Kerala and Sri KR Jyothilal IAS, Former Principal Secretary (Fisheries and Ports), Government of Kerala, for providing me with the permission to undertake the research work and conducive environment for the study.

I am indebted to Sri S Venkatesapathy IAS, Former Director of Fisheries, Kerala, who has been helpful in many ways in the conduct of the study and the preparation of the thesis. He also allowed me to use the library at the Directorate of Fisheries, Thiruvananthapuram.

I am immensely grateful to Dr B Madhusoodana Kurup, Former Vice-Chancellor, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, for the encouragement.

I am thankful to Dr KK Vijayan, Former Director, ICAR- Central Institute of Brackishwater Aquaculture (ICAR- CIBA), Chennai, for his advice in conducting the research work and providing many research references.

I am grateful to Dr A Gopalakrishnan, Director, ICAR- Central Marine Fisheries Research Institute (ICAR- CMFRI), Kochi, for permitting me to use the library of CMFRI.

I am also grateful to Dr M Jayanthi, Principal Scientist & SIC and Dr CP Balasubramanian, Principal Scientist, Crustacean Division, ICAR- CIBA, for providing me with many valuable reference papers.

I am grateful to Dr PK Asokan, Principal Scientist, Calicut Research Centre of ICAR- Central Marine Fisheries Research Institute (ICAR- CMFRI), for suggesting to include a management plan for the sustainable development of shrimp aquaculture in Kerala as a separate chapter and in providing valuable advice in formulating such a plan.

I am grateful to Dr K Dinesh, Head of the Department of Aquaculture, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, for the constant encouragement, support, and providing many published literatures without which I could not have completed the work in time.

I owe a great deal to Dr KS Purushan, Dean (Retd.), College of Fisheries, Kerala Agricultural University (KAU), Kochi, for his valuable advice and constant encouragement. He also extended assistance in getting much helpful information on the traditional farming of shrimp.

I am also grateful to Sri S Gopakumar, Deputy Director (Statistics), Directorate of Fisheries, Thiruvananthapuram, for the help rendered in the statistical analysis of the data and the thesis preparation.

I owe greatly to Dr Ranjeet K, Associate Professor, Kerala University of Fisheries and Ocean Studies, Kochi, for his constant help and encouragement during the study.

I am also thankful to the shrimp farmers of Kerala, who were willing to share valuable and difficult-to-get information on farming practices, the economics of farming, and their socio-economic conditions. In this regard, I also owe a great deal to Sri T Purushothaman, Progressive Shrimp Farmer and President, Aquaculture Development Co-Operative Society (ADCOS), Payyanur, Kerala. I am also thankful to Sri KX Sebastian, General Secretary, Kerala Aqua Farmers' Federation (KAFF), for providing me with much information on traditional shrimp farming.

I am grateful to the Marine Products Export Development Authority (MPEDA), Kochi, for providing much data for conducting the research work and permitting me to use its library facility.

My sincere thanks are also due to my colleagues in the Department of Fisheries, Kerala, erstwhile State Fisheries Resource Management Society (FIRMA) and Agency for the Development of Aquaculture, Kerala (ADAK), Kerala Aqua Venture's International Limited (KAVIL), various Fish Farmer's Development Agencies and Kerala State Co-operative Federation for Fisheries Development Ltd (Matsyafed) for sharing much information and for the help rendered in innumerable ways.

I am indebted to the management and staff of MES Ponnani College, Ponnani, Malappuram, for the help rendered in the conduct of the study and the preparation of the thesis. I thank my fellow doctoral students for their feedback, constructive criticism, and cooperation. Special thanks are also due to Ms Kripa NV, Ms Reyhanath PV and Mr Shahul Hameed PVP, who helped me in various ways during the research and preparation of the thesis.

I am grateful to the staff members of the libraries at Central Marine Fisheries Research Institute (CMFRI), Kochi, Marine Products Export Development Authority (MPEDA), Kochi, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi and Cochin University of Science and Technology (CUSAT), Kochi, MES Ponnani College, Ponnani for their help in getting many essential research references.

Finally, I express my profound gratitude to my parents, wife, and sons for providing me with unfailing support and continuous encouragement during the research and writing of the thesis. They had forsaken many happy moments of life and allowed me to collect data, reference material, and write the thesis. My sons have also provided me with great help in the statistical analysis of the data. Without the sacrifice of my wife and sons, I could not have devotedly pursued my studies.

Ponnani

18-02-2022 **SAHADEVAN P**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

GENERAL INTRODUCTION

Human societies face the great challenge of providing nutrition and livelihoods to a population of 11 billion people by the turn of the twenty-first century. The challenge enhances too many folds when addressing the negative impacts of climate change and environmental degradation on the cultivable resources. A unique, transformative, and integrative approach is imperative to change the world onto a sustainable and resilient path that leaves no one starved. Fisheries and aquaculture are keys to achieving sustainable development and making the world free of hunger. This sector is of vital importance in providing food, nutrition, and employment to millions of people, a large number of whom struggle to maintain reasonable livelihoods. Many recent studies reveal the enormous potential of the seas and inland water bodies presently and even more so in the days to come to contribute significantly to food security and adequate nutrition for the global population (FAO 2016).

Fish and fishery products are considered some of the healthiest and least impactful foods on the planet. For these reasons, they are recognised in national, regional and global food security and nutrition strategies and contribute to the ongoing transformation of food systems to eliminate hunger and malnutrition.

1.1. The scenario of fisheries and aquaculture in the world.

According to the Food and Agriculture Organisation of the United Nations, the world produced 178.5 million tonnes of fish in 2018 (FAO 2020). Of this, the contribution of capture fisheries was 96.4 million tonnes. Marine and inland capture fisheries provided 87.55% (84.4 million tonnes) and 12.45% (12 million tonnes) respectively of the total capture fish production. The aquaculture sector contributed 45.99% (82.1 million tonnes) of the total fish produced globally. The contribution of the sector was 52.63% if non-food uses were excluded. The total first-sale value of fisheries and aquaculture production in 2018 was estimated at US$ 401 billion, of which US$ 250 billion (62.34%) was the share of the aquaculture sector. With harvest from capture fisheries relatively static since the late 1980s, aquaculture has been responsible for the continuing remarkable growth in the supply of fish for human consumption. The aquaculture sector grows faster than other major food production sectors, and the rate of growth is 5.3% during the period 2001–2018.

Globally, China is the major fish producer, accounting for 35% of the total production in 2018. Excluding China, a significant share of production in 2018 came from Asia (34%), followed by the Americas (14%), Europe (10%), Africa (7%) and Oceania (1%).

Today fish and fish products are some of the most traded food items in the world. In 2018, about 38% of global fish production entered international trade in various forms for human consumption or non-edible purposes. World export quantity increased at an annual rate of 3%, from 17.3 million tonnes (live weight equivalent) in 1976 to 67 million tonnes in 2018 (FAO 2020). World trade in fish and fishery products also grew tremendously in value terms, with exports increasing from US$ 8 billion in 1976 to US$ 164 billion in 2018, 54% of which originated from developing countries, including India.

In per capita terms, food fish consumption grew from 9.0 kg in 1961 to 20.5 kg in 2018, at an average rate of about 1.5% per year. In 2017, fish accounted for about 17% of animal protein consumed by the world population. Further, fish provided nearly 3.3 billion people, with almost 20% of their average per capita animal protein intake (FAO 2020).

Scientific developments of the last five decades have led to a much-improved understanding of the functioning of aquatic ecosystems and global awareness of the need to manage them sustainably.

1.1.1. Aquaculture

According to FAO (2020), 114.5 million tonnes of seafood were produced through aquaculture globally in 2018. Of this, the production of food fish was 82.1 million tonnes (US$ 250.1 billion), and that of aquatic plants was 32.4 million tonnes (US$ 13.3 billion). Production of ornamental shells and pearls was 26,000 tonnes (US$ 1,79,000). Farmed food fish production was contributed by 54.3 million tonnes of finfish (US$ 139.7 billion), 17.7 million tonnes of molluscs (US$ 35.4 billion), 9.4 million tonnes of crustaceans (US$ 69.3 billion), and 9,36,700 tonnes of other aquatic animals such as turtles, sea cucumbers, sea urchins, frogs and edible jellyfish (US$ 6.5 billion). Farmed aquatic plants consisted principally of seaweeds and a much smaller quantity of microalgae.

Asia has accounted for about 89% of world aquaculture production. China, the major producer of farmed food fish in 2018, has produced more than the rest of the world combined every year since 1991. The other major producers in 2018 were India, Indonesia, Viet Nam, Bangladesh, Egypt, and Norway. China and Indonesia were the major producers of aquatic plants in 2018.

Farming systems are very diverse in terms of culture methods, practices, facilities and integration with other agricultural activities. Earthen ponds remain the most commonly used type of facility for inland aquaculture production, although raceway tanks, above-ground tanks, pens and cages are also widely used where local conditions allow.

1.1.1.1. Freshwater aquaculture

Inland aquaculture produces most cultured aquatic animals, mainly in freshwater; hence, it is called freshwater aquaculture in most fish farming countries. In 2018, inland aquaculture was the source of 51.3 million tonnes of food fish or 62.5% of the world's farmed food fish production. Finfish farming dominated inland aquaculture, accounting for 91.5% (47 million tonnes). However, this proportion was 97.2% in 2000, reflecting relatively strong growth in the farming of other species groups, particularly crustaceans in inland aquaculture in Asia, including shrimps, prawns, crayfish, and crabs. Inland aquaculture production includes some marine shrimp species, such as white-leg shrimp (Pacific white shrimp), that can grow in freshwater or inland saline-alkaline water after proper acclimatisation.

1.1.1.2. Coastal and marine aquaculture

Food and Agriculture Organisation (FAO) recorded 30.8 million tonnes (US$ 106.5 billion) of food fish production from marine and coastal aquaculture combined in 2018 (FAO 2020). In contrast to the dominance of finfish in inland aquaculture, shelled molluscs (17.3 million tonnes) constituted 56.2% of the combined production of marine and brackish water aquaculture. Finfish (7.3 million tonnes) and crustaceans (5.7 million tonnes) together accounted for

42.5%. Shrimps and prawns dominate the production of crustaceans typically farmed in coastal aquaculture and serve as important sources of foreign exchange for many countries in Asia and Latin America.

1.1.2. Species farmed

The substantial diversity of climatic and environmental conditions worldwide has resulted in a rich and varied number of species utilised in different aquaculture production practices. As of 2018, world aquaculture production was represented by a total of 622 "species items" (FAO 2020). A species item refers to a single species, a group of species (where identification to the species level is not possible), or an interspecific hybrid. However, aquaculture production by volume is dominated by a small number of "staple" species or species groups at national, regional, and global levels. Finfish farming, the most diverse subsector, relied on 27 species and species groups and accounted for over 90% of the total world fish production in 2018. The 20 most-produced species items accounted for 83.6% of the total finfish production. Compared with finfish, fewer species of crustaceans, molluscs, and other aquatic animals are farmed.

1.2. The scenario of fisheries and aquaculture in India

The fisheries sector occupies a vital role in the country's socio-economic development, as it contributes to nutritional security, economic growth and human welfare. In India, the fisheries sector has been identified as an important income and employment generator as it promotes the growth of many subsidiary industries and is a cheap source of food and a foreign exchange earner (Ayyappan and Krishnan 2004). Fisheries and aquaculture provide a livelihood to about 28 million fishers and fish farmers at the primary level and twice the number along the value chain (GoI 2020a). Fish and fishery products are increasingly finding a place in the diets of the Indian population as a result of their rising income, growing urbanisation, changing consumer behaviour and lifestyle, increasing number of working women populations, etc. The fisheries sector in India has recorded faster growth than that of land-based agriculture crop and livestock sectors (Kumar *et al*. 2006).

Further, aquaculture has been identified as a possible saviour for the overexploited capture fisheries sector and an essential nutrient source for the poor (FAO 1995; Williams 1996). With diverse water resources and more than 10% of the global biodiversity of fish and shellfish species, India has shown continuous and sustained increments in fish production since independence (NFDB 2020). Constituting about 7.56% of the global fish production (GoI 2020a), the fisheries and aquaculture sector plays a vital role in the economy of the country and the share of the sector in the total GVA (at current prices) in 2018-2019 is estimated at Rs. 2,12,915 crores which constitute about 1.12% of the GDP (GoI 2020b). The fisheries and aquaculture sector has shown steady growth in the National Gross Value Added (GVA) and accounts for 7.28% of GVA from agriculture, forestry, and fishing (GoI 2020b). Overall, from 2014-2015 to 2018-2019, the fisheries sector has registered an average annual growth of 10.87%, which is higher than the growth of the national economy (7.16%) at constant (2011-12) prices (GoI 2020b). The total fish production of 14.16 million tonnes (2019-20) presently has a 73.69% contribution from the inland sector (GoI 2020c). Fish production in the country has recorded an average annual growth rate of more than 7% in recent years (NFDB 2020). In 2018, the estimated total fisheries potential of India was 22.31 million tonnes, which consists of a marine fish potential of 5.31 million tonnes and an inland fish potential of 17 million tonnes (GoI 2020d). During 2019-2020, 70.24% of the marine fisheries potential and 61.35% of the inland fisheries potential have been harnessed. It indicates the vast potential further to increase fish production from both marine and inland sectors.

Seafood has emerged as the largest group in agricultural exports of India, with 11.49 lakh tonnes in terms of quantity and Rs. 43,717.26 crores in value in 2020-2021 (MPEDA 2021). Seafood export from the country accounts for around 5% of the total exports and nearly 19.23% of the agricultural exports (NFDB 2020).

1.2.1. Aquaculture

In India, capture fisheries have been the major source of inland fish production till the mid-1980s. However, the fish production from natural waters like rivers, lakes, etc., followed a declining trend, principally due to proliferation of water control structures, indiscriminate fishing, habitat degradation (Katiha 2000), water pollution, overexploitation, climate change, the spread of diseases, invasion of exotic species of aquatic weeds and fishes, unscientific fishing practices, widespread destruction of mangroves etc. The depleting resources, energy crisis, and resultant high cost of fishing have led to an enhanced realisation of the potential of aquaculture as a sustainable and cost-effective alternative to capture fisheries.

Globally, India stands second in fish production through aquaculture (FAO 2020). It is estimated that the country produced about 7.7 million tonnes of farmed fish during 2018-19, contributing to about 80% of the inland fish produced (GoI 2020b). The share of aquaculture to total fish production of the country has gone up from 46% in the 1980s to over 57% in 2018 (FAO 2020). Aquaculture in India has been showing an impressive annual growth rate of around 7% (Jayasankar 2018).

1.2.1.1. Resources for aquaculture

India has an Exclusive Economic Zone (EEZ) of 2.02 million square kilometres, a continental shelf of 0.53 million square kilometres, and a coastline of 8,119 kilometres (GoI 2014). The main inland fishery resources include about 1.07 million hectares of brackish water area, 9.20 million hectares of ponds and tanks, about 4.03 million hectares of reservoirs, 0.48 million hectares of beels, oxbow lakes, and derelict water bodies, 0.29 million hectares of estuaries and 0.96 million hectares of other water bodies besides about 0.25 million kilometres of rivers and canals (GoI 2020c). The total area available for the inland fishery is estimated at 8.24 million hectares, excluding rivers and canals (GoI 2020b). These resources offer immense scope and potential for the development of fisheries and aquaculture in India.

1.2.1.2. Freshwater aquaculture

Freshwater aquaculture in India showed an overwhelming seventeen-fold growth from 0.37 million tonnes in 1980 to 6.24 million tonnes in 2018, with an average annual growth rate of around 7.72%. Freshwater aquaculture contributes to over 95% of the total aquaculture production in the country. Freshwater aquaculture mainly comprises the culture of carps, catfishes, freshwater prawns, pangasius, and tilapia.

The current freshwater grow-out technologies in practice in India may be classified into (i) Polyculture of Indian carps or Indian and exotic carps together (composite carp culture), (ii) Mono- and polyculture of air-breathing fishes, (iii) Mono- and polyculture of freshwater prawns, and (iv) Integrated fish farming. The composite carp culture can further be classified into (a) Low input or fertiliser-based system, (b) Medium input or fertiliser- and feed-based system; (c) High input or intensive feed and aeration-based system; (d) Sewage fed water-based system, and (e) Aquatic weed-based system. Integrated fish farming includes (a) Paddy-cum fish culture, (b) Fish-cum-cattle farming, (c) Pig-cum-fish farming, (d) Duck cum-fish culture, and (e) Poultry-cum-fish farming (Mruthyunjaya 2004).

The three Indian major carps, namely Catla (*Catla catla*), rohu (*Labeo rohita*), and mrigal (*Cirrhinus mrigala*), contribute a significant part of the production to the tune of 70 to 75% of the total freshwater fish production in the country, followed by silver carp, (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon Idella*), common carp (*Cyprinus carpio*), catfishes like magur (*Clarias batrachus*) and singhi (*Heteropneustes fossilis*) forming a second important group contributing the balance of 25 to 30%. It is estimated that only about 40% of the available area of ponds and tanks have been put to use and immense scope for expansion of area exists under freshwater aquaculture in India (ICAR 2013).

In addition to finfishes, successful breeding and larval rearing of the giant freshwater prawn (*Macrobrachium rosenbergii*) and the river prawn (*M. malcolmsonii*) provided scope for the farmers to diversify their cultural practices. *M. rosenbergii*, the giant freshwater prawn, completely dominated the commercial freshwater prawn culture. In India, the farmed production of *M. rosenbergii* has shown a phenomenal increase since the mid-nineties (MPEDA 2021).

1.2.1.3. Coastal and marine aquaculture

Brackish water aquaculture has been a traditional activity in bheries (human-made impoundments in coastal wetlands) of West Bengal and pokkali fields of Kerala since a long time back. However, scientific shrimp farming in the country was initiated only in the late1980s. In the traditional culture system, tidal water is impounded in the inter-tidal mudflats by raising bunds. Tidal water with all assorted fish and shellfish seeds is allowed to enter through sluice-gates during the spring tides. Harvesting of marketable-sized fish and shellfish is done regularly during spring tides through traps placed near the sluice gates. There is no application of manures and feeds.

Farmed shrimp production recorded over a 30.12-fold increase from 28,000 tonnes in 1988-1989 to 8,43,361 tonnes in 2020-2021. Andhra Pradesh (75.85%) is the largest producer of shrimp in the country, followed by West Bengal (6.47%), Gujarat (5.99%) and Odisha (5.28%) (MPEDA 2021).

The introduction of white-leg shrimp (*Litopenaeus vannamei*) in 2009 spurred growth in shrimp production during the last few years and displaced the tiger shrimp (*Penaeus monodon*). In 2020-2021, the output of white legged shrimp rose to 8,15,745 tonnes, which is 96.69% of India's total farmed shrimp production. In 2020-2021, the area under shrimp production was 1,66,722 ha, which was up from 1,02,542 ha in 2009-2010. The area under white leg shrimp farming to the total area under shrimp farming rose from 0.28% to 65.09%, with a corresponding decrease in tiger shrimp farming from 99.72% to 34.91%. High export prices of crabs have made the fattening of species like (*Scylla serrata*) a remunerative farming practice. Among finfishes, technology for farming is available for milkfish (*Chanos chanos*), pearl spot (*Etroplus suratensis*), mullets (*Mugil* spp.), and sea bass (*Lates calcarifer*). However, brackishwater finfish farming is yet to develop in a meaningful manner in India.

Though the attempt at mariculture in India was made way back in 1958–1959, commercial mariculture in the country is mainly limited to the farming of mussels, edible oysters, and seaweeds undertaken in some coastal regions of Kerala and Tamil Nadu. In recent years, cage farming of seabass (*L. calcarifer*), cobia (*Rachycentron canadum*), and pompano (*Trachinotus blochii*) have gained increased attention from prospective farmers.

1.2.2. Species farmed

Despite being a global leader, the aquaculture sector in India has been highly conservative in terms of diversification of species and systems. A total of around 50 species of fishes and shellfishes are farmed in various aquaculture systems in the country with varying degrees of intensity.

Although around 30 species of fishes and shellfishes are farmed in freshwater aquaculture, carps remain the most important species item. The three Indian major carps, namely, catla, rohu and mrigal contribute a significant part of the freshwater aquaculture production (around 70-75% of the volume) in India (Jayasankar *et al.* 2018). The exotic carps, namely, silver carp, grass carp, and common carp form the second important group. Although the country possesses several other cultivable medium and minor carp species which show high regional demand, including *Labeo calabasu*, *L. fimbriatus*, *L. gonius*, *L. bata*, *L. ariza*, *Puntius sarana*, *Hypselobarbus pulchellus*, *H. kolus*, and *Amblypharyngodon mola*, as well as several others, commercial farming of these species is yet to take off (Ayyappan and Jena 2003).

Among the catfishes, magur (*C. batrachus*) is the only species that has received significant attention. Stinging catfish, singhi (*H. fossilis*) is another air-breathing catfish species being cultured to a certain extent in swamps and derelict water bodies, especially in the eastern states. In recent years, the farming of pangas (*Pangasius sutchi*) and nile tilapia (*Oreochromis niloticus*) has gained much attention. Other finfish species of importance include climbing perch (*Anabas testudineus*), murrels (*Channa striata*, *C. diplogramma*, and *C. marulius*), and pabdah catfish (*Ompok pabda*). Among the freshwater prawns, the giant freshwater prawn (*M. rosenbergii*) is the most important species, followed by the river prawn, *M. malcolmsonii*, though minimal.

The brackish water aquaculture sector is mainly supported by shrimp production. Until recent years, the black tiger prawn (*P. monodon*) was responsible for the bulk of the output. However, of late, the white leg shrimp *L. vannamei* has become the predominant species. To a limited extent, the Indian white prawn (*P. indicus*) is also being farmed in some parts of the country. *P. semisulcatus*, *Metapenaeus dobsoni*, *M. monoceros* are also important in the traditional prawn farming systems.

Among the molluscs, the major species farmed are the green mussel (*Perna viridis*), brown mussel (*P. indica*), and Indian backwater oyster (*Magallana bilineata*). Among the crabs, *S. serrata* has gained attention in recent times. Finfishes like pearl spot (*E. suratensis*), cobia (*R. canadum*), sea bass (*L. calcarifer*), milkfish (*C. chanos*), Grey mullet (*Mugil cephalus*) and other mullets (*Liza parsia*, *L. macrolepis*), Oysters (*M. gryphoides*, *M. rivularis*, *Saccostrea cuccullata*) and Japanese pearl oyster (*Pinctada fucata*) also have potential, though at present being farmed to a minimal extent. Among seaweeds, species like *Kappaphycus alvarezii* and *Gracilaria edulis* are cultivated.

1.3. The scenario of fisheries and aquaculture in Kerala

The fisheries sector has always been important in the socio-economic scenario of Kerala (Devadasan *et al*. 2008). With a 590-kilometre-long coastline, a continental shelf area of 39,139 square kilometres, around 4,00,000 ha of inland water bodies like brackish water lakes, backwaters, estuaries, rivers, reservoirs, ponds, tanks etc., and an estimated 10.44 lakh people dependent on fisheries for their livelihood, the sector plays a vital role in the state's economy and the nutritional status and security of the people. The number of active fishers in the state is around 2.48 lakh (DoF 2020). Besides the direct dependence of the population mentioned above on fisheries, it also offers other employment avenues in fisheries-related and ancillary industries.

As per GoI (2020c), Kerala stands seventh (2019-20) among Indian states in total fish production. Kerala's annual total fish production during the year is 6.8 lakh tonnes. The fisheries sector is also important from the point of view of its contribution to the state's gross domestic product. Fisheries and Aquaculture contribute 9.7% of the Gross State Value Added (GSVA at constant prices) in 2019-20 from the primary sector (GoK 2021). The fisheries sector's contribution in the total GSVA (at constant price) in 2019-20 constitutes 0.82% and accounts for 0.72% of Gross State Domestic Product (GSDP).

Fish also contributes to the country's export basket, and exports from the state contributed 13.3% in terms of quantity and 12.84% in terms of value to the total seafood exports from the country during 2018-2019, *i.e.*, 1,83,064 tonnes worth Rs. 6,014.7 crores (DoF 2020). The fisheries sector is also crucial from the point of view of nutritional security of the state. For the domestic consumer, especially those belonging to the lower echelons of society, fish is the only affordable source of high-quality protein and other essential nutrients. As a health food also, fish is gaining importance because of its curative and medicinal properties (Devadasan *et al.* 2008).

Marine capture fisheries have always dominated the total fish production in Kerala. However, fish production in the marine sector over the last ten years presents a more or less stagnant trend. The marine fish landing of the state has almost attained or even exceeded the optimum level of production. There is little scope for a further rise in fish production from the inshore marine capture fisheries sector by increasing the fishing effort (Devaraj 2008; Kutty *et al.* 2011).

Inland fish production of Kerala shows an increasing trend year after year, though with some fluctuations in between. From a meagre 24,806 tonnes in 1979-80, the inland fish production of Kerala reached 2.05 lakh tonnes in 2019-20 (GoI 2020c). It may be noted that the State of Kerala has excellent potential for increasing fish production from the inland sector, but the potential remains mostly untapped (Kutty *et al.* 2008).

Aquaculture is yet to take off in a meaningful way in Kerala (Sahadevan 2013; Sahadevan and Sureshkumar 2019). While the aquaculture sector is responsible for more than 57% of the total fish production in the country, the contribution of the sector to the total fish production of Kerala is less than 5% (Sahadevan and Sureshkumar 2019). Development of aquaculture on a sustainable basis in the state would require interventions and support at different levels. These include policies, research, and farmers' initiatives. With marine catches stagnating and aquaculture not taking off, Kerala's pre-eminence in the fisheries sector is slowly diminishing (Devadasan *et al.* 2008; Kutty *et al.* 2011). In this context, the present study assumed importance. The study was taken up to investigate the status of shrimp aquaculture and understand the reasons for its poor performance in Kerala.

1.4. Objectives of the study

The present research work was intended to understand the various aspects of shrimp farming in Kerala. The study was meant to assess the status of shrimp aquaculture and identify the reasons for its slow pace of growth with particular reference to the level of technology, production, productivity and profitability.

Among all the fish and shellfish farmed globally, shrimps have a unique position for various reasons, the most important being the higher economic returns that one gets in its farming. It is the backbone of the seafood export industry worldwide, including Kerala. Shrimps form a valuable seafood delicacy, high in demand, especially in developing countries. Shrimps are high in protein, lipids, vitamins, and minerals.

A high percentage of omega-3 fatty acids, including about 50% EPA (eicosapentaenoic acid) and 50% DHA (docosahexaenoic acid), an unusual omega-3: omega-6 ratio of approximately 1:1 and the presence of cholesterol-related compounds like clionasterol and campesterol (anti-inflammatory sterols) also make the shrimp meat unique in nutritional composition. Shrimps are also rich sources of antioxidants and anti-inflammatory carotenoid nutrient astaxanthin. Astaxanthin intake can provide antioxidant support to nervous and musculoskeletal systems. Further, studies showed that the selenium contained in the meat of crustaceans like shrimps, crabs, and lobsters could be well absorbed into the human body. Since selenium deficiency is linked with heart failure and other forms of cardiovascular diseases, Type 2 diabetes, compromised cognitive function, and depression, the intake of shrimps, has a unique role in one's meal plan to meet the selenium demand. Another micronutrient of health significance is its unusual concentration of copper. The copper-containing respiratory pigment called haemocyanin present in these animals contributes to the high content of copper in shrimps.

In the context of the above, studies on shrimp farming assumed importance and formed the focal point of the present investigation.

The main objectives of the present study are the following.

1. To assess the status of shrimp aquaculture in Kerala with particular reference to technology, production, and productivity.
2. To identify the reasons for the low production and productivity of shrimp farms in the state and to suggest ways to improve them.
3. To study the diversity of fishes, crustaceans, and molluscs in Kerala's traditional shrimp farming fields (pokkali and kaipad fields).
4. To study the economics of shrimp farming in Kerala and the socio-economic conditions of shrimp farmers of the state.
5. To present a management plan for the sustainable development of shrimp aquaculture in Kerala based on the above and various published studies.

1.5. Organisation of the thesis

The thesis is divided into six chapters. Chapter 1 is a general introduction that discusses the general status of fisheries and aquaculture globally, in India and in the State of Kerala. It also outlines the relevance of the study and the principal objectives. Chapter 2 provides information on the status of brackish water shrimp farming in Kerala in the light of the technology available globally and in other parts of the country. It also examines aspects like the production and productivity of shrimp farms and the constraints faced. Chapter 3 outlines the diversity of fishes, crustaceans, and molluscs in the traditional prawn filtration (pokkali and kaipad) fields. Chapter 4 deals with the aspects of the economics of shrimp farming. It covers topics like the cost of production, revenue and profitability of various systems of shrimp farming practised in the state. It also deals with the sensitivity and scenario analyses conducted under different conditions of risks perceived in shrimp farming. Chapter 5 covers information on the socio-economic conditions of shrimp farmers, which have relevance to farming and farm productivity. Chapter 6 discusses the reasons for the low production and productivity of shrimp farms in Kerala and presents a management plan for the sustainable development of shrimp aquaculture in the state, in the light of information collected in the present study and based on already published literature on the subject and related aspects. In the end, a summary of the study's principal findings and the significant conclusions are given.

1.6. The terms shrimps and prawns

The terms shrimps and prawns are common English names used synonymously due to the absence of any systematic basis to mark a distinction (Wickins 1976, Holthuis 1980). Holthuis (1980) traced the origin of the names shrimps and prawns and their usage in various countries to clarify the issue. In general, shrimps refer to the smaller animals and prawns to the larger ones. But according to Food and Agriculture Organization Convention, shrimps refer to marine penaeids while prawns refer to freshwater palaemonids (Solis 1988). However, the terms shrimps and prawns are used synonymously in the present manuscript.

Chapter 2

STATUS OF SHRIMP FARMING

2.1. Introduction

The maritime state of Kerala, located on the west coast of peninsular India, is blessed with a bounty of brackish water resources in the form of low-lying coastal lands suitable for brackish water aquaculture with varying degrees of intensity. Kerala has 65,213 hectares (ha) of brackish water areas (ADAK 1991; DoF 2020), which are primarily low-lying and amenable to scientific fish and shellfish production. Besides, Kerala has 12,873 ha of traditional prawn filtration fields where rice cum fish and shrimp farming are traditionally carried out (ADAK 1991). The state also has an extensive network of backwaters with 46,129 ha, ideal for open water farming operations. Kerala is also blessed with a coastline of 590 kilometres (km), a territorial sea extending to around 13,000 square kilometres, and a continental shelf of 39,139 square kilometres (DoF 2019). The state also has rich and diverse brackish water finfish and shellfish resources.

Kerala has a long history of farming shrimp in brackish water areas. However, a major portion of brackish water farming systems in the state is under traditional farming, wherein production and productivity levels are low (Sahadevan 2012). The traditional shrimp farming system is practised in the low-lying coastal brackish water fields in Central Kerala (Ernakulam, Alapuzha, Kottayam, and Thrissur) and North Kerala (Kannur, Kasargod, and Kozhikkode).

The traditional prawn farming system involves the entrapment of juvenile prawns brought in by the tidal water in the fields and catching them by filtration at regular intervals (Kurien and Sebastian 1982). This operation is seasonal, which is being done only from November to April. During the southwest monsoon (June- September), water in these fields becomes almost salt-free. A particular variety of salt-resistant and flood resistant paddy is grown in these fields (Unnithan 1985). This paddy cultivation does not require much fertiliser and chemical application. It is a short-term crop that lasts for 90-100 days.

Scientific prawn farming is practised in all coastal districts of the state *viz*., Thiruvananthapuram, Kollam, Alapuzha, Ernakulam, Thrissur, Malappuram, Kozhikkode, Kannur and Kasargod districts, in varying degrees. It is also practised in the Kottayam district, in the low-lying brackish water areas adjacent to the Vembanad lake.

In scientific farming, the ponds specially constructed for the purpose are used. Pond preparation is invariably done before stocking with hatchery-produced seeds of the commercially important varieties of prawns. It involves the eradication of weed and predatory fishes, fertilisation, and liming to correct pH. The prawns are fed with farm-made and/or factory-produced feeds. Water quality is regularly monitored in these farms. The farming period generally extends to four months, though very few farms undertake extended (150-160 days) or shortened (90-100 days) culture.

Although Kerala has a long tradition in shrimp farming and possesses plentiful resources and congenial environmental and climatic conditions for brackish water aquaculture development, the sector has failed to emerge as an important avenue for livelihood and socio-economic development. As per the data published by the Marine Products Export Development Authority, Kerala's total farmed shrimp production in the year 2020-21 was 1867.83 metric tonne (t) (MPEDA 2021). It represents 0.22% of the total farmed shrimp production of the country, which is estimated at 8,43,633 t. As per GoI (2019), the productivity of shrimp farms of Kerala (541.30 kg ha^{-1}) is the lowest among all shrimp farming states of India and is much lower than the estimated national average productivity.

In this context, there is an imperative necessity to investigate the status of shrimp aquaculture in the state, which would help unveil the reasons for the low-profile performance of the sector and the observed low productivity. The present study was aimed at understanding the current status of shrimp aquaculture in the state with particular reference to the area available, the area under cultivation, site suitability, species farmed, level of technology, management practices adopted, harvesting methods, production and productivity, marketing of the produce, major constraints faced by the farmers, awareness on environmental; degradation and the extreme events of climate change etc.

2.2. Review of literature

A reasonably large number of studies exist on Kerala's shrimp and shrimp fisheries. Such studies are mostly restricted to capture fisheries and various aspects of the biology of shrimps and prawns. Some studies also exist on the traditional prawn filtration practices in Kerala. However, studies on scientific shrimp culture in Kerala are relatively few. Further, though a few studies exist on the economic aspect of shrimp farming, there is a near-total lack of detailed studies on the socio-economics of shrimp farmers of Kerala.

Panikkar (1937) described the history of the shrimp industry, culture and fishing operations of the Malabar Coast. He gave several suggestions for the improvement of the sector. Hora (1943) briefly described the practices of paddy cultivation along with the fish culture in different parts of the country. Nataraj (1948) gave an account of the prawns of Travancore. Panikkar (1952) discussed the possibilities of expansion of fish and prawn culture practices in India. Menon (1954) investigated the paddy field prawn fishery of Travancore- Cochin and published results of trials on prawn culture. Different aspects of prawn culture, prawn fishing methods and gears employed were described by Gopinath (1956). Panikkar and Menon (1956) gave a detailed account of the paddy prawn fisheries of Travancore – Cochin. Kesteven and Job (1957) reviewed the shrimp culture practices in Asia and the Far East. Menon and Raman (1961) published observations on the prawn fishery of the Cochin backwaters. George (1962) studied the prawn seed recruitment in the backwaters of Cochin, Kerala.

Raman and Menon (1963) presented the results of an experiment conducted on paddy field prawn farming near Vaikom in Kerala. It was aimed at finding out the effect of variation in size and number of sluice gates, area of the field etc. on the catch. The authors were not possible to substantiate the common belief that the catch is influenced by the phases of the moon. However, it was found that catches on days around the full moon or new moon showed a rise quite likely due to the stronger tidal influence and consequent stronger flow in and out of the fields and longer duration of fishing. George *et al*. (1968) described the paddy field prawn filtration of Kerala in detail. Raman (1968) published the results of an experiment in prawn cum tilapia culture in the paddy field.

Meeran and Sebastian (1972) gave a detailed account of the larvae of the freshwater prawn (*Macrobrachium rosenbergii*). Thomas (1972) investigated the food and feeding habits of the tiger prawn, *Penaeus monodon* of Korapuzha estuary of Calicut district of Kerala. George (1974) studied various aspects of prawn culture in seasonal and perennial fields of Vypeen island of Ernakulam district of Kerala. The author investigated the species composition, size composition, yield and economics of the shrimp farming operations. He also studied the food composition of shrimp caught from Cochin backwaters. Kuttyamma (1974) studied the food and feeding habits of some penaeid prawns of the Cochin area. Pillai and George (1974) presented a detailed account of prawn fishery resources of Cochin backwaters. George (1975) studied the growth of various penaeid prawns in the paddy fields. Joseph and Sadanandan (1976) presented the results of the experiments on larval rearing of the freshwater prawn, *M. rosenbergii*. Meeran and Sebastian (1976) further discussed the mass rearing of the larvae of the freshwater prawn. Anzari (1977) and Pillai (1977) conducted studies on the benthic fauna of Cochin backwaters.

Alagarswami (1978) discussed the prospects of coastal aquaculture in India. Alikunhi (1978) described the role of hatcheries in the development of commercial farming of penaeid shrimp. Joseph (1978) published notes on larval rearing and culture of the giant freshwater prawn, *M. rosenbergii* in Kerala. Lakshmi (1978) investigated hydrology of the prawn culture fields at Narakkal of Ernakulam district. Muthu (1978) presented a general review of penaeid prawn culture. Nair *et al.* (1978) investigated the productivity and nutrient regeneration in the prawn fields adjoining Cochin backwaters. Rao (1978) assessed the seed requirements for the intensive culture of penaeid prawns in coastal waters, particularly in Kerala. Sebastian *et al.* (1978) reported preliminary experiments on the culture of tiger prawn and seed prospecting of penaeid prawns in Kerala backwaters. Silas (1978) discussed the status of prawn culture in India and strategies for its development. Silas and Rao (1978) prepared a master plan for developing prawn culture in central Kerala.

Kartha and Nair (1979) published details of prawn filtration practices in Kerala. Sundararajan *et al.* (1979) presented a report of an experiment on the monoculture of tiger prawn in a brackish water pond. Gopalan *et al.* (1980)

conducted case studies on the technical aspects and the economics of improved methods of paddy field shrimp culture in Vypeen island of Ernakulam district. Muthu (1980) gave details of site selection and types of farming for coastal aquaculture of prawns. Gopalan and Purushan (1981) discussed the present status of backwater shrimp culture in India. Rajendran *et al.* (1981) studied aspects of fish culture along with paddy in the pokkali fields of Kerala. George and Suseelan (1982) investigated the distribution of different species of prawns in the backwaters and estuaries with particular reference to coastal aquaculture. Experimental studies on high-density, short-term farming of the Indian white shrimp in pokkali fields were conducted by Gopalan *et al.* (1982). Environmental characteristics of seasonal and perennial prawn culture fields in the estuarine system of Cochin were investigated by Gopinathan *et al.* (1982). Kurien and Sebastian (1982) presented a detailed account of the prawn and prawn fisheries of Kerala, in which prawn farming has been discussed at length.

Suseelan and Kathirvel (1982) conducted studies on the recruitment of prawn seeds in the backwaters of Cochin. Verghese *et al.* (1982) discussed various aspects of improved prawn production through selective stocking. Mammen (1984) gave a detailed account of the brackish water fisheries of Kerala. He also analysed the impact of paddy protection works on inland fisheries, the possibility of taking up integrated farming practices, and the policy to be adopted to develop the sector. Purushan and Rajendran (1984) gave a critical account of prawn production in Kerala. Unnithan (1985) published a guide to prawn farming in Kerala. It contained details of the biology of cultivable species of prawns, aspects of selecting a site for scientific farming, farming techniques and economics of scientific farming of shrimp. He gave the merits of scientific shrimp farming over the traditional prawn filtration practices and advocated adopting the former. Chakraborti *et al.* (1986) studied the growth of *P. monodon* under different environmental conditions.

Purushan (1986) gave a detailed account of recent advances in paddy cum fish culture and its scope for further improvement in Kerala. Gopalan (1987) undertook a study on Kerala's inland fishery resources and their exploitation. Studies on palaemonid prawn resources of the estuaries of Kerala were conducted by Jayachandran (1987). Jhingran and Ghosh (1987) discussed aquafarming practices prevalent in coastal India. Jose *et al.*(1987) and Mathew and George (1987) studied the technical aspects of shrimp culture in the pokkali fields of Kerala. Purushan (1987a; 1987b) investigated technical aspects of traditional prawn farming in Kerala.

Alikunhi (1988) presented a detailed account of the problems and prospects of fish culture in Kerala. He highlighted the need for the development of freshwater prawn (*M. rosenbergii*) farming, use of formulated feed in fish farming, development of farming of fish in flowing waters, intensive rearing of fish and prawn seed and the culture of high yielding species of fishes and prawns. He also pointed out the need to bring every pond, tank, reservoir and other water body under scientific farming. Studies on the phytoplankton and zooplankton of some paddy cum prawn filtration fields in and around Cochin were conducted by Gopalakrishnan *et al.* (1988). Mathew (1988) presented the paddy cum fish culture trials conducted in pokkali fields and advocated adopting fish farming with paddy in the wake of low return from paddy cultivation. Nair and Thampy (1988) presented a detailed account of the hatchery production of seed and culture of the freshwater prawn in Kerala. Nair *et al.* (1988) studied the environmental conditions of some paddy-cum-prawn culture fields of Cochin Backwaters. Purushan (1988) conducted a case study of the prawn production potential of traditional paddy fields (pokkali fields) in Vypeen island of Ernakulam district. Surendran (1988) investigated the prospects and perspective of shrimp farming on Vypeen island. Nair *et al.* (1989) presented details of the mass production of the seed of giant freshwater prawn in Kerala. Purushan (1989) investigated aspects of semi-intensive shrimp farming and its relevance in Kerala. Sathiadhas *et al.* (1989) studied the economic aspects of paddy-prawn culture in pokkali fields.

The Balakrishnan Nair committee (Nair 1989) report contained recommendations for the management of brackish water fisheries in Kerala. The principal recommendations of the committee related to prawn farming included the conversion of prawn filtration farms into scientific farms and avoidance of the use of poisons in the harvesting of prawns in the prawn filtration fields. Ghosh and Chakrabarti (1990) described rice-fish production technology for coastal wetland management. Padmakumar *et al.* (1990) discussed the rice-fish farming system for wetlands with particular reference to Kuttanad, Kerala. ADAK (1991) published the results of a brackish water resource survey. It included taluk wise details of the extent of brackish water areas available in the state. Devi *et al.*(1991) studied the benthic fauna of Cochin backwaters. Ghosh (1991) discussed the level of fishing pressure exerted over Kerala's inland capture fisheries resources. He emphasised the need for introducing scientific prawn farming in the state. According to him, the present system of traditional prawn filtration needs to be checked, and appropriate low-cost scientific technologies have to be adopted for upgrading this aquaculture practice. The author observed the necessity for a shift in approach and planning to develop brackish water fisheries in Kerala. Jhingran (1991) discussed in detail prawn farming in Kerala. Aspects of paddy cum fish culture developments were discussed by Mathew (1991).

Aravindakshan *et al.* (1992) studied benthos and substratum characteristics of prawn culture fields in and around Cochin backwaters. Kurup *et al.*(1992) studied the fishery resources of pokkali fields of Vembanad lake. Nasser and Noble (1992) investigated the technical aspects and economics of prawn culture in Vypeen, Kerala. Edwards (1993) discussed the environmental issues in integrated agriculture- aquaculture and wastewater-fed fish culture systems. Jayagopal and Sathiadhas (1993) investigated the productivity and profitability of prawn farming practices. Johny (1993) studied marketing channels and price spread for aquaculture products in Kerala. Results of the selective culture of penaeid prawns were presented by Mathew (1993), and those on the culture of the giant freshwater prawn in pokkali fields were given by Mathew *et al.* (1993). Ninawe and Raj (1993) undertook studies on certain nitrogen cycle bacteria in the prawn culture fields of Kerala. Ignatius (1995) conducted ecological and productivity studies of prawn farms in central Kerala. Kumar and Antony (1994) and Kumar (1995) studied the benthic fauna of Cochin backwaters. Purushan (1995; 1996a; 1996b; 1996c) published various aspects of sustainability of traditional shrimp farming practices of Kerala. Some of the productivity characteristics of pokkali fields were studied by Arun (1996). Bundell and Maybin (1996) investigated the human and environmental costs of commercial prawn farming. Mazid and Hussain (1996) described the rice-fish farming practice. Ghosh (1996) published a book on scientific shrimp farming. It contained details of cultivable species of prawns, the biology relevant to culture, various methods of cultivation of shrimps, farming practices, feed management and economics of farming shrimps in Kerala. CIFE/CIBA (1997) detailed the impact assessment of ground realities of shrimp farming. Krishnani *et al.* (1997) investigated the soil and water characteristics of shrimp ponds affected with viral disease. Pillai *et al.* (1997) discussed the traditional system of brackish water aquaculture of Kerala.

Raju (1997) conducted detailed economic analyses of different aquaculture systems in Kerala. State Planning Board (1997) presented a task force report on fisheries and aquaculture. Pillai and Krishnan (1998) discussed some aspects of the biology and fishery of *Penaeus indicus* from traditional prawn filtration fields. Thampy *et al.* (1998) reported results of an experiment on the short-term culture of tiger prawn and milkfish in a low saline pond. Ahmed (1999) examined the policy issues deriving from the scope, determinants of growth, and changing structure of supply of fish and fishery products in developing countries. According to the author, supply will be determined by price, cost and availability of inputs, technology, infrastructure, support services, and environmental limits in aquaculture. Technological developments such as breeding and genetic improvement, infrastructure, and other support can significantly enhance aquaculture production in the medium term. However, the supply and management of land, water resources and feed inputs will be the most critical factors for sustainable long-term growth of the farming sector. Chandramohan *et al.* (1999) described various aspects related to pokkali fisheries of Kerala. Flaherty *et al.* (1999) critically considered decisions on the choice between farming rice paddy or shrimp. Pillai (1999) made a comparative analysis of yields from traditional pokkali fields and that from improved traditional prawn farming fields during 1996-1998. He also studied the species composition of shrimp yields.

Santhanakrishnan (1999) examined the present status of the Indian shrimp culture industry and its contribution to the national economy in terms of employment, income and foreign exchange earnings. He also analysed the environmental and social issues associated with the development of commercial shrimp farming and put forward many arguments in defence of the industry. According to him, the coastal shrimp culture does not cause much environmental degradation. His views were based on the findings of a study conducted by the National Environment Engineering Research Institute (NEERI) in 1994. He pointed out that shrimp culture does not cause seepage and salinisation at a distance of above 25 meters away from the pond. As farmers use saline water available in a natural open water system, it does not affect the quality and level of groundwater. Shrimp farm effluents were polluting the environment at a lower rate when compared to domestic and industrial wastewater and other forms of coastal pollution. The quantity of agrochemicals used in shrimp farming is much less than what is used in agriculture. Santhanakrishnan (1999) also reported that the expansion of shrimp farming was less responsible for the disappearance of mangroves. Mangrove soil is less productive and involves the cost of clearance also. Reclamation of mangroves in the coastal regions was done mainly for agriculture. According to the author, there was no competition between shrimp culture and agriculture for land and natural resources. Unproductive/ marginally productive lands were put into shrimp farming in many parts of the country. He also observed that shrimp culture operations are more labour intensive than agriculture. Daily wages are also higher in shrimp culture than in agriculture. Shrimp farming is mainly a small-scale industry. Shrimp farming does not give rise to multi-user conflict in coastal areas because it does not cause any damage to the usual economic activities of the coastal population. Loss of fish resources in the wild due to aquaculture was not successfully proved. Based on these arguments, the author tried to establish that the development of shrimp farming is environment-friendly and socially and economically beneficial.

Sinha (1999) gave a good account of the development of rural aquaculture and its various aspects like history, evolution, current status, impact on the socio-economics, the extent of rural aquaculture in different states of the country, production, marketing, contribution of rural aquaculture to rural development, rural aquaculture research and development programmes etc. The author pointed out that aquaculture makes significant contributions to the economy in terms of food production, income, employment and foreign exchange earnings.

He also found aquaculture to contribute to farm produce diversification, additional income and employment generation and thus brings in general prosperity to farmers. According to the author, poor farmers need considerable extension support to upgrade their traditional systems of paddy-fish culture to improve productivity. However, even at the low production level, farmers get higher net income from fish than from rice because the price of fish is many times more than rice. It is also pointed out that paddy-fish farming leads to higher labour engagement. While hired labour consists mainly of males, family labour showed much more women involvement. The author also pointed out the main constraints and environmental issues the farmers face.

Menon (2000) discussed the transition of rice granary's culture of kaipad cultivation. Nayak *et al.* (2000) worked out some of the ecological aspects of the wetlands of North Kerala, which include part of kaipad lands also. They have mentioned water quality parameters and some backwater flora and fauna. Srinath *et al.* (2000) advocated group farming for sustainable aquaculture and emphasised the need for extension work. Gupta *et al.* (2001) studied soil and water characteristics and the growth of shrimp *P. monodon* fed with formulated feed in experimental tanks. Kurup and Ranjeet (2002) investigated aspects of integration of freshwater prawn culture with rice farming in Kuttanad. Nair *et al.* (2002) briefly described the kaipad agroecosystem of North Kerala wetlands and its socio-economic aspects. These authors also discussed the lure of prawn culture and the waning of the culture of rice-fish farming in North Kerala. Pillai *et al.* (2002) gave a very detailed account of the traditional prawn filtration in Kerala. These authors discussed various features of traditional pokkali paddy fields used as shrimp farms in off-seasons, culture practices, harvesting and monitoring of the system. The study pointed out that pokkali shrimp farming is an eco-friendly system. The rotation of rice cultivation during the monsoon season and shrimp farming during the post-monsoon season in paddy fields is mutually beneficial. It ensures the cycling of internal resources and reduces dependence on external resources. Prein (2002) discussed the advantages of the integration of aquaculture into crop-animal systems.

Purushan (2002) discussed aspects of developing and managing the wetland ecosystem around pokkali areas. Padmakumar (2003) presented an account of the prospects of rejuvenation of the prawn farming sector in the Kuttanad region of Kerala. Pillai (2003) investigated fishery and production of shrimps from perennial and seasonal fields of Kerala. Pravin (2003) studied the economics of traditional shrimp farming in Kerala and gave a detailed account of shrimp harvesting methods in traditional farms. Purushan (2003a; 2003b) dealt with aspects of the eco-friendly pokkali cultivation and prawn filtration practices in Kerala. Mathew and Pillai (2004) examined the current status of brackish water aquaculture in India regarding production, the area under farming, and the level of technology. It was pointed out that during the period 1991-1992 to 2001-2002 the area under culture increased rapidly and production has increased faster. Still, only a tiny proportion of potential area has been brought under cultivation. The rate of growth in production slowed down to very low levels during the mid-1990s due to the outbreak of diseases, but the growth rate revived and rose to a level higher than what was in the pre-disease scenario towards the end of the 1990s. It was argued that despite the developments in seed and feed technology, management of water resources, and control of diseases, inadequacies still prevailed and constrained the industry's progress. Prakash (2004) discussed better management practices (BMP) in shrimp farming.

Cheruvat (2005) presented the results of ecological studies on kaipad, a traditional farming system in north Kerala. He also discussed in detail the fishery resources of the area and the environmental aspects of rice farming, aquaculture and nutrient enrichment. Further, the author discussed aspects of conservation and management of kaipad agroecosystem. Haneesh (2005) conducted a comparative study on the marketing and export of wild-caught and farmed giant freshwater prawn, *M. rosenbergii*. Kurup and Ranjeet (2005) discussed innovative and sustainable farming of the giant freshwater prawn in the polders of the Kuttanad region of Kerala. Muthuraman (2005) presented a technology package for sustainable scampi farming. Wang *et al.* (2005) studied the effectiveness of commercial probiotics in white shrimp ponds.

Anon (2006) prepared a master plan for aquaculture development in Kerala. Harikrishnan and Kurup (2006) examined the sustainability issues of the fishery of the giant freshwater prawn in Vembanad lake. Mohite (2007) investigated the efficacy and constraints in the adoption of improved aquaculture practices by shrimp farmers in the Raigad district of Maharashtra. Goswami *et al.* (2009) investigated the techno-economic viability of rice-fish culture in Assam. Nambiar and Raveendran (2009) evaluated the untapped potentiality of the coastal paddy fields of Kerala. The authors dealt in detail with the various factors contributing to the sustainability of shrimp farming. Ahmed *et al.* (2010) discussed the role of rice-prawn fields in the blue revolution. Jayan and Sathyanathan (2010) published an overview of farming practices in the waterlogged areas of Kerala. According to the authors, a clear perspective and a management system that ensures participation and regulation in resource use are essential. Haque (2011) discussed the efficiency and institutional issues of shrimp farming. Chandramohanan and Mohanan (2012) discussed kaipad rice farming in North Kerala. Sahadevan (2012) investigated the reasons for the low productivity of shrimp farms in Kerala. Sasidharan *et al.* (2012) discussed aspects of spatial and temporal integration of rice, fish and prawn in the coastal wetlands of central Kerala. Begum *et al.*(2013) investigated the technical efficiency of shrimp farming. Deo *et al.* (2013a) discussed the present issues and future strategies for shrimp farming in West Bengal. Joy (2013) evaluated the development impact on pokkali fields in the light of the establishment of the International Container Transshipment Terminal at Vallarpadam, Kochi.

The government of Kerala appointed an expert committee for formulating sustainable aquaculture practices in pokkali and kole lands of the state of Kerala in 2012. The committee submitted its report (Kurup *et al.* 2013) in January 2013. The committee report contained a compilation of authentic databases on the topics. The committee assessed the status of agriculture and aquaculture being carried out in pokkali and kole lands of Kerala, focusing on production and productivity. Committee further evaluated various sustainability issues plaguing aquaculture in pokkali and kole lands, emphasising the significant ecological transformations in these ecosystems, changes in the cropping pattern and cropping intensity and prevailing social problems. The committee gathered information through holding public consultation meetings and participation in workshops of stakeholders. The report contained 19 recommendations for the sustainable development of aquaculture in pokkali fields. It emphasised the need for undertaking paddy cultivation alternated with shrimp farming. The committee observed that the extent of pokkali fields in the state is shrinking year after year. In the light of this, it recommended that the state government take a concerted effort to preserve and conserve the available pokkali fields, maintain them as ‘heritage farming villages’, and find them a place in the global list of heritage village.

Sahadevan (2013) discussed various strategies for developing shrimp aquaculture in Kerala to enhance production and productivity. Sahu *et al.* (2013) presented a management strategy for shrimp (*P. monodon*) farming in West Bengal. Antony *et al.* (2014) studied the effects of rotational pokkali cultivation and shrimp farming on the soil characteristics of two different pokkali fields at Chellanam and Kadamakudi in Kochi. The authors investigated the variation in soil pH, conductivity, salinity, organic carbon, phosphate, nitrogen, sulphur and C: N ratio during the pre-monsoon period. Koteswari *et al.* (2014) studied the impact of aqua societies on shrimp farming in Andhra Pradesh. Sahu *et al.* (2014) examined the adoption of better management practices and constraints in shrimp farming in a selected district of Odisha. Vimala *et al.* (2015) reported various aspects of the use of chemicals and biological products in modern shrimp farming. Dinesh (2016) examined the history, status and thoughts for the future of shrimp farming in India. Joseph (2016) described rice cultivation in saline tracts of Kerala. Sahadevan (2016a) discussed the government interventions required to develop shrimp aquaculture in the state of Kerala. Srinivas and Venkatrayalu (2016) studied the present problems and prospects of shrimp farming in the West Godavari district of Andhra Pradesh. Chittem and Kunda (2017) made a constraint analysis of *Litopenaeus vannamei* culture in the Prakasam district of Andhra Pradesh. Mumthaz and George (2017) discussed the significance of pokkali fields at Kadamakkudy (Kerala).

Jayanti *et al.* (2018) made a detailed study on the impact of shrimp aquaculture development on important ecosystems in India. According to the authors, the rapid growth of aquaculture has raised environmental concern about the conversion of ecologically important areas such as mangroves and agricultural lands. The study explored the impact of shrimp aquaculture on land-use change in India’s coastal wetlands using Landsat satellite data, geographical information system techniques and field verification. From 1988 to 2013, the area under aquaculture has grown by 879%, which brought tremendous changes in the coastal land use pattern. Mangrove and agricultural lands have been used for 5.04% and 28.10% of the aquaculture growth. Mudflats, scrublands, saltpan, and water bodies have contributed to 51.65%, 1.76%, 1.73% and 2.37% of the aquaculture area expansion, respectively. Mangrove areas have undergone severe changes due to gain and loss at different places. Environmental factors influenced the changes in mangroves, and the overall extent of mangroves has increased by 13.44 %. Salunkhe (2018) investigated the efficacy and constraints in adopting *L. vannamei* culture practices by the farmers of the North Konkan region of Maharashtra. Rani *et al.* (2019) discussed adopting an integrated rice-fish farming system by farmers of Ramachandrapuram Mandal of East Godavari district in Andhra Pradesh. Patil and Sharma (2020) made an empirical analysis of constraints faced by shrimp farmers of Maharashtra.

2.3. Study area and methodology

Details of the study area and the methodology adopted are provided below.

2.3.1. Study area

The present study was conducted in the shrimp farming belt of Kerala *viz*., coastal areas of Thiruvananthapuram, Kollam, Alapuzha, Ernakulam, Thrissur, Malappuram, Kozhikkode, Kannur and Kasargod districts and the low-lying brackish water areas lying adjacent to the Vembanad backwaters in Kottayam district (Fig. 2.1).

2.3.2. Methodology

For the present study, both primary and, to a minimal extent, secondary data were employed. Information on the extent and type of water bodies suitable for inland aquaculture and areas available for brackish water aquaculture/ shrimp farming in different districts of Kerala was collected from secondary sources. Other information was collected from primary sources.

One of the primary sources of microdata for the present study is the field survey. The survey is a fundamental method for providing necessary information about farming technology, problems and constraints on aquaculture development as has been opined by Shang (1981).

Two types of farming are in practice in Kerala (Sahadevan 2013). They are traditional prawn farming (prawn filtration) and scientific prawn farming. Data on shrimp farming was collected for each category separately. Lists of all shrimp farms belonging to each of the above categories were collected from the Fish Farmers' Development Agencies (FFDA) functioning in various districts under the Department of Fisheries, Kerala, and the Marine Products Export Development Authority (MPEDA).

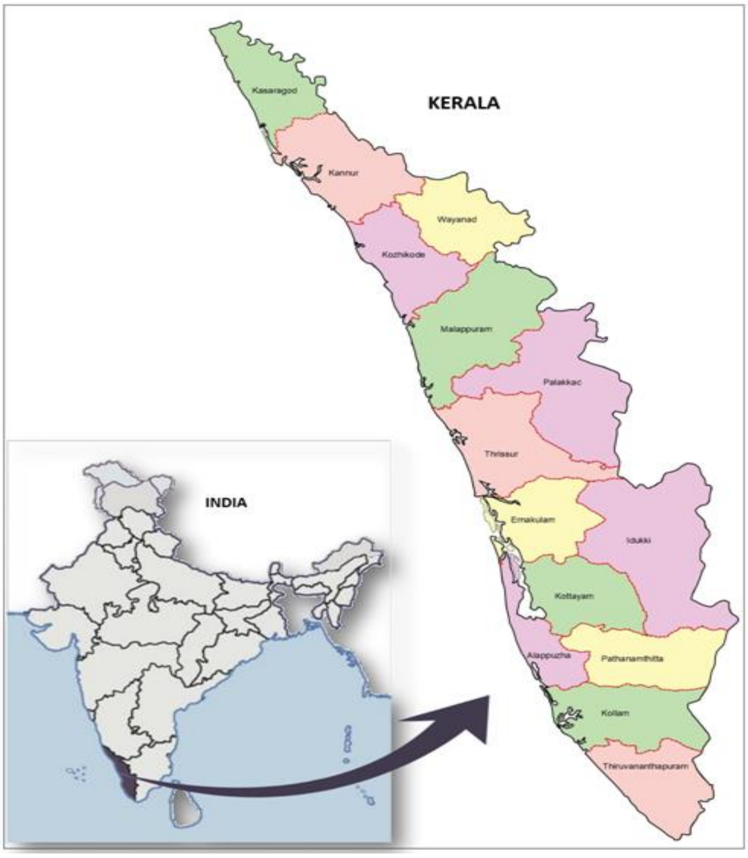


Figure 2.1. The area selected for the study on the status of shrimp farming.

The consolidated list for each category was prepared, avoiding duplications. These lists formed the basis for the present study. A sample was selected from each list by employing a simple random sampling method (Gupta 2018), and data on topics of interest in the present study were collected from the selected farm units. Details of shrimp farms and the number of farms selected under each category are provided in Table 2.1.

A pre-survey inquiry revealed that in Kerala, in traditional farms, seed stocking is done when salinity builds up after the monsoon (October- December), and final harvesting is done before the monsoon (April- May). In scientific tiger shrimp (*P. monodon*) farming, crops are taken in different farms either as summer crops (January/ March – April/ June) or as monsoon crops (April/ May-July/ August). Scientific white prawn (*P. indicus*) farming is generally done during December/ January – April/ May. In the farming of Pacific white shrimp (*L. vannamei*), the trend is for a year-round culture with no distinct crop season.

Table 2.1. Details of shrimp farms selected for the study.

	Traditional farms		Scientific farms	
	Number	Registered area (ha)	Number	Registered area (ha)
Shrimp farms enlisted	1576	8430.98	412	2168.28
Shrimp farms selected for the study	162	845.32	58	268.45
Per cent of shrimp farms selected for the study	10.28	10.03	14.08	12.38

Data were collected for three consecutive crops from September 2015 to May 2018 (except otherwise explicitly mentioned), and the average was taken, wherever relevant. Data for a more extended period were collected from farm books maintained by the farmers whenever found necessary.

Using the respondents' records supplemented by frequent visits, complete data were collected on various aspects of interest in the present study. Multiple visits were made to confirm data, especially during farming days. To collect data, a scientifically designed and pre-tested questionnaire was employed. The questionnaire was in vernacular language, *i.e.*, Malayalam. The information collected was analysed statistically, wherever relevant, to arrive at meaningful conclusions.

For the estimation of shrimp production, a slightly modified version of the sampling design developed by the Central Inland Capture Fisheries Research Institute (Indian Council of Agricultural Research) Barrackpore, West Bengal (India) and suggested by the Fisheries Division of the Department of Agriculture and Co-operation, Government of India (CICFRI 1991) was adopted. The sampling design adopted was a multistage stratified random sampling design. All farms contributing to shrimp production formed the population, and each farm therein constituted the sampling unit. Each shrimp farming district was divided into revenue blocks that formed the strata. For the convenience, the areas coming under the coastal municipalities were included in contiguous revenue blocks. All farms within a stratum were classified into two groups, *i.e.*, farms with areas up to one hectare and farms with areas above one hectare. Separate sampling was done in these two groups of units.

Farms falling in each stratum (revenue block) were listed serially without omission or duplication and with one-to-one correspondence with serial numbers. The area of each of the farms was indicated in the list against the serial number of the farm. This listing was done separately for units with up to one hectare and units above one hectare. From the serial numbers of the list prepared, farms were sampled with the help of a random number table until the total area of the sampled units crossed 10% of the total area of the farms in the stratum. The same procedure was followed for farms of sizes above one hectare in the stratum.

The selected sample units were visited once after the normal stocking period to record information on stocking, expected period of harvesting, etc. The information on the likely date/period of harvesting in each month was obtained from the farmer. The visits were scheduled to cover all farms during the last week of the month. Field trips were arranged in such a way to visit the farms, on the day of harvest itself to observe and record the weight and the species in the harvest. Data regarding the catch for other days of the month was also collected by inquiry. When it was not possible to be present at the harvest time, the sampled units were visited on any day in the last five days of the month to assess the production during the month, including species wise break up. The data on the catch for each of the sampled units for the whole month was obtained. If there was no harvest or catch in a particular month, 'nil' information was recorded. The estimation of shrimp production was done, as suggested by CICFRI (1991). Total shrimp production of the state (*Y*) was calculated as:

$$Y = \sum_{r=1}^{10} \sum_{s=1}^{nr} X_{rs}$$

Where, X_{rs} is the total production of shrimp in the s^{th} revenue block of r^{th} district. Here r = 1, 2, 3……10 and s = 1, 2, 3……nr, where nr is the number of revenue block in r^{th} district.

$$X_{rs} = \sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{k=1}^{m} \left(\frac{(x_{rs})_{ijk}}{(a_{rs})_k}\right)(A_{rs})_k$$

Where $(x_{rs})_{ijk}$ is the total production of k^{th} species of shrimp reported from the j^{th} size- class of farm of the i^{th} type of farming in the s^{th} revenue block of r^{th} district. The notion $(a_{rs})_k$ is the sampled area of k^{th} species in the s^{th} revenue block of r^{th} district. Whereas, the notion $(A_{rs})_k$ is the total area of production of k^{th} species in the s^{th} revenue block of r^{th} district.

The farm units fell into two categories, *viz*., those who previously kept records of the water quality parameters and those who maintained no records. 38.27% of the traditional farms and 72.41% of the scientific farms were found to be keeping records of some kind, but none included all the specific items required for the present study. Hence the respondents were requested to keep a note of the data needed for the study, which were collected every month from them and recorded in the survey files.

Besides, water quality parameters were also measured during the visit to farms. As instructed, farmers measured water temperature and pH twice daily between 6.00 and 7.00 hours and 18.00 and 19.00 hours. Dissolved oxygen was measured once every day in the morning (6.00 – 7.00 hours). Ammonia was measured once every week and total alkalinity and total hardness, twice during the entire culture period (*i.e*., once during the pond preparation period and once during the second half of the culture period). The data on these aspects were collected during the visit after proper calibration. At the time of the visits, the various field instruments at the farms were calibrated using a standard laboratory instrument carried along to ensure the accuracy of the field instruments and determine the measurement's traceability.

In the initial phase of the present investigation, a preliminary study was conducted to understand the physicochemical parameters of principal (potential) areas of shrimp farming in the state, *i.e.*, the water bodies which form the sources of water to the existing prawn farming units and to those that may come up in future. This was done because the state's present/ potential prawn farming areas are located beside the lakes/ backwaters/ downstream portion of the rivers and/or estuaries. The physicochemical qualities of these water bodies are expected to indirectly give an idea about the suitability of the areas for shrimp farming and the potential for future expansion of areas.

For this purpose, ten stations were selected, one each in Thiruvananthapuram, Kollam, Kottayam, Alapuzha, Ernakulam, Thrissur, Malappuram, Kozhikkode, Kannur and Kasargod districts. The details of the stations selected for the study are provided in Table 2.2. The parameters were measured once every month for 12 months from January 2015 to December 2015 in various stations. As far as possible, the data were collected during the morning hours (between 6.00 am and 7.00 am) and afternoon hours (2.00 pm and 4.00 pm) to make comparisons meaningful.

Table 2.2. Stations in downstream parts of rivers and lakes selected for the study on physicochemical parameters.

Station No.	Water body	District	Details	Latitude and longitude
1.	Kadinamkulam lake	Thiruanantha-puram	Near Muthalapozhi bridge	8.63353082°N 76.78778171°E
2.	Ashtamudi lake	Kollam	Near Neendakara fishing harbour	8.93620293 °N 76.54363632 °E
3.	Vembanad lake	Kottayam	Near Vaikkom boat jetty	9.74983241 °N 76.38914108 °E
4.	Punnamada lake (Vembanad lake)	Alapuzha	Punnamada in Alapuzha town	9.50129640 °N 76.35470314 °E
5.	Vembanad lake	Ernakulam	Vypin island, Kochi	10.08379761 °N 76.22391700 °E
6.	Kodungallur lake (Periyar river)	Thrissur	Near Moothakunnam ferry	10.19287482 °N 76.20293140 °E
7.	Tirur- Ponnani river	Malappuram	Near Koottayi regulator cum bridge	10.83613005°N 75.90593576°E
8.	Korapuzha river	Kozhikkode	Near Koilandi	11.43964725 °N 75.72772982 °E
9.	Kuppam river	Kannur	Near Madakkara	11.95746387 °N 75.30578613 °E
10.	Valiaparamba backwaters	Kasargod	Near Padanna	12.17896496 °N 75.13712883 °E

The various physicochemical parameters of water in the farms and the natural water bodies were measured using standard methods. In the absence of facilities for the measurement, the temperature of the bottom water was not measured. The surface water temperature was measured by using a mercury bulb thermometer and pH by the electronic method using a digital pH meter (HI 2202 edge®blu pH Bluetooth® Meter HANNA instruments). Dissolved oxygen was measured by a portable dissolved oxygen meter (HI8043 HANNA instruments). Total alkalinity was measured by using a chemical test kit (HI3811, HANNA instruments) that measures alkalinity by titration with hydrochloric acid and total hardness by a test kit (HI3812 HANNA instruments) that measures total hardness as $CaCO_3$ by titration with EDTA. Total ammonia was measured by a chemical test kit (HI3826 HANNA instruments) that uses the Nessler method, and nitrite- nitrogen was measured by a test kit (HI3873 HANNA instruments) that uses the chronotropic acid method. Nitrate-nitrogen (NO3- N) was measured by using a chemical test kit (HI-38050 Nitrate HANNA instruments) that uses the cadmium reduction method and ammonia- nitrogen (NH3-N) was measured by a portable photometer (HI-96700-meter HANNA instruments). Soil pH was measured by a portable soil pH meter (HI981030 GroLine Soil pH Tester HANNA instruments). The turbidity of the water in the downstream portion of the river/lake/ backwater was measured by using a turbidity meter (HI-98703 Turbidity Meter HANNA instruments). However, since the Secchi disc is more common in use in the shrimp farms of the state and since none of the farms had a turbidity meter, water turbidity was measured by using a Secchi disc in the farms.

Analysis of the proximate composition of shrimp feed was done by employing the standard AOAC (1980) method. All analyses were done in duplicate. The moisture content was determined by drying the sample at 105 ºC until a constant weight was reached. Total nitrogen was determined by the micro-Kjeldahl method in which samples were digested in concentrated sulphuric acid, and the resulting ammonium nitrogen was determined by titrating against standard sulphuric acid. The total nitrogen content multiplied by 6.25 was taken as the crude protein content. The crude fat content was determined by extraction for six hours with petroleum ether (boiling point, 40- 60 ºC) in a Soxhlet apparatus. The ash content was determined by incinerating the sample at 600 ºC for six hours in a furnace. All proximate compositions (other than moisture) were expressed on a dry weight basis, except otherwise mentioned.

Soil samples were collected from fields once during the study period. Sediment samples were collected from the bottom by a Van Veen grab. The sampling of soil was done at four points from each station. Soil pH was measured *in situ* or immediately after the collection to avoid subsequent changes. For analysis of other parameters, the collected samples were mixed, air-dried, ground to a fine powder by using a mortar and pestle and stored in airtight polythene bags. Soil texture and nutrients were got determined in the nearby soil testing laboratories owned by the Department of Agriculture, Government of Kerala and in the Regional Research Stations of Kerala Agricultural University (KAU) by employing standard methods.

Soil texture was determined based on the measurement of the proportions of the various sizes of the soil particles, *i.e.,* sand, silt, and clay. The size of the soil particles adopted for classification was as per the United States Department of Agriculture (USDA) classification system. The names of soil texture adopted were based on a soil triangle using data on percentages of sand, silt, and clay (USDA 2017). The textural triangle is a diagram that shows how the different textures are classified based on the per cent of sand, silt, and clay in each. The soil texture triangle is one of the tools to visualise and understand the meaning of soil texture names.

2.4. Results

Two sets of investigations were conducted. The first set was a priliminary one and was to understand the suitability of the low-lying brackish water areas of the state for scientific shrimp farming. For this, ten stations were selected in the downstream portion of major rivers/ backwaters, and the water quality parameters were studied at periodic intervals. This study was conducted during the period from January 2015 to December 2015. The second set of the study was carried out to know the status of shrimp farming in Kerala with the aim of understanding the reasons for the lukewarm development of the sector in the state and with the ultimate aim of evolving a management plan for the sustainable development of the sector. This study was conducted during the period from September 2015 to May 2018.

2.4.1. Areas suitable for inland fish production

Kerala has rich and diverse water resources. It has around 4.11 lakh hectares of inland water bodies amenable for fish production, in one way or the other.

Details regarding the type and extent of inland water resources available in the state for fish and shellfish production are provided in Table 2.3. It may be

pointed out here that the extent indicated here is inclusive of freshwater and brackish water bodies but is exclusive of marine waters. It also includes paddy fields that remain waterlogged during part of the year.

Table 2.3. Type and extent of inland water resources of Kerala.

Sl. No.	Type of water body	Number	Area (ha)
A	**Freshwater resources**		
1	Private ponds	35763	21986
2	Panchayath ponds	6848	1487
3	Quarry ponds	879	341
4	Holy ponds	2689	480
5	Village ponds and other water holds	185	496
6	Irrigation tanks	852	2835
7	Public sector freshwater fish farms	13	85
8	Freshwater lakes	9	1620
9	Rivers	44	85000
10	Check dams	80	259
11	Bund/ barrier/ anicut/ shutter water holds	70	879
12	Reservoirs	53	42890
13	Kole lands	-	17000
14	Kuttanad *padasekharams*	-	35000
15	Other paddy fields*	-	120000
B	**Brackish water resources**		
16	Brackish water area**	-	65213
17	Backwaters	53	46129
18	Prawn filtration fields	234	12873
19	Public sector brackish water farms	12	227
20	Estuaries	84	
21	Mangrove areas	-	1924

* Where fish culture can be practised
** Includes backwaters and canals but excludes the prawn filtration fields

2.4.2. Brackish water areas available for shrimp farming

Information on district wise availability of brackish water areas in Kerala, which may be harnessed for shrimp production, is provided in Table 2.4. It reveals that the Ernakulam district has the largest brackish water areas suitable for shrimp farming, followed in order by Alapuzha, Kollam, Kannur, Kottayam, and Thrissur Kozhikkode, Kasargod, Malappuram and Thiruvananthapuram districts. The area indicated does not include prawn filtration fields, including the pokkali fields of Central Kerala and the kaipad fields of North Kerala.

Table 2.4. District-wise details of brackish water areas available in Kerala*.

Sl. No.	Name of district	Area (ha)**
1.	Kasargod	3248.25
2.	Kannur	5944.10
3.	Kozhikkode	4162.44
4.	Malappuram	1796.26
5.	Thrissur	4271.94
6.	Ernakulam	16212.71
7.	Kottayam	4326.74
8.	Alapuzha	15222.92
9.	Kollam	8603.62
10.	Thiruvananthapuram	1423.98
	Total	65212.96

* ADAK (1991)
**Includes backwaters and canals but excludes the prawn filtration fields

2.4.3. Physicochemical parameters of potential areas for shrimp farming

The physicochemical parameters of water in various stations (in lakes/ backwaters/ downstream portion of the rivers) selected for the study are presented in Table 2.5. These waterbodies are the source of water to the shrimp farms functioning at present and the ones set up in the future.

As has already been mentioned, the traditional system of prawn farming is practised in the low-lying coastal brackish water fields in Central and North Kerala. The former is popularly known as pokkali prawn farming and the latter as kaipad prawn farming. Pokkali fields lie mostly in the coastal villages of Thrissur, Ernakulam, Alleppey and Kottayam districts in Central Kerala. Kaipad fields, on the other hand, are located in Kannur, Kasargod, and Kozhikkode districts in North Kerala.

In both the systems, soon after the paddy harvest, if the owners themselves do not do shrimp farming, the fields are leased out to prawn farmers for 5 to 6 months, *i.e.*, November to mid-April. The lease value varies depending upon the productivity of the field, which is decided by the location of the field and the proximity to the bar mouth.

2.4.4. Mode of shrimp farming

The distribution of traditional and scientific shrimp farming units in Kerala in terms of number and extent is provided in Fig. 2.2. The majority of the shrimp farming units in Kerala is under traditional farming.

Table 2.5. Physicochemical parameters of water in various stations.

Parameter		Stations									
		1	2	3	4	5	6	7	8	9	10
Temperature (°C)	Maximum	31.50	30.00	31.50	31.50	32.00	33.00	32.00	31.00	30.00	31.00
	Minimum	22.50	23.90	22.40	23.80	22.90	22.70	23.50	23.50	22.50	23.80
	Mean	26.50	26.90	26.00	25.90	25.00	25.60	26.80	26.10	25.70	26.00
	Standard deviation	2.50	2.10	2.30	2.10	1.90	2.20	1.90	1.70	1.80	2.10
Salinity (ppt)	Maximum	34.00	34.00	32.00	32.00	34.00	32.00	31.00	32.00	33.00	33.00
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mean	22.00	22.00	20.00	23.00	23.00	22.00	21.00	21.00	20.00	21.00
	Standard deviation	2.56	2.01	2.02	2.89	2.62	3.25	3.20	2.90	2.85	2.84
pH	Maximum	8.30	7.90	7.40	8.20	8.30	8.00	7.90	7.40	7.60	8.10
	Minimum	6.90	6.30	6.50	7.00	6.70	7.00	6.90	5.80	6.20	6.20
	Mean	7.39	6.60	6.76	7.52	7.31	7.19	7.52	6.54	6.93	7.00
	Standard deviation	0.43	0.42	0.25	0.42	0.44	0.47	0.42	0.56	0.49	0.54
Turbidity (NTU)	Maximum	12.00	10.00	12.00	9.00	8.00	4.00	7.80	9.20	10.00	6.90
	Minimum	3.00	2.00	3.00	0.40	0.30	0.00	0.00	0.00	1.00	0.00
	Mean	8.00	6.00	7.80	6.00	5.70	1.90	1.50	2.20	3.00	1.10
	Standard deviation	1.20	1.80	1.40	1.90	1.60	080	0.80	1.60	1.80	0.80
Dissolved oxygen (ppm)	Maximum	7.10	6.80	7.30	6.50	7.30	6.80	6.90	6.50	5.60	8.00
	Minimum	4.10	1.20	4.30	4.10	4.30	5.20	4.90	4.80	3.00	5.30
	Mean	5.66	3.89	5.74	5.51	5.74	6.14	5.68	5.79	4.00	6.62
	Standard deviation	1.03	1.73	1.02	0.78	1.02	0.48	0.70	0.66	0.99	0.78
Total alkalinity (ppm as $CaCO_3$)	Maximum	180.00	90.00	88.00	136.00	140.00	98.00	90.00	142.00	146.00	154.00
	Minimum	19.00	18.00	12.00	15.00	28.00	20.00	20.00	40.00	28.00	24.00
	Mean	68.00	56.00	56.00	70.00	80.00	56.00	84.00	97.00	78.00	89.00
	Standard deviation	12.00	12.00	11.00	19.00	12.00	14.00	16.00	24.00	22.00	19.00
Nitrate- N (ppm)	Maximum	2.90	2.80	2.70	0.98	0.71	0.80	0.60	0.50	1.00	0.65
	Minimum	0.40	0.50	2.07	0.00	0.12	0.13	0.12	0.01	0.05	0.05
	Mean	1.90	1.60	2.39	0.45	0.38	0.42	0.40	0.25	0.39	0.27
	Standard deviation	0.62	0.66	0.45	0.32	0.17	0.25	0.20	0.15	0.35	0.18
Ammonia-N (ppm)	Maximum	1.20	1.80	0.71	0.64	0.60	0.30	0.30	0.06	0.30	0.09
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mean	0.66	0.78	0.12	0.06	0.13	0.07	0.08	0.02	0.07	0.01
	Standard deviation	0.42	0.61	0.16	0.20	0.17	0.09	0.08	0.03	0.09	0.02

*Station 1: Kadinamkulam lake (Thiruvananthapuram district), Station 2: Ashtamudi lake (Kollam district), Station 3: Vembanad lake (Kottayam district), Station 4: Punnamada lake (Alapuzha district), Station 5: Vembanad lake (Ernakulam district), Station 6: Kodungallur lake (Thrissur district), Station 7: Tirur- Ponnani river (Malappuram district), Station 8: Korapuzha river (Kozhikkode district), Station 9: Kuppam river (Kannur district) and Station 10: Valiaparamba backwaters (Kasargod district).

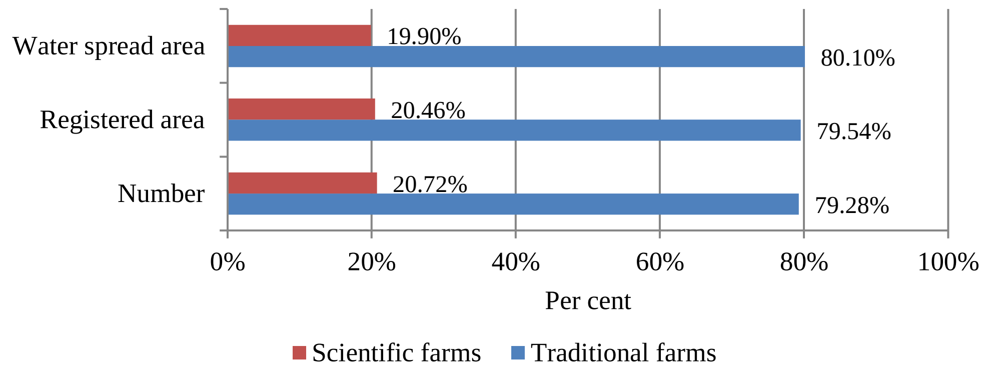


Figure 2.2. Percentage distribution of traditional and scientific shrimp farming units.

To commence the farming operation, the farmer prepares the fields by repairing the bunds, fixing sluice gates for regulating the flow of tidal water, and doing other work. Paddy stumps and straw left out in the field are not removed but are allowed to decay there to form good organic manure, which promotes the growth of algal pastures, including the periphyton. Stocking is done by letting tidal water into the fields at high tide. Along with the tidal water, juveniles of prawns from the adjoining backwater areas enter the field. They are attracted to the field by keeping a light source at the sluice gate during the night. When the tidal water starts receding during the low tide, a closely tied screen made of split bamboo or areca nut tree (nowadays mainly nylon nets fixed to the wooden frame) is inserted across the sluice gate and water alone is let out, trapping the juvenile prawns that have entered the field. This sort of entrapment is continued at every high tide throughout the operation.

Of late, obviously, on account of the scarcity of juvenile prawn in the adjoining water bodies and consequent failure in the natural stocking of shrimp seeds, most of the farmers undertake supplementary stocking at a low density with hatchery-produced seeds of black tiger prawn (*P. monodon*) @ 0.5-2 m^{-2} or Indian white prawn (*P. indicus*) @ 2-5 m^{-2} or Pacific white prawn (*L. vannamei*) @ 2-5 m^{-2}, in the fields. Harvesting, known as filtration, begins in mid-December. Harvesting is done during the low tide by operating a conical net fixed at the sluice gate. Sluice net operation (filtration) is done at dawn and dusk for 5 to 8 days around every new moon and full moon period (locally known as *thakkom*), during which the maximum tidal amplitude is experienced. The final total harvesting, locally known as *kalakki pidutham* or *kettu kalakkal* is done at the end of the season by operating a sluice net, cast net, and by handpicking.

Shrimps feed on natural foods that enter the pond regularly with the tides and are subsequently enhanced by organic or chemical fertilisers. If available at a lower cost, fresh fish or molluscan (mostly clam) meat are provided as supplementary feed. Since the stocking density is low, large-sized shrimps are harvested within six months.

Scientific prawn farming is practised in all coastal districts and the low-lying brackish water areas in the Kottayam district. Here the ponds constructed exclusively for the purpose are used for farming shrimp, adopting scientific management practices. It involves eradicating weed and predatory fishes, fertilisation, and liming to correct the pH. The ponds are stocked with hatchery-produced seeds of shrimps which are fed with farm-made and/or factory-produced feeds. Water quality is regularly monitored. The farming period generally extends to four months, though few farms undertake extended or shortened culture.

2.4.5. Species of shrimps farmed

In the study, 89.51% of the traditional shrimp farms were found to resort to supplementary stocking, and the rest were found not to. Of the farms which undertook supplementary stocking, 95.17% stocked *P. monodon,* 1.38% stocked *P. indicus,* and 3.45% stocked *L. vannamei* seeds. In terms of area, the corresponding figures were 95.57%, 1.25%, and 3.18%, respectively. In addition to the species stocked, *P. semisulcatus, Metapenaeus monoceos, M. dosoni and M. affinis* were harvested in prawn filtration fields. 91.38% of the scientific farms cultured *P. monodon,* 5.17% cultured *P. indicus,* and 3.45% cultured *L. vannamei*. In terms of area, the corresponding figures were 90.42%, 1.15%, and 8.43%, respectively.

2.4.6. Size of shrimp farms

Farm size is a crucial factor in deciding the success of shrimp farming. In the present study, the mean size (water spread area) of traditional shrimp farms was found to be 1.61 ha and that of the scientific farms, 1.53 ha. Information on the percentage distribution of shrimp farms based on their size is presented in Table 2.6.

2.4.7. Site selection for shrimp farming

The selection of a site for farming is one of the most critical aspects in determining the yield of shrimp and, in turn, the success of shrimp farming. Important information collected on various aspects of selecting a site for shrimp farming is provided below. These include topography, tidal flow, pollution, water source, various physicochemical qualities of soil (soil texture, soil nutrients, soil pH), and water (water temperature, water salinity), road access and electrical connectivity.

Table 2.6. Percentage distribution of shrimp farms based on their size (water spread area).

The size range of farms (water spread area in ha)	Traditional farms (%)	Scientific farms (%)
Less than 0.50	5.56	22.41
0.50-1.00	14.19	24.14
1.00-2.00	29.01	24.14
2.00-3.00	9.88	6.90
3.00-4.00	8.64	5.17
4.00-5.00	5.56	5.17
5.00-6.00	5.56	3.45
6.00-7.00	5.56	1.72
7.00-8.00	4.94	1.72
8.00-9.00	3.70	1.72
9.00-10.00	3.70	1.72
More than 10.00	3.70	1.72

2.4.7.1. Topography

All shrimp farms studied were found to be situated in low-lying brackish water areas. Traditional farms were tide-fed and were mostly not fully drainable except perhaps during the periods of the lowest low tide. On the other hand, scientific shrimp farms were pump-fed (at least partly), and a large number of them were fully drainable (Fig. 2.3).

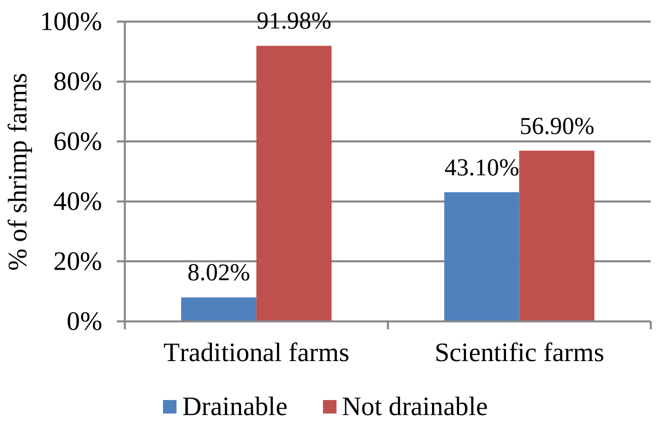


Figure 2.3. Percentage distribution of shrimp farms that are fully drainable/ not drainable.

2.4.7.2. Tidal flow

The traditional shrimp farms should invariably have free tidal water movements to ensure natural seed stocking and other benefits like water exchange. However, in the present study, it was found that the majority of the traditional farms do not experience sufficient tidal influence principally on account of reduction in the depth of water source (adjacent lakes/ rivers/ canals which feed water into these ponds) due to siltation, weed infestation, etc. or because of insufficient depth of ponds (Fig. 2.4).

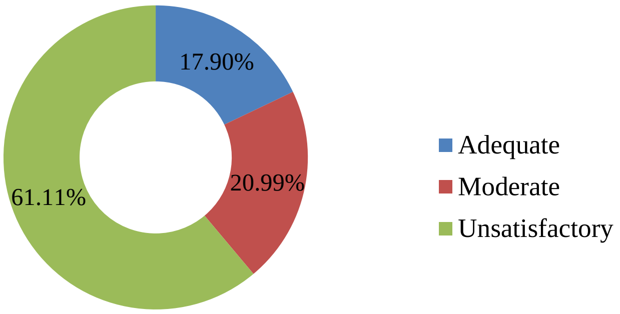


Figure 2.4. Percentage distribution of traditional shrimp farms based on tidal flow.

2.4.7.3. Pollution

For successful shrimp farming, the shrimp farming site must be free from pollution. The present survey indicated that the majority of the traditional farms and a sizeable number of the scientific farms are located in areas that are either polluted or are under the threat of pollution due to periodic discharge of pollutants from industrial, agricultural, hospital, sewage and/or other sources (Fig. 2.5).

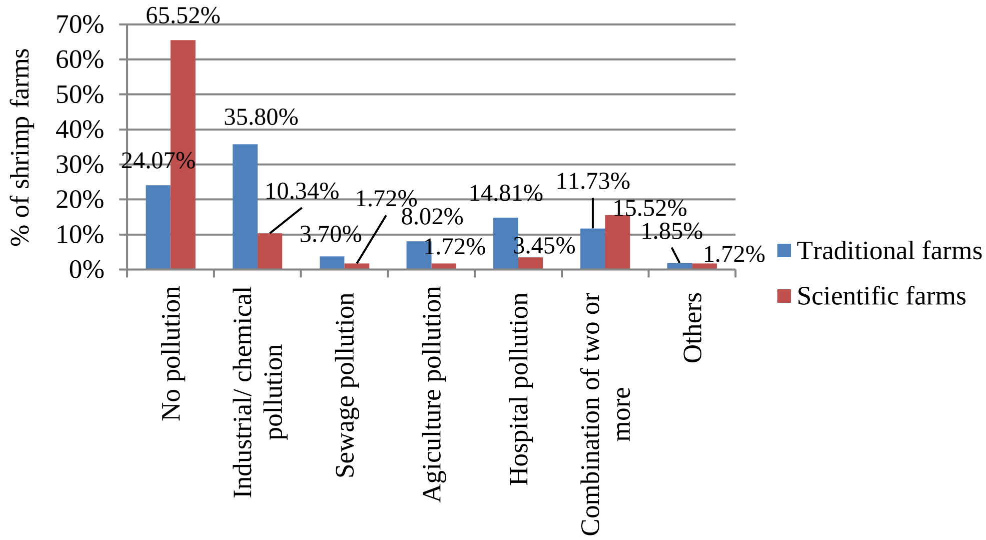


Figure 2.5. Percentage distribution of shrimp farms based on pollution risk.

Here, industrial/ chemical pollution also included pollution due to the retting of coconut husk. It may be mentioned here that the presence of pollution was ascertained based on visual observation, odour and/or based on the reports of the farmers/ local inhabitants of the area and/or recent reports of mass kill of fishes in the locality. No chemical analyses of water were carried out to ascertain the inference or identify the pollutants.

2.4.7.4. Temperature

Data on average high and low water temperatures at the water intake points of the traditional and scientific shrimp farms are presented in Fig. 2.6. The maximum temperature was recorded in May, and the minimum was noticed in December.

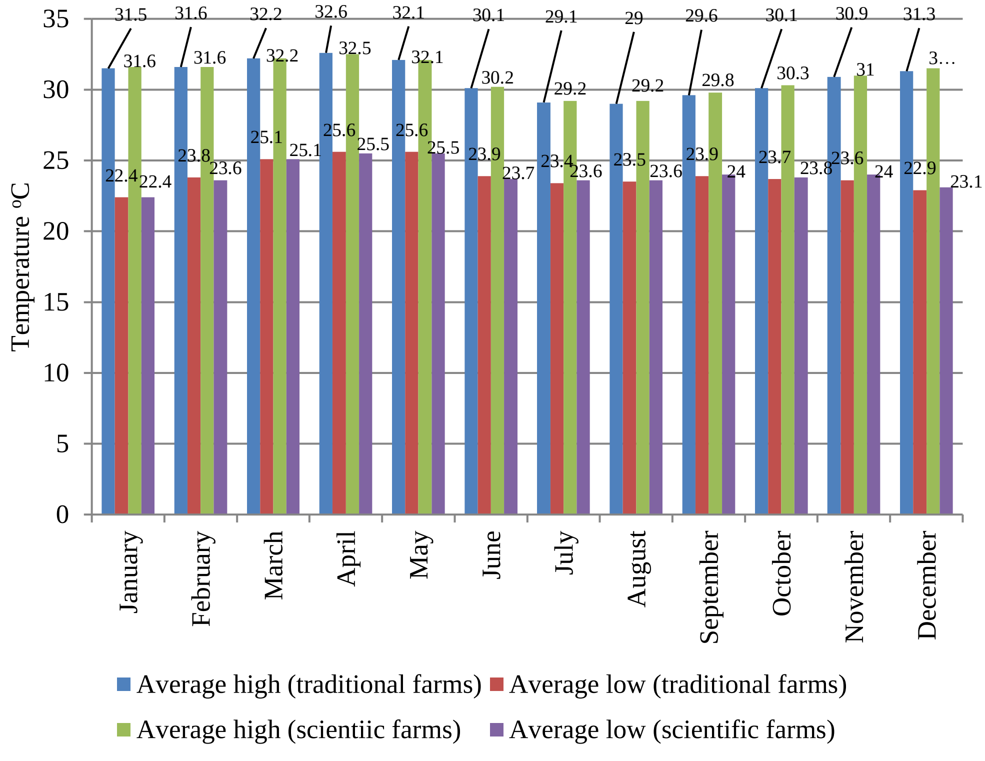


Figure 2.6. Monthly variation in average water temperature at the water intake points of the shrimp farms.

2.4.7.5. Salinity

The monthly variation of salinity at the water intake points of the traditional and scientific shrimp farms is presented in Fig. 2.7. In general, the maximum salinity was recorded during May, and the minimum was noticed during July.

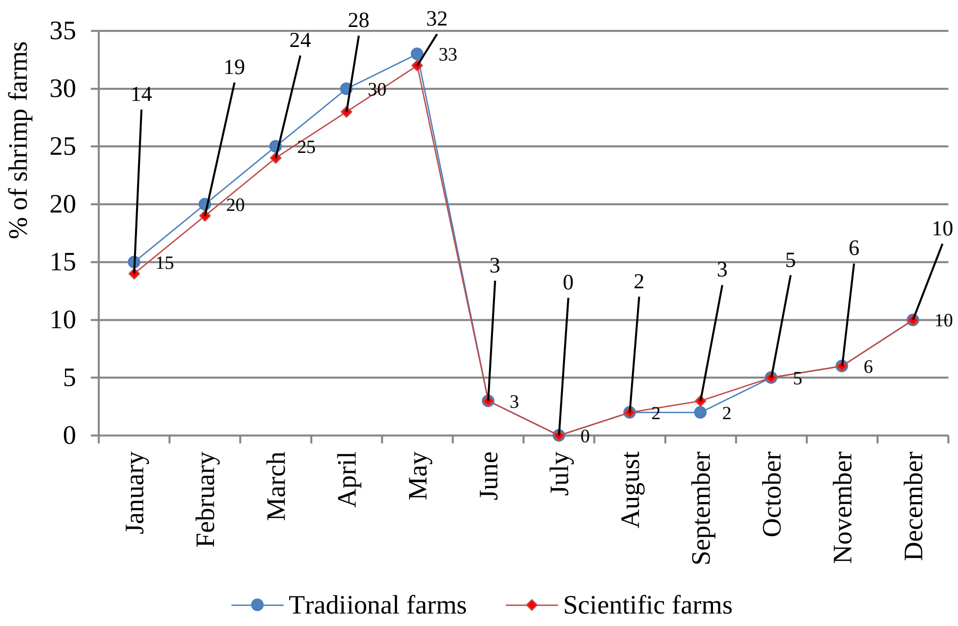


Figure 2.7. Monthly variation in average salinity at the water intake points of the shrimp farms.

2.4.7.6. Source of water

100% of the shrimp farms (traditional and scientific farms) were found to draw their water from adjacent backwaters/ brackish water lakes and/or canals connected to backwaters/ lower stretches of rivers. The traditional farms were found to be tide-fed. However, scientific farms were partly tide-fed and partly pump-fed. When the tidal effects re insufficient to bring in or drain sufficient water, the scientific farms resorted to pumping. No farms were found to use groundwater.

2.4.7.7. Soil texture

The soil plays a vital role in determining the fertility of shrimp ponds. The primary criterion for selecting a site for the construction of ponds is that the soil should not be porous. The information on the soil texture of the shrimp farming sites is provided in Table 2.7. The percentage distribution of shrimp farms based on the soil texture is given in Fig. 2.8.

In general, the soil in shrimp farming areas was sandy clay loam. The soil was relatively stiff and somewhat impervious. The soil in these fields was hard and created fissures when dry and sticky when wet. During the summer months, the soil became saline due to the ingression of saltwater from the sea.

Table 2.7. Soil texture of shrimp farms.

Type of farms	Sand (%)	Silt (%)	Clay (%)
Traditional farms	55.00	21.00	24.00
Scientific farms	59.00	19.00	22.00

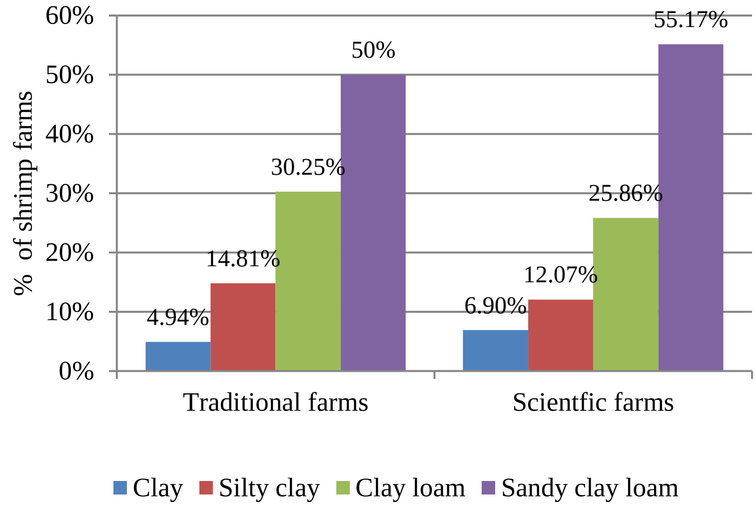


Figure 2.8. Percentage distribution of shrimp farms based on the texture of the soil.

2.4.7.8. Soil nutrients

Information on principal soil nutrients in traditional and scientific shrimp farming areas are presented in Table 2.8.

Table 2.8. Nutrient content of shrimp farming areas.

Nutrient	Traditional farms		Scientific farms	
	Range	Mean	Range	Mean
Organic Carbon (%)	0.44- 3.96	1.90	0.52-3.34	1.68
Nitrogen (kg ha^{-1})	140.26- 787.13	364.32	178.63- 678.85	344.95
Phosphorous (kg ha^{-1})	13.93- 54.29	42.95	8.55-51.28	23.77
Potassium (kg ha^{-1})	1469.93- 3564.07	2369.81	1339.08- 3430.05	2208.82
Calcium (mg kg^{-1})	856.66- 2664.00	2062.60	812.65-2275.00	1909.46
Magnesium (mg kg^{-1})	26.43- 46.71	36.90	21.30-43.60	35.68

2.4.7.9. Soil pH and potential acidity

Information on the soil pH of shrimp farms in Kerala is provided in Fig. 2.9. In general, the soil was found to be acidic, the pH being 3.3- 6.8. In Kerala, 83.95% of the traditional shrimp farm units and 75.86% of the scientific farm units were located in acid sulphate/ low pH areas (pH less than 6). Some traditional farms (11.73%) and scientific farms (1.72%) were also located in coconut retting areas containing a high concentration of hydrogen sulfide, which is lethal to shrimp. Percentage distribution of shrimp farms according to soil pH is provided in Fig. 2.10.

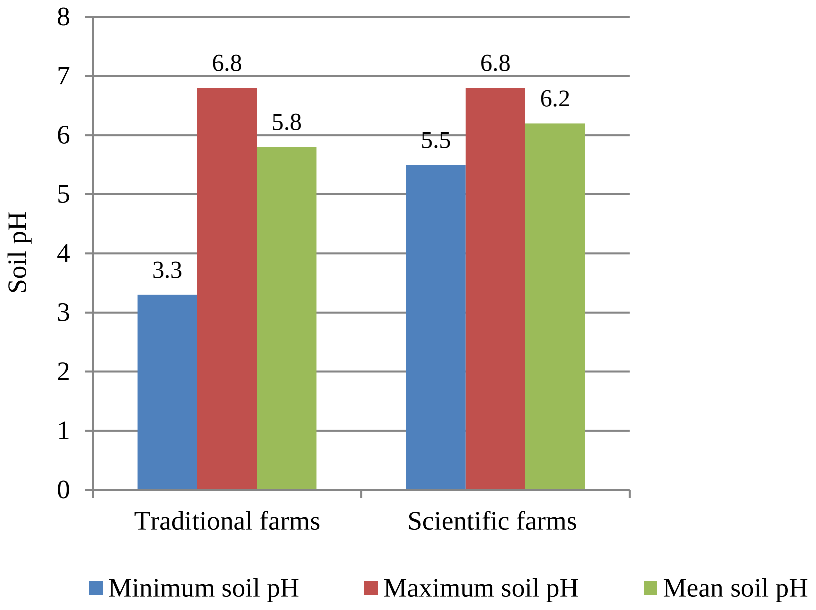


Figure 2.9. Soil pH of shrimp farms.

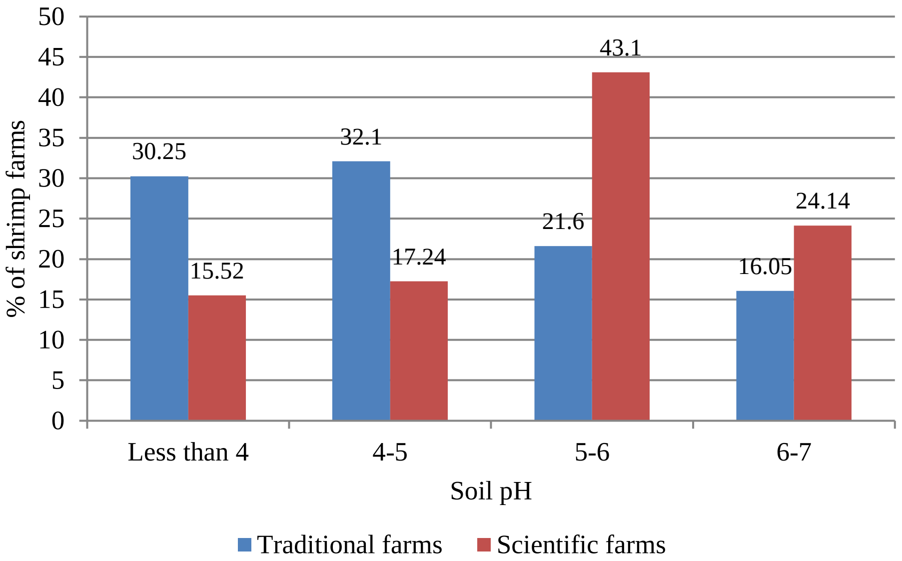


Figure 2.10. Percentage distribution of shrimp farms based on soil pH.

2.4.7.10. Access to power and road

Only 16.05% of the traditional farms and 27.59% of the scientific farms were found to have electric power connectivity (service connection from Kerala State

Electricity Board). 17.90% of traditional farms and 53.45% of the scientific farms depended on generator sets for power. Others did not have access to electric power. Similarly, only 35.80% of the traditional farms and 51.72% of the scientific farms had road connectivity.

2.4.8. Farm design and construction

Various information collected on the design and construction of shrimp culture ponds are provided below.

2.4.8.1. Size of pond

Traditional shrimp farms were found to have ponds ranging in size between 0.22 and 5.5 ha. The average size was 0.48 ha. On the other hand, scientific shrimp farms were found to have ponds ranging in size between 0.10 and 2.26 ha, and the average size of ponds was 0.38 ha. The information on the size of shrimp ponds is provided in Table 2.9.

Table 2.9. The size range of shrimp ponds (ha).

Type of farms	% of the total number of ponds							
	<0.25 ha	0.25-0.5 ha	0.5-1 ha	1-2 ha	2-3 ha	3-4 ha	4-5 ha	5-6 ha
Traditional farms	22.22	39.50	11.11	9.88	9.88	2.47	2.47	2.47
Scientific farms	17.24	43.10	15.52	13.79	10.34	0.00	0.00	0.00

2.4.8.2. Shape of pond

The information on the shapes of shrimp ponds is provided in Table 2.10. Generally, ponds were found to be rectangular in shape. A sizeable number of traditional ponds are irregular in shape. Irregular ponds, in general, were found to be difficult to manage. They were seen to pose difficulties, especially during the harvest.

Table 2.10. The shape of shrimp ponds.

Type of farms	% of the total number of ponds					
	Triangular	Rectangular/ square /rhomboidal	Circular/ elliptical	Pentagonal	Octagonal	Irregular
Traditional farms	1.23	38.27	1.23	11.73	8.64	38.89
Scientific farms	0.00	77.59	0.00	17.24	3.45	1.72

2.4.8.3. Depth of pond

The majority of shrimp ponds had effective depths of less than 1.2 m. The details are provided in Fig. 2.11.

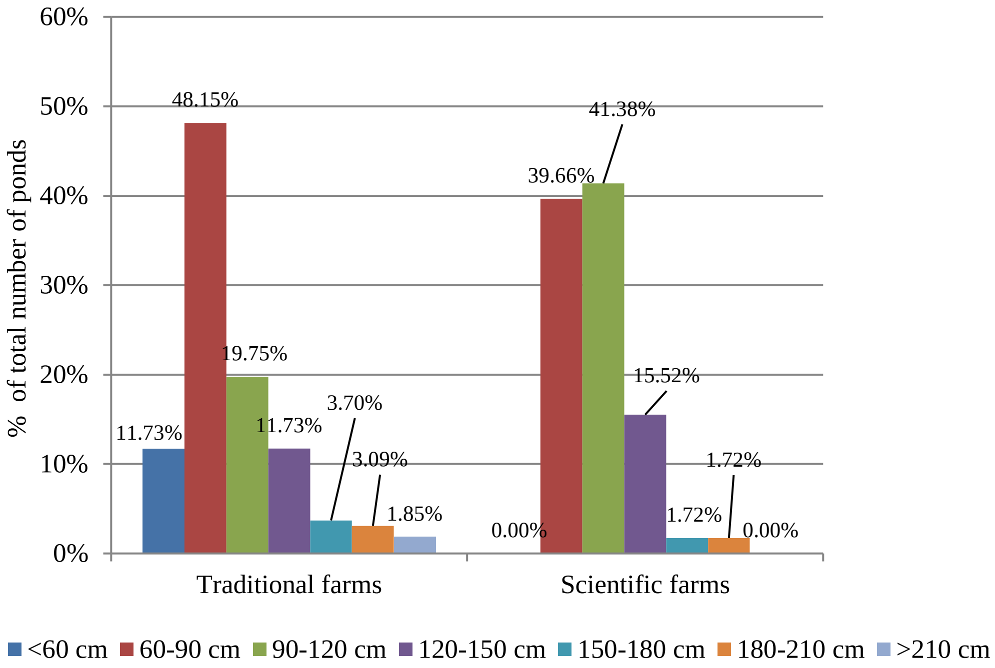


Figure 2.11. The effective depth of shrimp ponds (as % of the total number of ponds).

2.4.8.4. Water intake, distribution and discharge facility

All farms were observed to exchange their water directly through sluice gates provided for the purpose. 58.02% of the traditional farms and 82.76% of the scientific farms had concrete sluice gates, and the rest had wooden sluice gates. Farms generally did not have monks/ pipes/ turn-down pipes for water exchange. No farms were found to have separate water inlet and water outlet canals for water distribution/ exchange. The majority of the farms were observed generally to take in and discharge water through the same sluice gates, and in the case of pump-fed farms, the intake points and discharge points were found to be the same or not situated far apart. No farms were observed to have a central drainage system. Proper screening or water filtration is a pond management practice that has recently improved. Traditionally, the gate screen was made of bamboo slats with wooden frames. Of late, both traditional and scientific farmers have shifted to nylon screens instead of bamboo slats.

2.4.8.5. Intake reservoirs and effluent treatment ponds (ETP)

No farms had separate reservoirs for temporarily storing the water. Shrimp farms were generally found close to the backwaters/ brackish water canals so that they could pump water easily. No farms had Effluent Treatment Ponds (ETP). The farms (except zero water exchange units) were found generally to let out water directly to the backwaters/ canals during the low tide whenever required.

2.4.8.6. Aeration system

No traditional farms had aerators. 48.28% of the scientific farms were found to use aerators for artificial aeration; others used no aerators. Paddlewheel aerators were the only type of aerators in use in farms. Paddlewheel aerators in use were surface floating type and generally had 1 or 2 horsepower (hp) capacity. The former has two blades and the latter four blades.

2.4.9. Pond management

The various pond management measures adopted by the shrimp farmers are provided below. These include pre-stocking, stocking and post-stocking management.

2.4.9.1. Pre-stocking management

Pre-stocking management involves a series of activities of pond preparation before the stocking of seed. It includes draining the pond, repairing the bunds and sluice gates, drying the pond bottom, reconditioning the bottom soil, water filling, eradicating weed and predatory fishes, ensuring sufficient plankton production (development of watercolour), pond disinfection and associated activities.

2.4.9.1.1. Draining the pond, drying and ploughing the bottom

Generally, traditional farms were found not to drain the ponds entirely and dry the pond bottom as a pre-stocking management measure. On the other hand, 86.21% of the scientific farms were observed to drain and dry the pond bottom as a pond management measure. Others were generally observed not to drain and dry the pond bottom. 46% of the scientific farms which drain and dry the ponds were found to plough the pond bottom.

2.4.9.1.2. Repair of bund and sluice

All farms (traditional and scientific) were found to repair bunds and sluice gates before beginning the farming operation.

2.4.9.1.3. Liming

64.20% of the traditional farms and 100% of the scientific farms were observed to resort to liming as a measure of pond preparation, principally to correct the soil pH and improve total alkalinity. The dosage of lime application varied with soil pH and was found to be between 200 kg ha^{-1} and 1500 kg ha^{-1}.

Agriculture lime ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) were the most common lime materials in use. The lime was applied as basal dose during pond preparation and subsequently during the grow-out phase whenever the water pH lowered. In general, the quantity of lime to be used was determined based on trial and error or based on the farmer's experience.

2.4.9.1.4. Eradication of predatory and weed fishes

37.03% of the traditional shrimp farms and 100% of the scientific farms were observed to eradicate weed and predatory fishes before seed stocking. 60% of the farms that eradicated weed and predatory fishes used tea seed cake to kill the fishes. 10% of the farms used mahua oilcake, 15% used a mixture of ammonium sulphate and lime, 10% used quick lime or calcium oxide, and 5% used other plant toxicants to eradicate weed and predatory fishes. 5.17% of the scientific farms were seen to drain the pond and dry the bottom as the sole measure to eradicate weed and predatory fishes. 50% of the scientific farms were found to use tea seed cake, 10.34% mahua oilcake, 10.34% a mixture of ammonium sulphate and lime, 12.07% bleaching powder, and 12.07% quick lime (calcium oxide) to eradicate these fishes. 18.97% of the scientific farms were seen to use only one method to eradicate fishes, while 81.03% were found to adopt more than one method for the purpose. The doses of various chemicals/ toxicants in use are provided in Table 2.11.

2.4.9.1.5. Fertilisation

67.90% of the traditional farms and 72.41% of the scientific farms were found to undertake fertilisation to improve soil fertility and facilitate the growth of phytoplankton. Fertilisation was done at the time of pond preparation (either as basal fertilisation or during water preparation). Cow dung and chicken manure were the organic fertilisers in use. Dolomite, superphosphate, Mussoorie rock phosphate and urea were found to be the principal inorganic fertilisers used. The doses of different fertilisers used are provided in Table 2.12. The rate of fertilisation was mainly based on the prior experience of the farmer or by trial and error.

Table 2.11. Doses of fish toxicants used in shrimp farms to eradicate weed and predatory fishes.

Fish toxicant	Dose (ppm)	Method of application
Mahua oil cake	200-250	Soaked in water and spread over the water surface
Tea seed cake	10-20	Soaked in water and spread over the water surface
Quick lime	100-200	Broadcast over the water surface/ mixed with water and applied over the water surface
A mixture of ammonium sulphate and lime in 1:1.8 to 1: 5 ratios	10-15 (ammonia)	Broadcast over the water surface/ mixed with water and applied over the water surface In some farms, lime is applied first to raise the pH of the water to above 8, and then ammonium sulphate is applied.
Bleaching powder (chlorine content: (24-30%)	5-20 (available chlorine)	Broadcast over the water surface/ mixed with water and applied over the water surface

Table 2.12. Doses of fertilisers in use in shrimp farms

Fertiliser	Dose kg ha^{-1}	Method of application
Cow dung	500-2000	Basal fertilisation before water filling
Chicken manure	150-750	Basal fertilisation before water filling
Nitrate fertiliser	50-200	Broadcasting over the water surface/ mixed with water and applied over the water surface after filling water to 30-60 cm level
Phosphate fertiliser	50-200	Broadcasting over the water surface/ mixed with water and applied over the water surface after filling water to 10-30 cm level

Fertilisers, in general, are applied by any one of the following methods (i) Direct broadcasting (ii) Dissolved in a tank/ bucket of water, and the resultant mixture/ liquid is dispersed over the entire surface of the pond (iii) Kept in an empty feed bag or fertiliser cage at the sluice gate, allowing the water currents to dissolve them slowly.

2.4.9.1.6. Ensuring adequate plankton production

Adequate plankton production ('development of watercolour') is crucial to ensure before seed stocking. It may be ascertained by observation of watercolour supported by Secchi disc reading. Most of the shrimp farms (100% of the traditional farms and 60.34% of the scientific farms) were not seen paying adequate attention to ensure sufficient plankton growth and healthy watercolours (green, brown, brownish-green and yellowish-green) in shrimp ponds before stocking. In most shrimp ponds, watercolour was not seen developed, indicating insufficient phytoplankton growth.

2.4.9.1.7. Pond disinfection

No traditional farms were found to disinfect their ponds as a management measure. On the other hand, 12.07% of the farms were seen to use bleaching powder to disinfect the pond water and/ or kill the eggs and juveniles of fishes, crustaceans, and other organisms that reach the ponds through the incoming water. Bleaching powder (chlorine content: 24-30%) @ 5- 20 ppm available chlorine was observed to be used to disinfect the ponds.

2.4.9.1.8. Use of probiotics

Several products under the name probiotics are used by farmers to enhance beneficial chemical and biological processes and improve soil quality. No traditional farms were found to use these products. However, 81.03% of the scientific farms were observed to use such chemicals regularly or occasionally. 65.52% of the scientific farms regularly used probiotics and bacterial consortiums as a pond management measure. No effort was made in the present study to collect evidence to the effect that any of these products would improve soil quality or growth of prawns. Scientific farmers in the study area in gereral were seen convinced about the advantages of using probiotics.

2.4.9.2. Grow-out stocking

As mentioned in section 2.4.5, 89.51% of the traditional shrimp farms were found to resort to supplementary stocking. Of the total farms which undertook supplementary stocking, 95.17% stocked *P. monodon,* 1.38% stocked *P. indicus,* and 3.45% stocked *L. vannamei* seeds. Similarly, 91.38% of the scientific farms cultured *P. monodon*, 5.17% cultured *P. indicus,* and 3.45% cultured *L. vannamei*.

2.4.9.2.1. Source of seed

59.79% of the traditional farms that undertook supplementary stocking (48.15% of the total traditional farms) and 72.41% of the scientific farms depended on seeds produced in hatcheries functioning outside the state of Kerala. The seeds were mainly brought from Tamil Nadu, Pondicherry, Andhra Pradesh and Karnataka. The rest of the farms depended on hatcheries functioning inside the State for their seed requirement. 43.59% of the traditional farms that depended on seeds from hatcheries functioning outside Kerala were found to source the seeds through seed supply agents. The rest were found to procure the seeds directly from the seed production centres. Similarly, 38.10% of the scientific farms that depended on seeds from hatcheries functioning outside the state were found to get them through seed supply agents. The rest procured the seeds directly from the hatcheries.

There is no system for seed certification, and none of the hatcheries had accreditation. But they were registered under competent authorities under the CAA act and/ or under the concerned state act.

2.4.9.2.2. Seed transport

All farmers were found to observe proper time for seed transport and stocking keenly. To ensure higher survival, the harvest and transport of seeds must be done at the earliest possible time to reach the pond before sunrise. Seed transport was seen generally done during the night hours, in the case of seeds from distant places. Stocking, including acclimation, were observed to be finished, generally, not later than 9.00 am, *i.e.*, before the temperature rise. Transport of seed was done with the use of oxygenated plastic bags. The bags were placed inside styrofoam boxes. Older or bigger seeds were seen transported in aerated tanks. In both cases, ice was found used to reduce and maintain the water temperature at 20-22 °C during transportation to reduce the metabolic rates. Counting of seed was found to be done at the source (hatchery). It was found to help farmers stock the seeds immediately on reaching the farm without undergoing the hassles of counting.

2.4.9.2.3. Age of the seed

Information on the age/ size of shrimp seeds used by shrimp farmers is provided in Table 2.13. The majority of the farms were found to use seeds, which were 20 days or less in age.

Table 2.13. Age of seeds used for stocking in the shrimp farms.

Type of farms	< PL 20	PL 20- 25	PL 25-30	>PL 30
Traditional farms	51.85%	34.57%	11.73%	1.85%
Scientific farms	67.24%	18.97%	10.34%	3.45%

Traditional farms were generally found not to use nursery reared seeds for grow-out pond stocking. A very few farms had temporary nurseries as part of the grow-out ponds where they rear the seeds occasionally. On the other hand, 13.79% of the scientific shrimp farms were seen to undertake nursery rearing of seeds for 15-20 days. To reduce the costs, some farmers were found to use net enclosures in the grow-out ponds themselves, where the juveniles were intended to be stocked. The rest of the farms were found to directly stock hatchery-produced seeds in grow-out ponds.

2.4.9.2.4. Seed quality

54.32% of the traditional farms and 87.93% of the scientific farms were found to undertake checking of quality of seeds before stocking. 77.27% of the former and 94.12% of the latter were seen to undertake the PCR test, but others were satisfied with visual observations and/or stress tests. Further, 41.18% of the traditional farms and 91.67% of the scientific farms that undertook PCR tests were found to get the test done by them. Others depended on the test results provided by the hatchery operators/ other agencies.

2.4.9.2.5. Acclimatisation

Acclimatisation of seed is an important management measure that has to be done with great care. 31.03% of the traditional farms undertaking supplementary stocking (27.78% of the total traditional farms) and 55.17% of the scientific farms were found to undertake adequate acclimatisation of seeds before stocking. 55.17% of the traditional farms undertaking supplementary stocking

(49.38% of the total traditional farms) and 36.21% of the scientific farms were found to undertake the acclimatisation of seeds but were inadequate. 13.79% of the traditional farms undertaking supplementary stocking (12.34% of the total traditional farms) and 8.62% of the scientific farms were found not to undertake acclimatisation of seeds.

10.34% of the scientific farms were found to use pond stocking survival buckets to evaluate stocking mortality for 48 hours. However, none of the traditional farms was found to adopt such a measure.

2.4.9.2.6. Stocking density

Information on stocking density adopted by the traditional and scientific shrimp farms is provided in Fig. 2.12 and Fig. 2.13, respectively.

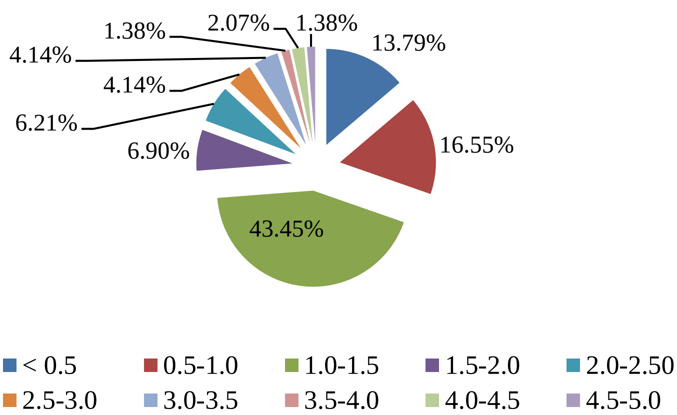


Figure 2.12. Percentage distribution of traditional shrimp farms based on stocking density (seed m^{-2}).

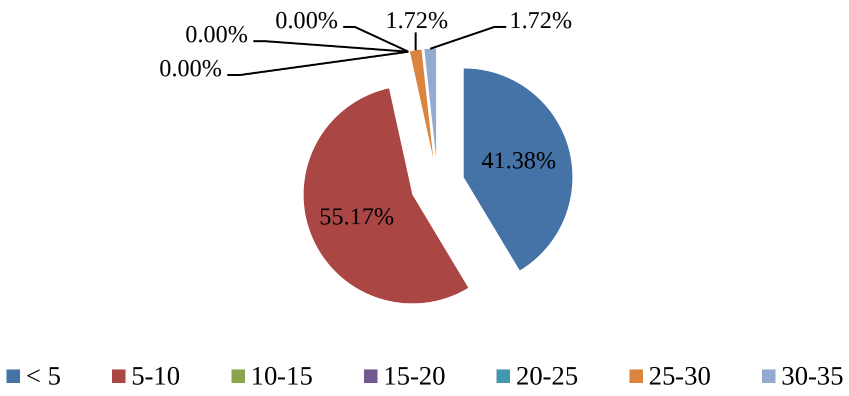


Figure 2.13. Percentage distribution of scientific shrimp farms based on stocking density (seed m^{-2}).

In the former, the stocking density shown is based on the supplementarily stocked seeds, and it does not include the naturally stocked seeds. The farmers were found to have no idea about the number and type of seeds entering the ponds with the incoming water. The percentage shown refers to the farms that undertook supplementary stocking (*i.e.*, 89.51% of the total traditional farms). In traditional farms, the average stocking density in the case of *P. monodon*, *P. indicus*, and *L. vannamei* were 1.25, 3.50, and 4.20 postlarvae m^{-2}, respectively. The corresponding average stocking densities in scientific farms were 5.71, 7.59, and 32 postlarvae m^{-2}. The stocking density in the traditional farms was observed to be decided more often based on the availability of stocking material and its price rather than any scientific considerations.

2.4.9.3. Post-stocking management

The most critical post-stocking management measures in shrimp farming include water quality management, feed management, disease management, control of weed and predatory fishes and assessment of growth and survival (biomass management).

2.4.9.3.1. Water quality management

It includes regular monitoring and controlling water quality parameters such as water temperature, water salinity, water pH, total alkalinity, total hardness, water turbidity etc.

2.4.9.3.1.1. Water temperature

In traditional farms, the average low surface water temperature varied between 22.8 °C and 25.7 °C and the average high surface water temperature varied between 30.1 °C and 32.6 °C in different months of the culture period, which extended from October/ December to April/ May. In scientific farming, the average low surface water temperature varied between 22.4 °C and 25.7 °C and the average high surface water temperature, between 31.5 °C and 32.70 °C in different months of the culture period (January/ March – April/ June), in the case of 65.52% of the farms. In 34.48% of the farms, the average low surface water temperature varied between 23.6 °C and 25.7 °C and the average high surface water temperature between 29.4 °C and 32.70 °C, in different months of the culture period (April/ May- July/ August).

2.4.9.3.1.2. Dissolved oxygen

Data on the percentage distribution of scientific farms based on average dissolved oxygen content (ppm) during the farming period recorded is presented in Table 2.14. Only 19.75% of the traditional farms and 65.52% of the scientific farms have facilities to measure dissolved oxygen at the farm level. As has already been mentioned under section 2.4.8.6., no traditional farms were found to have aerators. 48.28% of the scientific farms were found to use aerators for aeration; others used no aerators. Only 1.72% of the farms operated aerators for more than 12 hours per day.

Table 2.14. Percentage distribution of shrimp farms based on dissolved oxygen content (ppm) during the farming period.

Stage of crop (days)	Traditional farms (%)					Scientific farms (%)				
	Average dissolved oxygen content					Average dissolved oxygen content				
	5 and above	4-5	3-4	2-3	1-2	5 and above	4-5	3-4	2-3	1-2
30 days	43.83	41.98	14.20	0	0	41.38	41.38	17.24	0	0
30-60	41.98	38.27	19.75	0	0	39.66	34.48	18.97	6.90	0
60-90	38.27	35.80	22.22	3.70	0	36.21	34.48	22.41	6.90	0
90-120	31.48	35.80	25.93	4.94	1.85	29.30	32.76	29.31	5.17	3.45

The average duration of working (hours per day) of aerators in scientific farms is provided in Fig. 2.14. It does not include the use of aerators during emergencies.

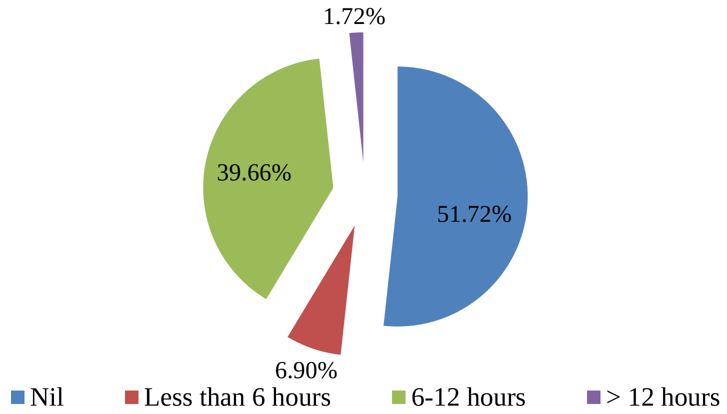


Figure 2.14. The average number of hours per day during which scientific shrimp farms operated aerators.

2.4.9.3.1.3. Water pH

Information on the percentage distribution of shrimp farms based on average water pH during the farming period is presented in Table 2.15. 22.22% of the traditional farms and 74.14% of the scientific farms were found to have facilities to measure water pH at the farm level.

Table 2.15. Percentage distribution of shrimp farms based on water pH during the farming period.

Type of farms	Average water pH				
	6-7	7-8	8-9	9-10	10-11
Traditional farms (%)	11.73	22.22	54.94	8.02	3.09
Scientific farms (%)	10.34	27.59	51.72	8.62	1.72

2.4.9.3.1.4. Total alkalinity

Information on the percentage distribution of shrimp farms based on the total alkalinity of water during the farming period is provided in Table 2.16. Total alkalinity includes carbonate (CO_3--), alkalinity, bicarbonate (HCO_3-) alkalinity and hydroxide (OH-) alkalinity.

Table 2.16. Percentage distribution of shrimp farms based on total alkalinity (as ppm $CaCO_3$) of water during the farming period.

Type of farms	Total alkalinity					
	< 20	20-100	100-200	200-300	300-400	400-500
Traditional farms (%)	6.17	35.80	38.89	15.43	1.85	1.85
Scientific farms (%)	3.45	39.66	44.83	5.17	5.17	1.72

2.4.9.3.1.5. Total hardness

Information on the percentage distribution of shrimp farms based on the total hardness of water during the farming period is provided in Table 2.17.

Table 2.17. Percentage distribution of shrimp farms based on total hardness (as ppm $CaCO_3$) of water during the farming period.

Type of farms	Total hardness					
	< 20	20-100	100-200	200-300	300-400	400-500
Traditional farms (%)	6.17	33.95	37.04	12.96	8.64	1.23
Scientific farms (%)	5.17	34.48	39.66	6.90	6.90	6.90

2.4.9.3.1.6. Water salinity

Information on the average salinity of shrimp farms during the culture period is presented in Fig. 2.15.

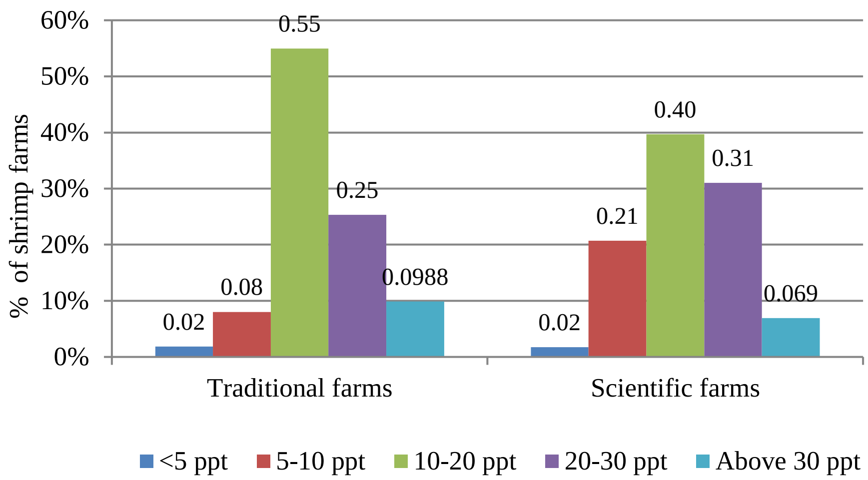


Figure 2.15. Percentage distribution of shrimp farms based on average salinity.

2.4.9.3.1.7. Water turbidity

No attempt was made in the present study to understand the substances that cause turbidity. There was also no attempt to relate the turbidity with the nature of the pond basin and the nature of inflowing water.

In the study, most traditional shrimp farms were found to maintain a Secchi disc turbidity range between 40 and 60 cm. The turbidity of most of the scientific farms was between 30 and 50 cm. The details are provided in Fig. 2.16.

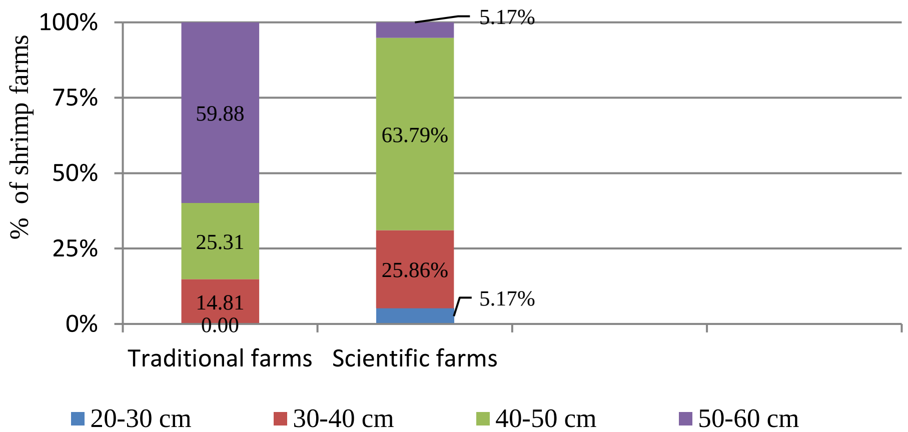


Figure 2.16. Percentage distribution of shrimp farms based on average Secchi disc turbidity (cm).

Secchi disc reading gives an idea about the plankton production in the pond, which may be corroborated with the visual observation of watercolour. Shrimp farmers, in general, were not seen paying adequate attention to developing and managing healthy watercolour in ponds.

2.4.9.3.1.8. Water exchange

Information on the average quantity of water exchanged per day by various traditional farms is provided in Fig. 2.17, and that by scientific farms is provided in Fig. 2.18. Most scientific farms do not resort to water exchange because they undertake zero-water exchange culture. Traditional farms generally are at the mercy of tides for water exchange. On the other hand, scientific shrimp farms depend partly on tides and partly on water pumps.

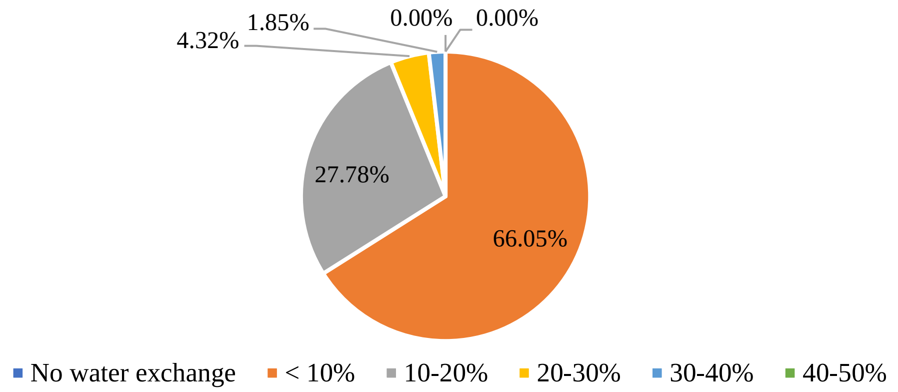


Figure 2.17. The average quantity of water exchanged in traditional shrimp farms.

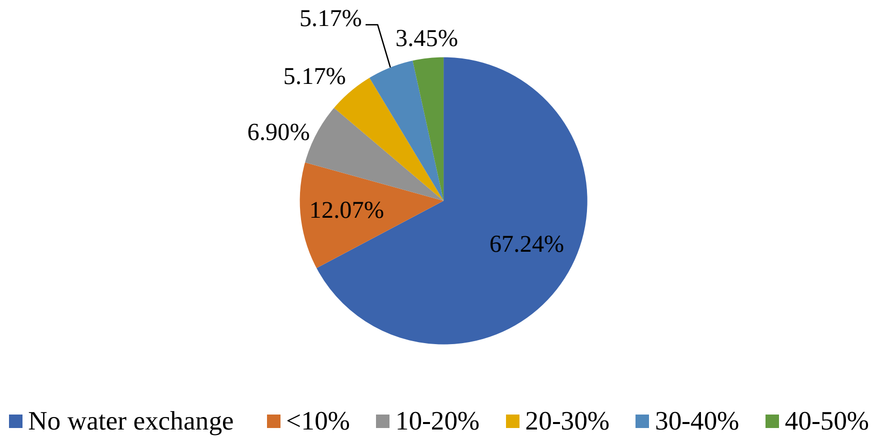


Figure 2.18. The average quantity of water exchanged in scientific shrimp farms.

2.4.9.3.2. Feed management

Information gathered on various aspects of feed and feed management are provided below.

2.4.9.3.2.1. Type of feed

Most of the traditional farms in the state were found not to use any good quality formulated feeds. Some were found to use farm-made feeds, the composition of which is decided more by economic consideration rather than nutritional. Groundnut oil cake, dry trash fish, dry clam meat, rice bran, wheat flour were the primary raw materials in use for making farm-made feeds. Vitamin and mineral mix were also found to be added by some farmers. Groundnut oil cake, which was abundantly in use in farm-made shrimp feeds until a couple of years back, was not widely used nowadays because of its escalating price. Coconut oil cake has replaced it, at least in some cases. Most of the scientific farms were found to use factory-produced feeds, and a few farms used farm-made feeds. Information on the type of feed used in shrimp farms is provided in Table 2.18. Clam meat is the most important wet feed used by shrimp farmers.

Table 2.18. Feeds used in traditional and scientific farming.

Type of farms	% of the total number of farms		
	No external feeds	Farm-made feeds	Factory-made feeds
Traditional farms	29.01	61.73	9.26
Scientific farms	0	8.62	91.38

2.4.9.3.2.2. Method of feeding

In all the farms observed, feeding has been done by broadcasting either from the bund or from small boats. Dinghies or small boats were seen used mostly in large ponds.

2.4.9.3.2.3. Assessment of demand for feed

In the present study, only 16.67% of the traditional farms and 87.93% of the scientific farms were found to ascertain the demand for feed with the help of feed check trays. The rest of the farms were observed to fix the quantity of feed based on farmers' assumptions or previous experience rather than any scientific assessment of the demand for feed. Extension workers of feed factories were also found to give advice on these aspects.

2.4.9.3.2.4. Frequency of feeding

Information on the number of meals provided in different farms is given in Table 2.19.

Table 2.19. Frequency of feeding (number of meals per day).

Type of farms	% of the total number of farms				
	No external feeding	Frequency of external feeding			
		Once	Twice	Thrice	Four times
Traditional farms	29.01	61.73	9.26	0	0
Scientific farms	0%	15.52	50.00	25.86	8.62

In farms where feeding was done once a day, it was seen given in the late evening hours (mostly 6.00 pm). In farms where feeding was done twice daily, the feeding was found scheduled at 6.00 am (40% of the daily feed ration) and 6.00 pm (60% of the ration). In the case of farms in which feeds were given thrice daily, the feeding times were usually 6.00 am (30% of the ration), 6.00 pm (40% of the ration) and 10.00 pm (30% of the ration). Similarly, in the case of farms in which feeds were given four times daily, the feeding times were usually 6.00 am (25% of the ration), 10.00 am (20% of the ration), 4.00 pm (35% of the ration) and 10.00 pm (20% of the ration). The percentage distribution of feed ration shown is indicative and changed according to the instructions given by the feed manufacturer, the water temperature, stage of moulting, observation of the feed consumption in the feed check trays, etc.

2.4.9.3.2.5. Feed ration

Traditional farms were unable to ascertain the quantity of feed to be offered daily, as they could not estimate the biomass of shrimp and finfish available in each pond. Here the amount of feed was seen ascertained primarily based on wild assumptions and experience. A few traditional farms used feed check trays to understand the demand for feed. In the case of the majority of the scientific farms, the feed ration given was found to be ascertained based on an estimate of biomass of cultured animals, instructions given by the feed manufacturer, the water temperature, stage of moulting, observation of the feed consumption in the feed check trays, etc. The observation of feed consumption in check trays was found to be done based on the instruction of the feed manufacturer, and the interval varied between 45 minutes and two and a half hours depending on the growth stage of the prawn stocked. Two to four check trays were found to be used for every one-hectare pond. The average feed ration provided in scientific farming of *P. monodon*, *P. indicus*, and *L. vannamei* were found to be as given in Table 2.20, 2.21, and 2.22, respectively.

Table 2.20. Feed ration in scientific farming of tiger prawn.

	Weight of prawn (g)							
	Up to 1.0	1.0-5.0	5.0-10.0	10.0-15.0	15.0-20.0	20.0-25.0	25.0-30.0	30.0-35.0
Feeding rate (% of biomass)	8.0-12.0	5.5-6.5	5.0-5.5	4.5-5.0	4.0-4.5	3.5-4.0	3.0-3.5	2.7-3.0

Table 2.21. Feed ration in scientific farming of Indian white prawn.

	Weight of prawn (g)									
	0.02-1.5	1.5-2.5	2.5-4.0	4.0-7.0	7.0-9.0	9.0-11.0	11.0-13.0	13.0-15.0	15.0-17.0	>17
Feeding rate (% of biomass)	15.0-20.0	13.0-15.0	8.0-13.0	6.0-8.0	5.0-6.0	4.5-5.0	4.0-4.5	3.5-4.0	3.0-3.5	2.5-3.0

Table 2.22. Feed ration in scientific farming of Pacific white prawn.

	Weight of prawn (g)						
	0.02-1.5	1.5-2.5	2.5-4.0	4.0-7.0	7.0-15.0	15.0-22.0	>22
Feeding rate (% of biomass)	15.0-20	13.0-15	8.0-13.0	6.0-8.0	4.0-6.0	3.0-4.0	1.0-3.0

2.4.9.3.2.6. The nutritional composition of feeds

The average nutritional composition (proximate composition) of various farm-made feeds and wet feed (clam meat) used in different shrimp farms is provided in Fig. 2.19.

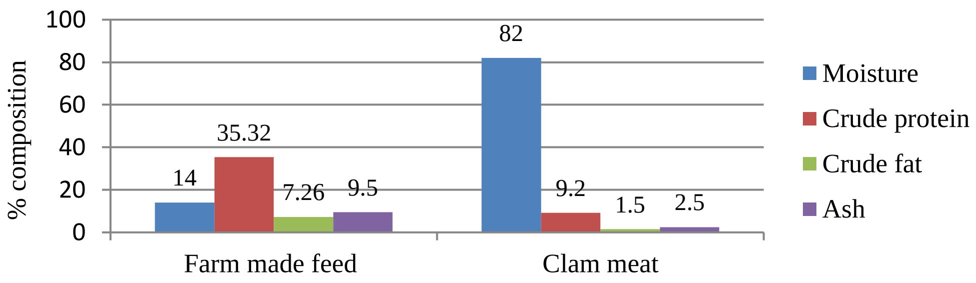


Figure 2.19. The average nutritional composition of farm-made feeds (% dry weight) and clam meat used (% wet weight).

The nutritional composition of various factory-made feeds used in shrimp farms is provided in Tables 2.23 and 2.24. It may be noted that since no feeds were available in the market exclusively for *P. indicus*, farmers used the feed meant for *L. vannamei* in the farming of *P. indicus*.

Table 2.23. The nutritional composition of factory-made feed for tiger prawn (% dry weight).

Type of feed*/stage of growth	Proximate composition (% dry weight)				
	Moisture	Crude protein	Crude fat	Crude fiber	Ash
1	11.0-12.0	38.0-41.0	4.0-6.0	3.0-5.0	15.0-16.0
2	11.0-12.0	38.0-41.0	4.0-6.0	3.0-5.0	15.0-16.0
3	11.0-12.0	38.0-41.0	4.0-6.0	3.0-5.0	15.0-16.0
4	11.0-12.0	38.0-41.0	4.0-6.0	3.0-5.0	15.0-16.0
5	11.0-12.0	38.0-40.0	4.0-5.0	3.0-5.0	15.0-16.0
6	11.0-12.0	38.0-40.0	4.0-5.0	3.0-5.0	15.0-16.0
7	11.0-12.0	38.0-40.0	4.5-5.0	3.0-5.0	15.0-16.0
8	11.0-12.0	38.0-40.0	4.5-5.0	3.0-5.0	15.0-16.0

* By type of feed is meant starter 1, starter 2, grower 1, grower 2, finisher, etc. or any other names designated by feed manufacturing companies.

Table 2.24. The nutritional composition of factory-made feed for white prawns* (% dry weight).

Type of feed**/stage of growth	Proximate composition (% dry weight)				
	Moisture	Crude protein	Crude fat	Crude fibre	Ash
1	11.0-12.0	36.0-41.0	4.0-6.0	3.0-5.0	15.0-16.0
2	11.0-12.0	36.0-41.0	4.0-6.0	3.0-5.0	15.0-16.0
3	11.0-12.0	35.0-36.0	4.0-5.0	3.0-5.0	15.0-16.0
4	11.0-12.0	35.0-36.0	4.0-5.0	3.0-5.0	15.0-16.0
5	11.0-12.0	35.0-36.0	4.0-5.0	4.0-5.0	15.0-16.0
6	11.0-12.0	35.0-36.0	4.0-5.0	4.0-5.0	15.0-16.0
7	11.0-12.0	35.0-36.0	4.5-5.0	4.0-5.0	15.0-16.0
8	11.0-12.0	35.0-36.0	4.5-5.0	4.0-5.0	15.0-16.0

* Used for both *P. indicus* and *L. vannamei*
** By type of feed is meant postlarval feed, starter 1, starter 2, grower 1, grower 2, finisher, etc. or any other names designated by feed manufacturing companies

2.4.9.3.2.7. Shrimp feed handling and storage

73.33% of the traditional farms and 90.57% of the scientific farms that use factory-made feeds were found to store the feed under satisfactory conditions. Feeds were considered to be stored satisfactorily if they were found stored in separate ventilated, non-humid, and relatively cool rooms. On average, the storage period of feeds was found to be 46 days (Table 2.25).

Table 2.25. Duration of storage of shrimp feeds.

Type of farms	% of farms that use factory-made feed		
	Storage period (months)		
	1-2	2-3	3-4
Traditional farms	80.00	13.33	6.67
Scientific farms	75.47	22.64	1.89

2.4.9.3.3. Periodic assessment of growth and survival/ biomass assessment

Periodic sampling is required to ascertain the growth and survival of the shrimp and to estimate the quantity of feed to be given. 22.22% of the traditional farms and 100% of the scientific farms were found to do periodic sampling. Farms were generally found to do sampling by cast netting. They were generally found to start monitoring shrimp weight and growth after 30 or 40 days of seeding. Sampling is conducted once per week or once every 10 days.

2.4.9.3.4. Management of predatory birds and predatory and weed fishes

Birds are important predators of farmed shrimp, both in traditional and scientific farms. Eighteen species of birds belonging to six families were found to prey on farmed shrimps/ fishes in the state (Table 2.26). Among all, cormorants, herons, egrets, and kingfishers were found to cause severe damage to shrimp crops. However, in the present study, no effort was made to assess the extent of the damage caused to the shrimp stocks by the predatory birds combined or species wise.

All traditional and scientific farms were found to use bird deterrents/ bird deterrent methods to avoid birds (Fig. 2.20). These include the manual method, auditory method (like making sound with tin, plastic bottles with few marbles tied to ropes, etc.), netting the ponds, providing overhead lines/ threads/ ropes, etc., tying reflective tapes/ ribbons/ video reels, etc., others (polythene bags, scarecrows, mirrors, etc.), a combination of methods (manual method, use of reflective tapes/ ribbons/ video reels and/or overhead lines, threads, ropes, etc.). The above methods were found to be used by various farmers to scare away the birds with varying degrees of success. However, no effort was taken in the present study to evaluate the usefulness or the comparative performance of the different methods. It may also be mentioned here that no farms were found to use lethal methods to control predatory birds as killing of birds is not approved by the existing laws. Farmers were generally well aware of such prohibition.

Table 2.26. List of predatory birds observed in the shrimp farms.

Sl. No.	Common name	Scientific name	Family
1.	Little cormorant	*Phalacrocorax niger* (Vieillot)	Phalacrocoracidae
2.	Little egret	*Egretta garzetta garzetta* (Linnaeus)	Ardeidae
3.	Western reef egret	*Egretta gularis* (Bosc)	Ardeidae
4.	Grey heron	*Ardea cinerea* (*rectirostris*) Gould	Ardeidae
5.	Purple heron	*Ardea purpurea manilensis* Meyen	Ardeidae
6.	Night-heron	*Nycticorax nycticorax*(Linnaeus)	Ardeidae
7.	Large egret	*Casmerodius albus* (Linnaeus).	Ardeidae
8.	Indian pond heron	*Ardeola grayii* (Sykes)	Ardeidae
9.	Smaller egret	*Mesophoyx intermedia* (Wagler)	Ardeidae
10.	White-bellied sea eagle	*Haliaeetus leucogaster* (Gmelin)	Accipitridae
11.	Osprey	*Pandion haliatus* (Linnaeus)	Pandionidae
12.	Whiskered tern	*Chlidonias hybrida* (Pallas)	Laridae
13.	Brown-headed gull	*Larus brunnicephalus* Jerdon	Laridae
14.	River tern	*Sterna aurantia* J.E. Gray	Laridae
15.	Pied kingfisher	*Ceryle rudis* (Linnaeus)	Alcedinidae
16.	Common kingfisher	*Alcedo atthis* (Linnaeus)	Alcedinidae
17.	Stork-billed kingfisher	*Pelargopsis capensis*	Alcedinidae
18.	Black-capped kingfisher	*Halcyon pileata* (Boddaert)	Alcedinidae

The entry of weed and predatory fishes (after the initial water filling and seed stocking) was prevented by using fine-meshed bags during water intake. However, the appearance of weed and predatory fishes during the culture period was found to be very common in both traditional and scientific shrimp farms, no matter how they tried to filter the water. In traditional farms, 107 species of fishes and shellfishes were noticed, of which 85 species were observed during the shrimp farming phase (Chapter 3). In these farms, the unwanted fishes and shellfishes were caught during periodic harvesting and/or cast netting. In scientific farms, the most common species found were tilapia (*Oreochromis mossambicus*), goby (*Glossogobius giuris*), glassy perchlets (*Ambassis* spp., *Parambassis* spp.), tarpon (*Megalops cyprinoides*), ten-pounder (*Elops machnata*), sea bass (*Lates calcalifer*), crabs (*Scylla serrata, Varuna litterata*), etc. Some farmers engaged in scientific farming were found to remove them by operating cast nets, etc., whenever required. Some also used gill nets or traps to catch bigger fishes as and when noticed. Small fishes were often found in feeding trays which were removed whenever observed. Some scientific farms (17.24%) used selective poisons like tea seed cake/ powder to kill finfishes

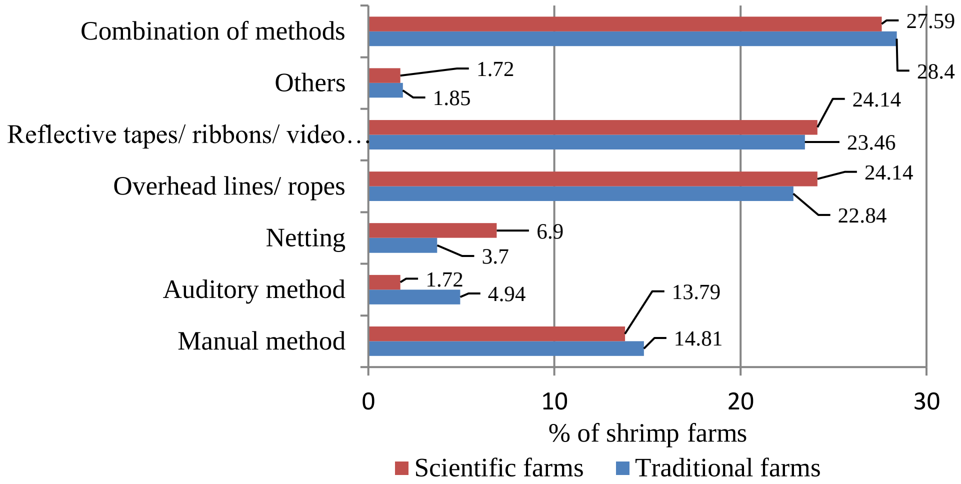


Figure 2.20. Methods employed by shrimp farms to avoid predatory birds.

2.4.9.3.5. Disease management

Information collected on various aspects of disease and disease management are provided below.

2.4.9.3.5.1. Frequency of incidence of disease

The frequency of incidence of diseases in farms during the last five years is taken as an index of assessing the risk associated with the disease. The information collected during the present study is presented in Fig. 2.21.

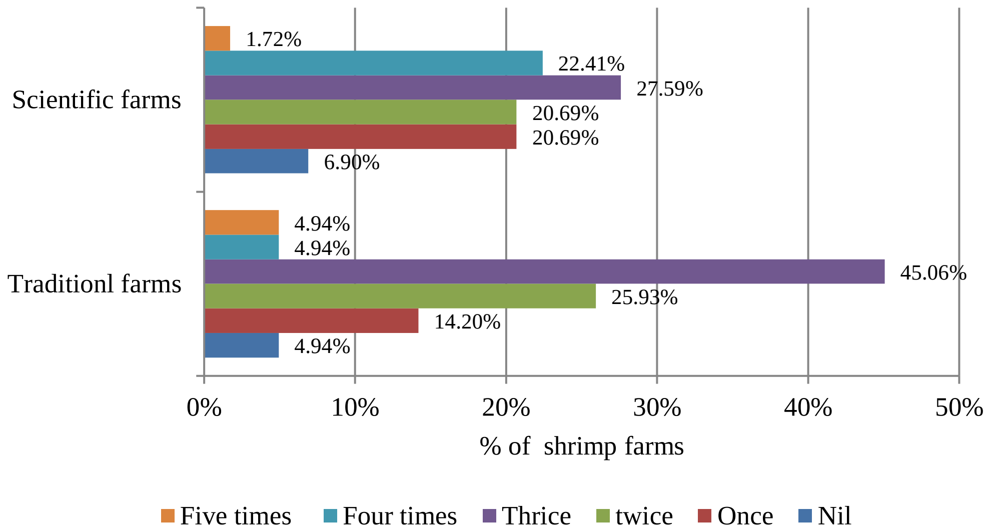


Figure 2.21. Frequency of incidence of diseases in shrimp farms (in five years).

2.4.9.3.5.2. Treatment of disease

Diseases were found to be common in shrimp farms. These included those caused by bacteria, fungus, viruses, protozoa, and those due to nutritional deficiency and/or environmental changes. Except, in the case of viral diseases, farms were generally found to manage/ treat diseases by using good quality seed, feed, feeding clam meat, proper water exchange, use of lime, use of probiotics and/or some common chemicals like potassium permanganate, copper sulphate, etc. However, on suspect/ confirmation of viral diseases, farmers were generally found to harvest the ponds.

2.4.9.3.5.3. Use of antibiotics

None of the traditional or scientific shrimp farms was found to use any antibiotics to treat diseases.

2.4.10. Harvesting

In traditional shrimp farming, periodic harvesting was found to be done by filtration nets attached to the sluice gates. Harvesting was generally found to begin from mid-December and continue till the middle of April. This was done by operating a conical net fixed at the sluice gate. Sluice net operation was found at dawn and dusk for 5 to 8 days around every new moon and full moon. At the end of the season, the final harvesting was done by operating a sluice net, cast netting, drag netting, draining, and handpicking. After emptying the water, prawns scattered in small pools were collected by hand nets. In scientific farming, harvesting was observed to be done by cast netting, drag netting, draining and handpicking.

2.4.11. Post-harvest management

Information collected on various aspects of post-harvest management of farmed shrimp is provided below.

2.4.11.1. Hygienic handling

All farms (traditional and scientific farms) were found to have reasonably good knowledge of the need for hygienic handling of harvested shrimp. In the case of shrimps meant for export, a couple of days before the harvest, the farmers negotiated with the agents of freezing plants/ commission agents and arrived at a final price for the various shrimp counts. On the day of the harvest, the agents were observed to reach the farm gate (or a nearby area in case the farm was not accessible by road) with refrigerated/non-refrigerated trucks loaded with a sufficient quantity of ice. The shrimps were washed well on harvest, weighed, and were iced in a 1:1 ratio and loaded in the refrigerated/non-refrigerated trucks. Harvested prawns were also graded in different counts (number kg^{-1}). The farmers were observed to take the utmost care not to damage or bruise the shrimp and expose them to direct sunlight, as they were well aware that the price realized depended on the quality of the shrimp and their count. The price of shrimp was found to be decided based on their count. Shrimps and fishes meant for the local market/ and those meant for drying were not generally iced at the farm. The harvest was seen washed well and was transported for direct sale/ drying under the sun.

Shrimps meant for export were washed, cleaned, and weighed immediately after harvesting before transferring to ice water at 0 ºC. They were then transported in rectangular crates to the processing plants by insulated trucks. The shrimp were cleaned and sorted into various grades in the processing plants to suit export needs. Shrimps were processed into several forms depending on market requirements, such as simple block frozen, ready-to-eat, whole chilled, IQF, and cooked products and exported by container ships or air cargo. As part of the comprehensive marketing strategy, major processors and exporters have adopted HACCP and ISO quality control systems.

2.4.11.2. Marketing and channels of marketing

The present study observed that fishes/ shrimps harvested from the farms were marketed principally through seven channels (Fig. 2.22). Fishes and small shrimps from traditional farms were marketed through channels one, two, and three indicated in Fig. 2.22. Large shrimps from traditional farms and all shrimps from scientific farms were marketed either through channel four or five (they reached the consumers in frozen form). Tiny shrimps from traditional farms were marketed after drying, especially during good harvest periods (channels six and seven). The simple system of the producer selling the product directly to the consumers was also in vogue, though rarely. Traditional shrimp farming existed as a small-scale rural activity, and the products were mainly sold locally. Only larger sized shrimps were meant for the overseas market. Vendors and retail merchants were found to buy a small quantity of fish at pond bunds from the marginal farmers and sold to domestic consumers.

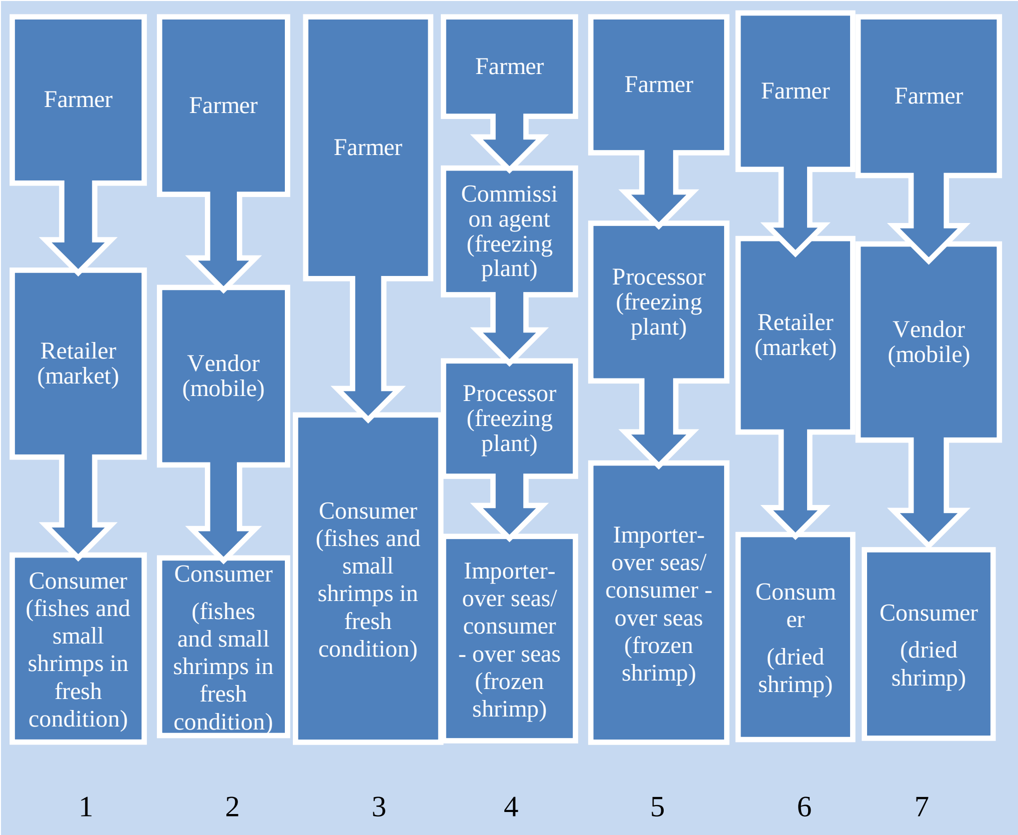


Figure 2.22. Marketing channels for farmed shrimp/ fish.

The shrimps meant for export in traditional farms were found to be given to specific commission agents/ representatives of freezing plants who were fixed based on long-standing relationships, acquaintances, and trustworthiness. The price paid to the farmer was the prevailing market rate on the day of the transaction. In scientific farming, a couple of days before the harvest, the farmers were found to negotiate with the commission agents/ representatives of the freezing plants directly and fix the price for various counts of shrimps. The commission agents/ representatives of the freezing plants were found to reach the farm site on the day of harvest with a sufficient quantity of ice. The shrimps were seen sorted count-wise, weighed in the presence of the farmer or his representatives, iced and taken by the agent/ representative of the processing plant. The payment was found usually effected within a period of one to two weeks. The present study indicated that 39.66% of the scientific shrimp farms sold their produce to the commission agents and 60.34% directly to freezing plants. The study also revealed that 100% of the traditional farms sold their products to specific agents/ freezing plants. On the other hand, 41.38% of the scientific farms were observed to sell their products to specific agents/ freezing plants and 58.62% to any agents/ freezing plants.

Weighing and ascertaining the shrimp count (number of shrimps per kg) before icing and after keeping it in ice for some time were in vogue. The purchaser generally was found to prefer the former. A field-level comparison was made to ascertain the relative advantages and disadvantages of both practices. It was found that there is a 4.5-6.0% weight advantage for the farmer in the latter case.

2.4.12. Farm performance

Information on growth, survival, production, productivity and food conversion ratio is provided below.

2.4.12.1. Growth performance

Since harvesting is done each month partially in traditional farms, stretching over many days, and since the harvest is a heterogeneous mix of different species and size classes, no attempt was made to collect such data. In scientific farming, the average body weight (ABW) at harvest of tiger prawn, Indian white prawn, and Pacific white shrimp was 30 g, 12 g, and 22 g, respectively, within 120 days. The average growth of the three shrimp species (*P. monodon, P. indicus,* and *L. vannamei*) at 15 days intervals is provided in Fig. 2.23.

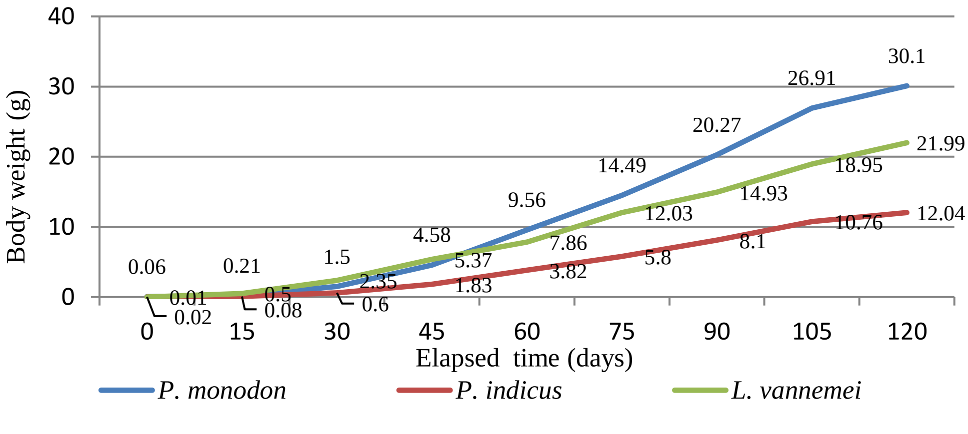


Figure 2.23. Average growth of shrimp obtained in scientific farms (at average stocking densities of 5.71 m^{-2}, 7.59 $m^{-2}$and 32 m^{-2} for *P. monodon, P. indicus, and L. vannamei*, respectively).

The observed excellent growth performance of *L. vannamei* in one of the newly constructed farms of area 0.6 ha in the present study is worth mentioning. The farm in which *L. vannamei* was stocked at the age of 10 days (PL 10) at a stocking density of 30 seeds m^{-2} recorded 3.4, 5.6, 7.9, 11.2, 14.2, 17.1, 20.2, 24.1, 26.2 and 29.8 g on 30th, 40th, 50th, 60th, 70th, 80th, 90th, 100th, 110th and 120th day of culture. The final survival obtained in this case was around 85%.

2.4.12.2. Survival rate

In traditional farms, the survival rate could not be calculated as no information was available on the exact number of seeds that entered the field along with the incoming water. The average survival rates obtained by scientific shrimp farms were 56.21%, 65%, and 60.07% in *P. monodon, P. indicus, and L. vannamei*. Information on the survival rate obtained by scientific shrimp farms is presented in Table 2.27.

Table 2.27. Survival rate obtained by scientific shrimp farms.

Per cent survival	Per cent of the total number of scientific farms
Less than 10	0.00
10-20	0.00
20-30	6.90
30-40	13.79
40-50	12.07
50-60	44.83
60-70	10.34
70-80	5.17
80-90	3.45
90-100	3.45

2.4.12.3. Production

The total annual farmed shrimp production of Kerala during the study period was estimated to be 2952.56 t. The relative share of traditional and scientific farming sectors to total farmed shrimp production of the state is presented in Fig. 2.24. Finfishes and crabs constituted the total production in traditional farms apart from shrimps. The relative contribution of prawns, finfishes and crabs in the harvest of traditional farms is presented in Fig. 2.25.

In traditional farms, *P. monodon, P. indicus, M. monoceos, M. dobsoni, L. vannamei, P. semisulcatus* and *M. affinis* were harvested. The percentage composition of the different species of shrimps in the harvest from traditional farms is provided in Fig. 2.26. Indeed, the species composition of traditional farms was expected to be significantly influenced by the supplementary stocking. In the context, for comparison, an attempt was also made to understand the species composition of those traditional farms which did not undertake any supplementary stocking, details of which are provided in Fig. 2.27. The percentage contribution of different species of prawns in the total prawn harvest of traditional farms (value realization) is presented in Fig. 2.28. Month wise catch data of traditional prawn farms are presented in Fig. 2.29.

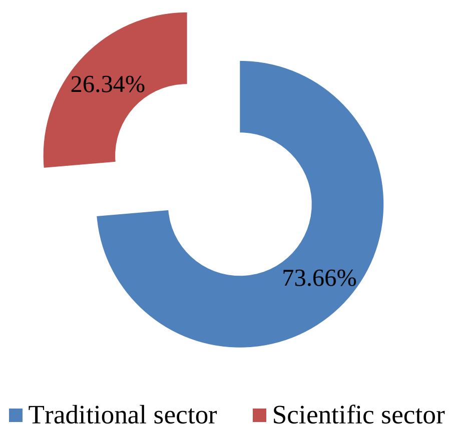


Figure 2.24. The relative share of traditional and scientific farming sectors to total farmed shrimp production.

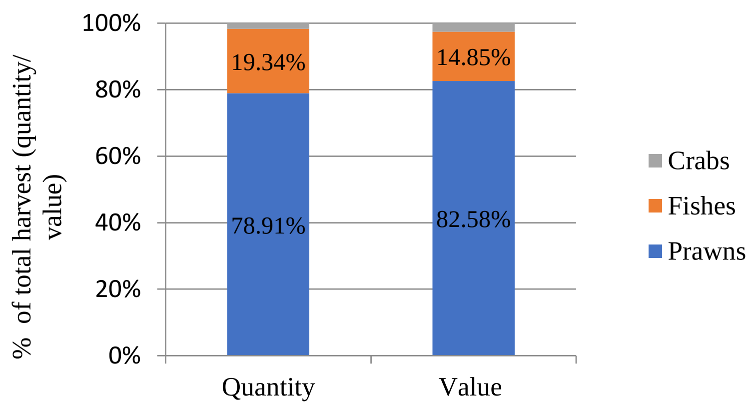


Figure 2.25. The relative contribution of prawns, finfishes and crabs in the harvest of traditional farms.

Tiger shrimp (*P. monodon*) accounted for 70.56% of the total shrimp production from scientific farms. Indian white prawn (*P. indicus*) and Pacific white shrimp accounted for 0.55% and 28.89, respectively. Estimated species wise farmed shrimp production in Kerala is presented in Table 2.28.

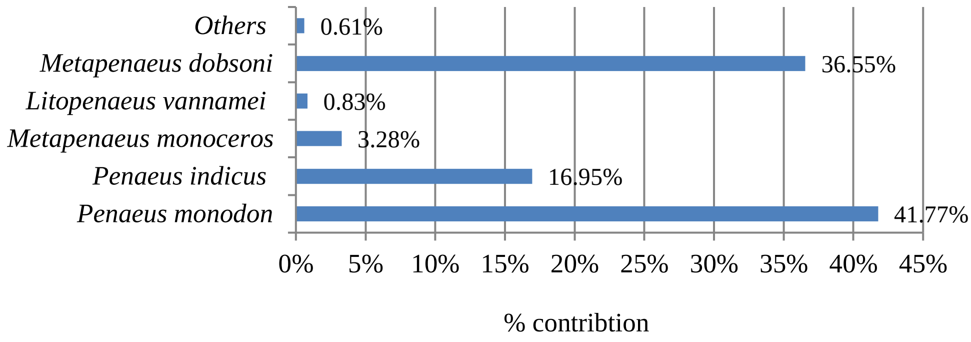


Figure 2.26. Percentage contribution of different species of shrimps in the harvest (weight) in traditional shrimp farms.

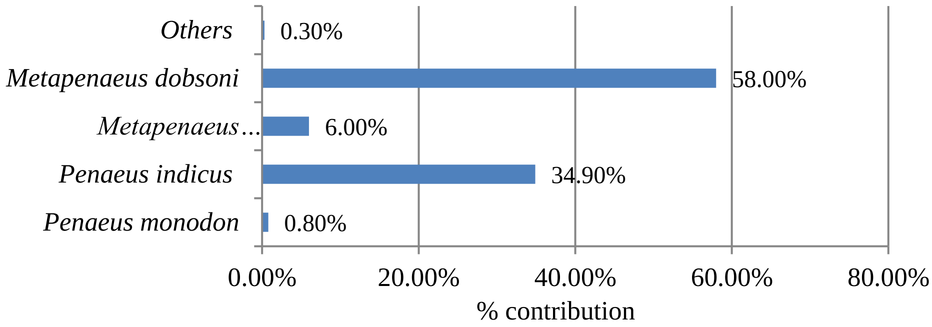


Figure 2.27. Percentage contribution of different species of shrimps in the harvest (weight) in traditional shrimp farms that do not undertake supplementary stocking.

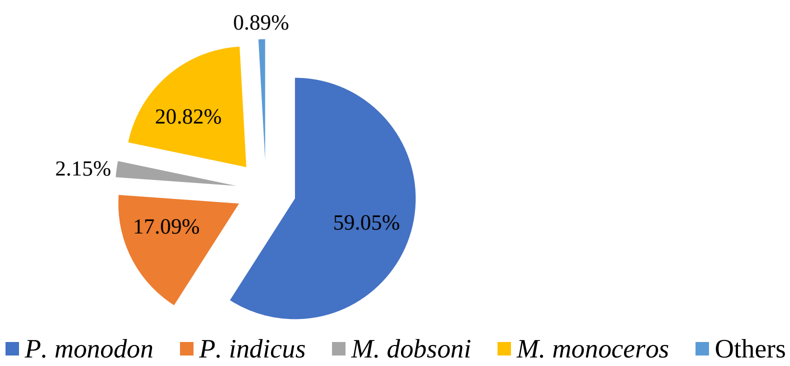


Figure 2.28. Percentage contribution of different species of prawns in total prawn harvest of traditional farms (value realization).

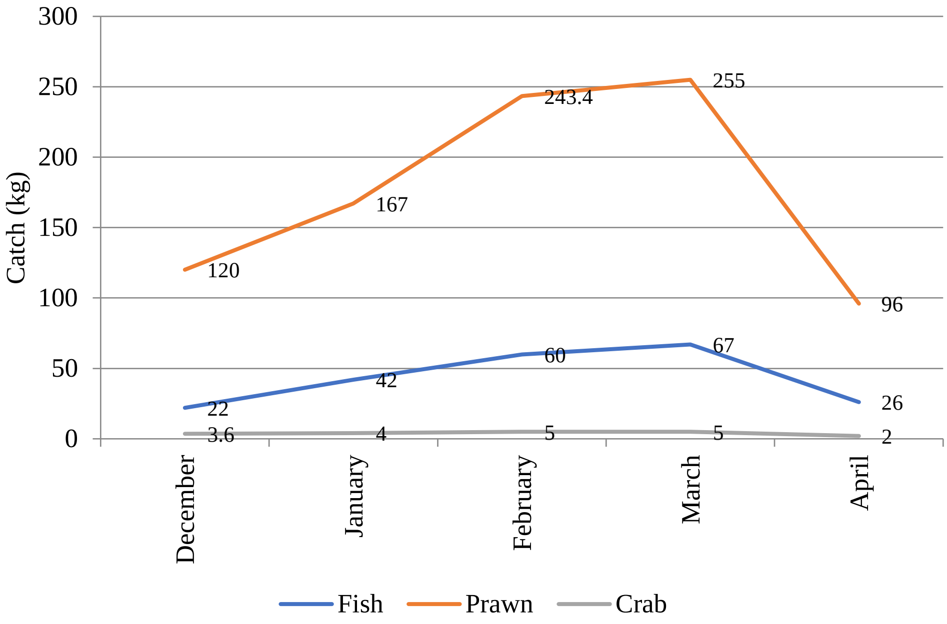


Figure 2.29. Month wise catch data of traditional prawn farms (kg).

Table 2.28. Estimated species wise farmed shrimp production in Kerala.

Farming system	Shrimp production in tonnes						
	P. monodon	*P. indicus*	*M. monoceros*	*M. dobsoni*	*L. vannamei*	Others*	Total
Traditional farms	908.52	368.66	71.28	794.94	18.11	13.29	2174.80#
Scientific farms	548.80	4.29	0.00	0.00	224.67	0.00	777.76
Total	1457.32	372.95	71.28	794.94	242.78	13.29	2952.56

*Mainly *P. semisulcatus* and *M. affinis*
#In addition, 344.83 t of finfish and 49.74 t of crabs were harvested from the traditional shrimp farms.

2.4.12.4. Productivity

Shrimp productivity refers to the average weight of shrimp harvested per unit area (hectare) per year. The productivity of traditional and scientific farms is presented in Fig. 2.30. It may be seen that the productivity of shrimp farms in Kerala is low. Productivity was also calculated for various other situations like traditional farms (with supplementary stocking): 881.40 kg ha^{-1} $year^{-1}$; traditional farms (without supplementary stocking): 605.46 kg ha^{-1} $year^{-1}$; Scientific farms (overall): 1233.83 kg ha^{-1} $year^{-1}$; *P. monodon* (traditional and scientific): 468.99 kg ha^{-1} $year^{-1}$; *P. indicus* (traditional and scientific): 146.56 kg ha^{-1} $year^{-1}$ and *L.vannamei* (traditional and scientific): 1916.02 kg ha^{-1} $year^{-1}$. The overall productivity of shrimp farms in Kerala (traditional and scientific farms) was 932.08 kg ha^{-1} $year^{-1}$.

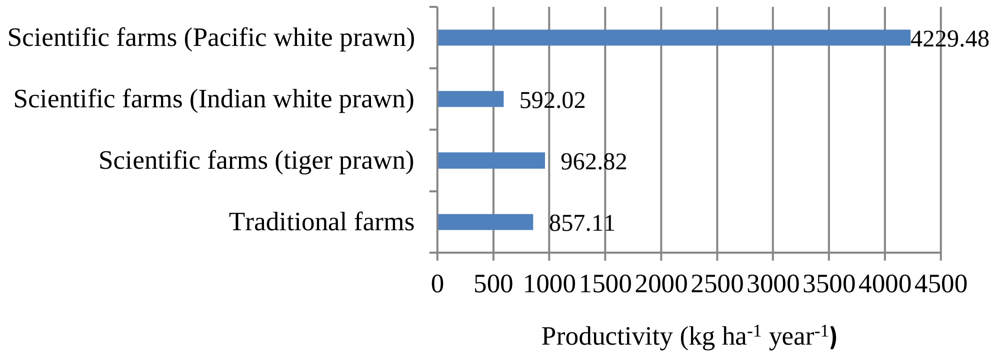


Figure 2.30. Productivity (kg ha^{-1} $year^{-1}$) of shrimp farms.

2.4.12.5. Feed conversion ratio

Information on feed conversion ratio (FCR) obtained by various farms is presented in Fig. 2.31.

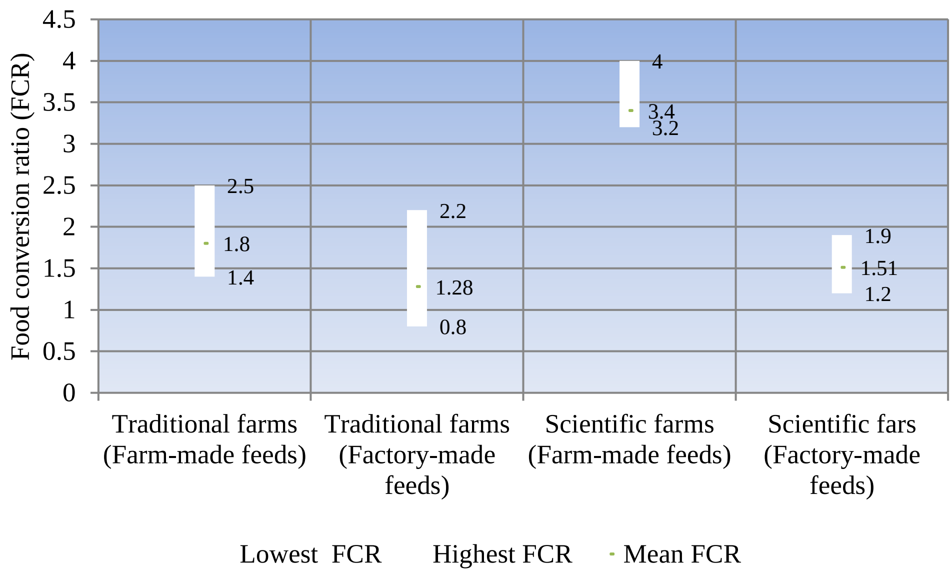


Figure 2.31. Feed conversion ratio (FCR) of traditional and scientific shrimp farms.

The mean FCRs obtained in scientific farming of tiger prawn, Indian white prawn, and Pacific white shrimp (using factory-made feed) are presented in Table 2.29.

Table 2.29. The mean food conversion ratio for different species of prawns.

Species	Mean food conversion ratio (FCR)
Tiger prawn (*P. monodon*)	1.52
Indian white prawn (*P. indicus*)	1.60
Pacific white shrimp (*L. vannamei*)	1.50

2.4.13. Crop failures

During the last 10 years, 100% of the traditional farms and 82.76% of the scientific shrimp farms met with crop failures at least once. Here a crop was considered as a failure when more than 90% of the crop was lost. The details of the incidence of crop failures are provided in Fig. 2.32.

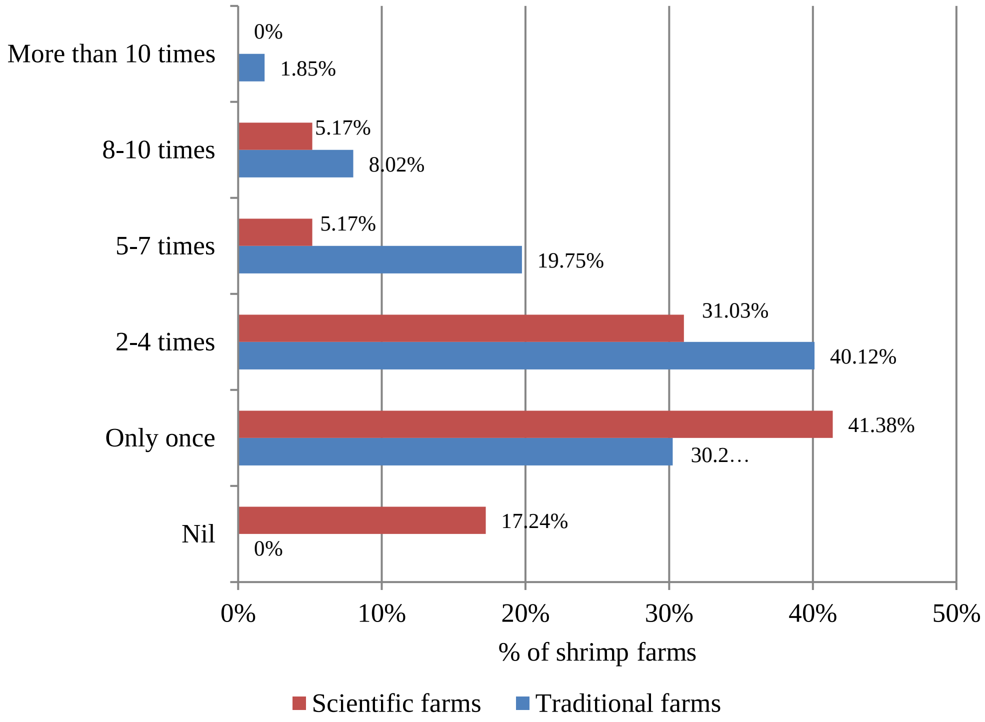


Figure 2.32. Frequency of crop failures during the last ten years.

2.4.14. Maintenance of farm records

Only 38.27% of the traditional farms and 72.41% of the scientific farms were found keeping records of some kind. Others did not keep any farm records.

2.4.15. Crop duration

Information on the duration of the utilization of traditional farms for shrimp culture is presented in Fig. 2.33. Fig. 2.34 depicts the duration of the utilization of scientific farms for shrimp culture as a percentage of the total number studied. In general, the duration of each crop in scientific farming is 120-130 days. However, some farms adopt extended culture (150 days). These farms adopt relatively low stocking density and expect a higher survival rate and bigger prawns (higher body weight) at harvest. Of late, especially in the context of disease outbreaks, some farmers started shortened culture (90 days).

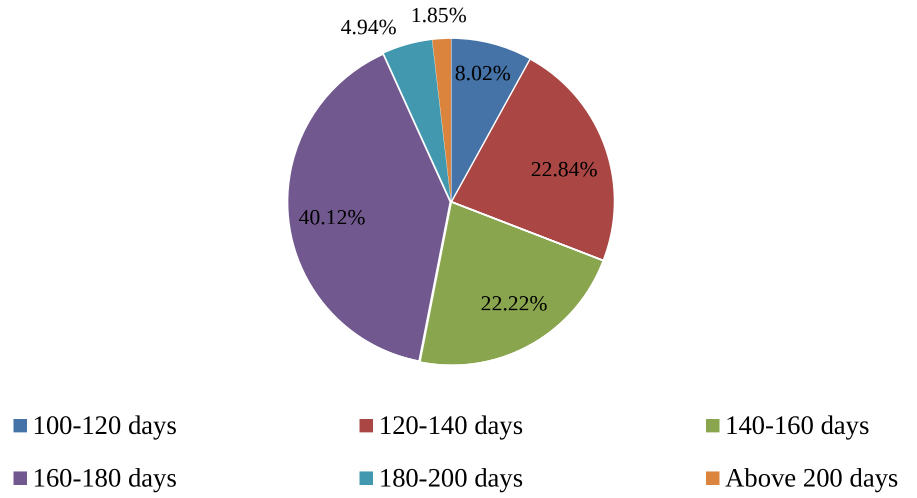


Figure 2.33. Duration of traditional farms under shrimp culture (as per cent of the total number).

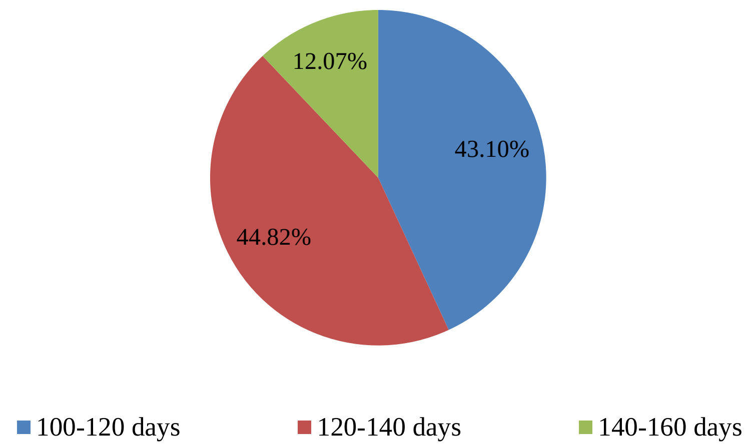


Figure 2.34. Duration of scientific farms under shrimp culture (as per cent of the total number).

2.4.16. Crop rotation

63.16% of the traditional farms were found to undertake no rice farming. Only the rest of the farmers undertook both rice and shrimp farming. In the case of scientific farms, no rotation of crops was found to be practised.

2.4.17. Major constraints

Srimp farmers of Kerala face a variety of constraints the degree of which varies from place to place and from season to season. It also varies according to the intensity of farming operation adopted.

The major constraints faced by the traditional shrimp farmers were water pollution and dumping of wastes, decrease in tidal flow due to siltation, weed chocking, reduction in the water carrying capacity of natural water bodies that brings water into the ponds etc. Poor recruitment of shrimp seed/ shrimp resource depletion in the natural water bodies also posed constraints to aquafarming. The smooth farming operation was also reported to be hampered by disease outbreaks, competitive land use, and insufficient or non-availability of good quality shrimp seed at the right time. The other bottlenecks in the functioning of traditional farms were difficulty in getting power connection, inadequate road access, shortage of skilled labourers, poaching, insufficient extension machinery, increasing cost of production, lower / fluctuating shrimp price, insufficient insurance coverage, lack of leasing policy and poor credit availability. When asked to identify the most critical constraint from the above, 30.86% of the farmers recognised water pollution (including the dumping of wastes), 30.86% recognised a reduction in tidal flow due to siltation, weed chocking etc., 24.07% recognized the outbreak of diseases and 14.20%, insufficient recruitment of seeds in the backwaters.

The major constraints faced by the scientific shrimp farmers were shortage/ unavailability of quality shrimp seed at the right time, disease outbreak, water pollution and dumping of wastes, insufficient insurance coverage, difficulty in getting power connection, poor credit availability, poaching, inadequate extension machinery, shortage of (local) labourers, inadequate road access, lower / fluctuating shrimp price, increasing cost of production, decrease in tidal flow due to siltation, weed chocking, etc. and the consequent reduction in the water carrying capacity of natural water bodies, lack of leasing policy and competitive land use. When asked to identify only one principal constraint from the above, 55.17% of the farmers reported recurring outbreaks of shrimp diseases, 34.48% reported insufficient availability/ unavailability of quality shrimp seed at the right time, and 10.34% reported water pollution (including the dumping of wastes) as the most critical constraint.

The percentage of farmers who reported different constraints are presented in Fig. 2.35. It gives an idea about the gravity of major constraints faced by various shrimp farms.

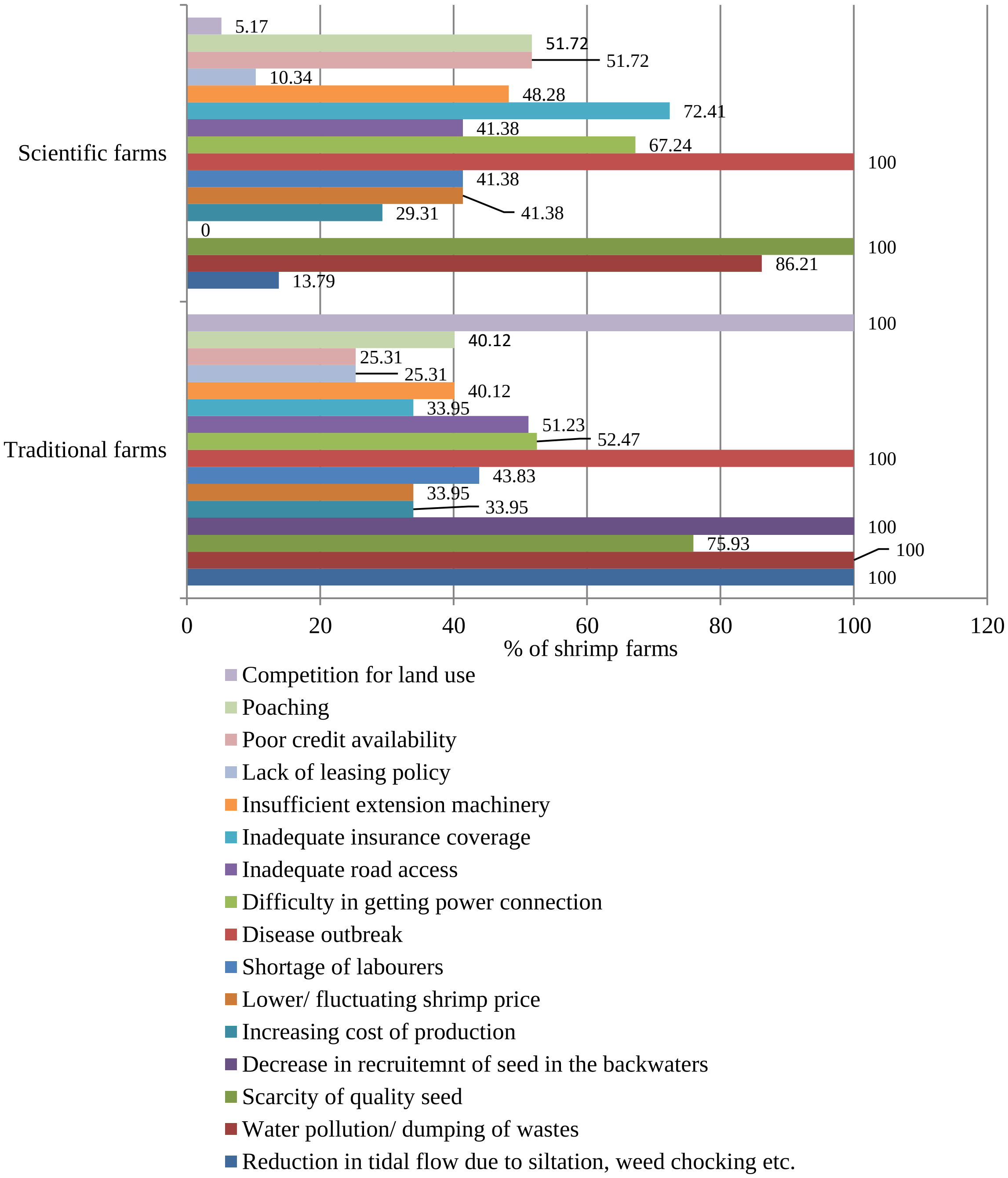


Figure 2.35. The gravity of major constraints faced by shrimp farms (as per cent of the total number of farms).

2.4.18. Awareness of the impact on the environment

In the present study, an enquiry was made to understand whether farmers were aware of the impact of shrimp aquaculture on the environment. The enquiry was limited to awareness of the possible negative impact of shrimp aquaculture on the surrounding environment. The majority of the traditional farmers (61.73%) and scientific farmers (77.59%) were aware of the possible impact of shrimp aquaculture on the environment. However, they did not adopt any remedial measures to rectify the adverse effect.

The possible negative impacts of shrimp aquaculture on the environment identified in the order of priority were deterioration of soil and water quality, depletion of mangrove forest, depletion of biodiversity, saline water intrusion in groundwater, local water pollution, decrease in the extent of rice cultivation and change of local hydrology.

2.4.19. Awareness of the climate change

In the present study, an enquiry was also made to understand whether farmers are aware of climate change and its impact on shrimp farming. Only 56.17% of the traditional farmers and 65.52% of scientific farmers were found to be aware of climate change in the context of shrimp farming. However, they, too, had only preliminary knowledge on the subject.

The shrimp farmers were also reported to have experienced more or less similar climate change extremes, though there was a difference in the order of priority. The climate change impacts identified on priority were seasonal changes, heavy rains, floods, and cyclones. These were reported to result in extremely high or low temperatures, inundation of bund, un-seasonal rainfall, and low tidal amplitude in the shrimp farming areas. The seasonal changes were mainly temperature variations and delays in the monsoon. The water inundation in ponds was expected due to heavy rainfall caused by floods and cyclones. Cyclones were not a problem in these areas as they were not a very frequently occurring event. Floods and seasonal changes were reported to be under extreme risk category, whereas heavy rain and cyclone were under the high-risk category in these areas. High temperatures, floods, and low rainfall were under the high-risk category, while low tidal movement and low temperatures were under the medium risk category in these areas.

2.4.20. Legal compliance

The study made an effort to understand whether the shrimp farmers comply with the relevant acts and rules framed under them. The present study was limited to understanding the compliance of the Coastal Aquaculture Authority (CAA) Act 2005 and Kerala Inland Fisheries and Aquaculture Act 2010. In the study, 64.81% of the traditional farms and 93.10% of scientific farms were found to be registered under the CAA Act. Further, 80.25% of the traditional farms but no scientific farms were found to have registration and license under Kerala Inland Fisheries and Aquaculture Act.

2.5. Discussion

Kerala has a large extent of water bodies suitable for inland aquaculture. It includes 3,30,358 ha of freshwater areas in the form of ponds, rivers, canals, paddy fields, reservoirs etc. (DoF 2002). This area can be utilized for freshwater fish and prawn production, in one way or the other. The state also has 78,086 ha of brackish water area (ADAK 1991; DoF 2002), which may be harnessed for rearing brackish water fishes, crustaceans, and molluscs. The extent of the brackish water area indicated includes the backwaters, whose extent comes to 46,129 ha and the prawn filtration fields with 12,873 ha (ADAK 1991). It may be mentioned here that the total brackish water area available in India is 11,60,162.50 ha (GoI 2019). Despite the availability of rich and varied brackish water resources, shrimp farming is yet to develop in a meaningful way in Kerala (Sahadevan 2013).

The official data on the extent of water bodies available for aquaculture development in Kerala is based on the survey conducted by the Agency for Development of Aquaculture, Kerala (ADAK) during 1989-1991 and a quick survey conducted by the Fish Farmers' Development Agencies under the Department of Fisheries during 1997-2000 (Sahadevan 2013). However, many of these water bodies have been later reclaimed for non- aquaculture purposes and are now unavailable for aqua farming (Sahadevan 2016a). In this situation, there is a neeed to ascertain the extent of the water bodies available for aqua farming afresh.

2.5.1. Physicochemical parameters of brackish water bodies

At the outset a preliminary study was conducted to understand the physicochemical parameters of the water of the principal lakes/ backwaters/ downstream portion of the rivers, which are the main sources of rearing medium for the existing shrimp farms and the farms that are expected to be set up in the future in Kerala. These interconnected backwaters are unique ecosystems supporting rich biodiversity, including many finfishes and shellfishes. The backwaters are preferred habitats for about 200 resident or migratory fish and shellfish species and form the backbone of Kerala's 62,500 ha backwater fishery resource (Unnithan *et al*. 2005). These wetlands also serve as the nursery grounds of many species of finfishes and shellfishes.

The optimum levels of various water quality parameters for shrimp farming are temperature: 26-32 °C, salinity: 10-25 ppt, pH: 6.8-8.7, transparency: 35 cm, ammoniacal nitrogen: less than 1 ppm (https://agritech.tnau.ac.in/fishery/fish_shrimps.html). According to (Chen 1985), water quality parameter ranges suitable for farming *P. monodon* are temperature: 28-33 °C, pH: 8.0-8.5, dissolved oxygen: 3.7 ppm (critical value), salinity: 15-25 ppt and ammonia 0.1 ppm. Meade (1989) and Tucker and Robinson (1990) reported the desirable total alkalinity range for aquaculture as ≥100 or 150 ppm. CIBA (2013) gave the optimum water quality parameters for intake waters for shrimp farming as temperature: 25-33 °C, salinity: 10-34 ppt, pH: 7-9, transparency: 25-50 cm, dissolved oxygen: 4-6 ppm, total alkalinity: 50-300 ppm, nitrate- N: < 0.03 ppm, nitrite- N: < 0.01 ppm, ammonia- N: < 0.01 ppm and heavy metals: nil to 0.0001 ppm.

When selecting a site for shrimp farming, seasonal and yearly fluctuations in availability and quality parameters of source water need to be carefully considered. Boyd (1990) and Boyd and Fast (1992) discussed these considerations in detail. Shrimp species commonly cultured in ponds grow best at temperatures in the range of 25 to 30 °C (Boyd and Fast 1992). Concentrations of carbon dioxide below 20 mg l^{-1} are not harmful, provided dissolved oxygen concentrations are sufficient. The un-ionized form of ammonia is most toxic to shrimps. Concentrations of un-ionized ammonia above 1 mg l^{-1} are potentially lethal, and concentrations greater than 0.1 mg l^{-1} adversely affect growth. At pH 9 and salinity 30 ppt, about 25% of total ammonia is un-ionized. Therefore, total ammonia concentrations above 0.4 mg l^{-1} could negatively affect growth when pH is higher. Nitrite in shrimp ponds is seldom at concentrations significant enough to kill shrimp, but growth may be adversely affected by concentrations above 4 or 5 mg l^{-1}. Inorganic nitrogen compounds (nitrate and ammonium) and phosphate are nutrients that commonly determine phytoplankton abundance.

Plankton creates water turbidity, producing organic matter and dissolved oxygen and absorbing deleterious substances. Optimum phytoplankton densities are associated with Secchi disc values of 25 to 35 cm. High concentrations of settleable solids in influent pond water result in increased sedimentation rates in ponds. This causes loss of pond volume, destruction of benthic organisms and often results in greater oxygen demand in bottom soil.

The preceding discussion indicates that values of the various physicochemical parameters of water of the inland brackish water bodies observed in the present study are congenial for the growth and survival of different farmed shrimps like *P. monodon, P. indicus* and *L. vannamei.* However, it must be remembered that the present study did not cover the presence of chemical pollutants, agriculture pesticides, coliform bacteria, pathogens etc. which have a significant bearing on determining the suitability of a site for shrimp farming and hence the recommendation made based on the present study must be approached with reservation.

Many studies exist on the water quality parameters of the various lakes and other water bodies of Kerala and of other parts of the country (Sankaranarayanan and Qasim 1969; Anilakumari and Azis 1992; Dhamijia and Jain 1994; Balasubramanian *et al.* 1995; Nair 1995; Madhukumar 1996; Bhadran 1997; Menon *et al.* 2000; Laluraj *et al.* 2002; Varma *et al.* 2002; Sultan *et al.* 2003; Prema *et al.* 2004; Resmi 2004; Salve and Hiware 2006; Sujatha *et al.* 2009; Manjare *et al.* 2010; Meera and Nandan 2010; Ravaniah *et al.* 2010; Joseph *et al*. 2011; Sarmah 2011; Pradhan *et al.* 2012; Koshy 2013; Varadharajan and Soundarapandian 2014; Grace 2015; Kannappan 2015, Mogalekar *et al.* 2015a; 2015b; 2015c; Seema 2015; Kumar *et al.* 2017; Praveena and Santhosh 2018; Rajeswari *et al.* 2018). The values recorded in the present study fall very well within the range reported by these authors. However, these cannot directly be compared with those of the earlier workers as the studies were conducted under different conditions and at different points of time. It may be pointed out here that at the same station, during the same day, the values may differ depending upon the time of collection of data, tidal condition, prevailing weather conditions, etc. Similarly, the values may vary within the same water body at different locations (Santhosh and Badusha 2017).

2.5.2. Mode of farming and species farmed

Most of the shrimp farming units in Kerala are under traditional farming (79.28% in terms of number, 79.54% in registered area, and 80.10% in water spread area), wherein production and profitability are low. These farm units fall under the subsistence farming system, are located in tidal areas, and are tide-fed. According to land boundaries, the ponds are irregular in shape and are generally larger and easily constructed by manual labour for cost reduction (FAO 2005).

Unnithan (1985) discussed the demerits of the traditional system of prawn farming in detail. According to him, the yield would be a mix of economically important and less important species of prawns in the traditional system. Since no adequate time is provided for the growth of the prawns trapped inside, the catch contains undersized prawns to a great extent. Predatory organisms reaching the field along with the tidal water eat away a good proportion of the prawns. Since stocking is wholly dependent on nature, no control over the stocking density commensurate with the extent and productivity of the field is possible, and the fields may sometimes be overstocked or understocked. Owing to competition for food and space, overstocking leads to poor growth of prawns. On the other hand, understocking hinders the full exploitation of the field. The above author advocated the adoption of scientific shrimp farming in these fields. The failure of the state to shift from the low input and low output traditional farming system to more evolved scientific farming may be one of the reasons for the lower production and productivity of its shrimp farming systems, as observed by Sahadevan (2012) and Sahadevan and Sureshkumar (2019).

Scientific shrimp farming systems are generally classified into extensive, semi-intensive and intensive systems. Indeed, many other terminologies are in use in various parts of the world like modified traditional, modified extensive, super-intensive, ultra-intensive etc. CIBA (2015) gave a detailed account of shrimp farming systems based on management, stocking density, and production level. However, the classification adopted by Apud *et al.* (1983), the Southeast Asian Fisheries Development Center (SEAFDEC) Aquaculture Department (as cited in Apud *et al.* 1985) and Fast (1992a) is adopted in this manuscript. This classification shows that scientific shrimp farming in Kerala, except that of *L.*

vannamei, is extensive or semi-intensive. *L. vannamei* farming in practice may be classified as semi-intensive.

Shrimp farming systems vary significantly according to the intensity of management with which they utilize resources (such as land, capital, labour, fuel, water, feed, and fertiliser). The economic desirability of different systems and their ecological impact depends on the availability of such resources and how they are managed under the farm operation. Other specific circumstances such as site conditions and the socioeconomic status of the farmer will decide the relative desirability of different systems. High intensity may result in high yields (measured in both production volumes and profitability), but they require rigid monitoring and a great degree of knowledge on the part of the farmer. While intensive and super-intensive shrimp farming technologies may be beneficial by using little land and producing high output, these technologies are generally more challenging to manage, and the risks involved are high. It indicates the need for adopting an optimum management intensity in shrimp farming, considering the availability of resources and the level of risk one is ready to take.

In the study, it has been seen that only 10.49% of the traditional farms were engaged in the original 'trapping and holding' system of farming. 89.51% of the traditional shrimp farms resorted to supplementary stocking to increase their production and income. Most farms (95.17%) that undertook supplemental stocking used hatchery-produced tiger prawn seeds. Others stocked the seeds of white prawns (Indian white prawn and Pacific white prawn). Superficially, the rationale behind supplementary stocking of tiny hatchery-produced seeds of shrimps in a system with no control over the entry of weed and predatory fishes is questionable. However, it is found to bring better results in practice, as is evident from the analysis of production and productivity figures of the farms that resorted to supplementary stocking and the farms that did not (Section 2.4.12.3 and 2.4.12.4).

In the scientific farming sector, 91.38% of the farms were found to grow *P. monodon*, 5.17% of farms were found to culture *P. indicus* and 3.45%, *L. vannamei*. In terms of extent, the corresponding figures were 90.42%, 1.15% and 8.43%, respectively.

It means that brackish water shrimp culture in Kerala is at present more or less limited to a single species, *i.e.*, the tiger prawn (*P. monodon*) and a minimal extent to the Indian white prawn (*P. indicus*) and the Pacific white shrimp (*L. vannamei*).

As per the reports published by the Marine Products Export Development Authority (MPEDA 2021), the total area under *L. vannamei* farming in Kerala is limited to 52 ha. Similar statistics are also provided by GoI (2019). The findings in the present study (53.12 ha) also corroborate the above statistics. Interestingly, in India, *L. vannamei* is farmed in 61.27% of the total area under shrimp farming. Further, except in Kerala and West Bengal (7.47%), *L. vannamei* occupies most areas under shrimp farming in all states of the country. Thus *L. vannamei* is grown in 97.07% of the total area under shrimp farming in Andhra Pradesh, 99.28% in Gujarat, 99.89% in Tamil Nadu, 100% in Maharashtra, 97.07% in Odisha, 100% in Goa and 56.92% in Karnataka, in the year 2017-2018 (GoI 2019). The present study reveals that Kerala is the only state in India that relies almost entirely on *P. monodon* for farming.

According to Kungvankij *et al.* (1986), the shrimp species cultured in Asian countries belong to two genera (*Penaeus* and *Metapenaeus*) of the family Penaeidae. Among the dozen species cultured, *P.monodon, P. japonicus, P. merguiensis, P. indicus, P. orientalis* and *Metapenaeus ensis* are the more important ones. Pullin *et al.* (1998) concluded that around 60 species of crustaceans had been farmed experimentally or commercially. There is scope for further diversification in the farming of crustacean species, especially more penaeid shrimp species. It may be further pointed out that according to FAO (2018), in the world, 54 species of crustaceans are cultured commercially, of which *L. vannamei* and *P. monodon* are the most dominant species. The share of *L. vannamei* to total farmed shrimp production in the world in 2016 was 85.56% (FAO 2018).

The reluctance of the state of Kerala to change from *P. monodon* to *L. vannamei* is another principal reason for the poor performance of the shrimp farming sector of the state, as the latter can be farmed at high density resulting in higher productivity. Sahadevan (2012) made a similar observation. The author attributed the lack of species diversification as one of the principal reasons for the low-profile performance of shrimp farming units in the state. Sahadevan (2013) also attributed the reluctance of farmers to shift from tiger prawn to pacific white prawn to the observed low productivity of shrimp farms in Kerala. Various authors highlighted the importance of species diversification in brackish water shrimp farming in Kerala (Unnithan 1985; Sahadevan and Sureshkumar 2019) and elsewhere in the country and outside (Liao 1992; Muthu *et al.* 1992; Kutty 1999; Ravisankar *et al.* 2005; Sathiadhas *et al.* 2006; Ayyappan *et al.* 2009; Shofiquzzoha *et al.* 2009; Dinesh 2016; Anand 2019; Rao 2019; Vijayan 2019). Muthu *et al.* (1992) provided details of 12 species of prawns that may be used in brackish water aquaculture in India under different conditions.

Aquaculture development is an interplay of diversification and specialization (Carolsfeld *et al.* 2017). How these processes interact is locally distinct, subject to history, socioeconomic conditions and markets. Overall resilience of the sector at a country or global level is undoubtedly afforded by the cumulative tool kit of species and technologies. However, individual farmers and businesses are more likely to optimize their operation through specialization – including adaptations to changing conditions. Diversification is most natural at times of evolving or unstable markets, which provide new entrepreneurial opportunities.

There is little evidence of diversification (of culture system and species) currently being used to respond to climate change challenges. Instead, increased specialization affords established aquaculture practices increased resilience to change and capacity to capitalize on climate-induced aquaculture production deficits. Diversification is a policy objective for the aquaculture development of many countries, both domestically and internationally. This may aim for improved resilience, ecological balance, and diversification of markets in developed countries while providing more accessible technologies or socio-technological development processes for farmers in developing countries. The scale and nature of aquaculture producers and their objectives are diverse, as are their appropriate paths for diversification. Aquaculture diversification is primarily pursued in search of new economic opportunities, but it is increasingly considered a hedge against impacts such as climate change and disease outbreak. But the capacity of individual farmers to tap into this is limited.

2.5.3. Size of farm

The present study revealed that most shrimp farming units in Kerala were tiny or small-scale units whose water spread area is limited. The mean size (water spread area) of traditional shrimp farms was 1.61 ha and that of the scientific farms, 1.53 ha. 72.84% of the traditional farms were less than 5 ha in area. On the other hand, 70.69% of the scientific farms were less than 2 ha in extent. This observation agrees with the average size of shrimp farms in Kerala as per the data published by the Coastal Aquaculture Authority of India (http://www.caa.gov.in/farms.html). In India, more than 90% of shrimp farmers are small landholders who own less than two hectares (http://www.fao. org/fishery/countrysector/naso_india/en). From a technical point of view, the farm size does not directly influence production. However, farm size has great economic significance as a commercial operation optimising profit.

Gordon and Bjorndal (2009) showed that farm size is important because of a strong positive relationship with profits and because the results suggest important scale effects in production. These results indicate that small farms are disadvantaged not because they are unproductive or lack the skills to manage but because many farms are too small to achieve economic potential. Economies of scale are the cost advantages that farm units obtain due to their scale of operation, with the cost per unit of shrimp produced decreasing with increasing scale. Based on economies of scale, there may be technical, organizational or related factors to the degree of market control.

Economies of scale apply to shrimp farming units at various levels. When average costs start falling as the production of shrimp increases, then economies of scale occur. Some economies of scale, such as capital cost of farm facilities and cost of transportation, have a physical or engineering basis. Another source of economies of scale is the possibility of purchasing farm inputs at a lower per-unit price when they are purchased in large quantities. The idea of obtaining larger production returns through labour division is also important. Large farms are usually more efficient in the long run. In general, it may be opined that the larger the farm, the more the cost savings and higher the profit. The small scale of operation also impedes the use of machinery in farm construction and operation.

Further, small scale farmers are often in a weak bargaining position when selling their output and purchasing their inputs, usually because the existing marketing agencies are exploitative (Shang 1981). Shrimp farms vary greatly in scale in terms of both areas used and production. Small farms may be half a hectare or less, while semi-intensive farms in some parts of the country may cover hundreds of hectares. Small-scale operations are characterised by low investments and interplay with other operators, often more sophisticated and larger-scale, in their vicinity.

2.5.4. Site selection

The selection of a site is perhaps the most important aspect in determining the success of shrimp farming. However, it was found that farmers have taken no adequate care in selecting sites for shrimp farming in Kerala.

Shrimp farms require good quality water in adequate amounts throughout the culture period. The present study showed that all the shrimp farms (traditional and scientific), whether tide-fed or pump-fed, draw their water from adjacent backwaters/ brackish water lakes and/ or canals connected to backwaters/ lower stretch of rivers. As a direct result, the quality of surrounding water directly influences the quality of rearing water inside the pond and hence is important in determining the suitability of a site for shrimp farming.

Generally, a site should not be selected for shrimp farming because it is available at a lower price or near the farmer's residence (Sahadevan 2012). The topography of the site determines to a very great extent the cost of construction of farms and their subsequent management. The site must have an adequate tidal flow to ensure good water exchange. Temperature, salinity and other physicochemical parameters of the water and soil must be congenial for the growth and survival of the shrimps farmed. The site must also be free from pollution. Access to an inexpensive power source and road connectivity are important factors in selecting a shrimp farming site. Besides the technological and environmental aspects of aquaculture (biological, physical and chemical), the socio-economic aspects covering social, economic and legal issues are vital parameters to be considered while selecting the site for setting up a shrimp farm. It is also required to look into the previous use(s) and topography of the site to determine the suitability of the site and the cost of farm construction. Care must be taken to ensure that shrimp farms are harmoniously integrated into the local environment and social settings. By identifying the limitations that influence the suitability of a site, it is possible to incorporate corrective measures in the farm design and formulate remedial measures for the negative impacts likely to arise out of these limitations.

Poernomo (1990) observed that in developing coastal shrimp ponds, selecting a good site is the initial step that can be considered a crucial factor determining the operation's success. During the site selection phase for coastal shrimp farms, a mistake may result in higher construction and operation costs and create environmental problems. Considering the high investment cost for the development of shrimp farms and the possible risks and the negative impacts which might emerge due to an oversight in selecting the site, field studies have to be taken up with great care before an investment decision is made (Poernomo 1990).

Nagesh *et al.* (2009) observed that the farm establishment begins with proper site selection, which plays an important role in shrimp farming. The selection of a site for shrimp farming is made only after a thorough analysis of the information on topography, ecosystem, meteorological and socioeconomic conditions concerning farm design, species compatibility and economic viability.

According to CIBA (2013), the desired water quality parameters for shrimp culture are as follows. Temperature: 28–33 ℃, pH: 7.5–8.5, salinity:15–25 ppt, dissolved oxygen: > 5 ppm, transparency: 25–45 cm, total alkalinity: 80–200 ppm, nitrite-N: < 0.01 ppm, nitrate-N: < 0.03 ppm, ammonia-N: < 0.01 ppm, mercury: < 0.001 ppm, cadmium: < 0.01 ppm, chromium, copper, zinc: < 0.1 ppm. It means that a site selected for shrimp farming must have water quality parameters within the range mentioned above. The environmental (meteorological) factors, climatic conditions, socio-economic conditions of the locality, pollution problems, availability of seed from the vicinity, availability of freshwater, transportation and marketing facilities of the farm produce, social and political factors, and technical guidance need also to be considered before selecting a site for shrimp farming (CIBA 2013). Wang and Fast (1992) recommended not to overlook cloud cover (solar insulation) and rainfall patterns in site selection. These factors are critical in estimating necessary flood protection measures and time requirements for maintenance and repair purposes. An estimation of the dry and wet seasons should be as precise as possible so that all construction, operation, and maintenance phases are properly planned. CAA (2006) gave detailed guidelines which should be adopted for site selection for shrimp farming in India to avoid subsequent social and environmental impacts.

The present study showed that water pollution acts as a significant hindrance to improving the shrimp productivity in many farms. Industrial pollutants, coconut retting, domestic and city sewage, hospital wastes, pesticides from agriculture fields, etc. were important pollutants inhibiting the growth of shrimp and thereby reducing the productivity of ponds. Sahadevan (2012) also observed that pollution of the water body is a grave issue in some parts of Kerala. The author found that pokkali fields in some parts of Ernakulam district have become unsuitable for shrimp farming due to industrial pollution. Similarly, in the Vadakkumpad area of the Tellicherry region of Kannur district, ponds have become unfit for shrimp farming due to the discharge of wastes from hospitals functioning in the locality. It may be mentioned here that the presence of pollution in the present study was ascertained based on visual observation, odour and/ or based on the reports of the farmers/ local inhabitants of the area and/ or recent reports of mass kill of fishes in the locality. No water analyses were carried out to ascertain the inference and identify the nature of pollutants. Hence the results of the present study must be taken only as indicative.

The hydro-meteorological data of the area is critical in selecting a site for shrimp farming, developing the farm's design, and ensuring acceptable water quality in the farm. The most vital data required in this regard are rainfall, tidal fluctuation, wind direction and velocity, flood levels, frequency and time of natural calamities such as storms, cyclones, hailstorms etc. Construction of farms in cyclone-prone areas and places where natural disasters such as floods occur should be avoided.

The environmental factors observed in the present study are conducive to successful shrimp farming. The list of environmental factors that affect shrimp production in ponds is long. The most widely recognized factors are water temperature, salinity, pH, dissolved oxygen, hydrogen sulphide, ammonia, nitrite, nutrient concentrations, plankton abundance, settleable matter, organic matter concentrations, soil texture, soil pH, the redox potential of soil, and condition of the soil at the beginning of each crop (Boyd and Fast 1992). Several variables, including temperature, salinity, soil texture, soil nutrients, and soil pH, are related primarily to site selection, and others are determined mainly by the shrimp culture system employed, especially by fertilisation or feeding.

The degree and annual variation in temperature of a water body have a significant bearing on its productivity, in general. The temperature influences all metabolic and physiological activity and life processes such as feeding, reproduction, movement, and distribution of aquatic organisms (Jhingran 1991). Temperature also influences the speed of chemical changes in soil and water and the content and pressure of dissolved gases. Temperature shows diurnal as well as seasonal variation. All organisms, including prawns, possess well-defined temperature tolerance limits, with the optimum lying somewhere in between. The study area had a water temperature range between 22.4 ℃ (average low) and 32.6 ℃ (average high), which is within the tolerable limit for most of the penaeid prawns like *P. monodon P. indicus, L. vannamei* etc. A detailed discussion on the topic is provided under section 2.5.6.3.1.1. One must remember here that the temperature measured in the present study is that of the surface water.

In coastal brackish water areas, there is profound variation in salinity during different periods of the year. During the study period, the maximum salinity was recorded during May, and the minimum was noticed in July. Shrimp farming is usually done in low-lying coastal areas where seawater and freshwater mix regularly. Salinity levels in rivers and canals that supply water to shrimp ponds are regulated by the proportions in which seawater and freshwater mix. In Kerala, wet and dry seasons are well defined, and during the wet season, river discharge increases and salinity declines.

Conversely, river discharge decreases during the dry seasons and salinity increases. The high value in salinity correlates with the entry of saline waters from the adjoining lake/ backwaters into the field through sluice gates during the high tides. Likewise, a low level is due to the flow of saline water back into the sea and the entry of rainwater into the field, which is the period suited for paddy cultivation. Similar observations were made by many earlier investigators like Gupta *et al.* (2001), Pillai *et al.* (2002), Jayan and Sathyanathan (2010), Sasidharan *et al.* (2012), Vanaja (2013), Antony *et al.* (2014) and Deepa (2014).

The salinity of the rearing water directly bears the productivity and profitability of the farming operation. According to Unnithan (1985), farmers should have a thorough knowledge of the salinity profile of the tidal water of the site before selecting the site for the construction of the farm. It should also be ascertained that there is no chance of heavy freshwater influx to the farm, which would cause a sudden fall in salinity, giving stress to the prawns. Most of the prawn farming sites in the state had a salinity range that is congenial for shrimp growth. A more elaborate discussion on the topic is provided under section 2.5.6.3.1.6.

Bottom soil is considered the pond's laboratory where vital biochemical reactions takes place (Unnithan 1985). Bottom soils play vital roles in storing and releasing nutrients into the water, mineralising organic bottom deposits, providing food and shelter for bottom-dwelling organisms, and acting as a bed for algal growth. Fish, like agriculture crops, is primarily a product of the soil (Unnithan 1985).

Soil texture refers to the relative amount of clay, sand and silt, in the soil. The soil texture of the shrimp ponds in Kerala found in the present study (sandy clay loam) falls under the categories which various authors reported as suitable for prawn farming. According to Boyd and Fast (1992), almost any type of soil makes an adequate substrate for most shrimp species, but soils must contain reasonably high clay content for suitable pond construction. High concentrations of organic matter lead to high oxygen demands. Peat soils usually are unsuitable for pond construction.

Soil texture is important in deciding the success of shrimp farming. The soil should be free from vertical and lateral seepage (Jhingran 1991). Generally, clayey loam soils are preferred for shrimp farming. Such impervious soils are ordinarily heavy clay, silty clay, clay loam etc. High capital and operational cost will be required in maintaining a farm in the sandy area such areas are also to be avoided due to the high-water seepage through the sandy soils and potential environmental damage which could arise from it. The quality of soil should also be ascertained for soil permeability, bearing capacity and heavy metal content.

One of the most critical soil characteristics for shrimp culture is the ability of the soil to hold water. Good soil should contain a layer of impermeable material thick enough to prevent excessive percolation. Clays and silty clays are good impervious materials, while sandy clays are sometimes satisfactory (Wang and Fast 1992). According to Kovari (1984) and Deo *et al.* (2013b), a soil permeability of less than $K = 5x10^{-6}$ m s^{-1} is desirable for shrimp farming.

The water retention capacity of soil depends on the soil texture. Clayey loam soil is ideal for brackish water farms as it has low permeability and high fertility. Clayey loam contains textural components like 20–50% sand, 15–30% silt, and 25–40% clay. The area containing a higher percentage of sandy soil should be avoided as it causes seepage and results in salinization problems in the adjacent areas.

Ideal soil nutrients for shrimp farms recommended by the CAA (2006) and CIBA (2013) are as follows- organic carbon: 1.5-2.5%, available nitrogen: 0.5-0.75 mg g^{-1} soil, available phosphorous: 0.04-0.06 mg g^{-1} soil and calcium carbonate: more than 5%. The macronutrient content of the soils obtained in the present study is comparable to the values recommended above, indicating the suitability of the areas for shrimp farming. The values obtained are also in concord with the nutrient levels reported by many earlier investigators.

In the present study, the organic carbon content of traditional farms was found to vary between 0.44 and 3.96% (mean: 1.90%) and that of scientific farms between 0.52and 3.34% (mean: 1.68%). The relatively high organic carbon in the soils of the traditional farms may be attributed to the incorporation of stubbles and straw after harvest of rice crop in the field itself or from the remnants of the shrimp reared during the high saline regime prevailing from November to April. It may also be due to the diverse flora (mangroves) and fauna present in the soils. Antony *et al.* (2014) reported an organic carbon content of 1.46 ± 0.45% and 3.96± 2.18% in two pokkali fields. Saraswathy *et* *al.* (2016) observed an organic carbon content of around 1.4% in soil samples collected from shrimp farms of the Alappuzha and Ernakulam districts of Kerala. According to her, the high organic carbon content in these soils is due to the wetness of the soil throughout the year. She believes that the organic carbon content of these soils can be reduced by adequately drying the farm, which could help to increase the decomposition rate. Santhi *et al.* (2017) reported an organic carbon content of 0.53 - 3.34% in kaipad fields.

The available nitrogen content varied from 140.26 to 787.13 kg ha^{-1}(mean: 364.32 kg ha^{-1}) in traditional fields and between 178.63 and 678.85 kg ha^{-1} (mean: 344.95 kg ha^{-1}) in scientific farms. The medium to the high value of available nitrogen content may be due to the high amount of organic matter in these soils and the faster mineralization of nitrogen due to the activity of micro-organisms (Leiros *et al.* 1999; Santhi *et al.* 2017). Antony *et al.* (2014) reported a nitrogen content of 0.88 ± 0.72% and 0.21± 0.07% in two pokkali fields. Santhi *et al.* (2017) found the available nitrogen content of the sampled locations of kaipad regions to vary from 173.47 kg ha^{-1} to 1083.80 kg ha^{-1} with a mean value of 544.95 kg ha^{-1}.

In the present study, the available phosphorus content in traditional fields was found to vary from 13.93 to 54.29 kg ha^{-1} (mean: 42.95 kg ha^{-1}) and in scientific farms between 8.55 and 51.28 kg ha^{-1} (mean: 23.77 kg ha^{-1}). The present observation is in disagreement with the observation of Nair and Money (1972) and Samikutty (1977), who reported that the saline soils of Kerala are deficient in phosphorus content. However, many authors reported phosphorous levels somewhat in agreement with the values obtained in the present study. Thus Chandramohanan and Mohanan (2012) reported the value of available soil phosphorus content in kaipad soils to range from 7.2 to 34.2 kg ha^{-1}. Padmakumar *et al.* (2002) linked the tidal influence in estuarine situations to the high plant nutrients such as nitrates and phosphates in these soils. Antony *et al.* (2014) reported a phosphate content of 6.87 ± 7.67 mg g^{-1} and 0.14± 0.05 mg g^{-1} in two pokkali fields. Santhi *et al.* (2017) reported the phosphorus content of kaipad fields to vary from 8.65 kg ha^{-1} to 50.27 kg ha^{-1}.

The available potassium content observed in the soils in the present study was 1469.93- 3564.07 mg kg^{-1} (mean: 2369.81 mg kg^{-1}) in the case of traditional farms and 1339.08- 3430.05 mg kg^{-1} (mean: 2208.82 mg kg^{-1}) in the case of scientific farms. This may be linked to incorporating paddy stubbles in the soil after cultivation or due to the excrements of shrimps deposited during the prawn farming periods. It was reported by Samikutty (1977) that the potassium content in the saline soils is higher than that of the other paddy soils of Kerala. He explained that this is due to the continuous submergence of these soils with salt water for over 6 to 8 months in a year and the recurrent barrage by the brackish waters owing to the tidal effect. Santhi *et al.* (2017) made similar observations of high potassium levels ranging from 1239.02 to 4630.05 kg ha^{-1} in kaipad fields.

The available calcium contents recorded were very high, ranging from 856.66 to 2664.00 mg kg^{-1} (mean: 2062.60 mg kg^{-1}) in traditional farms and between 812.65 and 2275.00 mg kg^{-1} (mean: 1909.46 mg kg^{-1}) in scientific farms. This extremely high calcium content may be attributed to lime shell deposits associated with iron pyrite in the sampled locations. The rice shrimp farming practised in the traditional fields may also contribute to the high calcium content. Similar findings were reported by Iyer (1989) in the kaipad soils of North Kerala. Santhi *et al.* (2017) found the available calcium content of kaipad fields to vary between 826.25 mg kg^{-1} and 3275.00 mg kg^{-1}. However, Saraswathy *et al.* (2016) reported $CaCO_3$ values lower than the minimum level required for aquaculture in shrimp farms in Alappuzha and Ernakulam districts.

The magnesium contents recorded in the present study were reasonably low, ranging from 26.43 to 46.71 mg kg^{-1} (mean: 36.90 mg kg^{-1}) in traditional farms and between 21.30 and 43.60 mg kg^{-1} (mean: 35.68 mg kg^{-1}) in the case of scientific farms. A study by Santhi *et al.* (2017) also reported low levels of available magnesium in kaipad fields. The above authors found the available magnesium content of the study locations in kaipad fields to range from 21.30 mg kg^{-1} to a maximum value of 43.60 mg kg^{-1} with a mean value of 35.71 mg kg^{-1}.

The low magnesium content in the saline hydromorphic soils of kaipad may be accounted for the presence of the cation in the exchange complex sites, which is not readily available in the soil solution (Santhi *et al.* 2017). The low magnesium content in the saline hydromorphic soils of pokkali fields was also reported by Varghese *et al.* (1970) and Samikutty (1977). They reported that even though magnesium is a major exchangeable cation in the pokkali soils, existence in the exchangeable complex accounts for its low levels. Aryalekshmi (2016) reported a magnesium content of 26.17 mg kg^{-1} in pokkali soils.

Before selecting a site for shrimp farming, soil pH should invariably be ascertained. Soil with low pH of below five (for example, acid sulphate soils) should be avoided. The optimum soil pH for shrimp farms is 7-8 (CAA 2006). The present study revealed that the soil in the brackish water areas is generally acidic (pH between 3.3 and 6.8). 83.95% of the traditional shrimp farm units and 75.86% of the scientific farm units are located in acid sulphate/ low pH areas (pH less than 6). Soil pH values much lower than the values observed in the present study were reported by Saraswathy *et al.* (2016) in soil samples collected from the shrimp farms of Alappuzha and Ernakulam districts of Kerala. The average pH values reported by her were 4.5 and 4.8, respectively. The study by the above authors was done on a few farms in two districts, whereas the observations in the present study pertain to a large number of farms located all over the shrimp farming districts of the state. According to Torres (1990), one of the most important problems facing shrimp culture in the coastal environment is the occurrence of acid sulphate soils. Approximately five million hectares of coastal area in South and Southeast Asia are potential or actual acid sulphate soils. This is due to the formation of pyrites in the decomposition process of swamp forest debris. When pyrite is exposed, sulphuric acid is formed, and the soil becomes acidic.

According to CIBA (2013), the ideal soil pH for shrimp farming is 6.5–7.5. Soils with low pH and acid sulphate areas are not generally considered suitable for prawn farming because it results in escalation of cost of cultivation and takes a longer period for yielding the desired shrimp production level. The fact that a sizeable portion of the shrimp farms in Kerala are located in acid sulphate soils or low pH areas is one of the important reasons for the inadequate performance of shrimp farms in Kerala (Sahadevan 2012). Ponds in acid sulphate soils cannot be drained and dried as drying will result in capillary upward movement of sulphuric acid from beneath the soil, reducing the soil pH significantly (Sahadevan and Sureshkumar 2019).

A few traditional farms (11.73%) and scientific farms (1.72%) were also found to be located in coconut retting areas where a high concentration of hydrogen sulphide, which is lethal to shrimp, is expected to be present. Hydrogen sulphide is a by-product of the decomposition of coconut husk. This accumulates on the pond bottom and turns the soil black. The pH regulates the distribution of total sulphides among its forms (H_2S, HS-, S- -). Unionized hydrogen sulphide is poisonous to aquatic organisms; the ionic form, however, have no appreciable toxicity (Krishnani *et al.* 2001). The percentage of hydrogen sulphide decreases as the pH increases. Therefore, the presence of sulphides is considered an indicator of organic pollution under reducing conditions. The accumulation of hydrogen sulphide results in oxygen depletion leading to the mortality of prawns. The concentrations of 0.01 to 0.05 mg l^{-1} of hydrogen sulphide may be lethal to aquatic organisms. The safe levels of hydrogen sulphide are less than 0.003 mg l^{-1} for prawns (CIBA 2001).

Access to power connection is important in selecting a site for shrimp farming. Artificial aeration is required for enhancing the stocking density beyond a certain level. It also has a direct bearing on the cost of shrimp production and, hence, on the farming operation's profitability. The absence of electric connectivity is one of the reasons for the low productivity of shrimp farms in Kerala. It is also one factor that hinders species diversification in shrimp farming. Electric power from the State Electricity Board (KSEB) is cheaper than that from diesel-based generator sets installed at the farm site. Thus it influences the cost of production and the profitability of the farming operation. In the present study, it was ovserved that only 16.05% of the traditional farms and 27.59% of the scientific farms have electric connectivity from KSEB. It is also one of the reasons why most of the scientific farms in Kerala do not adopt the farming of *L. vannamei*. *L. vannamei* is generally farmed at high stocking densities for which artificial aeration is imperative.

It may be important to note that 64.20% of the traditional shrimp farms and 48.28% of the scientific farms in Kerala do not have road connectivity. The farm site must be accessible by road passable by vehicles to facilitate transportation of supplies and harvest (Apud 1988; Poernomo 1990). It helps reduce the cost of production of shrimp. Accessibility of the site to land transport is also required to facilitate supervision (Apud 1988). Road facility is also important for minimising spoilage of the shrimp harvested, as refrigerated vehicles can reach the farm gate if the farm has adequate road connectivity.

2.5.5. Farm design and construction

Proper design and construction of shrimp farms are essential for efficient management and ensuring environmental protection. In Kerala, traditional shrimp farms, in general, are found to utilize ponds not designed based on engineering principles. However, scientific farms are mainly designed and constructed on scientific lines but compromising liberally on the locally prevailing limitations and finance available. Apud (1988) believes that farms meant for scientific farming should be designed following the standard requirements of pond elevation, size, depth, gates and canal system, road access, and provisions for pumps, electrical, and aeration system. Good site selection and incorporation of mitigation features in the farm design are the best ways to avoid floods, storms, erosion, seepage, water intake, and discharge problems. A site-specific approach to the design and construction of shrimp farms is necessary as site characteristics vary significantly from place to place.

2.5.5.1. Size, shape and depth of ponds

A shrimp pond should be designed based on the characteristics of the selected site and the culture system. There is no ideal design for a shrimp pond, but a functional farm layout plan and design should be according to the physical and economic conditions prevailing in the locality. Orientation, size and shape of ponds determine the magnitude and cost of production by influencing water management and harvesting. In general, small ponds are easy to manage. However, the net realization of water area for farming will be relatively less in these cases.

In the present investigation, pond size was found to vary greatly, even within a farm. The traditional farms were found to have ponds with a size range of 0.22-5.5 ha (mean size: 0.48 ha) and the scientific ponds with a size range of 0.1-2.26 ha (mean size: 0.38 ha), which are within the size range recommended by various authors. Generally, it is recommended to use moderately sized ponds for easier management. Kungvankij *et al*. (1986) suggested a pond size between

0.25 ha and 1 ha for intensive, 0.5 and 2 ha for semi-intensive and 1 and 10 ha for extensive shrimp culture systems. With intensification and increased management attention, pond size decreases (Fast 1992a).

According to Mandal and Dubey (2015), individual ponds of 500 m^2 to 10,000 m^2 are ideal for *P. monodon* farming. For semi-intensive farming, a smaller size is preferred. Wang and Fast (1992) believe that intensive or semi-intensive shrimp ponds should not be smaller than 0.1 ha for economic reasons. On the other hand, given the difficulties in maintaining a smooth and evenly-sloped bottom and the hardship in harvesting, there is usually little reason to make these ponds larger than 2 ha. Extensive shrimp ponds require much less care than semi-intensive or intensive ponds. The need for pond bottom maintenance is much less with extensive culture, and these ponds are often much larger than semi-intensive or intensive ponds.

In the present study, it has been seen that a sizeable portion of the ponds in traditional farms and more than 75% of the ponds in the scientific farms are rectangular or have other manageable shapes as recommended by various authors.

The shape of ponds may not have a direct bearing on production and profitability. However, they are important from the point of view of pond management and to avoid dead spaces in the pond. For example, a rectangular or square pond is easy to harvest. Feeding is easy in a rectangular or square pond, and even broadcasting of feed can be ensured. Kungvankij *et al.* (1986) believe that rectangular or square ponds are appropriate for shrimp culture. According to Torres (1990), square ponds are the most economical of the geometrical figures. This shape enhances water circulation and facilitates central drainage, especially if the pond is equipped with paddle wheels. A rectangular pond (same area as a square pond) with a length twice the width will require 6% longer dykes (Torres 1990). For big ponds, rectangular shape facilitates better management, as pond workers can feed the shrimps from the dykes.

Further, the longest axis of the pond should be parallel to the prevailing wind direction (Unnithan 1985; Kungvankij *et al.* 1986; Torres 1990). This facilitates water movement generated by wind action, increasing dissolved oxygen and minimizing water temperature fluctuations in warmer months. The breadth of a pond depends mainly on the purpose and the operating system employed. According to Mandal and Dubey (2015), square or rectangular-shaped ponds with a width-length ratio of 1:2 are preferable for culturing *P. monodon*.

The present study revealed that most shrimp farms in Kerala have less than 1.2 m effective water depth. From a biological point of view, an aquaculture pond should have a depth of 2m ((Sinha 1983; Jhingran 1991). Depth of ponds has a direct bearing on the physical and chemical qualities of water. On it, but varying with water turbidity, depends the limit of sunlight penetration which, in turn, determines the temperature and the circulation patterns of the water and the extent of photosynthetic activity (Jhingran 1991). In shallow ponds, sunlight penetrates up to the bottom, warms up the water and facilitates the growth of algal mats at the bottom. Uncontrolled growth of algae may upset the dissolved oxygen balance of the pond and have a deleterious effect on the growth and survival of shrimp. In tropical countries like India, ponds shallower than one metre get heated up in the summer, inhibiting the shrimp's survival. Coastal Aquaculture Authority recommended a minimum water depth of 80-100 cm for farming of *P. monodon* (CAA 2006) in India. According to Mandal and Dubey (2015), individual ponds with a depth of one metre are ideal for *P. monodon* farming. For semi-intensive farming, a depth of 1.5-2.0 m is preferred.

Light passing through pond water is quickly quenched, and the rate at which it is quenched increases as the quantity of particulate matter (turbidity) in the water increases (Boyd 1989). Therefore, plankton blooms reduce light penetration. The heavier the bloom, the less light is available for photosynthesis at a given depth. As a result, photosynthesis occurs most intensively in the surface layer of water, and dissolved oxygen concentrations decline with depth (Hepher 1962; Boyd 1973,1982). In deep ponds, dissolved oxygen concentrations may fall to 0 mg l^{-1} at depths of 1.5 or 2 m. The rate at which dissolved oxygen declines with depth increases with turbidity. In ponds, phytoplankton is often the major turbidity source (Almazan and Boyd 1978).

For this reason, it is advantages to have shallow ponds (1-1.5 m deep) for shrimp farming because they dwell primarily on the bottom, and low dissolved oxygen concentrations at the pond bottom would be especially harmful (Boyd 1989).

2.5.5.2. Water intake and discharge facilities

Farms were found to exchange their water through sluice gates, mostly made of concrete. Monks/ pipes/ turn-down pipes were not in use for water exchange. Farms generally did not have separate water inlet and outlet canals. In most farms, water intake points and discharge points were the same or situated nearby. No farm had a central drainage system.

Torres (1990) believes that the water intake of shrimp farms should ideally be located where abundant good quality water is readily available throughout the year. The site must also have adequate protection against natural calamities, such as big waves, floodwaters etc. The water distribution system should be as short as possible. Wang and Fast (1992) observe that proper pond drainage is perhaps the most neglected and, in that sense, the most important element in shrimp pond design. Good drainage is an integral part of good water management and disease control, except for very extensive operations.

Separate inlet and outlet gates facilitate effective water exchange, pond preparation and harvesting. The farms, which had no provision for inlet/outlet, may encounter problems with pond preparation and water exchange and hence, the higher disease incidence. According to Nagesh *et al.* (2009), the incidence of diseases ranged from 50% of the farms that had separate inlets and outlets to 80% of the farms where there was no provision for inlet/outlet. Leung *et al.* (2000) recorded lower disease incidence in farms with separate inlets and outlets. Contrary to this, Baticados *et al.* (1986) could not find any association of inlet/outlet with soft-shelling in *P. monodon*.

It may be interesting to note that shrimp farms in the state had no separate reservoirs for storing water and effluent treatment ponds for regenerating the wastewater. Kongkeo (1990) has given a detailed account of the advantages of providing a reservoir that allows the pumped water to have a period during which the suspended sediments can settle. If water is pumped directly into the grow-out pond, the sediments will settle on the pond bottom. Mixed with leftover feed, this sediment will lead to unfavourable pond conditions by producing hydrogen sulphide, which is toxic to the shrimp. Also, more expenditure would be required to dredge the pond bottom frequently on which a thick layer of silt accumulates. The direct pumping of water into the grow-out pond has other harmful effects. The temperature difference between the pond water and the pumped water can cause shock to the shrimp, especially at the start of high tide when the water level in the canal is still low, and its temperature is warm during the daytime. In such a case, water pumping has to be done during the short period of the highest tide to have the maximum water supply in a limited time. However, this would reduce the efficiency in screening out predators since it would be necessary to use screens with a larger mesh size to allow a greater volume of water to flow through.

CAA (2006) has recommended constructing intake reservoirs and effluent treatment ponds in shrimp farms. According to the guidelines of CAA (2006), in areas where the source water is turbid due to suspended particles, an intake reservoir for settling the silt is essential. Similarly, in areas where shrimp farms are overcrowded, and the intake and outlets are the same waterbodies (*i.e.*, creek, estuary, backwater), the intake reservoir with provision for water treatment is required. In areas where the tidal current is swift and tidal amplitude is high, the wastewater from the farm can be directly let out during the low tide. However, in areas where the tidal current is very low, the wastewater must be treated in an effluent treatment pond (ETP) before releasing it into the natural system. An ETP, a reservoir for holding and regenerating wastewater, is mandatory for farms larger than 5 ha. Untreated effluent water could be a vehicle that spreads diseases. The disease could spread from one farm to neighbouring farms if they all use the same source of water, causing a larger outbreak in the region. Once that happens, it will be highly difficult to combat and may lead to large scale economic loss.

A minimum of 10% of the total farm area should be reserved for ETP (CAA 2006). It is also necessary that smaller farms located near each other (farm clusters) consider setting up common ETP to avoid self-pollution and release of excess nutrients and suspended solids, leading to eutrophication of the water body. For better water management, individual culture units should be within

5 ha in extent and a suitable feeder channel system should be provided within the farm so that the water intake can be effectively managed in all the individual units.

2.5.5.3. Aeration facilities

The non-use of artificial aeration is one of the reasons for the low productivity of shrimp farms in Kerala. In the study, it was found that traditional farms in the state do not use aerators. On the other hand, nearly half of the scientific farms use aerators for artificial aeration; others use no aerators. Paddlewheel aerators were the only type of aerators in use in shrimp farms. These aerators are 1-2 hp in capacity.

The most important function of an aerator is to ensure adequate dissolved oxygen levels in the pond. Artificial aeration is unnecessary for a well-managed farm at stocking rates of less than five individuals per square metre (Torres 1990). At higher stocking rates, artificial aeration is required. Various types of aeration equipment like paddlewheel, blower, diffuser, turbine etc., are used in aqua farms (Sahadevan 1990; Torres 1990), though paddlewheel aerators are more common in shrimp farming.

2.5.6. Pond management

Production of shrimp crops, with desirable levels of survival and yield, requires applying suitable pond management measures (Fast and Boyd 1992). Pond management practices adopted by prawn farmers vary according to culture system and style. According to Apud (1988), the management practices considered seriously by prawn farmers, regardless of the culture system being used, are adequate pond preparation, the appropriate size of stock and stocking procedure, feed and feed management, water management, control of pests and predators, harvest and postharvest procedures, and marketing strategies.

2.5.6.1. Pre-stocking management

Pre-stocking management includes pond bottom conditioning and preparation, eradicating predatory and weed fishes, fertilisation, and ensuring sufficient phytoplankton growth. These steps have great significance and often decide the stocking and post-stocking management practices to be adopted. Inadequate pond preparation is one of the most important problems of shrimp growers. Pond bottom ploughing, pond desilting and pond preparation duration are significantly associated with the incidence of diseases as has been observed by Nagesh *et al.* (2009).

2.5.6.1.1. Pond bottom conditioning

The present study found that the traditional farms and a part of scientific farms do not drain the ponds completely, dry and till the pond bottom as a pre-stocking management measure. Only 39.66% of the total scientific farms (46% of the farms that drain and dry the pond) were found to plough the pond bottom. Inadequate pond bottom conditioning (draining, drying, ploughing etc.) often leads to poor performance of shrimp farms, as is evident from the ensuing discussions.

In shrimp farming, as a general rule, pond bottoms should be allowed to dry and crack, principally to oxidize the organic components left from the previous culture cycle. Drying and tilling the pond bottom also helps better sunlight penetration and loosen the soil (Apud 1988). Mineralization of the organic matter liberates more nutrients that will become available to enhance primary productivity, mainly phytoplankton, during the following culture cycle. Adequate drying also allows the oxidation of hydrogen sulphide in anaerobic sediments. The presence of hydrogen sulphide inhibits primary productivity and may reach levels during the next culture cycle sufficient to inhibit the healthy growth of shrimp. Drying also eliminates fish eggs, crab larvae and potential predators in the humid and wet areas, which play a vital role in decreasing the survival rate of shrimp and thereby in decline in shrimp production. However, it must be remembered that ponds in acid sulphate soils should never be allowed to dry as it may lead to a sharp drop in pH values. Many researchers emphasized the importance of drying of pond bottom (Apud 1988; Wang and Fast 1992; Sahadevan 2012; Galib e*t al.* 2013; CIBA 2015; Sahadevan and Sureshkumar 2019). Pond desilting is necessary to remove the fouled layer of the pond bottom. Sedimentation occurs due to heavy organic inputs (feed, fertilisers, plankton) and suspended materials introduced through water exchange or surface run-off during the rainy season. A shrimp pond’s carrying capacity will decline if organic matter is allowed to accumulate on the pond bottom (Lin

1989; Wang and Fast 1992). Akiyama (1992) recommended a 10-20 cm desilting depth depending on the pond bottom condition.

Desilting is necessary in farms where stocking densities are more than six postlarvae per square metre and those that had experienced diseases during the previous crop (Nagesh *et al.* 2009). If the sludge is removed correctly, the management of the pond becomes easier during high pH periods (MPEDA/NACA 2003). Nagesh *et al.* (2009) reported a significant association between pond desilting and disease occurrence. The disease occurrence was increased with the reduction in the depth of desilting. The accumulation of unconsumed feeds, shrimp excreta and decayed matter from the pond biota could favour the proliferation of pathogens in those ponds, which was not desilted or desilted to less than optimum levels. Kongkeo (1995) also made a similar observation. According to Kongkeo (1995), ploughing exposes hidden layers of sediment to the sun and eliminates toxic gases such as ammonia, hydrogen sulphide and methane. Saraswathy *et al.* (2016) reported that the availability of nutrients (nitrogen and phosphorus) would be increased by drying and ploughing of pond bottom during pond preparation. According to CIBA (2015), tilling bottom soils enhances aeration and accelerates the oxidation of organic matter. However, pond bottoms should not be tilled when they are too wet as the tillage machinery may not function to its capacity (CIBA 2015).

The occurrence of the disease has been correlated with pond bottom drying by some workers. Nagesh *et al.* (2009) observed that disease incidence was higher in the ponds that did not plough the pond bottom and stock more than ten postlarvae per square metre. The disease incidence abated with the increase in the number of ploughs. Sukumar (1998) made a similar observation, who recorded a reduction in disease incidence from 100 to 50% when pond ploughing increased from one to four times. By this process, the organic waste will be oxidized. Ploughing also reportedly diminishes soil iron content in culture ponds with acid-sulphate soils (Cook *et al.* 1984). Ploughing on wet soil is particularly recommended for ponds if the stocking density is between six and ten postlarvae per square metre and when the sludge cannot be adequately removed by manual or mechanical methods (MPEDA/NACA 2003). However, Leung *et al.* (2000) found no significant association between desilting and disease occurrence. They stated that silt removal exposes disease-producing sediments, or the newly exposed sediments somehow stress shrimp, leading to disease problems. However, the observation by Leung *et al.* (2000) must be construed as due to inadequate ploughing and oxidation of organic matter.

The vast majority of ponds in Kerala are tide-fed and cannot be drained completely and dried as and when required. This inhibits the mineralization of organic matter in the pond bottom, which lowers the primary productivity and results in unhealthy bottom conditions. As a result, the best growth of shrimp can not be obtained in many cases. Failure to drain, dry, and till the pond bottom also directly impacts disease outbreaks, which is very common in the state.

2.5.6.1.2. Liming

The present study showed that scientific farms generally resorted to liming as a measure of pond preparation. However, a sizeable portion of traditional farms was found not to lime their ponds. In Kerala, farmers were found generally to believe that lime is applied to correct the acidity of the pond soil and water. However, in addition to the above, the lime application serves many other functions in a shrimp pond. Lime acts as a fertiliser supplying calcium, one of the essential nutrients for the growth of prawns. Lime accelerates the decomposition of organic matter, releasing carbon dioxide from the bottom sediments. It raises bicarbonate content, and the lack of carbon dioxide will not become a limiting factor for photosynthesis. Liming a pond establishes a strong pH buffer system. It counteracts the toxic effect of excess magnesium, potassium and sodium ions. It also neutralises harmful acids such as humic acids and inorganic acids. The calcium content of lime displaces certain other fertilisers from the organic colloidal system, thus making available more quantities of such ions as K^+ and PO_4^- when applied as fertliser. Lime application is also done to sterilize the soil, control diseases, and neutralize disease conditions (Apud 1988). By its toxic and caustic action, lime destroys bacteria and parasites in their various life-history stages. Though not well documented, industry experience indicates the role of lime in inducing moulting in shrimp (Sahadevan 2012). According to Subosa (1986, as cited in Apud 1988), lime stimulates the growth of nitrogen-fixing bacteria and other heterotrophic soil organisms and promotes the microbial decomposition of waste materials, including green manure, waste food, and organic fertilisers. It also reduces the concentration of hydrogen ions and the solubility of iron, aluminium, and manganese while increasing the availability of phosphates, molybdates, and exchangeable calcium and magnesium. Further, lime generally improves water quality. According to Saraswathy *et al.* (2016) application of lime has benefits like increasing the soil pH, calcium carbonate content and reducing the effects of harmful substances.

The dosage of lime application adopted by the farmers was found to vary between 200 kg ha^{-1} and 1500 kg ha^{-1}. The rate of application was based on prior experience of the farmer rather than any scientific consultations. Scientifically, the lime requirement of a shrimp pond must be based on the pH of the soil. A newly developed pond with a pH of 4-5 may require a sizeable amount of lime to raise its pH to the desired level of at least seven (Apud 1988). According to the author, a rate of 1000-2000 kg hydrated lime ha^{-1} is applied for conditioning or prophylactic purposes.

CIBA (2013, 2015) provided information on the amount of lime (t ha^{-1}) to raise the soil pH to seven. As per the recommendation, if the soil pH is 6.0 to 6.5, the dolomite required is 5.7 to 2.8 t ha^{-1}. In the case of agricultural lime and quick lime, the respective quantities are 5.5 to 2.8 and 4.6 to 2.3 t ha^{-1}. When the pH is between 5.5 and 6.0, the quantity of dolomite, agriculture lime and quicklime required would be 8.5 to 5.7, 8.3 to 5.5, 6.9 to 4.6 t ha^{-1}, respectively. Similarly, when the pH is between 5.0 and 5.5, the quantities of dolomite, agriculture lime and quicklime required are 11.3 to 8.5, 11.1 to 8.3, 9.2 to 6.9 t ha^{-1}; when the pH is between 4.5 to 5.0, the respective quantities are 14.2 to 11.3, 13.9 to 11.1 and 11.5 to 9.2 t ha^{-1}. For pH from 4.0 to 4.5, the amounts of the three-lime material required are 17.0 to 14.2, 16.6 to 13.9, 13.8 to 11.5 t ha^{-1}, respectively. It reveals that, in general, the rates of lime application adopted by the farmers in Kerala are less than the adequate quantity.

2.5.6.1.3. Eradication of weed and predatory fishes

In the present study, it was found that though scientific farms eradicate weed and predatory fishes before seed stocking, most traditional farms do not adopt such measures. They generally allow all fishes and shrimps that enter the field through the incoming tides to grow. As a direct result, there is a large-scale occurrence of weed and predatory fishes in the fields, which compete with the shrimps for food and space. Predatory fishes also take a heavy toll on shrimps. Some of these fishes like tilapia also breed in ponds and outnumber the shrimp stocked. Thus the presence of weed and predatory fishes results in slow growth and survival rates of farmed shrimps. The impact of weed and predatory fishes in aquaculture ponds has been discussed by Alikunhi *et al.* (1955), Alikunhi (1957), Ibrahim (1957) and Chaudhuri (1960). Inadequate eradication of weed and predatory fishes is perhaps one of the reasons for the low performance of the traditional shrimp farms in Kerala.

Repeated drag netting is the customary method of removing unwanted fishes from shrimp ponds. However, certain bottom-dwelling fishes are difficult to be caught by repeated seines. The position worsens in deeper waters. Dewatering of ponds, even by resorting to pumping, should be done to eradicate unwanted fishes and shellfishes. If, however, pumping is found unfeasible or uneconomic, the pond should be poisoned. The object of poisoning a pond is merely to eradicate undesirable fishes and shellfishes so that the pond becomes free of them and the shrimp can survive and grow. However, it is to be borne in mind that the same poison will also destroy them if left loose in the pond where shrimps grow. In this context, it is pertinent to remark that commonly used agriculture pesticides, insecticides are inimical to shrimp ponds. The object of shrimp culture is served by using a particular poison in specified doses only at the chosen moment and at not any time.

A variety of chemicals and plant toxicants are used to eradicate weed and predatory fishes worldwide. According to Villaluz *et al.* (1969), this practice should be eliminated in prawn farms to avoid residual effects. SEAFDEC encouraged using organic poisons such as derris root, tea seed cake, and tobacco dust in shrimp farming to eradicate weed and predatory fishes (Apud *et al.* 1983).

Proper screening or water filtration is one pond management practice that has been improved recently. Traditionally, the gate screen is made of bamboo slats with wooden frames. This allows many unwanted species to enter the pond at the egg or larval stages, which compete with cultured species in due time. A modification has been made by farmers recently placing a close-meshed nylon screen over the bamboo slats. Although this is helpful, the flow of water is very much interrupted.

2.5.6.1.4. Fertilisation

Fertilisation is another standard practice in pond preparation, particularly in extensive and semi-intensive culture systems. Fertilisers include both organic and inorganic fertilisers. In the state, most traditional and scientific farms were found to undertake fertilisation to improve soil fertility and facilitate the growth of phytoplankton. Fertilisation was observed to be done at the time of pond preparation. Prawn farmers were found to apply organic manure (cow dung) at 0.5-2 t ha^{-1}. Some also used chicken manure at 150-750 kg ha^{-1}. Usually, inorganic fertilisers such as dolomite, superphosphate, Mussoorie rock phosphate, ammonium phosphate and urea at 50- 200 kg ha^{-1} were added to enhance the growth of natural food. The rate of fertilisation was based on the prior experience of the farmer rather than any scientific consultations.

According to CIBA (2013), the dose of fertilisers to be applied depends on the fertility status of the soil. Organic fertiliser like dry cow dung at the rate of 500 - 2000 kg ha^{-1} and inorganic fertilisers like urea and single superphosphate at 25 - 100 kg ha^{-1} can be applied depending on the organic carbon content (1.5-2.5%), available nitrogen (50-75 mg 100 g^{-1} soil) and available phosphorus (4-6 mg 100 g^{-1} soil) content in the pond. From the total dose, 10% may be applied fortnightly to maintain the desired level of phytoplankton production.

Shrimp being bottom dwellers, benthic organisms constitute their main food items. According to CIBA (2015), the productivity of benthic organisms may be low in ponds with concentrations of organic carbon below 0.5 to 1.0%. Hence fertilisation of soil instead of water is more effective (CIBA 2015). Organic fertiliser can be applied to such soils to enhance organic matter concentration. Chicken and other animal manures have been applied at 1,000 to 2,000 kg ha^{-1} to pond bottoms during the fallow period. In brackish water conditions, the decomposition of cattle dung is slow, so the application of chicken manure, if available, is advisable. The rate of chicken manure is one-third of cattle dung. In shrimp farming, both organic manures and inorganic fertilisers are supplementary, and one cannot be exchanged for the other. Applying organic and inorganic fertilisers together as a basal dose during the pond preparation is always better for optimum results.

In the state, shrimp farmers were generally found either to directly broadcast the fertilisers or make them into a mixture with water and disperse them over the pond's surface. They are also kept in empty feed bags or fertiliser cages at the sluice gate and allowed to disperse due to water movements. Various methods of applying fertilisers to shrimp ponds are in practice the world over- the solution method, the spreading method, the pile method, the platform method and the bag method. However, the last two methods are regarded as the most effective and efficient methods (Shang 1981).

Adequate plankton production (making of watercolour) is one of the important aspects to be ensured before seed stocking. It may be ascertained by observation of watercolour supported by Secchi disc reading. Most of the shrimp farms in the study area were not paying adequate attention to ensuring sufficient plankton growth and maintaining healthy watercolour in shrimp ponds before stocking. This aspect has been discussed further under section 2.5.6.3.1.7.

2.5.6.1.5. Pond disinfection

Pond disinfection has become an important management measure in the recent past. Most of the farms in the study area were fou has nd not to undertake disinfection of their ponds as a management measure to kill the pathogenic organisms or the eggs and juveniles of fishes, crustaceans and other organisms that may reach the ponds through the incoming water. However, 12.07% of the scientific farms used bleaching powder (@ 5- 20 ppm available chlorine) to disinfect the pond. Bleaching powder available in the market in this part of the county has a chlorine content of 24-30%. According to Villalon (1991), in areas characterized by anaerobic soils, it may be necessary to use strong chemical oxidizers such as chlorine and plough the affected area. Chlorine is used in aquaculture to disinfect and oxidise the organic matter of source water. Disinfection refers to the eradication of disease-causing organisms. Chlorination will also successfully eliminate toxic plankton (dinoflagellates) and aquatic animal pests and competitors that come in with the water supply.

Since chlorine is a potent oxidizing agent, it will react with iron, manganese, hydrogen sulphide, free ammonia and organic matter in the water (CIBA 1998). CIBA (2019) recommended a dose of 10 ppm available chlorine to kill any potential vectors or carriers in the source water. However, it is advised to calculate the actual dose based on the chlorine demand of water (which may change with dosage, time, temperature, pH, nature and amount of impurities in water) and the actual chlorine content in the bleaching powder.

Water for filling shrimp ponds is often passed through fine screens or filters to avoid unwanted organisms. While filtration will reduce the possibility of fish and other relatively large organisms entering ponds, it will not prevent many disease organisms and smaller vectors of disease organisms. According to Boyd (2019), the most effective way of controlling the entry of disease organisms through the water supply is disinfection. The disinfectant can be applied to water held in a reservoir or done directly in water-filled ponds. Various disinfectants such as calcium hypochlorite, chloramine T, potassium permanganate, copper sulphate, hydrogen peroxide, iodine compounds, benzalkonium chloride and glutaraldehyde are in use in shrimp farming. The most effective one probably is calcium hypochlorite. Calcium hypochlorite may also be applied over wet areas. Application of 100 to 200 g m^{-2} of this disinfectant often are used. Boyd (2019) observed that copper sulphate, formalin and potassium permanganate, though used widely for soil disinfection, are not as effective as lime or calcium hypochlorite.

2.5.6.1.6. Use of probiotics

Shrimp farmers were observed to use many commercial products to improve soil quality and enhance production. These products included cultures of live bacteria, enzyme preparations, composted or fermented residues, plant extracts, and other concoctions under the name probiotics. No traditional farms used these products. However, the majority of the scientific farms used such chemicals, some regularly and others occasionally, as a pond management measure. However, it may be mentioned here that no effort was made in the present study to collect evidence to the effect that any of these products would improve soil quality or growth of prawns. However, in general, scientific farmers in the study area are convinced about the advantages of using probiotics.

2.5.6.2. Grow-out stocking

Stocking management involves selecting good quality postlarvae, ensuring optimum stocking density, proper acclimatisation and stocking in ponds, which significantly influence the success of shrimp farming. The different topics are discussed below.

2.5.6.2.1. Stocking material

Good quality stocking material is a prerequisite for the success of any aquaculture venture. To a great extent, the productivity and profitability of the farming operation depend on the quality of the stocking material. Most shrimp farms in Kerala (48.15% of the traditional farms and 72.41% of the scientific farms) were found to depend on seeds produced in hatcheries functioning outside the state. 43.59% of the traditional farms that depended on hatcheries outside Kerala got the seeds through supply agents. The rest procured the seeds directly from the seed production centres. Similarly, 38.10% of the scientific farms that depended on hatcheries outside the state got the seeds through seed supply agents. The rest procured the seeds directly from the hatcheries.

With the existence of a very large number of hatcheries all over the country, a grow-out pond operator can avail of postlarvae throughout most of the year. At present, India has more than 330 organized shrimp hatcheries (http://www.caa.gov.in/ hatcheries_approved.html) catering to the seed requirements of the shrimp aquaculture sector. However, the number of shrimp seeds produced in Kerala is grossly inadequate to meet the demand from the farming sector (Sahadevan 2016a; 2016b). Insufficient local seed supply forces the farmers to rely on seeds produced outside the state or adopt less than optimum stocking density. Seeds from distant places are often weak due to stress caused by handling and transportation, resulting in lower survival rates, productivity and profitability. Suboptimal stocking density amounts to the under-utilization of precious water resources. Lower profitability may make shrimp farming less attractive. It may be recalled here that the productivity of shrimp farms in Kerala is the lowest among all shrimp-producing states of the country (GoI 2019; https://mpeda.gov.in/?page_id=684) and is much less than the national average.

Nagesh *et al.* (2009) observed a significant association between the source of seeds and disease incidence. A higher disease incidence (76%) was noticed in the farms which stocked hatchery-produced seeds. In contrast, Corsin *et al.* (2001, 2003) could not notice any significant association between either source or activity of seeds and white spot syndrome virus (WSSV) disease in *P. monodon*. They related it to the variety of suppliers and treatments, leading to a lack of statistical power.

Seed quality directly influences the survival and growth of cultured shrimps and determines the success of shrimp farming. The majority of the traditional (54.32%) and scientific farms (87.93%) were observed to check the quality of seeds before stocking. Most of the farms (77.27% of the former and 94.12% of the latter) undertake the PCR test, but others were satisfied with visual observations and/ or stress tests. Further, 41.18% of the traditional farms and 91.67% of the scientific farms who undertake PCR tests got the test done by themselves. Others depended on the test results provided by the hatchery operators/ other agencies.

In the absence of any accreditation system for hatcheries in the state, a sizeable number of the farmers use the un-tested seed for farming. A lower price for such seeds acts as an attraction for the action. Further, there are not many seed testing laboratories in Kerala. Farmers generally do not take the hassle of testing seed quality in laboratories outside the state. CAA (2006) has given detailed guidelines to ensure shrimp seed quality.

Farmers, in general, were found to observe scientific principles in the transport and stocking of shrimp seeds. Seed harvest and transport were done at the earliest possible time to reach the pond before sunrise to ensure the best results. Stocking, including acclimation (whenever done), was found to be completed in the morning before the sun gets heated up. The use of ice helps reduce the metabolic activities of seeds and thereby reduce the depletion rate of oxygen in the transport medium. Lowering temperature also lowers the excretion rate of seed and build-up of toxic ammonia gas in the transportation bag. Counting of fry at the source avoids handling at the time of pond stocking. This helps prevent stress at the pond site where facilities are not as good as in hatcheries. All these actions help reduce the mortality rate at pond stocking.

The majority of shrimp farmers in Kerala were found to use seeds that are 20 days or less in age. In shrimp farming the world over, some farmers stock their postlarvae directly in grow-out ponds, while others choose to stock them first in nursery ponds, hapa nets, or net enclosures. Stages of postlarvae usually supplied in the hatchery range from 5 to 25 days old (PL 5 - PL 25). Regardless of the source, prawn operators prefer older stages of postlarvae for stocking in grow-out ponds (Apud 1988) as such seeds are expected to result in a higher survival rate.

The size of the seed has a direct bearing on shrimp productivity. While in the case of white prawn (*P. indicus* and *L. vannamei*), it may be ideal to stock seeds at PL 5 – PL 10, PL 20 stage is ideal in the case of the black tiger prawn (Sahadevan 2013, 2014). Because of the acute shortage of shrimp seeds within the state, especially during the peak periods of farming, farmers in Kerala often have to be content with lesser/ over aged seeds leading to lower shrimp production. Though it may be suitable to stock older postlarvae (PL 30-PL 35) or juveniles in grow-out ponds (Apud 1988), transportation of such seed will lead to heavy mortalities. This necessitates the need for *in situ* nursery rearing. In Kerala, 100% of the traditional farms and 86.21% of the scientific farms were found not to adopt nursery rearing of seeds. Nursery rearing aims to produce juvenile stages suitable for stocking in grow-out ponds from the earlier stages of PL 5 to PL 10.

Properly designed shrimp nursery systems are high-bio security facilities to grow postlarvae at high densities. The objective is to produce healthy, strong and uniform sized juveniles with significant potential for compensatory growth after their transfer for final grow-out. This juvenile production phase occurs when the postlarval shrimp body weight reaches approximately 2 mg and can continue until the individual shrimp weighs 300 mg or more. During this stage, proper growth and development condition the animals to manage the problems faced in the more challenging grow-out environments. It will directly improve the final survival rate. Other advantages of nursery rearing include control and biosecurity, efficiency in operation and improved health and disease management. Farmers are increasingly adopting separate nursery infrastructures due to their value from biological and economic perspectives.

Many authors observed benefits of nursery rearing of seeds before grow-out socking (Apud and Sheik 1978; Cholik 1978; Apud 1979; Fernandez 1979; Gabasa 1982; Duenas *et al.* 1983; Hirono 1983; Pretto 1983; De La Pena and Prospero 1984; Cifford 1985; Unnithan 1985, Apud 1988; SEAFDECAQD 1989; Villalon 1991; Sturmer *et al.* 1992; Yta *et al.* 2004; CIBA 2015; Browdy *et al.* 2016, 2017).

Incorporating a nursery phase into the production cycle is an effective management strategy adopted by many progressive shrimp farmers in many parts of the world. 6% of the shrimp farmers in Ecuador produce 20% of the crop using this two-phase pond system (Hirono 1983). Two-phase grow-out is the standard technology for semi-intensive and intensive shrimp farming in the United States (Lawrence *et al.* 1985; Lawrence and Huner 1987) and in many other parts of the world (New and Rabanal 1985). In Kerala, shrimp farmers, except a very few, generally do not undertake nursery rearing despite its importance.

2.5.6.2.2. Acclimatisation of seed

In the present study, it has been observed that scant attention is paid to acclimatizing the seed in many cases. Only 27.78% of the traditional farms and 55.17% of the scientific farms were observed to undertake adequate acclimatisation of seeds before stocking. A sizeable portion of farms either did not take adequate care in acclimatising seeds or did not acclimatise at all. 10.34% of the scientific farms use pond stocking survival buckets to evaluate stocking mortality for 48 hours. However, none of the traditional farms adopted such a measure. It is expected that a sizeable proportion of seed might be dying on the day of stocking or the days that follow immediately. But, since the seeds are vey small in size, the mortality may go unnoticed.

Hatchery reared juveniles or postlarvae may require acclimation to pond conditions. Failure to gradually adjust the salinity and temperature of transport water to that of the pond water during seed stocking can result in high mortality. Some traditional farmers were found to not care about the salinity and temperature of transport and pond water. On the other hand, most scientific prawn farmers were particular about the salinity level of the fry source. When it differed from their pond salinity, they were reported to request the hatchery or nursery source to adjust the salinity of the transport water to that of their pond. The importance of acclimatisation of seed before stocking cannot be overemphasized. Perhaps proper acclimatisation is one of the most critical management tools for enhancing shrimp production.

The appropriate time for seed stocking is early morning or late evening. The seed should never be stocked when the water temperature is high. Generally, adjusting salinity by about 2 ppt per hour is advisable (Apud 1988; Sahadevan 2012). According to Boyd (1989), the rate of salinity change should not exceed 1 to 2 ppt per hour. The adjustment of salinity by about 3 ppt daily is advised by (CIBA 2015). For the best results, seeds are distributed throughout the area when released into the pond. Villalon (1991) gave a detailed account of the acclimatisation and pond stocking of shrimp seed.

Akiyama (1993) observed that shrimp larvae would die without acclimatisation, and the actual stocking density would be less than expected. Insufficient acclimatisation would ultimately lead to the mortality of shrimp succumbing to stress and diseases. Nagesh *et al.* (2009) noticed a significant association between acclimatisation and disease incidence in shrimps. The disease incidence was more (82%) in farms that did not acclimatise the shrimp. Kumlu and Jones (1995) recorded 100 and 80% mortality of postlarvae of *P. indicus* when they were transferred from a salinity level of 30 to 5 ppt and 10 ppt, respectively, without acclimation. Leung *et al.* (2000) stated that the longer the duration of acclimatisation, the lower the disease occurrence. Corsin *et al.* (2001) could not observe any association between the method of acclimatisation and white spot syndrome baculovirus (WSBV) presence at the harvest.

2.5.6.2.3. Stocking density

The scientific shrimp farms in the state were found to adopt a stocking density between 5000 seeds ha^{-1} and 3,50,000 seeds ha^{-1}, the average in the case of *P. monodon*, *P. indicus* and *L. vannamei* being 57,100, 75,900 and 3,20,000 seeds ha^{-1} respectively. Traditional shrimp farms resorted to average stocking densities of 12,500 seeds ha^{-1}, 35,000 seeds ha^{-1} and 42,000 seeds ha^{-1} for supplementary stocking of *P. monodon*, *P. indicus* and *L. vannamei*.

Stocking density is dependent on the species cultured the culture system, including food availability, water depth and efficiency in water management. In tiger prawn, stocking densities in extensive operations may vary from 20,000 to 80,000 ha^{-1}. These stocking density levels are based on industry experience and the results of various studies on prawn grow-out (Mochizuki 1979; Apud *et al.* 1981). Shrimp growth highly depends on water management and depth as well as on the quality and quantity of feed provided. Stocking densities for semi-intensive and intensive systems range from 1,00,000 to 4,00,000 ha^{-1} with the optimum of 1,50,000-2,50,000 ha^{-1}. For white prawns, higher densities may be adopted. According to Briggs *et al.* (2004), *L. vannamei* is amenable to the culture at very high stocking densities of up to 150 m^{-2} in pond culture and even as high as 400 m^{-2} in controlled recirculated tank culture. Although such intensive culture systems require a much higher level of control over environmental parameters, it enables high shrimp production in limited areas, resulting in better productivity than that currently achievable with *P. monodon* in Asia. However, *P. monodon* can be aggressive, has high protein requirements, and maybe more demanding of high-water quality, making it difficult to culture as intensively as *L. vannamei.*

Stocking density strongly influences the level of waste generated in the pond (CAA 2006). The higher the stocking density, the larger the quantity of feed that has to be used. Higher stocking densities also stress the animals leading to a greater incidence of disease. In ponds with excessive stocking and feeding rates, the wastewater is generally of low quality and has more potential to cause water pollution than wastewater from ponds stocked at lower densities. Because of the strong impact of stocking densities on the sustainability of farming practices, low stocking densities are generally recommended in shrimp aquaculture. For the improved traditional system of farming *P. monodon*, the stocking density permitted in India is 4-6 seeds m^{-2} (Aquaculture Authority 1999). The stocking densities recommended for the culture of specific pathogen-free *P. monodon* and *L. vannamei* by the Coastal Aquaculture Authority in India are 30 seed m^{-2} and 60 seed m^{-2}, respectively (CAA 2014).

As has already been mentioned, stocking density plays a vital role in deciding the growth and survival of shrimp and the productivity of the pond.

Management practices have to be devised often based on stocking density alone. A significant association between stocking density and disease incidence was observed by Nagesh *et al.* (2009). The authors found that disease intensity increased with increasing stocking densities, ranging between 25% in farms stocked at 3-6 m^{-2} and 86% in farms stocked at 15-18 m^{-2}. As stocking densities increase, the culture system is overloaded with nutrients. Active microbial decomposition can cause oxygen depletion and a reduced environment leading to slower growth (Ray and Chien 1992) and even causing diseases such as gill rot, external protozoan infestation or nematode parasitism (Liao *et al.* 1985). Increased prevalence of the disease has been associated with increased stocking density by Overstreet (1973), Hanson and Goodwin (1977), Doubrovsky *et al.* (1988) and Nagesh *et al.* (2009). Baticados *et al.* (1986) recorded increased incidence of soft-shelling with increased stocking density from extensive to semi-intensive and intensive culture systems. Contradictory to the above findings, Hegde (1997) and Corsin *et al.* (2001), however, recorded WSSV incidence in the shrimp ponds irrespective of the stocking density. According to Sahadevan (2012), under the climatic conditions prevailing in Kerala, the maximum stocking density that may be adopted in black tiger shrimp farming with no artificial aeration is 70,000 ha^{-1}. However, Torres (1990) believes that artificial means of aeration is not necessary for a well-managed farm at stocking rates of less than 50,000 seeds ha^{-1}.

2.5.6.3. Post-stocking management

Post-stocking management in a shrimp farm covers all activities performed after the seed stocking till the harvest. It includes water quality, feed and disease management, control of weed and predatory fishes and assessment of growth and survival (biomass of shrimp).

2.5.6.3.1. Water quality management

The water quality variables most often monitored in shrimp farms are water temperature, water pH, water salinity, dissolved oxygen, plankton abundance and water transparency (Boyd and Fast 1992). Total alkalinity and total hardness are also measured in many farms, though at less frequent intervals. These variables can be measured with satisfactory accuracy using simple means, and it is possible to make meaningful management inferences from the data collected. Water quality problems in shrimp farms are often related to culture intensity. In general, low-intensity farms have few problems with water quality.

2.5.6.3.1.1. Temperature

The water temperature range observed in various farms in the present study is within limits reported by various authors for optimum growth of penaeid prawns. According to Boyd and Fast (1992), shrimps commonly cultured in ponds grow best at temperatures in the range of 25 to 30 °C. Some species will grow at less than 20 °C, but temperatures of 35°C and more are lethal. However, Krishnani *et al.* (2001) believe that the optimum temperature level for most of the brackish water shrimp species is 28-32 °C. In shallow brackish water ponds, where regular exchange between the tidal water and the pond water is not maintained during the hot, dry months, the water temperature may shoot up beyond the tolerance limit causing mortality of prawns. According to Schmidt-Nielsen (1999), oxygen consumption rate increases constantly and regularly with temperature elevation within the tolerated temperature variation range. In general, an increase of 10 °C results in two to three times higher oxygen consumption in prawns. Such increase is denominated thermal coefficient and represents the degree of sensibility of an organism to temperature (Schmidt-Nielsen 1999).

According to Unnithan (1985), the water temperature optimal for penaeid prawn farming is 25-30 °C. The optimum temperature range for farming of *P. monodon* is between 26 and 30 °C (Kontara 1988) and 26 and 33 °C (Ramanathan *et al.* 2005; Soundarapandian and Gunalan 2008; Mandal and Dubey 2015). CAA (2006) reported a temperature between 28 °C and 33 °C as the optimum level for the farming of *P. monodon*. Krishnamoorthy *et al.* (2008) reported the upper and lower lethal temperatures for the postlarvae of *P. indicus* as 43.5 °C and 8 °C, respectively. *P. monodon* frequents waters with temperatures of 18–34.5 °C (Branford 1981; Chen 1985). On the other hand, Jackson and Burford (2003) reported that while temperature had a substantial and regular influence on growth rate (more growth rate at higher temperatures), the effect on survival was not apparent, within a temperature range of 20 and 32 °C. Wyban *et al.* (1995) reported the optimum range of temperature for the farming of *L.*

vannamei as 23- 30 °C. Villalon (1991) stressed the need to reduce the diurnal oscillation in temperature in the farming of *L. vannamei*. Experiments conducted by Wyban *et al.* (1995) demonstrated that in *L. vannamei,* growth is susceptible to small changes in temperature. According to these authors, reduced growth and feeding could be expected in *L. vannamei* when the water temperature is below 23 °C or above 30 °C.

According to Briggs *et al.* (2004), although *L. vannamei* would tolerate a wide range of temperatures, it grows best between 23 and 30 °C (comprising the majority of the tropical and subtropical world), with the optimum being 30 °C for small (1 g) and 27 °C for larger (12-18 g) shrimp. They will also tolerate temperatures down to 15 °C and up to 33 °C without problems, but at reduced growth rates (Wyban and Sweeney 1991). *L vannamei* can thus be profitably farmed during the cool season in Asia (October-February). This is traditionally the low season for *P. monodon* farmers in this part of the world, meaning that increased yearly harvests may be possible using this species (*L vannamei*). Recent experiences in Thailand, Ecuador and elsewhere have shown that when the water temperature drops to less than 30 °C, increased problems with viral diseases such as WSSV and Taura Syndrome Virus (TSV) occur not just with *P. monodon,* but equally with *P. vannamei*.

There are numerous studies on the effect of temperature on the survival and growth of penaeid and non- penaeid crustaceans. In general, these studies show peak survival and growth at temperatures near those of the natural habitats (Guest and Durocher 1979; McKenney and Neff 1979; Chittleborough 1975; Lester and Pante 1992). Tolerance to variation in temperature often differs among closely related species due to genetic differences (Yagi and Uno 1980, 1981, 1983; Vanhaecke *et al.* 1984; Lester and Pante 1992).

2.5.6.3.1.2. Dissolved oxygen

Dissolved oxygen is perhaps the most important critical factor in any aquaculture system. In addition to the direct effect on survival, low dissolved oxygen retards the growth of shrimp and increases the susceptibility to diseases and toxic gases like carbon dioxide, ammonia and hydrogen sulphide. The present study showed that dissolved oxygen level in a large number of the farms in the state was lower than the level required for the best growth and survival, especially during the third and fourth months of rearing. It must be remembered that the values of dissolved oxygen indicated is the monthly average value, implying that extremely low values were possible in many instances. The concentration of dissolved oxygen in shrimp ponds can fall so low that shrimp in ponds is killed. However, adverse effects of low dissolved oxygen more often are expressed as retarded growth and greater disease susceptibility. In ponds with chronically low dissolved oxygen concentrations, shrimp will consume less food, and they will not convert food to flesh as efficiently as in ponds with normal dissolved oxygen concentrations (Andrews *et al.* 1973; Boyd 1982; Lai-Fa and Boyd 1988).

The volume of oxygen dissolved in water depends on its temperature and the concentration of dissolved salts. Under a given set of conditions, there is a nonlinear inverse relation between water temperature and dissolved oxygen, the latter always tending to maintain a normal value towards the saturation point (Welch 1952). There is also an inverse relationship between the water salinity and the dissolved oxygen content (Boyd 1989). It means that the concentration of dissolved oxygen decreases with an increase in temperature and salinity.

For prawn farming, the dissolved oxygen level should not go below 3.5 ml l^{-1} (Suseelan 1978). According to CAA (2006), the optimum level of dissolved oxygen for the farming of *P. monodon* is 5-7 ppm (above 50% air saturation). Mandal and Dubey (2015) recommended a dissolved oxygen content of more than 5 ppm for *P. monodon* farming. According to Boyd (1982) concentration of less than 1 mg l^{-1} is lethal to shrimp if exposure lasts for more than a few hours. Growth will become slow if exposure to low dissolved oxygen (1-5 mg l^{-1}) is continuous. The best condition for good growth occurs when dissolved oxygen concentration is between 5 mg l^{-1} and saturation. Boyd and Fast (1992) reported that dissolved oxygen concentrations of zero to 1.5 mg 1^{-1} could be lethal to most of the cultured shrimps depending upon exposure time and other conditions. According to these authors, very high dissolved oxygen levels (supersaturation) are potentially harmful to shrimps.

Minimum dissolved oxygen requirements for different shrimp species are not well established. However, a few studies exist on the subject. Seidman and

Lawrence (1985) observed critical dissolved oxygen levels for *P. monodon* and *P. vannamei* of 2.2 and 1.9 mg l^{-1} respectively for small shrimp (0.2 to 0.5 g), below which growth and survival were reduced. Oxygen concentration for "normal" growth in *P. monodon* is probably 3.7 mg l^{-1} or higher, with lethal dissolved oxygen concentrations of 0.5 to 1.2 mg l^{-1} depending on exposure duration (Chamberlain 1988).

Pond dissolved oxygen concentrations are dynamic, and they exhibit both diel cycles and vertical stratification. Concentrations are greatest in the afternoon and least near dawn as a result of community photosynthesis and respiration. Oxygen concentrations are greatest near the surface during daylight hours because of light extinction with depth and thermal stratification. The magnitude of dissolved oxygen fluctuation during 24 hours and the degree of vertical stratification increase with increasing phytoplankton abundance. Fertilisation and feeding increase phytoplankton abundance. Therefore, problems with low dissolved oxygen increase with increased shrimp production per unit area.

The influence of the daily cycle of dissolved oxygen on the growth of shrimp is not well understood, but most workers feel that good growth can be achieved as long as the dissolved oxygen level does not fall below 25 or 30% of saturation during the night and does not remain at this low level for more than 1 or 2 hours (Boyd 1982).

In the state, traditional farms and the majority of the scientific farms generally do not use aerators. Among the farms which use aerators, the average duration of working (hours per day) is also limited. Artificial aeration is required at higher stocking densities. Aeration is necessary for culture ponds when organic loading drives the pond ecosystem from autotrophy to heterotrophy (Madernjian 1990). Aeration supplements the natural dissolved oxygen and facilitates the organic load to accumulate at the centre, which can be removed easily. According to Nagesh *et al.* (2009), diseases in shrimp farms are significantly associated with aeration. In his study, he observed that among the disease affected farms, 87% did not aerate the ponds. In contrast, Leung *et al.* (2000) could interestingly notice increased disease occurrence with aeration in semi-intensive systems, which may be due to the result of disease rather than the cause.

2.5.6.3.1.3. Water pH

The pH of water is critical to the survival of most aquatic plants and animals.The hydrogen ion concentration of shrimp ponds is an important environmental factor, the variations of which, among other causes, are linked with the species composition and life process of animal and plant communities inhabiting them. An increase in the concentration of hydrogen ion (H^+) results in a lowering of pH value. Conversely, a reduction in the H^+ concentration increases pH value. The pH of normal brackish water usually is between 7 and 9 (Boyd 1989).

The present study revealed that most shrimp farms in Kerala have average water pH between 7 and 8, which is ideal for the growth of shrimp. Further, the average pH values of all the ponds were found to lie between 6 and 11. However, it may be remembered here that the pH values indicated are the mean values, and the exact value may lie beyond the range conducive for eliciting the best growth in shrimps, at least during some part of the day. The pH of pond water undergoes a diurnal change, and it is alkaline in mid-afternoon and acidic just before daybreak (Boyd 1989; Jhingran 1991). Well-marked seasonal variations in pH is unlikely to occur in shrimp ponds.

Swingle (1967) stated that waters with a pH range of 6.5 to 9.0 as recorded before daybreak are most suitable for pond culture, and those having pH values of more than 9.5 are unsuitable because carbon dioxide in the latter is not available. Shrimp dies at about pH 11. Similarly, acid waters reduce the appetite of the shrimp, their growth and tolerance to toxic substances. The toxicity of hydrogen sulphide (H_2S), copper and other heavy metals to shrimp increases at lower pH. On the other hand, the toxicity of ammonia to shrimp is more at higher pH. pH values above and below the optimum level indirectly influence aquatic organisms by similar harmful effects, thus weakening their biogenic capacity. The shrimps get prone to the attack of parasites and diseases in acid waters. According to Apud (1988), the production would be poor in ponds with pH below 6.5. At pH 9.0 and above, ammonia in water becomes toxic to animals (Norfolk *et al.* 1981). According to Boyd and Fast (1992), pH values below four and above ten may be lethal to shrimp; and the best range is 7 to 9. Alkaline water with a pH ranging from 7.5 to 8.5 is conducive to prawn culture (Muthu 1980).

There are little data on the effect of pH on shrimp, but it is safe to assume that shrimp respond to pH much the same way as fish (Boyd 1989). The effect of pH on aquaculture species is outlined by Boyd (1982). According to him, a pH of four is considered the acid death point; at pH values between four and six, slow growth of shrimp results. A pH between 6 and 9 is considered the best for shrimp growth, whereas slow growth results at pH between 9 and 11. A pH of 11 is considered the alkaline death point. Brackish waters are well buffered against pH change, and water pH generally does not fall below 6.5 or rise above 10. However, in acid sulphate soils, the pH may drop considerably and pose problems in shrimp farming. CAA (2006) reported a pH range of 7.5-8.5 as the optimum level for the farming of *P. monodon.* Boyd and Fast (1992) view that with ponds constructed in or near acid-sulfate soil, pH monitoring of pond water is necessary to assure that excessively acidic conditions do not develop.

2.5.6.3.1.4. Total alkalinity

The total alkalinity of water is mainly caused by the cations of calcium, magnesium, sodium, potassium, ammonium and iron combined either as carbonates and/ or bicarbonates or occasionally as hydroxides. It is defined as the total concentration of titratable bases in water (Boyd 1989). During the mid-afternoon, it is occasionally encountered in surface layers in waters showing intense photosynthesis. A mixture of carbonate and bicarbonate alkalinity is generally encountered in waters of pH ranging from 8.4 to 10.5 (Jhingran 1991). Bicarbonates are reduced in higher pH values. At pH values less than 8.3 but more than 4.5, practically no carbonate is present, but free carbon dioxide and bicarbonates may be present (Jhingran 1991).

In the present study, most of the farms (90.12% of the traditional farms and 89.66 of the scientific farms) were found to have total alkalinity between 20 and 300 ppm ($CaCO_3$), which is congenial for the optimum growth and survival of shrimp.

According to Krishnani *et al.* (2011), total alkalinity determines the buffering capacity of the water. It primarily decides the magnitude of dial fluctuation of pH of water. Waters with low alkalinity (20 mg l^{-1}) has low buffering capacity against pH changes. This results in wide fluctuations in pH value from 6 to 7.5

at dawn to 10 or even higher in the afternoon. Very high alkalinity coupled with low hardness (<20 mg l^{-1}) results in a rise in the afternoon pH beyond 11 and cause alkaline death of shrimp. Very high alkalinity in water may also suffer from poor productivity due to the limitation of carbon dioxide for photosynthesis. The pH of water with moderate to high alkalinity values usually fluctuates between 7.5 and 8 at dawn and between 9 and 10 in the afternoon.

Schaperclaus (1933) believes that the most productive water has 200-500 ppm equivalent $CaCO_3$. Alikunhi (1957) stated that in highly productive waters, the total alkalinity ought to be above 100 ppm. Swingle (1967) opined that such a classification of the suitability of waters for fish culture might be valid where soils are located in moderate to heavy rainfall areas and modern practices of liming and fertilisation are not adopted. CAA (2006) recommended total alkalinity of 200 ppm as the optimum level for the farming of *P. monodon*.

2.5.6.3.1.5. Total hardness

Total hardness is the total concentration of divalent cations in water (Boyd 1989). Many workers consider yoyal hardness the same as total alkalinity since when both are expressed as $CaCO_3$, their values may be approximately equal. However, hardness in principle is the total of soluble calcium and magnesium salts present in the water expressed as its $CaCO_3$ equivalents. The total harness also includes the sulphates and chlorides of calcium and magnesium. In most natural waters, the predominant ions are bicarbonates associated mainly with calcium, to a lesser degree with magnesium and still less with sodium and potassium. Sulphates and chlorides of calcium and magnesium predominate in brackish and marine waters. These salts, calcium sulphates and chloride, while available in waters for plant and animal assimilation, do not serve as effective buffers for the storage of carbon dioxide (Jhingran 1991). In the present study, most of the farms (92.59% of the traditional farms and 87.94% of the scientific farms) were found to have a total hardness between 20 and 400 ppm ($CaCO_3$), which is well within the acceptable range for eliciting the best growth in most farmed penaeid prawns.

The importance of hardness is closely related to alkalinity (Krishnani *et al.* 2011). According to the authors, water with low hardness contains insufficient calcium ions. Hardness and alkalinity are essential for the formation of the exoskeleton of prawns.

2.5.6.3.1.6. Salinity

Salinity refers to the total concentration of dissolved ions in water. Seven ions (sodium, potassium, calcium, magnesium, chloride, sulfate, and bicarbonate) contribute most to the salinity of the water. The other dissolved substances in water usually contribute little to salinity or total dissolved solids, but they may be biologically important. Water usually contains only trace amounts of phosphorus, inorganic nitrogen, iron, manganese, zinc, copper, boron, and certain other elements, but small amounts of these elements are essential for phytoplankton growth (Boyd 1989). In the present study, it was found that the shrimp farmers in the state maintain salinity within the 5- 30 ppt range during the farming period, which is expected to elicit optimum growth and survival.

There are many reports on the optimum salinity range for the culture of penaeid shrimps. Tiger prawn was reported to survive and grow well at very low salinities (Musig and Ruttanagosrigit 1982; Boyd 1987, 1989). According to Boyd (1989), *P. monodon* can grow very well in the salinity range of 4 to 36 ppt, ensuring good water management and good quality feed with a proper feeding programme. It will survive and grow well at lower salinities, too (Boyd 1989). According to the author, *P. monodon* can tolerate freshwater for about one month. CAA (2006) reported 15-25 ppt as the optimum level of salinity for the farming of *P. monodon*. Sahadevan (2012) reported that tiger prawn grows satisfactorily well at different salinity conditions ranging from zero to well above 60 ppt. However, according to the author, though it is advantageous on specific occasions to grow at very low or high salinities, the best growth and the lowest food conversion ratio in *P. monodon* are obtained at a salinity range of 10-25 ppt. Mandal and Dubey (2015) recommended a 15-35 ppt salinity for *P. monodon* farming. In pond conditions, *P. monodon* can generally tolerate a wide range of salinity from 5 to 40 ppt, but juvenile and adolescent stages of *P. monodon* can tolerate salinity conditions as low as 1-2 ppt (http://www.fao.org/fishery/culturedspecies/*Penaeus_monodon*/en). Sahadevan (2019) and Sahadevan and Sureshkumar (2019, 2020a) reported the claim of many farmers in India that *P. monodon* can be grown in freshwaters.

A correlation between salinity and pond production of *P.monodon* was reported by Chakraborti *et al.* (1986). Rajyalakshmi and Chandra (1987) reported a higher survival rate at 15 ppt (82%) compared to that at 20 ppt (74%) and 0 ppt (68%). These studies indicated that *P.monodon* could survive in extremely low salinity, even in freshwater, for a short period. They also observed the best growth rate at 15 ppt followed in order at 20, and 0 ppt salinities (15 ppt > 20 ppt > 0 ppt). Navas and Sebastain (1989) observed that the growth of juveniles of *P.monodon* was significantly high above 2 ppt salinity. Allan and Magiure (1992) observed the absence of any significant difference in the growth at salinities between 15 and 30 ppt *in P. monodon*. The results of the experiment by Abraham and Sasmal (2009) indicated the positive effect of salinity on the growth and the overall health status of shrimp.

Though *P. indicus* can survive in salinities below 5 ppt (Gorge *et al.* 1982, as cited in Unnithan 1985), the salinity range ideal for the culture of the species is 10-35 ppt (Muthu 1980). According to Kumlu and Jones (1995), postlarvae of *P. indicus* can tolerate a wide range of salinities from 5 to 40 ppt.

Many authors reported the growth and survival of *L. vannamei* at low salinities of 1.7- 2.3 ppt (Bray *et al.* 1994; Moya *et al.* 1999; Samocha *et al.* 1999). Though 15 to 25 ppt salinities are considered ideal, *L. vannamei* can be cultured successfully at lower and higher salinities (Boyd 1987). Many farmers claim that this species can be cultured in freshwater (Boyd 1989; Sahadevan and Sureshkumar 2019). Although these prawns can tolerate freshwater for several weeks, practical experience indicates that salinity of at least 0.5 to 1 ppt is necessary for survival and growth ((Boyd 1989). According to him, hand-held refractometers (salinometers) used by shrimp farmers do not measure salinity accurately when salinity is low. Therefore, the salinity is not necessarily 0 ppt when a salinometer indicates 0 ppt. The shrimp *L. vannamei* , which tolerates a wide range of salinities, from 0.5 to 45 ppt, is comfortable at 7-34 ppt (Briggs *et al.* 2004) but grows particularly well at low salinities of around 10-15 ppt where the environment and the blood are isosmotic (Wyban and Sweeney 1991). However, the white leg shrimp, *L. vannamei*, tolerates 2-45 ppt salinity (Parker *et al.* 1974; Samocha *et al*. 1998). Several authors have reported good growth and survival of *L. vannamei* in the brackish water of 1.7- 2.3 ppt (Bray *et al.*

1994, 1999; Emberson *et al.* 1999; Moya *et al.* 1999; Samocha *et al.* 1999). Bray *et al.* (2000) even succeeded in spawning *L. vannamei* after rearing in salinity of 2.2 ppt.

A large number of studies also exist on the salinity tolerance, growth and survival of the various species of farmed penaeid prawns under different conditions with varying results (Nair and Kutty 1975; Brett 1979; Branford 1981; Raj and Raj 1982; Chen, 1990; Pante 1990; Huang 1993; Bray *et al.* 1994; Bukhari *et al.* 1994; Musig and Boonnom 1998; Samocha *et al.* 1998; Ye *et al.* 2009; Antony *et al.* 2019). A consensus of various studies indicates in unambiguous terms that *P. monodon, P. indicus* and *L. vannamei* grow well in waters with salinity ranging from 5 to 30 ppt revealing that the salinity maintained by the shrimp farmers of Kerala is well within the optimum range for growth.

2.5.6.3.1.7. Turbidity and watercolour

Most of the traditional shrimp farms in Kerala were found to maintain a Secchi disc turbidity level between 40 to 60 cm. On the other hand, most scientific farms maintained a Secchi disc reading between 30 and 50 cm. Both are well within the acceptable levels, as evident from the following discussion. It is assumed that the turbidity is predominantlycaused by plankton production.

Water turbidity directly bears the production and productivity of shrimp farms. The turbidity of water may be either due to suspended inorganic substances such as silt and clay or due to planktonic organisms (Jhingran 1991; Boyd 1989). Turbidity varies significantly with the nature of the basin, degree of exposure, nature of inflowing sediments etc. Ponds with clay bottoms are likely to have high turbidity, and ponds in which sand, gravel and humus predominate are likely to have low turbidity. Turbidity due to the profusion of plankton indicates the pond's high fertility, but that caused by silt or mud beyond a limit is harmful (Jhingran 1991).

Turbidity caused either by living or non-living objects greatly influences the transparency of water which affects photosynthesis in the water body. Turbidity restricts light penetration into pond waters, and less light at pond bottom discourages the growth of troublesome filamentous algae and aquatic weeds

(Boyd 1989). According to Krishnani *et al*. (2001), turbidity due to silt and clay particles may also affect the growth of benthos and can cause uneasiness and stress to the shrimp leading to disease. Suspended silt and clay particles will adsorb considerable nutrients, making them unavailable to primary production. Suspended clay particles (>4% by volume) damage the gills of fishes (Nikol'sky 1963; Sinha 1983) and prawns (Krishnani et al. 2001) by clogging them.

Turbidity from phytoplankton is much more desirable than turbidity from suspended soil particles. Phytoplankters represent the base of the food web that culminates in shrimp. Clear ponds have little phytoplankton, and there may be little natural food for shrimp. In some clear ponds, algae grow on the bottom (benthic algae) and provide natural food for shrimp, but most pond managers prefer a pond with adequate phytoplankton growth. Clear ponds usually have low plant nutrient levels, so chemical fertilisers or manures should be applied to promote phytoplankton growth and provide more natural food for shrimp. Excessive phytoplankton growth in shrimp ponds can cause oxygen depletion and consequent mortality of shrimp.

Turbidity in pond waters can be measured most easily with a Secchi disc. The optimum Secchi disc reading for shrimp ponds is 40 to 60 cm (Boyd 1989). According to Krishnan *et al.* (2001), a high value of transparency (>60 cm) is indicative of poor plankton density and therefore, water should be fertilised with the right kind of fertilisers. A low value indicates a high density of plankton, and hence fertilisation rate and frequency should be reduced. According to Krishnani *et al.* (2001), the optimum transparency range is 25-35 cm. Transparency less than 20 cm indicates that the water is unsuitable for shrimp culture and should be changed immediately to flush out excess growth. The optimum level of turbidity recommended by CAA (2006) for farming of *P. monodon* is 25-45 cm and by Villalon (1991) for farming of *L. vannamei* is 25-30 cm. It must be noted here that both types of turbidity affect the Secchi disc visibility. The farmer must decide if the turbidity is from phytoplankton, suspended soil particles, or both.

Despite the importance, farmers in Kerala, in general, are not seen paying sufficient attention to developing and managing plankton growth and maintaining healthy watercolour in shrimp ponds. In most shrimp ponds, watercolour is not seen developed during the start-up stage, indicating insufficient phytoplankton growth.

Experienced farmers worldwide who had to face repeated mass shrimp mortalities relate shrimp mortality to clear water and lack of 'watercolour' in their ponds (Sahadevan 2012). The phytoplankton community in shrimp ponds consists of many species of various taxonomic groups, and the colour resulting from phytoplankton blooms is highly variable. According to Sahadevan (2012), although the actual function and benefit of one colour over another are difficult to tell, the intensity and liveliness of the colour, actually indicating the condition of phytoplankton growth, are thought to be more pertinent than the variety of colours per se.

Healthy phytoplankton functions as a nutrient sponge absorbing dissolved ammonia, amines, urea, nitrite, nitrate, phosphate, other metabolic wastes from shrimp, and toxic substances such as heavy metals and pesticides (http://shrimp care.com/newwp/lab-services/water-plankton-microscopic). Further, phyto-plankters producing abundant oxygen under sunlight are efficient aerators. The phytoplankton growth also enhances the production of zooplankters and benthic animals, which serve as natural food for shrimp. Phytoplankton growth also reduces light penetration, making the shrimp feel more pleasant in the well-shaded pond bottom. Another significant benefit of phytoplankton growth is the prevention of the development of benthic algae.

2.5.6.3.1.8. Water exchange

Except in zero water exchange systems, periodic water exchange is essential for keeping the quality of the rearing medium. Also, adequate water exchange is required in the case of traditional farms where incoming water is the primary source of shrimp seeds and natural feed. Water exchange ensures replenishment of dissolved oxygen, removal of accumulated organic wastes, correction of turbidity and other water quality parameters. Proper water exchange ensures the healthy growth of the shrimp and helps avoid diseases. In Kerala, a vast majority of the shrimp farms are tide-fed, which depend upon the prevailing tides for water exchange. Water exchange is at the vagaries of nature and cannot be carried out at the desired time. Many scientific farms were also found not to undertake sufficient water exchange. Thus, inadequate water exchange has a hand in the observed lower shrimp productivity in these farms (Section 2.4.12.4).

The periodic change of water is a critical management practice that prawn farmers should adequately observe. Apud (1988) provided details of water exchange to be effected in various shrimp farming systems. The total water replacement during the entire culture period varies according to the stocking density, water quality, environmental conditions and feeding scheme. Typically, the amount of water replaced for every water change is 20 to 50%. The change frequency is minimal during the initial period - once or twice a month for the first month, three or four times in the second month. In the third month, water is changed twice a week and every four to five days in the fourth. The frequency and amount of water change are based on pH, dissolved oxygen, salinity, turbidity and other water quality parameters.

Cole and Boyd (1986) have shown a strong/positive correlation at low water exchange rates between feeding rates and water quality parameters, such as ammonia, nitrite, chlorophyll-a, chemical oxygen demand and carbon dioxide. Dissolved oxygen at dawn was negatively correlated with the feeding rate. Greater water exchange with higher quality water would reduce these undesirable concentrations and allow a greater standing crop of fish. The same relationships should exist for crops such as shrimp. Low water exchange rates of 5% per day or less do not benefit water quality or standing crops (Cole and Boyd 1986).

Nagesh *et al.* (2009) observed a significant association between the mean water exchange per day and disease outbreaks in shrimps. The disease incidence was the maximum (100%) in farms with no water exchange. The water exchange reportedly removes accumulated organic load and toxic metabolites, brings natural food, influences water quality parameters, and stimulates moulting in shrimp (Parker and Suttle 1987), thus influencing disease occurrence. However, Kongkeo (1995) believes that water exchange introduces viruses, other pathogens, excess organic loads, ammonia and other toxic particles released by nearby farms if proper care is not taken. The absence of water exchange or even inadequate water exchange might have resulted in the accumulation of organic load and deterioration of water quality, thereby causing stress and disease to shrimp. Baticados *et al*. (1986) related insufficient or infrequent water exchange to soft-shelling in shrimp. Leung *et al.* (2000) recorded low disease occurrence with increased water exchange frequency towards the end of culture in the intensive system, but not in semi-intensive and extensive culture systems. McGee and Boyd (1983) found no significant differences in water quality parameters for catfish yield, with water exchange rates varying from zero to 5% day per day. The same situation almost certainly exists with marine shrimp (Fast and Boyd 1992). Hirasava (1985) has demonstrated production increases for *P. monodon* from 10 to 25 t ha^{-1}, corresponding to increased water exchange rates of 20% per day and 100% per day, respectively.

According to CAA (2006), nutrients and organic wastes produced in shrimp ponds consist of solid matter (mainly uneaten feed, faecal matter and dead plankton) and dissolved metabolites (mainly ammonia, phosphate, carbon dioxide, nitrite and nitrate). Various management measures may be followed to maintain these within the tolerable limits. Among these, the most economical is water exchange. Water exchange of 5 – 30% per day may be done in shrimp farming, depending on water availability and pond water quality.

2.5.6.3.2. Feed management

The cost of feed and feeding represents one of the most significant recurring expenditures of a shrimp farm (New 1976; Biddle 1977; Shang and Fujimura 1977; Wyban *et al.* 1988; Abesamis 1989; Pascual, 1989; Akiyama *et al*. 1991; Molina 2009; Tacon *et al*. 2013). Hence the suitability and cost-effectiveness of the feed are of paramount importance to commercial success in shrimp farming. The yield of shrimps and, in turn, the profitability of farming operations depends greatly on the quality and quantity of the feeds used. This applies alike to traditional pond rearing and the more evolved, restrictive and rigidly controlled intensive shrimp farming. In traditional farming, a significant part of the nutrient requirement is met by natural feed either produced inside the pond or are brought along with the incoming water. However, the more intensive the shrimp farming system, the greater is the importance of quality feeds and the greater the proportion of feed cost to the total cost (Sahadevan 1992). CAA (2006) has given detailed guidelines for feed and feed management in prawns farming.

2.5.6.3.2.1. Type of feeds and method of feeding

A sizeable number of the traditional farms in the state were found not to use any good quality formulated feed. They depended on the natural productivity of the pond, which in many instances has been improved by fertilisation. Many used farm-made feed, the composition of which was decided more by economic consideration rather than nutritional. Groundnut oil cake, dried trash fish, dried clam meat, rice bran, and wheat flour were the principal raw materials used to make farm-made feeds. These feeds were sometimes fortified by commercially available vitamin and mineral mix available in the market (for veterinary use). Groundnut oil cake that was commonly used in farm-made shrimp feeds until recently is not widely used nowadays because of its escalating price. Coconut oil cake has replaced it, at least in some cases. However, the nutritional composition of coconut oil cake as a shrimp feed is inferior to ground oil cake. A similar observation was made by Sahadevan (2012, 2016a). Only 9.26% of the traditional farms used factory-made feed. On the other hand, 91.38% of the scientific farms used factory-made feed. The rest used farm-made feeds. Feeding is generally done by broadcasting.

Feeding is a proven technique for increasing production. However, overfeeding results in deterioration of water quality, phytoplankton blooms, and lowering dissolved oxygen concentrations during the night. If feeds are applied in excessive quantity, dissolved oxygen depletion can occur, which result in shrimp mortality. In this context, adequate feed management is critical for efficient production and to minimize environmental impacts. Good feed management practices will result in maximum shrimp growth and survival concurrent with the lowest feed conversion ratio. Inadequate feed management will lead to suboptimal production, the onset of various diseases, and deterioration of water quality. Shrimp production systems and their feed management must be considered together and require an understanding of the biological aspects of the target species and the chemical and biological processes that control water and bottom quality, and require continuous system monitoring and feedback to provide appropriate and timely inputs and adjustments. Several steps are involved in proper feed management- selection, reception, storage, handling, application methods and feeding regimes.

In general, the nutritional performance of a shrimp feed depends upon five interconnected factors, namely, the nutrient content and composition of the diet being fed, the physical properties and water stability of the diet being fed, the transportation and storage of the diet before providing in the farm, the feeding method employed, and the farming system, stocking density, water management and availability of natural foods (Tacon *et al.* 2013). The commercial shrimp feed manufacturer has direct control over the first two factors, while farmers control the last three. Therefore, it follows that the eventual nutritional performance and economic success (or failure) of a shrimp feed depend upon a close collaboration and partnership between the feed producer and the farmer. Feeding without considering the nutritional composition and the nutritional requirements of the animals under culture may eventually prove to be a costly method of pond fertilisation. The feeding method also plays a very important role in determining the performance of shrimp feed.

2.5.6.3.2.2. Demand for feed, frequency of feeding and ration size

Deciding when to feed and how much to feed requires the determination of shrimp activity patterns, feeding frequency and time (subject to change with geographical location, species, age, size, stocking density, season, environmental conditions and other stimuli). The quantity of feed to be given varies according to the composition of the feed, the environmental condition, including the water temperature, state of moulting and the intensity of farming adopted. The quantity of feed required is a function of the shrimp biomass and may be ascertained based on the average body weight and the assessed survival rate which are estimated by periodic sampling. Periodic sampling is required to understand the growth, survival and well-being of the shrimp. However, periodic sampling of prawns was not regularly being practised in many cases in Kerala. It has was found in the present study that 77.78% of the traditional farms do not undertake periodic sampling. However, regular sampling is a prerequisite for scientific feed management to know whether the shrimps grow on expected lines. Daily demand for feed may be ascertained with the help of feed trays installed at selected places in the pond. In the present case, only 16.67% of the traditional farms and 87.93% of the scientific farms were found to ascertain the demand for feed with the help of feed trays. The rest of the farms fixed the quantity of feed to be given by wild assumptions or based on previous experience. Most traditional farms were found to give feed only once daily, and some farms twice daily.

On the other hand, most scientific farms were observed to give 2 to 4 rations per day, though a few farms provide only once. A significant part of the daily feed ration was found to be given at night. According to CAA (2006), since the shrimps require about 4 hours to digest feed, feeding frequency should be 4 to 6 times a day. Since *P. monodon* is nocturnal, more than 60% of the meal should be given at night (CAA 2006).

In the present study, it has been observed that traditional farms could not ascertain the quantity of feed to be offered accurately, as they are unaware of the biomass of shrimp and finfish available in each pond. In the case of a majority of the scientific farms, the feed ration given was found to be ascertained based on the estimate of biomass of cultured animals and the instructions given by the feed manufacturer and, indeed, considering the water temperature, stage of moulting, observation of the feed consumption in the feed trays etc. In general, the average feed ration provided in scientific farming was found to vary between 8-12% (initial phase of culture) and 2.7- 3.0% (final phase) in the case of *P. monodon*, between 15-20% (initial phase) and 2.5-3% (final phase) in the case of *P. indicus* and between 15-20% (initial phase) and 1- 3% (final phase) in the case of *L. vannamei*. Apud (1988) recommended a 3.5 -10% feeding rate for different growth stages of *P. monodon*. CAA (2006) recommended a daily feeding rate of 2- 4% of the biomass for different sizes of *P. monodon*. Villalon (1991) recommended a daily feeding rate of 6.7 to 19% of the body weight for *L. vannamei* when stocked at 150-200 postlarvae m^{-2} for different growth stages, while for the same species, the same author recommended a feeding rate of 1.59- 6% when the stocking density was 6.9- 9 juveniles m^{-2}. Various authors have suggested different feeding rates for prawns (*eg*., Sanhotra 1994; Apud 1988; Akiyama *et al.* 1992; Villalon 1991; CAA 2006; Hung and Quy 2013; Tacon *et al.* 2013; Jory 2016; Antunes *et al.* 2018). Different feed manufacturing companies also have their recommendations on the rate of feeding. However, these figures cannot be compared among one another or with the present observations because the feeding rate varies significantly according to the species, growth stage, moulting stage, stocking rate, prevailing environmental conditions, water quality, feed quality and management intensity. The present author's experience shows that other things being constant, more feed is to be given in the first days of culture for *L.vannamei* compared to *P. monodon*, though the latter is larger in size at the time of stocking compared to the former.

Shrimp moults periodically during their lives, and this is a stressful period during which their appetite and feed intake diminish significantly. It can take 2 to 5 days for regular feeding to resume. When there is a high incidence of moulting in a pond, it is essential to adjust feeding rates accordingly to avoid feed wastage. At the moulting time, the feed ration can be reduced by 20%. Water quality parameters like temperature, dissolved oxygen, pH and salinity influence food intake by shrimps. So environmental conditions should be considered when determining daily feed inputs. According to Goddard (1996), water temperatures and dissolved oxygen levels are primary factors that influence feeding activity, metabolism and growth. In general, being a poikilothermic animal, which cannot maintain thermal homeostasis, shrimp feeds more when the temperature is higher within the optimum range for growth. Similarly, shrimp may feed less when the dissolved oxygen concentration is low or under stress. Factors such as high ammonia levels may limit feed intake (Boyd and Tucker 1998). Low light levels due to cloudy conditions limit photosynthetic activity, hence lowering dissolved oxygen concentrations. Warm, sunny, or calm days may cause algal bloom crashes, pond stratification, and high temperatures that affect shrimp feeding activity. Consequently, weather conditions should be taken into account and daily rations increased, reduced or avoided in anticipation of water quality problems.

Calculation of feed rations involves estimating survival and biomass, size distribution and natural food availability. Feed requirement may also vary according to the physical and chemical properties and the nutrient content of the feed itself. Adjusting feed input involves population sampling and monitoring of various water parameters. Proper feeding strategies must consider physiological processes that affect feed intake and digestion in the targeted shrimp species. These include relationships between feeding activity and circadian rhythms, gastric evacuation times, moulting cycle stage, etc. Shrimp are bottom feeders, and it is challenging to estimate feed consumption rate unless feed trays or lift nets are used. Feed trays are perhaps the best and the cheapest tool available to manage and adjust feed inputs and prevent under- and over-feeding. Ineffective practices often include applying feed during times convenient for farmers but not necessarily optimal for shrimp. It also involves giving inadequate or excess quatity of feed.

According to Anand *et al.* (2013), feed monitoring should be done with check tray evaluation for optimum feed management. The feeding area can be shifted at least once in 7 to 10 days, depending on the bottom condition along the feeding area. He advised reducing feeding during periods of low dissolved oxygen, plankton crash, rainfall, extremes of temperature etc. Slightly underfeeding is better than overfeeding, saving money and reducing risks during disease outbreaks (Anand *et al.* 2013).

Proper feed management is essential for successful and profitable shrimp culture. According to CIBA (2013), feed management means control and use of feed so that feed utilisation is optimum with minimum wastage, resulting in a negligible impact on the environment, achieving the best feed conversion ratio and maximum growth of shrimp. CIBA (2013) has given a detailed account of the feeding schedule, pellet size of shrimp, guidelines for calculating feed dose etc. It also discussed the importance of farm-made feeds to small shrimp farmers.

The present study also observed that farms that used the same brand and quality of feed from the same production batch resulted in different food conversion values ranging from 1.2 to 1.9. Tacon (1993) made a similar observation, who obtained food conversion values ranging from 1:1 to 2.6:1, showing that the same feed can produce different results under different farm conditions and feed management practices.

Important technical information is available on shrimp-feeding behaviour, and interpreting this information can sometimes be difficult because some data can often seem contradictory. The data obtained depend on a large number of specific variables and circumstances that are seldom the same between studies and observations. In general, one must be careful not to interpret observations more broadly than in the context in which they are made.

When natural food is readily available, the demand for formulated feeds will decrease. This is typical when the biomass of stocked shrimp is low, during the first few weeks following seed stocking, and until a critical biomass equivalent to the natural carrying capacity of the pond (depending on several factors) is reached. After this critical biomass, added formulated feed becomes increasingly important to supply the nutritional requirements of stocked shrimp.

2.5.6.3.2.3. Nutritional composition

The present study was restricted to analysing moisture and macronutrients like crude protein, crude lipid, crude fibre and ash. No attempt was made to analyse the micronutrients like vitamin and mineral content of the diets. Hence the current discussion is limited to the macronutrients alone.

The nutritional quality of feed used is critical in commercial shrimp farming. Shrimp eat to fulfil their nutritional and energy requirements, and if the feed they consume does not have enough energy or nutrients, their feeding activity will enhance. Feed attractability and palatability are also essential factors to be reckoned with. Water stability of the feed is another critical factor to be considered as it determines what portion of the nutrients ultimately reaches the prawn body and reflect in the growth of prawns.

In the present study, it was found that most of the traditional farms and a few scientific farms use farm-made feed made of groundnut oil cake, dried clam meat, rice bran, wheat flour, tapioca floor etc. fortified with or without vitamin and mineral mixture. In some instances, dried trash fish was used instead of dried clam meat, and in some other cases, both dried clam meat and dried trash fish were used in appropriate ratios. The average nutritional composition of shrimp feeds (dry weight basis) was moisture: 14%, crude protein: 35.32%, crude fat: 7.26% and ash: 9.5%. Some farmers also used only clam meat as a supplementary feed, the nutritional content (wet weight basis) of which was moisture: 82%, crude protein: 9.2%, crude fat: 1.5% and ash: 2.5%.

The factory-made feed in use in the state had a moisture content of 11-12%. Farmers generally used feed with slightly higher protein content (crude protein:

38-41%) in the farming of *P. monodon* compared to the feeds used for *P. indicus* and *L. vannamei*. The crude fat, fibre and ash content of the feed for *P. monodon* were 4-6%, 3-5% and 15-16%, respectively. In the absence of feed specifically meant for *P. indicus* in the market, farmers generally used the feed meant for *L. vannamei* to farm the former species. The average nutritional composition of this feed was as follows- crude protein: 35-41%, crude fat: 4-6%, crude fibre: 3-5% and ash: 15-16%.

It may be mentioned here that the composition of the feeds in use in the farming of the three species matches well with the nutritional requirement of the species reported by various workers under different culture conditions (Lee 1971; Andrews *et al.* 1972; Colvin 1976; Guary *et al.* 1976; New 1976; AQUACOP 1977; Colvin and Brand 1977; Kanazawa *et al*. 1977; Khannapa 1977,1979; Deshimaru and Yone 1978; Bages and Sloane 1981; Lin *et al.* 1981; Ali 1982, 1988, 1996; Bhasker 1982; Sambasivam *et al.* 1982; Alava and Lim 1983; Pascual *et al.* (1983); Smith *et al.* 1985; Bautista 1986; Gopal 1986; Millamena *et al.* 1986; Nezaki 1986; Chiu 1988; Hajra *et al.* (1988); Smith and Lawrence 1988; D'Abramo 1989; Chuang 1990; Gopal and Raj 1990; Shiau and Chou 1991; Cousin *et al.* 1993; McVey 1993; Davis and Gatlin 1996; Shivaram and Raj 1997; Shiau 1998, Chuntapa *et al.* 1999; McIntosh *et al.* 1999; Alagarswami and Ali 2000; Cuzon *et al*. 2000; Velasco *et al.* 2000; Guillaume 2001; Guzman *et al.* (2001); Rosas *et al.* 2001; CIBA 2002; Glencross *et al.* (2002); Kureshy and Davis 2002; Taw *et al.* 2002; Watanabe 2002; Dayal *et al.* 2003; Martinez-Cordova *et al.* 2003; Vijayagopal 2003; Hertrampf 2006; Kumaraguru *et al.* 2006; Hu *et al.* 2008; Shahkar *et al.* 2014, Sui *et al.* 2015, Gao *et al.* 2016, Lee and Lee 2018; Jana *et al* 2021).

According to Briggs *et al.* (2004), *L. vannamei* requires a lower protein (and hence cheaper) diet (20-35%) during culture than *P. monodon*, *P. chinensis* or *P. stylirostris* (36-42%). They can utilize the natural productivity of shrimp ponds, even under intensive farming conditions (Wyban and Sweeney 1991). In Thailand, current grow-out feeds for *L. vannamei* contain 35% protein and cost 10-15% less than the 40-42% protein feeds for *P. monodon* (Briggs *et al.* 2004). Additionally, feeding efficiency is better with *L. vannamei*, which yield an average FCR of 1.2, compared to 1.6 for *P. monodon.* With higher growth and survival rates, these factors are responsible for the 25-30% lower production costs for producing 20 g of *L. vannamei* than *P. monodon*.

2.5.6.3.2.4. Transportation and storage of feed

Shrimp farms in the study area were found to store the feeds under satisfactory conditions, and they stored the feeds in separate ventilated and non-humid rooms. Feeds were generally not stored for prolonged periods, and on average, the storage period extended to 1.5 months. In most cases, farmers used the feeds within three months, which agrees with the recommendations made by various workers in the field.

Shrimp feeds are composed of formulated mixtures of ingredients containing 40 or more essential nutrients (*e.g.*, proteins and amino acids, fats and fatty acids, carbohydrates and sugars, minerals and trace elements, and vitamins) that are prone to deterioration and loss or destruction upon improper transportation, unsatisfactory and prolonged storage before feeding (Tacon *et al.* 2013). Nutrient losses and destruction may result from the prolonged exposure of finished feeds to unfavourable storage conditions on or off the farm, either due to inadequate shelter and protection of the feed from the natural elements (light, heat, humidity, air and water) and/or due to microbial/pest infestation (bacteria, fungi, insects, rodents). As a general rule, shrimp feed should be stored under cool, well-ventilated conditions and not subjected to direct exposure to the sun and rain, including extremes of heat and humidity (Sahadevan 1991, 2012; Tacon *et al*. 2013). Under the above ambient conditions, feed shelf life should be no more than 2 to 3 months under tropical/warm (20–30 °C) storage conditions and no more than 4 to 6 months under temperate/cold (10–20 °C) storage conditions (Tacon *et al.* 2013). Whenever possible, formulated feeds should be stored in a dedicated roofed storage facility and used on the farm on a first-in-first-out basis. Sahadevan (1991) discussed the various aspect of transportation and storage of shrimp feed in detail. Inadequate management methods commonly include improper handling, transportation and storage practices for bulk feed storage and after feed distribution to the pond-side for daily feedings. Proper feed storage is also an essential component in the biosecurity plan (Anand *et al.* 2013) in reducing the wastage of feeds and improving the overall profitability of the farming operation.

2.5.6.3.3. Periodic assessment of growth and survival (biomass assessment)

Periodic assessment of biomass of prawns is a vital management measure in shrimp farming. Regular sampling is required to ascertain the shrimp's growth and survival and estimate the quantity of feed to be given. 22.22% of the traditional farms and 100% of the scientific farms were found to do periodic sampling for assessing the growth and survival. Though it may not be of great value in traditional shrimp farming, where stocking and harvesting is a continuous process, it provides excellent information on whether the growth and survival of prawns are on expected lines or not. It is also essential to determine the quantity of feed to be given and avoid wastage of feed. In that sense, periodic biomass assessment is vital in determining the profitability of the farming operation.

After stocking, growth and survival of the prawns should be observed at regular intervals by sampling with the help of a cast net (Unnithan 1985). First sampling may be done 15 days after the stocking and thenceforth at the weekly interval (Villalon 1991) or 10 days (Unnithan 1985). Although at 15 days of stocking, most of the shrimp will be small and therefore not captured by net, it is a prudent strategy to begin early sampling to establish a subjective evaluation of the population (Villalon 1991). A cast net is an ideal gear for sampling. Sampling time and the specifications of the cast net should not be altered throughout the culture period, except in the case of the mesh size of the net used for the sampling. It should also be considered that the density of the population of prawns will not be uniform throughout the pond bottom. Therefore, the netting has to be done at different representative locations in the pond, and the average number and average weight of prawns caught are calculated. Usually, the average weight will show an increasing trend during the consecutive sampling. If the above growth rate is not observed during sampling, it may be a symptom of unsatisfactory growth necessitating a change in the management strategy. Further, although capture frequency analyses are directly related to stocking densities, shrimp size (weight) and total pond surface area, if sampling procedures are correctly standardized, each pond can accumulate historical data over two or more culture cycles and be independently evaluated in comparison with past performance (Villalon 1991).

2.5.6.3.4. Management of predatory birds, weed and predatory fishes

In shrimp farms, predation by piscivorous birds can cause considerable losses. They may cause damage to shrimp or farm facilities directly, indirectly or both. Direct damage results when the shrimp is killed or seriously injured by the bird and is, therefore, lost from production. Indirect damage is highly variable and includes injury to shrimps, chronic stress and its resulting reduction in health or feeding efficiency; pathogen transfer, including bacteria, viruses and parasites; and sometimes even physical damage to the animal enclosure system leading to escape of the shrimps. The loss of a farm's “disease-free” status because of the introduction of an exotic pathogen by predatory birds can be much more significant and greatly exceed the value of any shrimp consumed by the bird. The overall damage by avian predators to a cultured shrimp population can vary greatly and, in some cases, be very costly, depending on various factors. Both juvenile and adult shrimp are very vulnerable to avian predators.

The abundance and diversity of fish fauna and the presence of mangrove vegetation in the nearby areas to rest on attract predatory birds to the shrimp farming sites. Piscivorous birds of the study areas were found to belong principally to the families Ardeidae (herons and egrets), Phalacrocoracidae (cormorants), Laridae (terns and gulls) and Alceonidae (kingfishers). Among the birds of the Ardeidae family, herons and egrets were more common. Of these, pond heron was the most abundant species. Other herons were seen in small numbers. Median egret and large egrets were seen in large numbers, and they too seemed to adversely affect the farmed shrimps, though to a limited extent. Among the predatory birds of the area, little cormorant followed by the herons were found to cause the most significant damage to farmed shrimps and fishes. A similar observation was made by Roshnath (2014), who found that among the different bird species, cormorants are the biggest threat to shrimp farming, followed by night herons, little grebe, egrets, kingfishers, storks, darter, green herons, and whistling ducks.

In terms of abundance, the heron was found to be the most dominant species. It catches its prey alone or in small numbers rather than in flocks and will stay in the same area throughout the year. Little cormorant was the next most abundant predatory bird in shrimp farms. Cormorants eat small to medium-sized fish and shrimp and cause extensive crop damage. The cormorant captures the shrimp by diving and swimming after them.

Villalon (1991) presented a detailed account of the potential losses caused by cormorants in shrimp farms. According to him, a cormorant may consume half its body weight of shrimp/ fish every day. It follows that if the bird weighs 1.5 kg, it could consume around 0.75 kg of shrimp every day. Assuming that the shrimp weight is 0.6 g each (say during the early days of farming), 1250 shrimp may be consumed by a single bird per day.

The kingfishers, brown-headed gull (*L. brunnicephalus*) and whiskered tern (*C. hybrida*) were also important piscivorous birds. Though primarily piscivorous, kingfishers do not cause extensive damages to shrimps as their number is usually low and since they are scattered throughout the field. Seagulls were found in farms near the sea or to the estuaries.

Bird predation remains one of the critical threats to the farmers (Dekker and Leeuw 2003; Roshnath *et al.* 2014). The studies on the food preference conducted revealed that bird species such as cormorants, herons, egrets, etc., mainly feed on shrimps.

All traditional and scientific farms use bird deterrents to avoid birds. These include the manual method, auditory method (like making sound with tin, plastic bottles with few marbles tied to ropes, etc.), netting the ponds, providing overhead lines/ threads/ ropes, etc., tying reflective tapes/ ribbons/ video reels, etc., other methods (polythene bags, scarecrows, mirrors etc.), or a combination of various methods. No farms use lethal methods to control predatory birds.

Farm management policy to control predatory birds should agree with local laws and regulations. Because laws protect many bird species, shrimp farmers must use only non-lethal techniques to control bird predators. There are different types of equipment commercially available for the protection of shrimp ponds from predatory birds. Curtis *et al.* (1996) presented an overview of such techniques for reducing bird predation at aquaculture facilities in different parts of the world. A detailed account of techniques to keep away predatory birds in shrimp farms is provided by Roshnath (2014). Villalon (1991) evaluated the usefulness of many methods for reducing bird predation. According to him, pneumatic discharge cannons, light reflectors, scarecrow windmills, etc., are relatively ineffective after the initial display, for most aquatic birds are adaptive and become readily accustomed to noise or visual stimuli produced by this equipment. The technique of a stretched wire grid over the ponds surface area may be effective for small ponds and small operations but is cost-prohibitive in large scale semi-intensive operations. Pre-recorded bird distress calls played on tape and amplified over loudspeakers mounted on a truck have had limited success. This technique may be impractical as it requires continual utilization of a farm vehicle that might be more efficiently employed in other activities. According to the author, the most effective and proven technique against bird predation is deploying farm personnel armed with shotguns and explosive rockets. The problem is minimized to a certain extent by scaring away birds from the vicinity of sluices and deeper part of the water by men. However, for this technique to be effective, farm personnel must continually and aggressively pursue flocks of birds from pond to pond, which is difficult in Kerala, where the human resources are relatively costly.

Various avian deterrent techniques may be used to control the damages due to birds, including auditory, visual, physical and lethal methods (Littauer 1990; Dekker and Leeuw 2003). The mechanical protection of farms with a net has been widely used to prevent bird menace, but it is relatively expensive. In addition to that, less expensive methods like tying ropes/ threads/ lines over the ponds, tying reflective taps/ribbons/ video reels over the ponds, tying polythene bags and floating thermocol pieces in water, burning crackers, or a combination of two or more methods are used commonly by farmers to scare away birds. The efficacy of different methods such as bird scares, noisemakers, distress calls, pyrotechnic devices like electronic noise-makers, scarecrows, predator models, mirrors and reflectors may also be tested in the field (Roshnath *et al.* 2014). At the same time, farmers should also be provided awareness about the conservation of birds and the existing laws against killing them.

There is inadequate information on the transfer of shrimp diseases through birds. The present study revealed only the list of bird species that prey on shrimps and fishes and the techniques used by the local farmers to mitigate the problem. However, more information is required on which bird causes more damage, in terms of predation, disease transfer etc., to suggest target species to control. The disease transmission by birds will affect the yield and sometimes leads to complete loss. A good understanding of the disease, extent of damage and control measures is also necessary. As per the guidelines of Coastal Aquaculture Authority, in the farming of *L. vannamei*, bio-security measures, including fencing and bird scare, are a must (CAA 2014).

Various authors discussed aspects of damages caused by predatory birds in aquaculture systems and their mitigation measures under different contexts (Spanier 1980; Schmidt and Johnson 1984; Littauer 1990; Kevan and Weseloh 1992; Keller 1995; Curtis *et al.*1996; Glahn *et al.* 1998; Hughes *et al.* 1999; Engstrom 2001; Roshnath 2014; Roshnath *et al.*2014).

The appearance of weed and predatory fishes during the culture period cannot wholly be avoided. A detailed account of finfishes and shellfishes found in traditional shrimp farms and their biodiversity aspects are provided in Chapter 3. In scientific farms, the presence of these unwanted species may create a big problem during the culture period. They may occur in large numbers and compete with cultured prawns for feed, space, and dissolved oxygen. The presence of predatory fishes in large quantities can drastically reduce the population of cultured shrimps in a short period. Some farmers engaged in an extensive culture system try to control the population of finfishes by catching them with the help of cast nets. Gill nets are also used to catch bigger fish. Small fishes like gobies, orange chromide, glassy perchlets etc. seen gathered in feeding trays or traps may also be removed frequently. However, the above measures do not entirely solve the problem. Farmers engaged in scientific farming face difficulties due to the unavoidable occurrence of finfishes, no matter how they try to filter water. However, selective poison like tea seed cake (which contains saponin) at 10 ppm is sometimes used in grow-out ponds with shrimp stock to eradicate finfishes during the farming phase. Tea seed cake is not lethal to shrimp but kills all finfishes at this dose.

Another organic pesticide that eliminates finfishes at levels tolerable to prawns is rotenone. Rotenone is a white, odourless crystalline substance that acts as an inhibitor of cellular respiration in fishes (Apud *et al.* 1983). It is extracted from derris root and comes out in powder preparation or liquid form at a level of 5-

8% rotenone. Selective elimination using derris root is also very promising. A bioassay of powdered derris root indicated its selective effect (Tumanda 1980). At 5-10 ppm, the powdered material kills most finfishes but does not affect the shrimps.

However, of late, many farmers in the state discontinued using selective poisons because they believe that, though not lethal to shrimp at the recommended dose, these cause stress to the shrimps, which may later become susceptible to diseases.

2.5.6.3.5. Disease management

Yet another vital aspect of shrimp farming is the management of diseases. The increase in shrimp production the world over has resulted in an intensification of production, which is directly linked with an increased incidence of diseases (Sahadevan and Sureshkumar 2019). Diseases, in particular, are a major constraint for the sustainability of farmed shrimp production in many countries, including India. The outbreaks of various viral diseases in shrimp farming and several environmental and social issues demand scientific management of shrimp farms (CIBA 2013).

In the present study, the frequency of incidence of diseases in farms during the last five years was taken to assess the risk associated with the disease. It may be interesting to see that there was an incidence of diseases in 95.06% of the traditional farms and 93.10% of the scientific farms. During the last five years, there were diseases four or more times in 9.88% of the traditional farms and 24.13% of the scientific farms. Almost all these diseases were reported to be due to viral aetiology. White spot disease syndrome is perhaps the most critical cause of massive shrimp mortality. Infectious Hypodermal and Haematopoietic Necrosis (IHHN) which results in retardation of shrimp growth, is also common in some areas. The absence of shrimp certification and accreditation system enhances the chances of an outbreak of diseases in the state. Frequent incidence of diseases affects the profitability of the farming operation and impedes the development of shrimp aquaculture. Sahadevan (2012) and Sahadevan and Sureshkumar (2019) observed a frequent outbreak of diseases as one of the most important reasons for shrimp farms' low production and profitability in the state.

Nagesh *et al.* (2009) reported that poor site selection, inadequate ploughing, inadequate pond desilting, inadequate pond preparation, poor quality of seed, inadequate stocking and post-stocking management of ponds, insufficient acclimatisation, excessive stocking density, poor aeration, inadequate water exchange, number of crops taken in a year etc. to have a positive correlation with disease occurrence. The above authors also noticed the occurrence of infectious diseases after an initial exert by non-infectious aetiology. A high incidence of infectious diseases was seen in the farms, which recorded a higher percentage of non-infectious diseases. Thus, it appears that an early assessment and subsequent management of non-infectious diseases would prevent the shrimp from succumbing to the infectious diseases and, thereby, help to avoid further losses. However, the authors said drawing generalisation must be made with great heed. The possible risk factors identified will have to be tested in intervention studies to evolve effective health management strategies.

There are no chemicals or drugs available to treat viral infections, but good management of pond, water, feed and health status of stock inputs can minimise their virulence (FAO 2021). Outbreaks of the most severe virus (white spot disease syndrome) always occur after dramatic changes in water quality parameters such as temperature, salinity caused by heavy rain, dissolved oxygen, hardness, and the stress to shrimp caused by deterioration in water quality and pond bottom environment (FAO 2021). Pond preparation by proper bottom cleaning or regular scraping of the fouled layer is also a key factor for preventing the shrimp stress caused by built-up waste and toxic gases and eliminating virus carriers, particularly crustaceans.

Responsible shrimp farms must consider the potential risk of disease introduction into the natural environment and its effects on neighbouring farms and the natural fauna. According to Anand *et al.* (2013), the intake water must be filtered with a fine mesh screen filter bag (<60 microns) to prevent the entry of viruses and carriers such as crabs, wild shrimps and to avoid entry of predatory or weed fishes or crustaceans. Disinfection of pond water with bleaching powder @60 ppm reduces the risk of pathogens. Preferably, there must be a 10-15% area for a water reservoir and treatment pond in a one-hectare pond. Disinfection of water and fertilisation for the growth of plankton can be performed in this reservoir before pumping into grow-out ponds as and when required. All equipment in operation (paddlewheel aerators, water pumps, siphon equipment, etc.) need to be disinfected with bleaching powder application before starting the shrimp culture. Anand *et al.* (2013) provided biosecurity measures to be adopted in shrimp farms. CIBA (2013) gave a detailed account of quarantine and other management measures to be adopted in case of suspected disease out beaks in shrimp farms.

A relatively large number of publications exist in the field of diseases of penaeid shrimps and their management (Villaluz 1974; Gacutan 1979; Lightner *et al.* 1987, 1992; Baticados 1986,1988 1990; Rao and Soni 1988; Bower *et al.* 1994; Johnson 1995; Karunasagar *et al*. 1998; Lavilla-Pitogo *et al.* 2000; Lightner 2011; Raja and Jithendran (2013); Lio-Po and Leaño 2016; Thitamadee *et al.* 2016). These provide information on diseases observed, causative agents, species affected, stages affected, gross signs, effects on the host, and methods of prevention and treatment. Soto-Rodriguez *et al.* (2009) gave an account of shrimp diseases and their molecular diagnostic techniques.

It may also be worth mentioning that no traditional and scientific shrimp farms were found to use antibiotics in Kerala. This is of great significance as the use of antibiotics in shrimp culture is strictly prohibited in India by Coastal Aquaculture Authority, as their use may result in the development of pathogens resistant to such drugs and the transfer of these pathogens into human beings might result in the development of resistance in human pathogens (CAA 2006). Coastal Aquaculture Authority has banned 20 antibiotics and pharmacologically active substances in shrimp culture. Many like the United States of America (USA) and the European Union (EU) countries importing shrimps from India have also banned antibiotic residues in shrimps exported to their countries.

2.5.7. Harvest and post-harvest management

2.5.7.1. Harvesting and handling

Harvesting is one of the most critical aspects of commercial shrimp farming as it influences the quality of the end product and the price realized. In traditional and extensive systems, prawn growers usually synchronize harvest with the spring tide during the new moon and full moon. It has been observed that prawns are active and hard-shelled two or three days after the peak of spring tide. A more significant percentage of harvest may be soft-shelled if the timing is off. To avoid this condition, prawns may be induced to moult five days before the expected harvest by abruptly changing the pond water from 50 to 70% to expose them to stressful conditions (Apud 1988). This is usually practised in intensive or semi-intensive farms to ensure a better quality of prawn. Though rarely, some chemicals are also used to induce moulting.

In traditional shrimp farming, repeated partial harvesting was found to be done by filtration nets attached at the sluice gates. This was done by operating a conical net fixed at the sluice gate. At the end of the season, the final harvesting was done by using a sluice net, cast netting, drag netting, draining, and handpicking. In scientific farming, harvesting was found to be done by cast netting, drag netting, draining and handpicking.

There are two methods of harvesting prawns in culture ponds: partial harvesting and total or complete harvesting (Apud 1988). Partial harvest is done when ponds have a wide range of stock sizes. Harvest gears generally used for this purpose are bamboo traps, cast nets, pond nets etc. The latter effectively select marketable sizes as similar prawns easily pass through the net mesh used in the trap. The total harvest is done using a bag net installed at the drain gate. During water draining, prawns tend to go with the water and hence they are collected inside the bag net. In some cases, farmers resort to handpicking. However, since it takes much effort and time, prawns harvested by handpicking quickly deteriorate and do not command a good price (Apud 1988). Despite this, handpicking may have to be resorted to ensure complete harvest in many instances.

Various methods employed in the harvesting of farmed shrimps have been discussed in detail by Reisinger (1985); Apud (1988); Fast (1992a), FAO (2021). Unnithan (1985), Purushan (1992) and Bijulal and Kumar (2003) discussed in detail the harvesting methods employed in shrimp farming in Kerala. Panikkar and Menon (1956), Kurien and Sebastian (1982) and Natarajan (1985) also discussed in detail the various methods of catching shrimps in the traditional prawn filtration fields of Kerala. Purushan (1992) gave a detailed account of the final harvesting in traditional prawn filtration fields. Here the fields are first drained to the minimum level during the daytime. Harvesting finfishes and shellfishes in the field is accomplished using cast nets, drag nets, and handpicking. The churning effect produced by the fishing activity asphyxiates the fish and shrimp, which come towards the surface gasping for air. These are caught by hand nets or scoops nets.

Deo *et al.* (2013c) suggested various criteria to retain the freshness and quality without muddy smell in the cultured shrimps. According to CAA (2006), the objectives of shrimp farming practices should be to produce contaminant-free products for consumers through responsible pond operations and good management practices that prevent, eliminate, or appropriately reduce levels of chemicals, drugs and pathogens that pose human health concerns. CAA (2006) has given detailed guidelines to achieve the goal.

The price of prawn realized by farmers depends largely on the quality. The best care for newly harvested prawns is to wash them thoroughly with good quality water and immerse them immediately in chilled water (10 °C), preferably while still alive. Those picked from the mud should be immediately released in clean water to give them the chance to remove mud and other impurities in the gills before chilling.

Based on the preference of the buyer, prawns were seen classified into different size groups (counts). Small prawns and soft-shelled ones were sold at a much lower price. Prices were found to fluctuate now and then, generally reaching their peak in November and part of December. The international markets were found to decide the price of shrimp mostly.

Some buyers were seen to take the weight and ascertain the count (number of pieces per kg) of the shrimp before icing, but some others preferred to do it after keeping it on ice for some time. It was found that there is a 4.5-6.0% weight advantage for the farmer in the latter case. Deo *et al.* (2013c) observed that the harvested shrimps, if immersed in a slurry of ice for not less than 15 minutes after washing, enhance freshness and increase their weight by 5%.

2.5.7.2. Marketing

Fishes/ shrimps harvested from the farms were found to be marketed principally through seven channels. Fishes and small shrimps from traditional farms were marketed through three channels locally. Large shrimps from traditional farms and all shrimp from scientific farms were exported in frozen form (two channels). A part of the tiny shrimps, especially during the periods of good harvest from traditional farms, were marketed after drying through two channels. In the study area, farmed shrimp/ fish marketing was found generally characterized by shorter channels than the marketing channels prevalent in the capture fisheries sector. The simple system of the producer selling the product directly to the consumers was also in practice, though not common. Traditional shrimp farming was found to exist as a small-scale rural activity, and the products were mainly sold locally, especially when there was a shortage of marine fish in the market. Vendors and retail merchants were found to buy a small quantity of fish/ small shrimp at pond bunds from the marginal farmers and sell them to domestic consumers.

The shrimps meant for export in traditional farms were given to specific commission agents/ representatives of freezing plants who are fixed based on long-standing relationships/ acquaintances and trustworthiness. The price paid to the farmer is the prevailing market rate on the day of the transaction. In the case of scientific shrimp farms, a couple of days before the harvest, the farmers were found to negotiate with the commission agents of freezing plants/ representatives of freezing plants directly and fix the price for various counts of shrimps. On the day of the harvest, the agents/ representatives of freezing plants were observed to reach the farm with refrigerated/ non-refrigerated trucks loaded with sufficient ice. The shrimps were weighed count-wise in the presence of the farmer or his representatives at the farm, iced and taken by the purchaser. The payment was found usually effected within a period of one or two weeks.

The shrimps were generally sold at the farm gate itself. The present study indicated that 39.66% of the scientific shrimp farms in the area sold their produce to the commission agents and 60.34% directly to freezing plants. Here, the crop was seen marketed through relatively shorter channels than traditional farms. Shorter marketing channels ensured more benefits to the producer as the share to be given to the intermediaries in the marketing channels were less here. The study also revealed that 100% of the traditional farms and 41.38% of the scientific farms sold their products to specific agents/ freezing plants. On the other hand, 58.62% of the scientific farms sold their produce to any agents. In these cases, the agents were found to be selected primarily based on the price offered.

Only a few studies exist on the marketing of farmed shrimps. Johny (1993) studied marketing channels for aquaculture products in Kerala. He observed that about 80% of the aquaculture products are flowing in the export channels, and the rest, 20%, reaches the domestic markets. The author found five export and five domestic marketing channels to exist. Another entirely different channel also existed to transfer inferior quality and rejected prawns from the export channels to the domestic markets. These observations in the present study are in agreement with those of the study mentioned above.

Marketing is a process by which goods and services are exchanged and the values determined in terms of the money process (Chhabra and Grover 2003). The American Marketing Association (1960) defined marketing as the performance of business activities that direct goods and services flow through producers to consumers or users. Thus, marketing includes all those activities carried on to transfer the goods from the producers to the consumers. It involves the exchange of goods and services for money. Kotler (1994) considered marketing as a social and managerial process by which individuals and groups obtain what they need and want through creating, offering and exchanging products of value with others.

The fish marketing system includes all those functions and activities involved, from harvesting fish to the point of final consumption (Sathiadhas 1992). The marketing system may be either the domestic marketing system or the export marketing system. Finfishes and small shrimps from the traditional farms constituted the items for domestic marketing. The entire quantity of shrimps from the scientific farms and the large shrimps from the traditional farms constituted the items meant for the export market.

Studies on the marketing of fish and the linkages between the production and marketing sectors are essential to appreciate the shrimp farmer's problems because, in most cases, the farmers are dependent upon those who market their catch. Marketing studies are of interest for their insights and because marketing improvements are considered indirect means to increase the shrimp farmer's income.

The present study presents a snapshot of the state's prevailing farmed shrimp marketing scenario. The study analysed the structure of the principal marketing channels for the shrimps derived from various farm sources. However, marketing economics, *i.e.*, cost of marketing, marketing margins, profits, and similar aspects, are not considered. It may be mentioned here that a major strong point of aquaculture the world over is that production can be market-oriented as opposed to the production-oriented marketing that has to be adopted in capture fisheries. A proper understanding of consumer demand and consumers' attitudes and behaviour is a significant asset in planning a viable aquaculture production programme (Pillay and Kutty 2005). Here the systems and technologies of farming to be adopted will also be governed by the nature of the markets. It is quite obvious that the quality and size of shrimp at harvest and the methods of processing and presentation depend very much on the market. Unnithan (1985) gave an account of the marketing of farmed shrimps in Kerala.

2.5.8. Farm performance

2.5.8.1. Growth and survival

In traditional farms, since partial harvesting is done every month and since the harvest is a heterogeneous mix of different species and size classes, no attempt was made to collect periodic growth data. In scientific farming, the average body weight (ABW) at harvest of tiger prawn, Indian white prawn and Pacific white shrimp was found to be 30 g, 12 g and 22 g, respectively, within 120 days. The mean growth per week (wk) computed for the three species, *P. monodon, P. indicus* and *L. vannamei* are 1.75, 0.7 and 1.28 g wk^{-1}, respectively. One must remember that the growth rate shown is the average of all farms, and many farms got much better growth than this.

Various authors reported different growth rates for *P. monodon, P. indicus and L. vannamei* under different culture conditions and densities. Liao (1977) and Sundararajan *et al.* (1979) observed growth rates of 0.32 to 0.39 g day^{-1} (2.24-2.73 g wk^{-1}) in *P. monodon*. Liao (1981) reported a weight gain of 31.5 and 31.3 g in 106 days with a stocking density of 16 postlarvae $m^{-2,}$ while Felix and

Sukumaran (1988) found a final harvesting weight of 19.0 g in 105 days with a stocking density of five postlarvae m^{-2}, in freshwater ponds. In another experiment in brackish water, Rahman (1990) reported a weight gain of 32 g in 126 days with a stocking density of 18 postlarvae m^{-2} and 26 g in 112 days with a stocking density of 17 postlarvae m^{-2}. Hossain *et al.* (1992) obtained 21.65 ± 0.81 g in 120 days with the stocking density of five postlarvae m^{-2}. In another experiment in brackish water, Hoq *et al*. (1994) reported a weight gain of 27.99 ± 2.07 g in 105 days with a stocking density of four postlarvae m^{-2}. Biswas (1996) reported a growth rate of 0.35 g wk^{-1} in freshwater ponds. Janakiram *et al*. (2011) reported a growth rate of 1.9 – 2.3 g wk^{-1} at a stocking density of 3-4 shrimp m^{-2}. Debnath *et al.* (2013) recorded growth rates varying from 1.4 to 1.86 g wk^{-1} and an ABW at harvest of 23.95- 31.75 g in *P. monodon* stocked at a rate of 2-14 m^{-2}, in a culture trial for 120 days. Anand *et al.* (2015) recorded a growth rate of 1.39 g wk^{-1} in *P. monodon* grown at a stocking density of 8 m^{-2} and an average body weight of 25.85 g at harvest at the end of 130 days of culture.

Compared to *P monodon*, growth studies in *P. indicus* are few. According to Unnithan (1985), *P. indicus* would grow to 10-12 g within 90 days of culture (0.78 - 0.93 g wk^{-1}). Lazarus *et al.* (1988) recorded a growth rate of 0.035 -0.098 g wk^{-1} in *P. indicus* in different ponds when grown for 79- 84 days. Apud (1985) reported a growth rate of 0.76 g in *P. indicus* (ABW: 9.8 g) at the end of 90 days of culture. Jayaprakas and Sambhu (1988) recorded a growth rate of 0.73 -0.78 g wk^{-1} with a final ABW of 12.68- 13.3 g in *P. indicus* when grown for 120 days. The present author observed a growth rate of 0.99- 1.17 g wk^{-1} with an ABW of 17-20 g at harvest (at a stocking density of 100 postlarvae m^{-2}) at the end of the culture for 120 days during the year 1990-1991 in Victory Aqua Farm Limited at Tuticorin in the Southern Tamil Nadu (India). Very recently, based on results of a series of experimental field level cultures of *P. indicus* at high densities and in a zero-water exchange system Central Institute of Brackishwater Aquaculture (CIBA) demonstrated growth rates in *P. indicus* , which are comparable with that of *L. vannamei*. An analysis of data published (CIBA 2017) revealed a growth rate of 1.51- 1.62 g wk^{-1} and 0.92- 1.08 g wk^{-1} in Balasore (Orissa), 1.05-1.17 g wk-^{1} in Kakdwip (West Bengal), 0.97 – 1.06

g wk^{-1} in Gudur (Andhra Pradesh), 1.04-1.30 g wk^{-1} in Nayarambalam (Kerala), 0.97-1.06 g wk^{-1} and 1 g wk^{-1} in Danti- Umbharat (Gujarat).

Trimble (1980) reported that *L. vannamei* grew 1.28 g wk^{-1} at a stocking density of 2.5 shrimp m^{-2}. Wyban *et al.* (1987) found a growth rate of 1.72 g wk^{-1} at a stocking density of five shrimp square metre. For *L. vannamei*, growth rates of 0.71 g (Sturmer and Lawrence 1988), 0.3- 0.5 and 1.4 g (Wyban *et al.* 1988), 0.94 g (Robertson *et al.* 1992), 1.67- 1.7 g (Samocha *et al.* 1993), 2.7 g (Bray *et al.* 1999), 1.0 g (Emberson *et al.*1999), 1.12, 1.47 and 1.49 g (Samocha *et al.* 1999), and 0.57 g (Appelbaum *et al.* 2002) per week were reported. Balakrishnan *et al.* (2011) reported average final size of 21.2, 18.9, 19.6 and 17.5 g at the end of 110 days of culture. Karuppasamy *et al. (*2013) observed a final mean size of 35, 24.5 and 19.5 g at stocking densities 10, 35 and 7 m^{-2}, respectively, at the end of 100 days of culture. Suriya *et al.* (2016) obtained an average body weight of 20, 22, 21 and 34 g at the end of 120 days of culture. Parvathi and Padmavathi (2018) got a mean final body weight of 19.5, 19.8, 19 and 19.8 g after 116 days of culture.

An analysis of growth rates reported for the three shrimp species revealed wide variations. However, despite the differences in the rearing methods described in various studies, the observation on growth rate in *P.monodon, P.indicus* and *L.vannamei* made in the present study is comparable to those obtained in the various studies reported above.

The growth in farmed prawns depends on the stocking density, quality and quantity of feed given, water quality, and the prevailing environmental conditions, especially the temperature. According to Tidwell *et al*. (2004) growth rate of shrimp depends mainly on the stocking density, feed utilization and the availability of natural food. Many authors reported an inverse relationship between stocking density and growth (Forster and Beard 1974; Primavera *et al.* 1976; Sandifer and Smith 1976; Willis *et al* .1976; Emmerson and Andrews 1981; Muthu *et al*. 1981; Wyban *et al.* 1987; Lazarus *et al.* 1988; Ahmed *et al.* 2000; Janakiram *et al.* 2011; Sookying *et al.* 2011; Parvathi and Padmavathi 2018). Temperature is perhaps the most important abiotic factor that affects growth in shrimp (Lutterschmidt and Hutchison 1997; Kumlu *et al.* 2010). Wyban *et al.* (1995) demonstrated that growth is susceptible to small changes in temperature. He reported that reduced growth and feeding could be expected in shrimp farming when pond temperature is below the optimum range. The growth rate is also related to food consumption (Segal and Roe 1975). Subrahmanyan (1973) has observed that the growth of *P. monodon* is affected by low temperature under laboratory conditions. Verghese *et al.* (1975) observed rapid growth of *P. monodon* coinciding with an increase in temperature.

Shrimps moult roughly every 21 days, showing a discontinuous growth pattern (Mishra *et al.* 2002; Franco *et al.* 2006). Growth models for *P. monodon* have been derived from the Gompertz (Jackson and Wang 1998) and the von Bertalanffy models (Huang *et al.* 2006). Reported growth curves for *P. monodon* are quite varied (Delmendo 1989). Under extensive conditions, there are few limits to maximizing growth potential. Feed type, feeding schedule, stocking density, and natural pond preparation will affect the initial growth rates of the shrimp. In general, higher stocking densities lead to slower growth rates.

Owing principally to the economic importance of penaeid shrimp worldwide, particularly in aquaculture, a great effort to understand the growth biology of *Penaeus* spp. has been made in recent years. This includes studies on the influence of environmental factors such as temperature (Dall *et al.* 1990; Wyban *et al.* 1995; Miao and Tu 1996; Ye *et al.* 2003), salinity (Lemos *et al.* 2001) and lunar cycles (Griffith and Wigglesworth 1993) on shrimp growth.

According to Briggs *et al.* (2004), *L. vannamei* has the potential to grow as fast as *P. monodon* (up to 3 g wk^{-1}) up to 20 g under intensive culture conditions (up to 150 m^{-2} stocking density). Although it will keep growing beyond 20 g, its growth rate may slow down (particularly males) to 1 g wk^{-1} once above 20 g in weight (Wyban and Sweeney 1991). In the present study, in one of the newly constructed farms, a growth rate comparable to that of *P. monodon* was observed when grown at a stocking density of 30 pieces m^{-2} within 120 days. Under commercial conditions in Asian earthen ponds, however, typical growth rates of 1.0-1.5 g wk^{-1} (with 80-90% survival) are common in the high-density pond system (60-150 m^{-2}) currently in use (Briggs *et al.* 2004). On the contrary, the growth and survival rate of *P. monodon* has been declining in recent years from 1.2 to 1 g wk^{-1} (and 55 to 45% survival) in Thailand (Chamberlain 2003) owing perhaps to disease load and/or genetic inbreeding. Such observations must also be expected in the case of other farmed species also.

A faster growth rate benefits a farmer in many ways to the profit equation. When shrimps grow faster, they are in the ponds for a shorter period, significantly reducing the risk of farming. There may also be instances to grow the shrimp to a larger size or increase the number of crops per year. A shorter period in the pond can result in higher survival and lower feed-conversion ratios. In addition, total operating costs are also reduced. All of these factors lead to higher yields and profits.

The primary factors that influence shrimps' survival and growth are the rearing water quality, feed quality and feed management. The survival of penaeid prawns in the rearing ponds mainly depends on maintaining optimum oxygen level (Verghese 1980) and other water quality parameters. The survival rate is also a function of stocking density and the management intensity adopted.

The survival rate obtained in the case of *P. monodon, P.indicus* and *L. vannamei* farming in the present study is well within the range of the survival rates reported by various authors under various conditions of farming (Forster and Beard 1974; Primavera *et al.* 1976; Sandifer and Smith 1976; Willis *et al.* 1976; Liao 1977, 1981; Sundararajan *et al.* 1979; Trimble 1980; Apud *et al.* 1981, 1985; Emmerson and Andrews 1981; Muthu *et al*. 1981; Unnithan 1985; Wyban *et al.* 1987, 1988; Felix and Sukumaran 1988; Lazarus *et al.* 1988; Sturmer and Lawrence 1988; Rahman 1990; Hossain *et al.* 1992; Robertson *et al.* 1992; Samocha *et al.* 1993, 1999; Hoq *et al.* 1994; Jayaprakas and Sambhu 1988; Bray *et al.* 1999; Emberson *et al.* 1999; Ahmed *et al.* 2000; Appelbaum *et al.* 2002; Balakrishnan *et al.* 2011; Janakiram *et al.* 2011; Debnath *et al.* 2013; Karuppasamy *et al.* 2013; Laureatte *et al.* 2012; Susilowati *et al.* 2014; Anand *et al.* 2015; Li *et al.* 2015; Parvathi and Padmavathi 2018).

2.5.8.2. Production and productivity

In the present study, farmed shrimp production in Kerala was estimated to be 2952.56 t. Of this, the contribution of the traditional farming sector was 2174.80 t (73.66%), and that of the scientific farming sector was 777.76 t (26.34%). The contribution of different species to total shrimp production was as follows. *P.*

monodon: 1457.32 t (49.36%), *P. indicus*: 372.95 t (12.63%), *L. vannamei*: 242.78 t (8.22%), *M. monoceros*: 71.28 t (2.41%), *M. dobsoni*: 794.94 t (26.92%) and others: 13.29 t (0.45%).

The present study revealed that, in prawn filtration fields in which supplementary stocking was practised, *P. monodon* (41.77%), *M. dobsoni* (36.55%), *P. indicus* (16.95%), *M. monoceros* (3.28%), and *L. vannamei* (0.83%) were the predominant species harvested. *P. semisulcatus* and *M. affinis* were also harvested, though to a minimal extent. A rather unexpected observation in the present study is the presence of *L. vannamei*, a species exotic to the country in the harvest from the traditional farms (in which supplementary stocking was practised). The percentage composition of different species in the present study is in variance with the observations made by many earlier researchers.

George *et al.* (1968) reported *P. indicus*, *M. affinis*, *M. dobsoni* and *M. monoceros* as the principal species of shrimps in the pokkali prawn filtration fields. They found *M. dobsoni* to contribute to more than 50% of the catch. George (1974, 1975) also stated that *M. dobsoni* represented more than 50% of the catch. George (1974) further reported a declining trend of the fishery of *M. dobsoni* and *M. monoceros* and the increased contribution of *P. indicus* in pokkali fields. George (1980) and Unnithan (1985) reported 36-43% *P. indicus*, 0.7-1% *P. monodon*, 53-57 *M. dobsoni* and 3.5- 6% *M. monoceros* in the catch. According to Mathew (1991), the shrimp catch is chiefly composed of *M. dobsoni* (65-80%), *P. indicus* (15-30%) and *M. monoceros* (5-10%).

Studies conducted by Pillai *et al.* (1997) indicated the dominance of *P. indicus* over *M. dobsoni* in a pokkali field. A gradual shift from this trend was noticed in the catches as the supplementary stocking of the pokkali fields with *P. indicus* seed caught up with the farmers in the late 1980s. According to Pillai (1999), the shrimp fishery of the pokkali fields was largely contributed by four species of penaeids, *P. indicus, P, rnonodon, M. dobsoni and M. monoceros.* He observed that in the year 1996-97, the major share (59%) was contributed by *P. indicus* followed by *M. dobsoni* (28.6%), *M. monoceros* (1.90%), and *P. monodon* (0.5%) in their order of dominance. In the subsequent year, the same author found *M. dobsoni* to dominate the catch (37.9%), followed by *M. monoceros* (31.1%) and *P. indicus* (30.7%). *P. monodon contributed* only 0.3% to the total catch. In the same study, the author found *that M. dobsoni (44.6%) dominated* the harvest in another field. But the next dominant species was *P. indicus* (33.8%) and then *M. monoceros* (21.6%). In yet another field, the catch was primarily contributed by *M. dobsoni* (57%). The shares of *P. indicus, M. monoceros* and *P. monodon* to the total fishery were 27.1%, 14.2% and 1.7%, respectively. The author attributed the observed difference in the species composition to poor recruitment of certain species during certain seasons and to the supplementary stocking of hatchery-produced seeds in some fields. Purushan (2003a) reported *M. dobsoni* (53-57%), *P. indicus* (36-42%) and *M. monoceros* (3-6%) to contribute to the shrimp harvest from pokkali fields. Cheruvat (2005) reported the percentage composition of shrimps in the kaipad fields. According to the author, *M. dobsoni* constituted 50-53% of the total shrimp harvest, followed in order by *P. indicus* (30-31%), *M. monoceros* (15%) and *P. monodon* (2-3%). Sudhan *et al.* (2016) recently reported *M. dobsoni, M. monoceros, P. indicus, P. monodon, P. semisulcatus* and *M. affinis as* the principal species harvested in pokkali fields.

The observed difference in percentage composition of various species in the present study with those reported earlier is principally attributed to the practice of supplementary stocking of hatchery-produced seeds of *P. monodon P. indicus* and *L. vanamei*. Many of the earlier reports related to the species composition of the harvest when there was no supplementary stocking of shrimp seeds in the fields. Stocking hatchery-produced seeds will shift the relative percentage in favour of the stocked species. This is evident when one observes the species composition recorded in the farms that did not undertake supplementary stocking. The species composition of harvest in these farms entirely agrees with the species composition reported by George (1980) and Unnithan (1985). The spatial and temporal variation in recruitment of different species may also be responsible for the observed difference, at least to some extent. It may be mentioned here that the various studies indicated above were conducted at different points of time and in farms located at different distances from the sea. It may also be pointed out that unanimity does not exist among the various earlier workers, too, in the case of the percentage species composition of the harvest of the traditional farms.

Marine Products Export Development Authority (MPEDA) published the statistics of farmed shrimp production in India and various states in 2017-2018 (https://mpeda.gov.in/MPEDA/cms.php). According to the statistics, Kerala's total farmed shrimp production is 1730 t, and the area under cultivation in the state is 3196 ha. The figure is much less than the production figure obtained in the present investigation. However, a careful analysis of the statistics reveals that the statistics published by MPEDA include the production of only two species, *P. monodon* and *L. vannamei*, which are generally exported from the country. However, the production figures obtained in the present study include other species, a sizeable part of which may not have much export value and are destined to be consumed domestically. If we subtract the production figures of these species *i.e., P. indicus, M. monoceros, M. dobsoni* and other minor species, from the total production figure obtained in the present investigation, the resultant figure is 1700.1 t which is in perfect agreement with the production figure published by the MPEDA (1730 t). This also agrees with the production figures published by GoI (2019) for 2017-2018.

The fact that the estimated quantity of farmed shrimp (*P. monodon* and *L. vannamei*) production in the present study is in accord with the figures published by the Marine Products Export Development Authority and the Government of India corroborates the validity of the multistage stratified random sampling methodology adopted in the present study. Though it is a bit cumbersome to follow, the method is quite helpful in estimating species and sector-wise farmed shrimp production. If the aim is only to estimate the total quantity of farmed shrimp production, the methodology can further be simplified.

As per the statistics published by MPEDA mentioned above, in India, 59,099 ha area is under *P. monodon* culture in nine maritime states producing 57,691 t with average productivity of 0.98 t ha^{-1} $year^{-1}$. The state of Gujarat recorded the highest productivity of 2.97 t ha^{-1} $year^{-1}$, followed by Tamil Nadu and Odisha with a productivity of 2.8 and 1.48 t ha^{-1} $year^{-1}$, respectively. The average productivity of Kerala is 0.48 t ha^{-1} $year^{-1}$. The productivity (t ha^{-1} $year^{-1}$) of other tiger shrimp farming states are Karnataka (0.19), Andhra Pradesh (1.44) and West Bengal (0.970). The states of Maharashtra and Goa do not have tiger shrimp farms.

Further, as per the statistics, the county has 93,496 ha under *L. vannamei* culture in nine maritime states producing 622,327 t, with Andhra Pradesh leading in total area under culture and production. All India average productivity is 6.66 t ha^{-1} $year^{-1}$, and the average productivity in Kerala is 4.01 t ha^{-1} $year^{-1}$. The productivity (t ha^{-1} $year^{-1}$) of other *L. vannamei* farming states are Maharashtra (4.71), Goa (2.47), Karnataka (3.67), Tamil Nadu (4.93), Andhra Pradesh (7.32), Odisha (4.2) and West Bengal (5.38).

As per the statistics published by MPEDA, both the species put together, the nine farming states have produced 6,80,018 t of shrimp, with Andhra Pradesh topping the production followed by West Bengal and Gujarat, in the year 2017-2018. In Kerala, the total area under the farming of these two species is 3196 ha with a production of 1730 t and an overall productivity of 0.54 t ha^{-1} $year^{-1}$. The position of the state of Kerala is the lowest among all Indian states in overall productivity. The productivity figures (t ha^{-1} $year^{-1}$) of other states are Gujarat (7.28), Maharashtra (4.70), Goa (2.40), Karnataka (2.20), Tamil Nadu (4.90), Andhra Pradesh (7.15), Odisha (3.57) and West Bengal (1.30).

The huge difference between the production figure of Kerala and that of other states is primarily on account of the difference in areas under farming. The difference in the productivity of shrimp farms of these states has also contributed to the difference in production. Further, in most of these states, *L. vannamei,* which can be farmed at higher stocking density and whose expected yield is higher, is the principal species being cultivated. However, in Kerala *P. monodon* is the prime species. This is one of the reasons for the low farmed shrimp production and low productivity of shrimp farms in Kerala. It may be mentioned here that the productivity of scientific farms culturing *L. vannamei* in Kerala (4.23 t ha^{-1} $year^{-1}$) is very high compared to the productivity of scientific farms cultivating *P. monodon* (0.963 t ha^{-1} $year^{-1}$) and *P. indicus* (0.592 t ha^{-1} $year^{-1}$) indicating the potential of the species in improving the farmed shrimp production of the state. It means that by shifting to *L. vannamei* and adopting techniques to suit the species, one can increase the shrimp production manifold.

The productivity of *P. monodon* farms recorded in the present study (0.469 t ha^{-1} $year^{-1}$) was similar to the figure reported by MPEDA (0.480 t ha^{-1} $year^{-1}$). It is also in agreement with the productivity figure reported by the Government of India for the year 2017-2018 (GoI 2019). Similarly, the productivity of scientific *L vannamei* farms obtained in the present investigation (4.23 t ha^{-1} $year^{-1}$) is also comparable with the productivity figure reported by MPEDA, which is 4.01 t (https://mpeda.gov.in/MPEDA/cms.php).

As already mentioned, of the total farmed shrimp production of Kerala 49.36% was contributed by *P. monodon*, 12.63% by *P. indicus*, 8.22% by *L. vannamei*, 2.41% by *M. monoceros*, 26.92% by *M. dobsoni* and 0.45% by other species. On the other hand, in the scientific farming sector, 70.56% of the total shrimp production is contributed by *P. monodon*, 28.89% by *L. vannamei* and 0.55% by *P. indicus*.

As per (GoI 2019), *L. vannamei* accounted for 91.52% of the total shrimp produced through farming in India as a whole in the year 2017-2018. Further, *L. vannamei* is the most predominant shrimp species in all shrimp farming states, other than Kerala. The species accounted for 99.41% of the total farmed shrimp production in Andhra Pradesh, 99.71% in Gujarat, 99.94% in Tamil Nadu, 100% in Maharashtra, 90.55% in Odisha, 100% in Goa, 96.13% in Karnataka and 31.03% in West Bengal, in the year 2017-2018.

Globally, *L. vannamei* and *P. monodon* together constitute 61.78% of crustacean production (FAO 2018). In the year 2016, the contribution of the former was 52.86%, whereas that of the latter was 8.92%. The balance was contributed by crawfish (11.70%), crabs (10.33%), freshwater prawns (6.44%) and other crustaceans (9.76%). The share of *L. vannamei* to total farmed shrimp production in the world in 2016 was 85.56%.

The overall productivity figure reported by MPEDA for the country as a whole is 4.45 t ha^{-1} $year^{-1}$ (https://mpeda.gov.in/MPEDA/cms.php). However, the productivity observed in the State of Kerala in the present study is 0.932 t ha^{-1} $year^{-1}$. It reveals in unambiguous terms that there is enormous scope for further improvement of the production and productivity of shrimp farms in Kerala. Enhancing the productivity of the existing farms and extending culture to new areas could be considered ways to enhance shrimp production of Kerala, as has been suggested by Kutty *et al.* (2011) while discussing the prospects of inland aquaculture in Kerala. Sahadevan (2012) examined the various reasons for the low productivity of shrimp farms in Kerala. He identified the prime reasons for the low productivity of shrimp farms of the state. Sahadevan (2013) and Sahadevan and Sureshkumar (2019) have given a detailed account of the strategies to improve the state's shrimp production and productivity through farming. Prevalence of traditional methods of shrimp culture, lack of species diversification, non-adoption of improved farm management measures, limited extension programmes for motivation of farmers to take up advanced technologies, absence of periodic maintenance of farms, joint ownership of production units, insufficient availability of quality seeds, inadequate facilities for credit, high risks involved, lack of crop insurance, competitive land-use policy etc. may be attributed to the relatively low level of productivity and profitability of shrimp aquaculture units in the state of Kerala. Despite having good climatic conditions for shrimp farming, production efficiencies in Kerala are low due to low survival and poor management practices.

A large number of studies and field trials in which varying results have been obtained exist on the production and productivity of traditional as well as scientific shrimp farms in India and various parts of the world (Panikkar 1937, 1952; Menon 1954; Gopinath 1956; Panikkar and Menon 1956; Raman and Menon 1963; George *et al.* 1968; Liao and Huang 1972; George 1974, 1980; Parker *et al.* 1974; Manik *et al*.1978; Apud *et al.* 1981; Gopalan *et al*.1982; Kurien and Sebastian 1982; Verghese *et al.* 1982; Liu and Mancebo 1983; Shang 1983a; Huang *et al.* 1984; Colvin 1985; Hirasava 1985; Hollin and Griffin 1985; Stokes *et al.* 1985; Unnithan 1985; Purushan 1986, 1987a, 1987b, 1988; 1995, 1996a, 2002, 2003a; Jose *et al.* 1987; Pudjiatno and Baliao 1987; Rhodes *et al.* 1987; Sandifer *et al.* 1987,1988 ; Fitzgerald 1988; Lazarus *et al*. 1988; Mathew 1988; Posadas 1988; Surendran 1988; Wyban *et al*. 1988; Sathiadhas *et al.* 1989, 2000, 2009; Yahaya 1990; Surendran *et al*. 1991; Fast 1992a, 1992b, 1992c; Nasser and Noble 1992; Jayagopal and Sathiadhas 1993; Usharani *et al.*1993; Shang *et al.* 1998; Pillai 1999, 2003; Prasad 1999, 2006; Sathiadhas and Joseph 2001; Nair *et al.* 2002, 2014; Pillai *et al.*2002; Joseph and Sathiadhas 2006; Krishnani *et al.* 2011; Saikia *et al.* 2015; Dinesh 2016; Sudhan *et al*. 2016; Antunes *et al.* 2018; Nguyen *et al*. 2019; Singh *et al*. 2019). Though these studies give some broad indications regarding the production and productivity of shrimp farms, the results are not comparable because they have been conducted under different conditions, with different management intensity, and for different periods. The average productivity recorded in the present investigation (traditional and scientific farms) falls broadly under the range reported by the various workers mentioned above.

Traditional shrimp farms' annual unit area production (*i.e.*, productivity) showed significant variation from year to year. Menon (1954) estimated average yearly production of 1074 kg ha^{-1} during 1951-1953 in the seasonal fields of Ernakulum district, while Gopinath (1956) observed a slightly higher production rate of 1184 kg ha^{-1} during 1952- 1955 from the same area. George *et al*. (1968) estimated productivity of 754 kg ha^{-1} from the traditional prawn fields of Mulavukad. The production rates of the fields of Vypin during 1969-1972 and 1977-1978 were estimated as 903 and 735 kg ha^{-1}, respectively (George 1974). Kurup *et al.* (1992) reported annual production of 754.4 kg ha^{-1} from the traditional prawn filtration fields. In the present investigation, the estimated shrimp productivity of the traditional prawn filtration fields doing supplementary stocking was 881 kg ha^{-1}. The fields not resorting to any supplemental stocking showed productivity of 605.46 kg ha^{-1}. The increment in productivity unambiguously reveals the role of supplementary seed stocking in enhancing the production and productivity of the traditional shrimp farming fields.

2.5.8.3. Food conversion ratio

Feed conversion ratio (FCR) is determined as the quantity of feed applied divided by the weight of shrimp harvested. A low feed conversion ratio indicates greater efficiency than a high value. In the present study, the feed conversion ratio obtained by traditional farms fed with factory-made feeds varied from 0.8 to 2.2, averaging 1.28. In the case of farms that used farm-made wet feed, the feed conversion ratio ranged between 1.4 and 2.5, the average being 1.8. In the case of scientific farms that used factory-produced feeds, the FCRs obtained varied between 1.2 and 1.9 (average: 1.51). In the case of scientific farms employing farm-made feed, the FCRs obtained ranged from 3.2 to 4.0 (average: 3.40).

Contrary to the general expectation, the traditional farms showed better FCR values than the scientific farms. In traditional farms, the external feed given is only supplementary, and a significant part of the nutritional requirement of the pawns are met by the natural feed generated within the ponds (autochthonous) or the natural feed brought in by the incoming tidal water (allochthonous). Farmed shrimp are scavenging, opportunistic feeders in their natural environment and under traditional farming conditions, are also able to harness food particles suspended in the water column (e.g., phytoplankton, zooplankton, microbial flocs, organic detritus etc.) and food organisms living on the pond bottom (e.g., plant and animal biota), in addition to applied artificial feeds (Nunes 2009). Further in these farms, a part of the harvest is contributed by shrimps that might have grown outside the culture ponds, *i.e.,* shrimps grown fully or partially elsewhere and brought in along with the tidal water thus reducing the FCR substantially.

In a well-prepared pond, natural production will provide a significant part of the postlarval shrimp's nutritional needs and improve initial growth rates. This contribution of natural pond biota decreases throughout the production cycle, with increasing shrimp size and biomass (Hunter *et al.* 1987; Allan and Magiure 1992; Hunter 1996; Lawrence and Lee 1997; Moriarty 1997; Focken *et al.*1998; Villamar 1999; Nunes and Parsons 2000; Gautier *et al.* 2001). Meiofauna is abundant in a pond prepared with a good fertilisation programme (Allan *et al.* 1995).

In contrast to terrestrial farm animals where compound feeds can be fed on a visual basis according to the appetite of the animals or to a pre-set feeding level, pond-raised shrimp are not directly visible to the farmer during feeding, and as such, animals have to be fed 'in the dark'. Consequently, compounded shrimp feeds are usually provided by farmers at a fixed daily rate based on shrimp body weight and an estimate of the total shrimp biomass present in the pond, with the feed usually being applied by hand several times daily. However, there are practical difficulties in accurately determining the total shrimp biomass within commercial grow-out ponds. In estimating dietary feeding levels for a particular diet and dietary nutrient density, farmers are usually forced to feed their animals on a targeted/expected weekly growth response (or attain a certain final shrimp target weight over a pre-set culture period). This practice comes with a consequent risk of over-or under-feeding, environmental pollution (owing to over-feeding), and suboptimal FCR and growth (Tacon *et al.* 2013). According to Tacon *et al.* (2013), the global average farm FCR for shrimp is 1.5:1. The values of FCR recorded in the present study agree with this.

Further, in general, the mean FCR obtained in the case of *P. indicus* is relatively high compared to that of *P. monodon* and *L.vannamei.* This observation is justified because *P. indicus* is more active in ponds than the latter and, hence, expend more energy for movement. *P. monodon* shows marked nocturnal activity, burrowing into the bottom substratum during the day and emerging at night in search of food as benthic feeders. On the other hand, *P. indicus* is non-burrowing, active both day and night and prefers a sandy mud bottom. Compared with other species, *L. vannamei is* more efficient in utilizing the natural productivity of shrimp ponds, even under intensive culture conditions (Wyban and Sweeney 1991). Feeding efficiency is also better with *L. vannamei* (Briggs *et al.* 2004). Hence this species exhibits a relatively low FCR compared with *P. monodon and P. indicus*.

Various authors have reported various FCR values in farmed shrimps under different farming conditions and feed types. These include (Forster and Beard 1974, Sandifer and Smith 1976; Willis *et al.* 1976; Liao 1977, 1981; Sundararajan *et al*. 1979, Trimble 1980; Muthu *et al.* 1981; Apud 1985; Unnithan 1985; Wyban *et al.* 1987; Felix and Sukumaran 1988; Lazarus *et al.* 1988; Sturmer and Lawrence 1988; Rahman 1990; Hossain *et al.* 1992; Robertson *et al.* 1992; Hoq *et al.* 1994; Jayaprakas and Sambhu 1988; Bray *et al.* 1999; Emberson *et al.* 1999; Samocha *et al.* 1999; Ahmed *et al.* 2000; Appelbaum *et al.* 2002; Balakrishnan *et al.* 2011; Janakiram *et al*. 2011; Debnath *et al*. 2013; Karuppasamy *et al.* 2013; Tacon *et al*. 2013; Susilowati *et al*. 2014; Anand *et al.* 2015; Li *et al*. 2015; CIBA 2017; Parvathi and Padmavathi 2018; CIBA 2017; Xue *et al.* 2021). The FCR values observed in the present study generally agree with the values reported by the authors mentioned above.

2.5.9. Crop failures

The frequency of crop loss is an important factor determining the success of shrimp farming and gives an idea about farm performance. It may be worth mentioning here that 100% of the traditional farms and 82.76% of the scientific shrimp farms in the study area met with crop failures at least once during the last 10 years. Crop losses in shrimp farming may be due to natural disasters, water pollution, disease outbreak, or other reasons like depletion of dissolved oxygen, unfavourable physicochemical water quality parameters, damage to farm structures (for example, bund collapse) etc. Shrimp farming is a precarious business, and crop failure from disease is quite common. With the intensification of farming operations, viral diseases have become very common in almost all shrimp farming countries. It is generally believed that most crop losses are caused by secondary pathogens that can invade shrimp when they are under environmental stress (Funge-Smith and Briggs 1998).

Crop failures due to the outbreak of diseases have occurred in several shrimp farming countries and, along with other macroeconomic reasons, have introduced an element of uncertainty in the market, resulting in price fluctuations. These fluctuations may be deleterious to the sustainability of shrimp farming operations. Disease outbreaks have recently led to the decline of shrimp farming in almost all shrimp farming regions worldwide. In some parts, the collapse has resulted in a shift away from shrimps to other species such as finfishes, molluscs, and crabs grown in polyculture. Furthermore, the returns from shrimp farming rarely match expectations in the long term. Although crop failure can be reduced through good site selection, farm design, farming technology and scientific management, severe disease outbreaks can be a problem in all farms, including the more extensive systems. Short-term losses can be considerable and difficult to absorb, especially in smaller farms.

Some of the diseases that lead to mass-scale losses to the shrimp farming industry are directly caused by environmental problems, while several other diseases are triggered or spread more effectively by the stress induced by ecological issues. In recent years, shrimp farming has been afflicted with outbreaks of viral diseases that have significantly undermined the profitability and sustainability of farming operations.

Diseases affecting shrimp and other aquaculture organisms may originate from local wild stock or other carrier organisms, from infected seed, infected broodstock, and possibly poor-quality feed. Information on the incidence and spread of disease can help locate the source, which allows for more effective disease management. A disease surveillance system is required to monitor and control the movement of organisms, test for the disease and keep detailed records for epidemiological purposes, and take action as appropriate when disease problems arise. Surveillance must undertake regular analysis of data collected to prevent diseases.

2.5.10. Maintenance of farm records

The present study revealed that only 38.27% of the traditional farms and 72.41% of the scientific farms keep farm records of some kind. Others do not maintain any farm records. FAO (2005) outlined the importance of record-keeping in aquaculture. Record keeping is the core of shrimp farm management, and it helps to achieve the maximum possible rate of shrimp production. It records all aspects of the fish farm operation and is vital to the farmer. Record keeping aids in evaluating the profitability and general economics of the pond/farm investment. It also provides critical management information for future planning, improvement, and development.

Coche *et al.* (1996) discussed the need for monitoring and record keeping in aquaculture. The extent of monitoring and record-keeping required depends on several factors such as the farmer's level of education and skill, the farmer's interest in good management and profit, the size and organization of the farm, the external assistance available to the farmer etc. It is also essential to evolve the best approach for the particular circumstance based on records.

Records are helpful to plan the entire crop cycle, including stocking densities for each pond, well ahead of its beginning. Farm records to be meaningful should contain information on pond preparation, stocking, periodic sampling (growth), water quality parameters, daily feed ration, source of various farm inputs, the incidence of diseases and their management, pond bottom management, and harvest. Panigrahi (2012) and Anand *et al.* (2013) emphasized the necessity of record keeping to identify various risks and rectify the problems in the pond environment and shrimp health at the earliest during the production cycle. Record keeping also helps the farmer learn from past mistakes, thus reducing risk and production costs in subsequent crops.

2.5.11. Crop duration and crop rotation

Because of fear of disease outbreaks, shrimp farmers in Kerala were found to take only one crop in a year, even in areas suitable for two crops. The present study indicated that no farms are being utilized for aqua farming year-round in the state. 93.21% of traditional farms used the fields for shrimp farming for less than 180 days each year. Similarly, 87.93% of the scientific farms undertook shrimp farming for less than 140 days in a year. During the rest of the periods, the fields remained idle, which means that the fields were grossly underutilized for most of the year. The duration for which the farms are utilised influences productivity and profitability. But it may have some beneficial effects, too.

There exists a significant association between the number of crops taken in a year and the incidence of disease. Nagesh *et al.* (2009) observed that the incidence of disease was high (85%) in farms that had two crops in a year compared to those which had only one crop (43%). The authors suggested 'crop holiday' or 'down time' (the interval or the duration between two successive crops) to reduce the disease outbreak as Villalon (1991) recommended. Those farms that take two crops in a year should have a minimum of 10-15 days between the crops. As the interval between crops is shortened, pond drying and preparation will not be proper, which results in severe management problems in the subsequent crop. However, Marichamy (1995) opined that four-month crop holidays did not prevent disease outbreaks. While agreeing to the need to provide sufficient time between successive crops, it may safely be concluded that a cropping system that allows year-round utilization of the ponds helps increase aquaculture production and profitability, as observed by Sahadevan (2012) and Sahadevan and Sureshkumar (2019).

Rotation of fish crops (one crop of shrimp followed by a crop of finfish or crabs) is one of the ways open to enhance the profitability of the farming operation. Verghese (1995) believes that alternative crops (rotation of crops) would provide ecological purification and, hence, reduce disease incidence. However, scientific farms generally do not practise crop rotation in Kerala. Farming of milkfish, pearl spot, sea bass, grey mullet, tilapia, crab etc., during the period when shrimps are not grown, will undoubtedly prove beneficial to increase aquaculture production and improve the profitability of shrimp farming units. The giant freshwater prawn may also be considered for farming during the low saline phase of the year. However, scarcity of seed is one of the most critical bottlenecks in popularizing the farming of these species.

When natural food is abundant, some farmers were found to stock 500-2000 milkfish fingerlings per hectare in extensive farming along with the shrimp crop. Combining prawn with milkfish is favourable to both species. Various studies on the biculture of milkfish and prawn (Pudadera 1980; Eldani and Primavera 1981; Apud *et al.* 1983) confirmed many beneficial effects. Eldani and Primavera (1981) pointed out that one of the benefits of culturing prawn with milkfish is the control of the population of chironomid larvae. Chironomid larvae can occur at very high density (40,000-50,000 m^{-2}) during certain periods and compete with favoured stock for food, oxygen and space. Gundermann and Popper (1975) reported the disappearance of chironomus larvae in ponds several weeks after stocking with *P. merguiensis* and *P. indicus*.

Agriculturists usually mix crop husbandry with livestock or poultry farming to reduce income variability and to minimise the risks associated with farming. Replacing, supplementing or rotating the shrimp farming with the culture of other high-value fish species like Asian sea bass (*L. calcarifer*), grouper (*Epinephelus spp.*), mullets (*Mugil spp*.) and milkfish (*Chanos chanos*) or with agri or animal crops may ease the risks in mono-cropping of shrimp and enhance profitability.

As has already been discussed, shrimp farming in Kerala is traditionally practised in pokkali fields and kaipad areas. Here shrimp farming alternates with rice farming. The varieties of paddy farmed are flood resistant and salt resistant, which requires no fertiliser or pesticide application. This type of paddy-shrimp farming benefits both rice and shrimp in many ways. The decayed organic wastes of paddy increase the fertility of the fields, which help improve shrimp production. Similarly, the organic wastes (excreta) produced by the shrimps acts as an excellent fertiliser to the rice, thus benefitting its growth. However, of late, obviously due to the noticeable drop in profitability, many farmers discontinued the paddy cultivation, which would have a pronounced negative effect on shrimp production. The present study shows that only 36.84% of the traditional farms undertake rice farming alternated with shrimp farming. The discontinuation of the paddy crop is expected to have severe repercussions for the sustainability of the ecosystem.

2.5.12. Major constraints

Shrimp farmers of the study area reported that they face many constraints. Decrease in tidal flow due to siltation, weed chocking etc., and consequent reduction in the depth of natural water bodies that brings water into the ponds is one of the critical constraints faced by all traditional farms. 30.86% of the traditional farms considered this the most crucial single constraint they face. However, it is not a severe constraint to the scientific farms. Only 13.79% of the latter viewed it as a constraint. The traditional shrimp farms should have free tidal water movements to facilitate water mixing throughout the pond, bring in sufficient seeds, nutrients and live food organisms, avoid water stagnation, regulate the water temperature and remove the wastes. Indeed, the traditional prawn filtration fields depend on water brought in by the tide for the stocking of seeds and maintaining the quality of the rearing medium, which determines the production and profitability of the farming operation. However, in recent times the depth and water flow in the lakes and backwaters have decreased due to anthropogenic activities, causing a threat to the very existence of traditional shrimp farms. According to Kurup *et al.* (2013), Cochin backwaters with which pokkali prawn filtration fields are connected have undergone considerable shrinkage during the past few decades. Apart from horizontal shrinkage, there was also vertical shrinkage (*i.e.*, reduction in depth) to the tune of 30% in the second half of the 20th century. As a result, the total water holding capacity of the system has been reduced by 20%. Gopalan *et al.* (1983) observed that Vembanad lake, the most extensive backwater system in Kerala, is undergoing man-made shrinkage at an alarming rate. Siltation and weed infestation are the primary reasons contributing to the progressive reduction in the depth of backwaters. The process of siltation occurring due to river discharge and tidal inflow has been accelerated by man-made alterations such as deforestation construction of dams, reservoirs and barriers. The amount of siltation in the backwaters of Kerala is reflected in the removal of 2.5 million cubic yards of silt by dredging every year to maintain the shipping channel at Cochin Harbour, where the rate of silting is 180 cm $year^{-1}$ (Kurup 1971). Anthropogenic activities have led to the shrinking of the water spread area of the Vembanad backwaters from 365 to 256 square kilometres (Balachandran 2007). These interventions have had a significant effect on the hydrodynamic aspects of the system, leading to dispersion of pollution and diminishing the system's bioresources.

Water pollution and dumping of household and city sewage (including hospital wastes) were reported as critical constraints faced by all traditional farms and 86.21% of the scientific farms. 30.86% of the traditional farms and 10.34% of the scientific farms considered this the most critical single constraint they face. Pollution of water acts as a major hindrance to developing shrimp farms in many areas. The site must be free from pollution to ensure success in shrimp farming. About 16 major and several minor industries are situated in the upstream regions of the Cochin backwater system. The effluents discharged in this area are around 0.105 million m^3 day^{-1} (Anon 1996). The discharge of treated and semi treated sewage, and the effluents discharged from fertiliser, pesticides, radioactive minerals, chemical wastes, discharged from allied industries, petrochemical plants, heavy metal processing plants, fish processing plants etc., finally get dumped in the estuarine systems. The fertilisers used in Kuttanad alone is reported to be 20,239 t $year^{-1}$ (Anon 1998). According to the report, part of the fertilisers drains into the Vembanad lake, situated towards the southern end of the backwater system. The backwater also receives organic waste to the tune of 260 t day^{-1} in addition to sizable dredge spoils (107 m^3) from the harbour area. Water from Periyar and Muvattupuzha mainly drains into the Cochin backwater system. The lower reaches of Periyar receive around 260 million litre industrial effluents per day. The major industrial pollutants are acids, alkalis, ammonia nitrogen, insecticides, dyes, chromium, mercury, zinc, etc., and radioactive minerals. At Ambalamugal, 16 km east of Cochin harbour, a giant fertiliser plant and an oil refinery are located from which large quantities of phosphogypsum are disposed into the tributaries of the Muvattupuzha river (Anon 1998).

The traditional farmers were found, in general, to feel that owing principally to the reduction in tidal flow, increasing water pollution, and overfishing in the nearby backwaters, the fish and prawn resources of the backwater system are depleting day by day. This has resulted in a drastic decline in the recruitment of seeds in these water bodies. Farmers reported that owing principally to the drastic decrease in recruitment, there is an acute shortage of shrimp seed that enters the fields, which adversely reduce production and productivity. In this context, the traditional farmers have to resort to supplementary stocking with hatchery-produced seeds of shrimps which directly enhances their cost of production. 14.2% of the traditional farms considered this the most critical single constraint they faced. Though all traditional farms identified the reduction in tidal flow as a significant constraint, none of the scientific farms reported it as a constraint to reckon with. It may be because scientific farms do not rely on tidal flow for seed stocking and water exchange. Many of these farms are pump-fed and undertake zero water exchange farming.

All shrimp farms (traditional and scientific) identified repeated occurrence of diseases as a major constraint. 24.07% of the traditional farms and 55.17% of the scientific farms considered this the most critical single constraint they faced. The disease outbreak is the most prominent nature-based risk factor in shrimp aquaculture, sometimes wiping out the entire crops. In many instances, disease led to investor flight from shrimp farming. Disease occurrences can be roughly divided into the ones that are environmental and opportunistic in origin, which mainly occur in poorly managed farms and the outbreaks that spread to almost all farms regardless of management. The first category is the easiest for the individual farmer to address, but outbreaks require concerted efforts. The risk of disease outbreaks is related to the capacity of the individual farmer to manage the farm, which can be improved as knowledge of shrimp farming improves. There is also a collective risk that arises as soon as one farmer mismanages a farm or introduces disease via seed or feed. Once the disease has been established in a region, it can affect relatively well-managed farms just as those less well managed. Managing this collective responsibility in an immature industry, as it is in most shrimp farming countries, requires good insight by regulators and farmers with sufficient knowledge to limit the disease risk.

Studies by Nayak *et al.* (2001) in Balasore district of Odisha, Sathe (2008) in Thane district of Maharashtra and Srinivas and Venkatrayalu (2016) in West Godavari district of Andhra Pradesh have shown the disease problem as a principal constraint faced by shrimp farmers. Tandel *et al.* (2016) have reported that disease is the primary limiting factor faced by shrimp farmers, and it has become the most burning and threatening issue for shrimp farming communities. Kumaran *et al.* (2017) also identified the disease as the major problem faced by shrimp farmers in the East and West coast of India. As per Salunkhe (2018), the disease is the major constraint faced by shrimp farmers of the Palghar and the Raigad district of Maharashtra.

The disease has made shrimp farming unsustainable in many areas of the world. To date, the responses have been reactive and ad hoc—mainly based on disease identification and treatment- coupled with efforts to promote improved management practices on individual farms. In practice, this approach has failed to prevent major losses to the industry, and in some cases, the losses have led to the abandonment of farming. If shrimp farming is to become more sustainable, a much more strategic and integrated approach is needed. In practice, this will require countries, and specific shrimp farming areas, to develop comprehensive disease prevention and management strategies. Such strategies should include measures to promote, facilitate, or require the following: improved understanding of disease epidemiology; high-quality, low-pathogen water supply to major farming areas and individual farms; high-quality, low-pathogen, or pathogen-resistant seed supply; high-quality, pathogen-free feed supply; optimal grow-out conditions; farmer competence in the rapid identification and correct treatment of disease; increased species diversity; and cautious intensification and implementation of different system models in response to local conditions. The topic of shrimp disease has been discussed in detail under the section 2.5.6.3.5.

In shrimp farming, treatment of diseases in most instances is cost-prohibitive. The focus must be to manage the diseases keeping prevention at the centre. Shrimp diseases may be prevented to a very great extent by adopting best management practices in farming. Crop rotation, species diversification, shifting farming season, change in marketing strategies etc. may be thought out to manage diseases. Shortening the crop duration is another strategy to follow. Maintaining shrimp in the ponds for a shorter period significantly reduces the risk of diseases in farming. According to Harkell (2017), there is a shift towards producing smaller shrimp globally because farmers are harvesting their shrimp ponds earlier, likely due to increased risks of diseases. In some areas of China, farmers harvest shrimp smaller than 200 count kg^{-1}. The share of tiny shrimp produced globally (60 counts or smaller) has significantly increased during recent years. In 2010, just 14% of shrimp were in this size category, but in 2017, the share of smaller shrimp reached 30%. In Asia, Anderson *et al.* (2017) also reported a shift towards producing smaller shrimp sizes (51-60 and smaller) since 2011. The share of small counts increased from 27% to 52% between 2010 and 2016. The shift to smaller shrimp seems to be driven by narrowing price margins between the small sizes and the larger counts and early harvests caused by diseases (Anderson *et al*. 2017).

The scarcity of good quality shrimp seed was a significant constraint for all scientific shrimp farms. However, only 75.93% of the traditional firms considered it a constraint. But, 34.48% of scientific shrimp farms felt it the most critical constraint. Moreover, there were problems associated with seed availability and distribution. The majority of farmers procured seeds from hatcheries functioning outside the state. In many cases, ponds could not be stocked on envisaged lines due to the scarcity of good quality seeds. Further, it was observed that the seeds that reach the farm after long-distance transport are weak and are of inferior quality. This leads to heavy mortality in farms and, therefore, directly affects the productivity and profitability of the farming operation.

Many authors reported the inadequate availability of quality seed as an important constraint in shrimp farming (Vimala *et al.* 2006; Rajarajan 2017; Koteswari *et al.* 2014; Jagadeesh 2015). The lack of good quality shrimp seeds might be due to the poor quality of broodstock, as was reported by Srinivas and Venkatrayalu (2016). Chittem and Kunda (2017) said mixed seed or differential seed size and high mortality of hatchery seed due to poor quality as the major constraints faced by farmers of Andhra Pradesh. Patil and Sharma (2020) also made a similar observation, who ranked inadequate seed quality as the third most important production constraint in shrimp farming. Some workers like Megahed *et al.* (2013), Koteswari *et al.* (2014) and Jagadeesh (2015), Patil and Sharma (2020) reported the high cost of seed as a vital production constraint.

All traditional farms identified competition for land use as a significant constraint. Land/water ownership and access or use rights in coastal areas are ambiguous in many cases. Such ambiguity has been identified as contributing to many social problems stemming from shrimp-farm development. The legal aspects of resource rights are often not fully understood, and legislation may be lacking or confusing. Traditional rights are still prevalent in some parts of the state, like the pokkali areas of Ernakulum district. In the traditional prawn filtration fields of Ernakulam district, the field owner has the right over the crop only up to the 15th of April of each year (effectively from November to April 15). After the 15th of April, local fishers can enter the field and catch whatever stock is available in the field, *viz.*, the fish stock in the fields becomes a common property resource. This acts as a deterrent for prolonging the crop in the pokkali areas beyond the date. Thus, traditional farmers are compelled to harvest their crops before the date mentioned, resulting in lower productivity.

Further, these areas are often subject to continuing illegal development from commercial interests. Land use controls are ineffective in many instances. Additionally, the pokkali fields are integrated paddy cum fish farming systems where paddy farming is alternated with shrimp farming. The fields are used for paddy cultivation during the southwest monsoon periods. They are used for shrimp farming only from October/ November to April. However, of late, farmers are reluctant to undertake it due to a fall in the profitability of paddy cultivation. They are willing to do only shrimp farming. However, the district administration is not willing to permit farmers to undertake shrimp farming without paddy cultivation. As a result, many farmers cannot continue shrimp farming in these fields. However, only 5.17% of the scientific farms considered it a constraint they faced.

Physical and electric connectivity is important from the point of view of improving the efficiency of farm management, reduction of cost of production, increasing productivity and profitability of the farming operation. 52.47% of the traditional farms and 67.24% of the scientific farms considered the difficulty in getting power connections from KSEB a critical problem they faced. In the absence of electric power, they could not operate aerators and found it challenging to increase the stocking density. Many scientific farms cannot effect a shift in species because of the non-availability of power connections. It is peobably one of the most important reasons why shrimp farms in Kerala remain ‘tiger prawn centric’ when all the states in the country have moved to the farming of high yielding *L. vannamei.* If artificial aeration can be provided, *L. vannamei* can be farmed at a very high density compared to *P. monodon* . In the absence of electric lights, there is also a limitation in controlling poaching and consequent crop loss. Swathilekshmi *et al.* (2008), Sahu *et al.* (2014), Srinivas and Venkatrayalu (2016) and Chittem and Kunda (2017) also reported lack of electric power as a significant constraint faced by shrimp farmers.

The absence of road access was identified as a constraint by 51.23% of the traditional farms and 41.38% of the scientific farms. Accessibility of the farm to land transport is required to facilitate supervision (Apud 1988), enable transportation of supplies and harvest (Apud 1988; Poernomo 1990), reduce the cost of production and avoid spoilage of the shrimp harvested.

33.95% of the traditional farms and 72.41% of the scientific farms considered insufficient crop insurance a critical constraint. Shrimp aquaculture is an inherently risky business activity, subject to the unpredictability of climate, input prices, product value and the possibility—indeed the likelihood—of disease and production failure. The extent and incidence of the disease depend on both the management of individual farms and the management of the industry as a whole. Minimizing disease risk is therefore only partly in the hands of the individual farmer. Government can play a significant role in reducing some of these risksin farming. In general, financial risks increase with intensity and decrease with improved site selection, design, technology, husbandry and management. The relationship between intensity, returns, risk, access to credit, and skill requirements should be carefully considered in the planning and designing of any shrimp culture project or programme. In the case of individual projects or aquaculture development programmes, the most important safeguard against financial risk is proper insurance coverage. However, in Kerala, insurance companies are generally reluctant to cover most shrimp diseases. In this context, there is a need for intervention from the Government side to persuade the insurance companies to extend crop insurance at an affordable rate. Srinivas and Venkatrayalu (2016) and Chittem and Kunda (2017) reported the lack of crop insurance as shrimp farmers' major constraint in Andhra Pradesh. Patil and Sharma (2020) also made similar observations among the shrimp farmers of Maharashtra.

Another critical issue the shrimp farms face in Kerala is the shortage of labourers. 43.83% of the traditional farms and 41.38% of the scientific farms considered it a significant constraint. The issue exists in other agriculture sectors, too, in the state. Shrimp farms need continuous and close surveillance for the best results. However, due to the acute shortage of labour force in the state, many farms remain ‘unmanned’. Thus ‘corrective pond management measures’ cannot be done on time, and poaching cannot be avoided, which leads to a decrease in shrimp production and productivity. Lack of specialized know-how by farm managers and workers is a significant risk factor to consider. The farmer should ensure that the employed staff have solid experience in shrimp farming and proper management practices. However, obviously because of the shortage of workforce in the state, most farms use the services of temporary migrant labourers with no prior exposure to shrimp farming.

A fundamental reason for the low survival rate and productivity in shrimp farms in Kerala is poaching. 40.12% of the traditional farms and 51.72% of the scientific farms reported poaching and resultant crop loss as a constraint. Poaching is a social issue and can be avoided only by creating awareness among the local people. To prevent poaching, watch and ward arrangements must be provided day and night, especially during the second and third months of the culture period (Unnithan 1985). Floodlights may be installed at strategic locations on the farm. Watchman's shed may be built preferably near the sluice gate. Dried twigs, non-corrosive barbed wires or other obstacles may be placed in appropriate locations in the pond along the borders to prevent cast netting from the bund.

33.95% of the traditional farms and 41.38% of the scientific farms considered decline/ fluctuation in shrimp price a significant constraint. Fluctuation in shrimp price was reported as a marketing constraint also by Rawool (2005), Salunkhe (2018), Rajarajan (2017), Sahu *et al.* (2014) and Patil and Sharma (2020). Chittem and Kunda (2017) and Swathilekshmi *et al.* (2008) reported the lack of information on price as a significant marketing constraint perceived by shrimp farmers of Andhra Pradesh.

One of the most important factors influencing the economic performance of a shrimp farm is the farm-gate price of the shrimp. Many cases of farm failure are caused by the crash in the prices of the produce. Prices may collapse during periods of a glut in production. The main factor in determining long-term supply projections for shrimp is aquaculture growth, which would undoubtedly influence the market (Ruckes 1994; Ferdouse 1996). The current outlook projects that aquaculture will provide an increasing part of total world shrimp production. According to Anderson *et al.* (2016) and FAO (2016), aquaculture accounted for some 54% of total shrimp supplies in 2015, and that share is increasing. This trend is likely to continue because several major shrimp capture fisheries are now declining. Therefore, it is reasonable to assume that farmed shrimp will have an increasing effect on market price. If supply cannot meet demand, the price will likely rise; if the industry suffers from over-investment and over-production, the price may decline significantly, leading to lower profit margins. However, the "boom and bust" syndrome is well known in most industries and is usually the sign of a new and immature sector. In practice, the disease has restrained farmed shrimp production, allowing the development of marketing channels and market demand approximately in balance with production. Short-term price fluctuations can significantly impact farm gate prices and farm viability in more isolated areas, where producers have limited access to distribution and processing infrastructure.

25.31% of the traditional farms and 51.72% of the scientific farms considered insufficient availability of credit a major constraint they face. Rajarajan (2017) also reported inadequate credit from banks as a significant financial constraint faced by farmers in the Nagapattinam district of Tamil Nadu. Srinivas and Venkatrayalu (2016) and Patil and Sharma (2020) also made a similar observation. Investment capital for scientific shrimp farming is substantial for limited-resource farms. Access to credit at fair market rates is an important prerequisite for a successful sustainable shrimp farming operation, as has been stressed by several authors (Zweig and Braga 1996; Holland 1998). Shrimp farmers commonly need credit for infrastructure and working capital during operations. This need is generally greater for small- and medium-size farms than for larger corporate farms, which have fairly easy access to the credit they need. To secure a financial basis for small- and medium-scale shrimp aquaculture, it is necessary to ensure that credit facilities are available locally and that the private investor/operator qualifies for such facilities. Credit could be channelled directly to the individual farmer or through cooperatives where the individual members share the risk. The credit system should ideally be set up in a way that helps the farmers survive at least one cycle of shrimp disease, possibly through some form of insurance or joint liability system that creates a crop protection fund in which individual farmers invest.

40.12% of the traditional farms and 48.28% of the scientific farms considered the lack of extension services by the government as an important constraint. In partnership with the farmers, extension services are responsible for directing programmes and projects for change. Although shrimp farmers of the state already have much knowledge about their environment and farming system, extension programmes can bring them other knowledge and information they do not have. Applying such knowledge often means that the farmer has to acquire new skills. Transferring knowledge and skills to farmers and their families is a vital extension activity. The extension also provides advice and information to assist farmers in making decisions and generally enable them to take action. This can be information about prices and markets. The technical advice will probably apply more directly to the production activities of the farm and to the action needed to improve or sustain the production. Much of this technical advice will be based on the findings of laboratory research and field trials. In many instances, however, farmers are also sources of valuable advice and information for other farmers, and agents should always try to establish a farmer-to-farmer link.

Chittem and Kunda (2017) also reported the lack of regular training programmes as a major constraint faced by shrimp farmers of Andhra Pradesh. Chandra *et al.* (2010) reported the lack of technical knowledge among shrimp farmers as a significant constraint. Patil *et al.* (2019a) noted the need to improve aquaculture extension personnel's professional competencies through training. Similarly, Patil *et al.* (2018) and Patil and Sharma (2020) stressed assessing shrimp farmers' competency and discrepancy scores for designing need-based training programmes. In the studies by Sawant and Sawant (2003), Rajarajan (2017), and Patil and Sharma (2020) also shrimp farmers reported inadequate support from the government as a significant constraint faced by them that need to be addressed.

33.95% of the traditional farms and 29.31% of the scientific farms considered increasing production cost a critical problem they face. The major production costs in a shrimp farm are those meant for construction, pond preparation, feed, fertiliser, stocking material, labour, water, marketing, interest and land lease (Boyd 1981). In many cases, these costs are beyond the control of individual shrimp farmers. In recent years, farmers have felt a substantial increase in the cost of all items other than seed and feed. However, the revenue realized by the sale of shrimp produced is determined by international forces, which does not show any increase. The shrimp price showed a declining trend during the last couple of years which worries the farmers. High electricity tariff and consequent hike in the cost of production was reported as major constraint faced by shrimp farmers in studies conducted by Jagadeesh (2015) and Koteswari *et al*. (2014). Rajarajan (2017) reported the high cost of supplementary feed as a major constraint of shrimp farmers in Nagapattinam district, Tamil Nadu. In a study conducted by Koteswari *et al.* (2014) in Andhra Pradesh, farmers ranked it as the third major constraint. Das *et al.* (2014) classified the high cost of feed as the fifth major constraint. Patil and Sharma (2020) also found high feed cost as one of the critical constraints in shrimp farming.

A sizeable portion of brackish water areas amenable for shrimp farming in Kerala is under the ownership of the Government or local bodies. Some of these water bodies, especially the traditional prawn filtration fields under the ownership of private persons, are leased out to entrepreneurs for shrimp farming for short periods extending to a maximum of six months. In the absence of a policy for leasing these water bodies for a long duration, farmers are unwilling to make capital investments in these fields. To circumvent the problem, a policy for leasing out the fields for extended periods may be evolved. 25.31% of the traditional farms and 10.34% of the scientific farms identified the lack of a leasing policy as a significant constraint.

Many earlier workers have reported various constraints similar to the ones observed in the present study in shrimp farming (Kurien and Sebastian 1982; Unnithan 1985; Apud 1988; Csavas 1988; BOBP 1992; Fast 1992a; Purushan 1992; Tookwinas 1999, Joseph and Sathiadhas 2006; Kurup *et al.* 2013; Sahadevan 2013, 2014; Hussan 2016; Saraswathy *et al.* 2016, Srinivas and Venkatrayalu 2016; Jory 2018, Gazi 2019; Patil and Sharma 2020). These constraints included non-availability of quality shrimp seed, non-availability of good quality feed, high cost of feed, absence of proper brackish water lease policy, poor infrastructure facilities, unorganized supply of farm inputs, environmental degradation, disease outbreaks, inadequate credit facilities, poor extension framework, poor marketing infrastructure, poor existence of cluster or group farming approach, climate change, natural disaster, high tidal amplitude, poor water quality, increase in salinity, untimely rainfall, pest and predator control, difficulty in the sourcing of inputs, inadequate human resources, lack of governmental support, land-use problems, poor soil condition, low tidal amplitude, poor cooperation among farmers, erratic power supply, differential rates of power tariff for shrimp culture etc. However, the gravity of the constraints varied from place to place depending on the intensity of management and prevailing socio-economic and climatic conditions. Some of these constraints are specific to individual farms, but others are common to the sector as a whole and beyond the farmer's capacity to address. Many of these authors also suggested strategies to overcome or minimise the impacts of the problems. According to CAA (2006), there should be an awareness of social conflicts, and the stakeholders together should discuss common issues and adopt appropriate management measures to avoid conflicts and increase the sustainability of the farming systems.

2.5.13. Awareness of the impact on the environment

The present study showed that 61.73% of the traditional farms and 77.59% of scientific farms are aware of the possible adverse effects of shrimp farming on the surrounding environment. However, generally, they do not adopt any remedial measures to rectify the potential negative impact.

Shrimp farming and the associated scale of its impact on the environment depends on a variety of interrelated factors, including species farmed, the type and mode of production, scale and intensity of cultural practices and physiographic location of the shrimp farm. Shrimp farming has long been causing severe threats to ecological systems, such as deterioration of soil and water quality, depletion of mangrove forest, a decrease of local variety of fish and shellfish, saline water intrusion in groundwater, local water pollution and change of local hydrology (Kabir and Eva 2014). Shahid and Islam (2003) reported that the recent expansion of shrimp cultivation has caused severe depletion of forest cover and led to a near-complete loss of mangrove forest and biodiversity of flora and fauna. Groundwater salinization and saline water intrusion in surrounding areas have caused severe ecological and socioeconomic damage in the coastal environment. Salinity has been dubbed a silent poison to the coastal regions due to extensive shrimp farming (Kabir and Eva 2014). The shrimp farming practices have caused loss of crop production, loss of much indigenous flora, drinking water and cooking fuel crisis (Karim 2003). Gradual increase in toxic elements contaminates lower-level soil; soil products also carry these harmful substances and create health hazards. FAO/NACA (1995) discussed the environmental assessment and management of aquaculture development in various shrimp farming nations. According to Alauddin and Hamid (1996), conflict associated with control of the large shrimp farms is one of the important causes responsible for social imbalance and deteriorating law and order in the coastal areas. De Walt *et al.* (2002) summarized the major issues connected with shrimp farming as ecological consequences of conversion and changes in natural habitats such as mangroves, associated with the construction of shrimp ponds and related infrastructure, discharge of pond effluent leading to water pollution in farming and coastal areas, seepage and discharge of saline pond water that may cause salinity changes in groundwater and adjacent agricultural lands, use of fishmeal and fish oil in shrimp diets, improper use of chemicals raising health and environmental concerns, the spread of shrimp diseases, transboundary movements concerning the spread of genetic materials, exotic species and diseases, biodiversity issues primarily arising from the collection of wild shrimp/prawn seed. Jayanti *et al.* (2018) made a detailed study on the impact of shrimp aquaculture development on important ecosystems in India. The authors found that from 1988 to 2013, the area under aquaculture has grown by 879%, which brought tremendous changes in the coastal land use pattern. Mangrove and agricultural lands have been used for 5.04% and 28.10% of the aquaculture growth. Mangrove areas have undergone severe changes due to gain and loss at different places. Environmental factors influenced the changes in mangroves, and the overall extent of mangroves has increased by 13.44 %.

Shrimp aquaculture has generated considerable debate on its environmental and social costs and benefits in recent years. Among the substantial ecological and social problems, the most important ones are water pollution, salinization of drinking water wells and paddy fields, destruction of fry of wild fish and crustacean species, various social conflicts related to land conversion and critically, the transformation of mangroves to shrimp farms, reduced agricultural production due to the reduction of farmland and soil fertility, a decrease of cattle production as a result of a decline in grazing land, human health hazards and diseases and reduction in mangrove forest (UNEP 1999). Rice farming has also suffered from prolonged waterlogging from extended shrimp seasons (Bhattacharya *et al.* 1999; FFP 1999). Destructive methods of collecting postlarvae from the wild have also had significant impacts on coastal biodiversity (FFP 1999; World Bank *et al.* 2002).

2.5.14. Awareness of climate change

Expected changes in climate, extreme weather conditions and climatic events, sea-level rise, ocean acidification and rise in temperature are expected to significantly impact coastal ecosystems and shrimp aquaculture (Jayasinghe *et al.* 2019). Adaptations for likely impacts of climate change are reachable through better management practices in site selection, pond construction and preparation, selection of postlarvae for stocking, pond management, bottom sediment management and disease management together with reducing non-climate stressors such as pollution, conservation of sensitive ecosystems and adoption of dynamic management policies. For this, a shrimp farmer must be well aware of climate change and its possible impacts locally, regionally, and globally.

However, in the present study, it was observed that shrimp farmers, in general, have only preliminary awareness of climate change and its impact on shrimp farming, indicating the urgent need to create awareness among them on this crucial subject and to urge them to take adaptation and/ or mitigation measures to ensure the sustainability of the sector.

According to Muralidhar *et al.* (2012), shrimp farming is threatened by changes in temperature, precipitation, drought and extreme climatic events (cyclones, storms, floods) that affect infrastructure and livelihoods, which can impact aquaculture. Ecological changes, inundation of low-lying lands and saline intrusions into freshwater regions are likely to cause substantial dislocation of communities and disruption of farming systems. In the face of potential complexities of climate change interactions and their possible scale of impact, the primary challenge for the shrimp farming sector will be to deliver food supply, strengthen economic output and maintain and enhance food security. It is expected that small-scale and traditional shrimp farmers will disproportionately feel the climate change impacts. The small-scale farmers are typically unorganized, and most farmers do not have access to technological innovations and scientific applications. There is a need to forecast the likely effects of climate change on the shrimp farming sector and develop strategies to assist farmers and rural communities adapt to the upcoming changes (Muralidhar *et al.* 2012).

Improving and applying knowledge on the constraints and opportunities for enhancing adaptive capacity is necessary to minimise vulnerabilities associated with climate change. The starting point for this is a common understanding of the concepts of adaptation, vulnerability, resilience, and gaps in current adaptation approaches. The most crucial adaptation measures are species shift, water exchange, feeding practice, lime application, adjusted harvest and delayed stocking for the irregular season, high temperature and uneven rainfall distribution. An increase in dyke height, shifting machinery, netting around the farm, moving to other occupations are adaptive measures for cyclones/storm surges and flood and freshwater mixing for drought. To increase the adaptive capacity of the farmers, the requirement of financial support, insurance and relief fund may be accorded the top priority during extreme climatic events.

The farmer can adapt to small weather patterns and short-term gradual climate change, but they may not be prepared for rapid changes or long-term continuous climate change. The farmer needs to be assisted by scientific research and technology development to find solutions that will allow them to adapt to the predicted future climate change. A solid focus on building general adaptive capacity can help the shrimp aquaculture communities to cope with new challenges. The farmers should commit to implementing the adaptive measures at the farm level (better management practices), and government departments and research organizations have to help them increase their adaptive capacity. Both central and state governments should make strong policies on climate change to improve the adaptation capacity of all the stakeholders involved in the shrimp farming sector. Integration of climate change considerations into the policies in the aquafarming sector can facilitate adaptation and ensure that they contribute to adaptive capacity from national to local levels.

Vulnerability is a function of exposure, the character, magnitude and rate of climate variation to which a system is exposed and its sensitivity to exposure (Muralidhar *et al*. 2012). The latter is the extent the system changes under exposure and its adaptive capacity. Vulnerability depends critically on context, and the factors that make a system susceptible to a hazard will depend on the nature of the system and the type of hazard in question. Vulnerability is also described as the extent to which a system is vulnerable to sustaining damage from climate change (Schneider *et al.* 2001). It can be considered a dynamic state or condition influenced by biophysical and socioeconomic conditions (Dow 1992; Bohle *et al.* 1994; Kasperson *et al.* 2001). Hossain and Hasan (2017) discussed the significant vulnerabilities, causes and adaptive measures in the shrimp farming sector in the context of climate change.

Jena and George (2020), Kurup *et al.* (2020) and Verdegem (2020) discussed the impact of climate change on aquaculture. According to Jena and George (2020), initial scientific observations indicate that a slight change in the physiology of fishes may be helpful for better biomass generation concerning farmed fishes. But the extreme events such as drought, flood, cyclones and others largely affect the aquafarming sector. Crop losses due to drought, flood and cyclones, climate change associated stress, and the outbreak of diseases in farmed resources have severely impacted aqua-farming from a climate perspective (Bell *et al.* 2013). Varying environmental conditions can induce foraging, growth, fecundity, alter metamorphosis, and affect endocrine homeostasis. Changes may be induced at the population and community level due to effects on performance, patterns of resource use, and survival. The addition of new areas that are inundated in coastal regions may be seen as an opportunity for more brackish water and coastal farming, but the damage due to sea-level rise is beyond imagination (Jena and George 2020). Kurup *et al.* (2020) stressed the need for developing climate resilient aquaculture. Very recently, many authors reported various aspects of the impact of climate change on the farming of fishes and shellfishes (Aswathi *et al.* 2020; Nag *et al.* 2020; Sahadevan and Sureshkumar 2020b; Saraswathi *et al.* 2020; Sarkar *et al*. 2020; Sundar *et al.* 2020)

2.5.15. Legal compliance

Apart from the general acts like the Water (Prevention and Control of Pollution) Act 1974, the Environment (Protection) Act 1986, the Wildlife (Protection) Act 1972, a shrimp farmer in Kerala is expected to comply principally with the provisions of three Acts specifically meant to regulate aquaculture and the Rules framed under them. They are Coastal Aquaculture Authority (CAA) Act 2005, Kerala Inland Fisheries and Aquaculture Act 2010 and Kerala Fish Seed Act 2014. The first is a central act, whereas the latter two are state acts. Though the Kerala Fish Seed Act 2014 came into being on 13th February 2014, it is yet to be enforced and gained popularity among the farmers. In this context, the present study was limited to the compliance of the first two acts. The study found that 64.81% of the traditional farms and 93.10% of scientific farms had registered under the CAA Act. Further, 80.25% of the traditional farms but no scientific farms were found to have registration and license under Kerala Inland Fisheries and Aquaculture Act.

The Coastal Aquaculture Authority Act 2005 (24 of 2005), enacted by the Parliament of India on 23 June 2005, provides for the establishment of the Coastal Aquaculture Authority for regulating the activities connected with aquafarming in coastal areas and matters connected therewith or incidental thereto. The Act mandates the Central Government to take all such measures as it feels necessary or expedient to regulate coastal aquaculture by prescribing guidelines to ensure that coastal aquaculture does not cause detriment to the coastal environment and the concept of responsible coastal aquaculture contained in the guidelines and to regulate coastal aquaculture activities to protect the livelihood of various sections of people living in the coastal areas.

One of the major requirements under the CAA is the registration of shrimp farms on the recommendations of the State and District Level Committees constituted for this purpose. All persons carrying on coastal aquaculture must register their farm with the Coastal Aquaculture Authority. Registration is made for five years, which can be renewed further.

Kerala Inland Fisheries and Aquaculture Act 2010 (Act 15 of 2010), which came into force on 8th September 2010, is a State Act and is to codify and amend the laws relating to the inland fishery sector and to provide for the sustainable development, management, conservation, propagation, protection, exploitation and utilisation of the inland fishery sector in the State and for promoting social fisheries and for regulating and controlling responsible aquaculture activities and for ensuring the protection of livelihood and traditional rights of fishers and for ensuring the availability of nutritious fish and food security to the people and for matters connected therewith or incidental thereto. The Indian Fisheries Act 1897 (Central Act 4 of 1897), existing in the Malabar District referred to in sub-section (2) of section 5 of the States Reorganisation Act, 1956 (Central Act 37 of 1956), ceased to operate to the said area and the Travancore-Cochin Fisheries Act, 1950 (Act 34 of 1950) was repealed consequent to the passing of the Kerala Inland Fisheries and Aquaculture Act 2010. According to this Act, no person shall engage in aquaculture filtration except with a certificate of registration and licence obtained under the provisions of this Act. It is the continuation of the licensing under the earlier Travancore-Cochin Fisheries Act 1950, in the case of prawn filtration fields, and hence most of the traditional farms have it. However, scientific farms generally think that since they have registered under the Central Act *viz*., CAA Act, they need not register under the state Act, pointing to the need to create large-scale awareness among the farmers. Kerala Fish Seed Act 2014 (Act 4 of 2015) intends to regulate the quality in production, marketing and stocking of fish seed and matter connected therewith or incidental thereto. However, it is yet to be enforced strictly and farms, in general, are yet to come under it.

2.6. Conclusion

The state of Kerala has a long tradition in shrimp farming and possesses plentiful resources and congenial environmental and climatic conditions for the development of shrimp farming. However, the sector has failed to emerge as an important livelihood and socio-economic development avenue. In this context, it is necessary to investigate the status of shrimp aquaculture in the state, which would help understand the reasons for the dismal performance of the sector. The present study was meant for this purpose and examined the current status of shrimp aquaculture in the state with particular reference to the area available, the area under cultivation, site suitability, species farmed, level of technology, management practices adopted, harvesting methods, production and productivity, marketing of the produce, major constraints faced by the farmers etc. The information collected in the present investigation is expected to serve as a solid base for understanding the weakness of the sector and for evolving a sound management plan for its sustainable development, which is discussed in detail in Chapter 6.

Chapter 3

FISH AND SHELLFISH DIVERSITY OF TRADITIONAL PRAWN FILTRATION FIELDS

3.1. Introduction

There is a unique system of farming shrimp with paddy in the coastal stretches of Kerala. In Central Kerala, the system is popularly known as pokkali prawn filtration, and in North Kerala, it is known as kaipad prawn filtration. Both the systems are essentially the same except in the variety of rice sawn. Paddy cultivation in these fields is restricted to a single crop from July to September when the surrounding backwaters are low in salinity. After harvesting the paddy crop, in October, the bunds provided with sluice gates are strengthened, and the water brought in by the high tide is allowed to enter the fields through the sluice gates. Fields are stocked with shrimps and fishes brought in by the incoming water. They are allowed to grow there using the natural feed available in the ponds. Periodic harvesting is carried out during full moon and new moon periods at low tides using bag nets provided at the sluice gates. As these ponds are tide fed, there is no control over the salinity and other physicochemical parameters of the water, species selectivity, number and size of seed stocked, entry of weed and predatory fishes, which result in low and unpredictable harvest.

Pokkali prawn filtration has traditionally been practised in fields lying beside the Vembanad backwaters, in Ernakulam, Thrissur, Alapuzha and Kottayam districts. Vembanad lake (Kerala, India) is a large expanse of water, which has outlets into the sea through many small openings. Several rivers open into the lake. In the monsoon period, when floodwater of rivers flows out into the sea through the lake, the salinity of water goes down to zero ppt (Kurien and Sebastian 1982). In the summer months, the salinity increases to 30-35 ppt. The region suitable for prawn culture is on either side of the backwaters, where the salinity is comparatively more than the other regions far removed from it. The fields nearer the estuarine mouth experience maximum tidal influence and are the most productive for prawns, followed by fields adjacent to these and the fields that are farther upstream, the least (Kurien *et al.* 2002). The far-inland fields are connected to backwater by canals through which tidal waters flow.

The southwest monsoon is very heavy in Kerala from June to the middle of September, and during this time, the salt content of the soil in the fields is washed away, making the fields fit for paddy cultivation. The rice variety that is cultivated is called pokkali. The fields are generally flooded, and for cultivation, the earth is cut and made into cones, the top regions raised above the water level. Paddy seeds are sown on the top after flattening them. There is only one crop of paddy, which is harvested in September. The Northeast monsoon, which is lighter in the state, is already in progress from September to the middle of November. Water is retained in the fields during this time also. After the monsoon, water becomes more and more saline due to the tidal flow. Tidal water is allowed to flow freely in and out of the fields after the harvest of the paddy crop to make them fit for prawn culture.

When the northeast monsoon stops, arrangements for letting in of prawn juveniles into the fields begin. At the outset, bunds are raised around the fields and sluice gates fixed for letting in and out the water during the tides. The sluice opens into the field on one side and the backwater or canal on the other. At the centre of the sluice gate, grooves are provided vertically on both sides, and many planks are inserted into them to block the water. As required, a few planks are taken out to let water in and out.

In actual working, sluice gates are kept open during the high tide to let in the prawn juveniles and other fishes along with the water current. Once let in, the water is kept for a day, and during low tide, the sluices are opened to let out the water. A bamboo mat /nylon net is placed inside the sluice gate to prevent the escape of prawns. Water is again let into and out of the field at subsequent high and low tides to increase the number of recruits. This process is repeated several times. By the middle of April, the operation comes to a close, and water in the field is filtered through a net tied to the outer edge of the sluice to collect the prawns and fishes. When the water is entirely emptied after the final filtration, prawns scattered in small pools are collected by hand nets. After the harvest, the earth in the fields is cut and made into cones. Paddy cultivation is taken up when the salt is washed off during the next monsoon (Kurien *et al.* 2002).

The soil in these fields is clay and sand mixed in different proportions (Kurien *et al.* 2002). The clay content is more in the fields north of the estuarine mouth, and sand is more in the southern fields. Various species of polychaetes and molluscs are found in the substratum. Water contains planktonic organisms like algae, fry of fishes, copepods, and larvae of crustaceans and molluscs (Kurien and Sebastian 1982).

Kaipad prawn filtration is practised in Kannur, Kasaragod, and to some extent in the Kozhikkode district of Kerala. Kaipad ecosystems consist of marshes, swamps, ponds and paddy fields. These swampy and water-logged areas flood during the monsoon periods when the salinity comes down to zero ppt. Tidal currents enter the kaipad fields during the high tide and flow out during the low tide. Saline water from the nearby backwater enters the fields from October onwards. In the summer months, the salinity reaches 30-35 ppt. Kaipad farms are made by raising the bunds around the fields, and these are protected by the mangrove vegetation growing along their outer boundaries.

Rice cultivation starts with drying the fields in April and ends in October. Before starting rice cultivation, the saline water is drained out completely, and the fields are left to dry for about one month. Mounds are prepared for sowing the paddy seeds. The mounds help leach away the salt content of the soil in the heavy rains during early June. The sluice gates are opened as soon as the river is filled with freshwater. By the beginning of June, the fresh river water washes away the salt content of the soil. The seeds are soaked in freshwater in jute bags for one day, and the wet seeds are kept for three days for germination. Local, salinity tolerant rice varieties like *kuthir nellu, orkazhama, kuttusan, chovverian* and *orthadian* are used for farming (Cheruvat 2005; Chandramohanan and Mohanan 2012).

After the onset of the southwest monsoon, 4- day old germinated seedlings are sown on the flattened tops of the mounds. After 45 days of seeding, the mounds are demolished, and the seedlings in clefts are distributed around the flattened mounds using spades. There are no other farming operations till the harvest except manual removal of weeds. Harvesting of paddy is done by the end of October. During the rice harvesting, only the panicles are cut. The remaining stalks are left to decay in the water, which feeds the prawns grown subsequently in these fields.

Prawn filtration is carried out in kaipad fields during the high saline phase from November to April. For this purpose, the bunds provided with sluice gates are strengthened, and the water brought in by the high tide is allowed to enter the fields through the sluice gates. The sluices are kept open to allow water from the lake along with fish and prawns to enter the farm. Fish is captured during low tide when water is released through the sluice. The daily tidal inflow and large quantities of organic matter (decomposed aquatic weed mass and paddy stubbles) make the kaipad fields fertile. Fishes, prawns, crabs, etc. in the backwaters that enter the fields grow there, feeding the harvested crop's leftovers. By the middle of April, the operation comes to a close. After the final filtration, the water is completely emptied, and the prawns scattered in small pools are collected using hand nets. After the prawns are collected, the earth in the fields is cut and made into mounds for paddy cultivation. The paddy draws nutrients from the excrement and other remnants of fishes and prawns.

The soil in the kaipad fields is clay and sand mixed in different proportions. Various species of polychaetes and molluscs are found in the substratum. Water contains planktonic organisms like algae, copepods, fry of fishes, crustaceans and molluscs (Cheruvat 2005; Chandramohanan and Mohanan 2012).

Systematic biological inventories lay the foundation for understanding ecological and survival requirements for individual species within communities. Though many studies exist on the farming practices of pokkali and kaipad fields and the species composition of the catch, there is a general lack of scientific information regarding the occurrence of fish and shellfish species and their status in these fields. Prevailing environmental factors greatly influence the growth, reproduction, and recruitment of fishes and shellfishes (Sahadevan 2016c). Further, the availability and abundance of these animals are also expected to be affected by climate change. Hence information on species richness and diversity is to be revalidated frequently. The present study was carried out with this point in mind. It was meant to investigate the diversity of fishes, crustaceans and molluscs of pokkali and kaipad fields separately and compare the diversity of the two ecosystems. The study also examined the temporal variation in the fish, crustaceans and molluscan species in these fields. Results of the present study would serve as baseline information on fishes, crustaceans and molluscs that help identify conservation and management issues in the future.

3.2. Review of literature

Many studies exist on various aspects of traditional shrimp farming in Kerala. These include Panikkar (1937, 1952), Hora (1943), Menon (1954, 2000), Gopinath (1956), Panikkar and Menon (1956), Kestevan and Job (1957), George (1962, 1974, 1975), Raman and Menon (1963), George *et al.* (1968), Pillai and George (1974), Alagarasami (1978), Lakshmi (1978), Muthu (1978), Nair *et al*. (1978, 1998, 2002), Rao (1978), Sebastian *et al.* (1978), Silas and Rao (1978), Kartha and Nair (1979), Sundararajan *et al.* (1979), Gapalan *et al.* (1980, 1982), Gopalan and Purushan (1981), Rajendran *et al.* (1981), George and Suseelan (1982), Gopinathan *et al.* (1982), Kurian and Sebastian (1982), Varghese *et al.* (1982), Mammen (1984), Purushan and Rajendran (1984), Unnithan (1985), Chakraborti *et al.* (1986), Purushan (1986, 1987a, 1987b, 1988, 1989, 1996a, 1986b, 1986c, 2002, 2003a, 2003b), Gopalan (1987), Jayachandran (1987), Jhingran and Ghosh (1987), Jose *et al*. (1987), Mathew and George (1987), Gopalakrishnan *et al.* (1988), Mathew (1988), Surendean (1988), Sathiadhas *et al*. (1989, 2012), Ghosh and Chakrabarti (1990), Aravindakshan *et al*. (1992), Kurup *et al.* (1992, 2013), Nasser and Noble (1992), Ninawe and Raj (1993), Balasubramanian *et al.* (1995), Arun (1996), Krishnani *et al.* (1997), Pillai *et al.* (1997, 2002), Pillai (2003), Raju (1997), Pillai and Krishnan (1998), Thampy *et al.* (1998), Chandramohan *et al.* (1999), Pillai (1999), Nayak *et al.* (2000), Srinath *et al*. (2000), Kurien *et al.* (2002), Pravin (2003), Cheruvat (2005), Joseph and Sathiadhas (2006), Nambiar and Raveendran (2009), Jayan and Sathyanathan (2010), Umesh *et al.* (2010), Chandramohanan and Mohanan (2012), Begum *et al.* (2013), Joy (2013), Antony *et al.* (2014), Deepa (2014), Sudhan *et al.* (2016), Mumthaz and George (2017). Some of these studies covered the species composition of the harvest from the traditional prawn fields. There are also many studies on the fish and shellfish diversity of the lakes that serve as sources of water and fish and shellfish seeds to these fields. However, only very few studies exist on the diversity of fish and shellfish populations of Kerala's traditional prawn filtration fields.

Shetty (1963) conducted a preliminary fishery survey of the Vembanad backwaters, and Shetty (1965) investigated the fish and fisheries of the Vembanad backwaters. Kurup (1982) carried out a detailed study on the systematics, distribution and ecology of fish species of the Vembanad lake from October 1978 to September 1980. He recorded 150 species of fishes belonging to 100 genera and 56 families from the Vembanad lake. Of this, 43 species were found to be resident species and were available throughout the year. Seventy-four species were classified as migrant species, while 17 were vagrant species. Kurup and Samuel (1983) studied systematics and distribution of fishes of the family Leiognathidae of the Vembanad lake. Kurup and Samuel (1985, 1987) and Kurup *et al.* (1989, 1993a, 1993b) studied the fish and fisheries of the lake. Kurup *et al.* (1993b) have recorded 115 species of fishes belonging to 84 genera, six species of penaeid prawns, four species of palaemonid prawns, and three species of crabs in Vembanad lake. Unnithan *et al.* (2001) investigated the ecology, fisheries and organic pollution of Vembanad lake.

Sreedharan (2004) studied the fish diversity of the downstream part of Valapatnam River, which serves as a source of water to many kaipad fields. Cheruvat (2005) enlisted 84 species of finfishes, 27 crustaceans and ten molluscs from the kaipad prawn filtration fields. However, his attempt was limited to just enlisting the various species (species richness). The author did not study other aspects of diversity. Analysis of the data on species availability was also not attempted by him. Narayanan *et al.* (2005) conducted studies on the ichthyofauna of Aymanam panchayath in the Vembanad wetland. ATREE (2009) has reported 51 species of finfish representing 26 families and 35 genera and 11 species of shellfish belonging to six families and seven genera from the southern part of Vembanad. It included two critically endangered, four endangered and five vulnerable species of fish. ZSI (2009) reported the faunal diversity of Vembanad lake in detail.

Harikrishnan *et al.* (2011) have studied the status of exploited fishery resources of Azhikode estuary, a part of the Vembanad ecosystem. The authors have found 30 species of finfishes belonging to 18 families, six species of penaeid shrimps, two species of palaemonid prawns, two species of crabs and four species of bivalves to contribute to the exploited fishery of the region. Jayachandran *et al.*

(2012) investigated the influences of environmental factors on fish assemblage in the Kodungallur-Azhikode Estuary. Krishnakumar and Ranjan (2012) have reported the results of Vembanad fish count (2008-2011), in which the authors have recorded 67 species of fishes belonging to 46 genera and 34 families. The list included five species of fishes exotic to the lake. Nandan *et al.* (2012) investigated the status of fisheries and seasonal variation in fish diversity in the Kodungallur- Azhikode Estuary. The Authors reported 60 species of finfishes (belonging to 34 finfish families), six species of penaeid shrimps, two species of palaemonid prawns, two species of crabs (four crustacean families), six species of bivalves and two species of edible oysters (three molluscan families). In a study, Asha *et al.* (2014) have reported 80 species of finfishes, five species of penaeid shrimps, three species of palaemonid prawns and two species of crabs in the lake, in which three species were classified as vulnerable. Deepa (2014) reported 50 species of fishes belonging to 29 families and 11 orders in the pokkali fields. Among these, nine species of fishes were reported during the paddy cultivation period. Mogalekar *et al.* (2015a) studied the biodiversity of the decapod crustacean in the Vembanad lake in the Panangad-Kumbalam region. Mogalekar *et al.* (2015b) investigated the fish diversity and their seasonal variation and abundance in Vembanad lake at Panangad-Kumbalam backwater in Kochi. The authors found 39 species of finfishes belonging to 27 families, 11 orders and 31 genera. Fish abundance was high during the pre-monsoon season, whereas low during the post-monsoon season. They quantified the fish species diversity and species abundance. Mogalekar *et al.* (2015c) studied the temporal variation in the hydrobiology of Vembanad Lake at Panangad-Kumbalam mangrove patches of Kochi, Kerala.

Sahadevan (2016c) reported 57 species of finfishes, 19 species of crustaceans and 11 species of molluscs from the Puduvypeen area, which lie beside the Vembanad lake. Sudhan *et al.* (2016) studied the faunal diversity of fishes, crustaceans and molluscs of pokkali fields. The authors reported six species of shrimps, three species of prawns, three species of crabs, and 23 species of fishes from these fields. However, the study was limited to the prawn filtration season only, and it did not cover the freshwater phase of the ecosystem. Ansar (2017) investigated finfish and shellfish diversity and seasonal variation in their distribution and abundance in Vembanad lake in the Kumarakom region of the Kottayam district. Athira and Jaya (2020) investigated the fish diversity of the downstream part of the Anjarakandi river, which acts as a water source to many traditional shrimp farms in the area. Krishnan *et al.* (2020) surveyed the species diversity of selected sites in Vembanad lake.

3.3. Materials and methods

The present research work is a part of a more extensive work that continued from September 2015 to May 2018, which covered three filtration seasons and two rice farming seasons. However, the data from January 2017 to December 2017 alone was used for the study on the diversity of fishes, crustaceans, and molluscs. It covered both the freshwater phase and the brackish water phase of the fields.

3.3.1. Study area

The study was conducted in the pokkali and kaipad rice- prawn filtration fields of Kerala (Fig. 3.1). The former is distributed in central Kerala in Thrissur, Ernakulam, Allapuzha and the low-lying brackish water areas of the Kottayam district. Kaipad fields are located mainly in the coastal belt of Kannur district and to a limited extent to the coastal belt of Kasargod and Kozhikkode districts.

3.3.2. Methodology

Data was collected from pokkali fields and kaipad fields separately. Information on the fishes and shellfishes was collected from 162 prawn filtration fields selected at random by a random sampling procedure discussed in Chapter 2. Data were collected from the filtration fields during all months of the study. The field visits were scheduled to cover all water bodies selected during the last week of every month. During the farming period, as far as possible, an attempt was made to synchronise the visit with the day of monthly harvest (8- 10 days a month) and during the total harvest in April- May to assess the species composition catch. During the non-prawn farming periods, field visits were made during the last weeks of the months, and fishes were caught using a cast net. Fishes and shellfishes were mainly identified at the site of collection, and the unidentified samples were preserved in 8% formalin and brought to the laboratory for species-level identification following Day (1878), FAO (1984), Fisher and Hureau (1985), Talwar and Jhingaran (1991), Jayaram (1999), Munro (2000), Fishbase (https://www.fishbase.de/.) and Sealifebase (https://www.sealifebase.ca. Scientific names adopted are as given in the World Register of Marine Species *viz.*, WoRMS (http://www.marinespecies .org/about.php). The red list status of various fishes was ascertained based on IUCN (2018).

Figure 3.1. Area selected for the study on fish and shellfish diversity.

3.3.3. Biodiversity

Biological diversity can be quantified in various ways. Richness and evenness are the two main factors considered when measuring diversity. Richness measures the number of different types of organisms present in a given area. Evenness compares the similarity of the size of the population of each species present. To calculate the various indices, the number of individuals of different species present in 100 ha areas each of the pokkali and kaipad fields was sampled each month. The data was analysed month-wise as well as annually. The month-wise data were pooled together to get the overall picture for pokkali and kaipad fields separately for the year. A comparison between different biodiversity indices of pokkali and kaipad fields was also conducted.

3.3.3.1 Species richness

Species richness (S) is the simplest measure of biodiversity and counts the number of species in a particular area. This measure strongly depends on sampling size and effort. Margalef's diversity index (Margalef 1958) tries to address this problem. The data was collected for pokkali and kaipad fields separately for each month.

3.3.3.2. Margalef's diversity index

Margalef's diversity index was computed using the formula,

Margalef's diversity index (D_{Mg}) $= \frac{S-1}{\text{In}N}$

Where N = the total number of individuals and S = the number of species recorded.

3.3.3.3. Shannon-Wiener diversity index

The most commonly used diversity index in the ecological literature is the Shannon-Wiener diversity index (Shannon and Weaver 1949; Pielou 1975). It considers that individuals are randomly sampled from an infinitely large community and that all species are represented in the sample. The Shannon-Wiener index was calculated using the equation:

$H' = \sum Pi \, \text{In} Pi$

Where P_i is the proportion of individuals found in the i^{th} species.

3.3.3.4. Simpson's index

Simpson's Index (Simpson 1949) measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species).

Simpson's index was calculated as given below.

Simpson’s Index (*D*) = $\frac{\sum n(n-1)}{N(N-1)}$

Where n = the total number of organisms of a particular species and N = the total number of organisms of all species.

With Simpson's Index, 0 represents infinite diversity, and 1, no diversity. That is, the bigger the value of D, the lower the diversity. The value may seem neither intuitive nor logical, so to get over this problem, D was subtracted from 1 to give Simpson's Index of Diversity ($1 - D$) in the present study.

The value of this index varies between 0 and 1, but now, the greater the value, the greater the sample diversity, which is more meaningful. In this case, the index represents the probability that two individuals randomly selected from a sample will belong to different species.

Another way of overcoming the problem of the counter-intuitive nature of Simpson's Index is to adopt Simpson's Reciprocal Index, which was calculated as:

Simpson's Reciprocal Index = $(1 / D)$

The value of this index starts with one as the lowest possible figure. This figure would represent a community having only one species. The higher the value, the greater is the diversity. The maximum value of the index is the number of species in the sample.

3.3.3.5. Sorensen's coefficient

Community similarity (what the communities have in common in terms of species) between pokkali and kaipad fields was assessed by employing Sorensen's Coefficient (Sorensen 1948), calculated by the following equation.

Sørensen's Coefficient (SC) = $\frac{2C}{S1 + S2}$

Where S_1 is the total number of species found in pokkali fields, S_2 is the total number of species found in kaipad fields, and C is the number of species the pokkali and kaipad fields has in common.

The index of dissimilarity was calculated as 1- SC.

Sorensen's coefficient gives a value between 0 and 1. The closer the value is to 1, the more the communities have in common. Complete community overlap is equal to 1; complete community dissimilarity is equal to zero.

3.3.3.6. Lorenz curve

A Lorenz curve is the perfect representation for evenness ranking, independent of the number of species concerned (Taillie 1979 and Gosselin 2001). It was obtained by plotting the cumulative proportion of individuals (%) on the x-axis against corresponding cumulative proportions of species (%) on the y-axis.

3.3.3.7. Rank abundance curve

Nearly all diversity and evenness indices are based on the relative abundance of species, thus on estimates of Pi in which;

$$P_i = \frac{Ni}{N}$$

Where N_i is the abundance of the i^{th} species in the sample and

$$N = \sum_{i=1}^{s} Ni$$

Where *s* is the total number of species in the sample.

When the abundance of different species was recorded in the sample, it was found that some species were rare, whereas others were abundant. This feature of ecological communities was found independent of the taxonomic group or the area investigated. An essential goal of ecology is to describe these consistent patterns in different communities and explain them in interactions with the biotic and abiotic environment. The rank abundance curve is one of the best known and most informative methods to study the species-abundance distribution. Species were ranked in sequence from most to least abundant along the horizontal (X) axis. Their abundances were typically displayed in a log format on the vertical (Y) axis so that species whose abundances span several orders of magnitude was accommodated on the same graph.

3.4. Results

Traditional prawn filtration fields in Kerala have an impressive richness of fish and shellfish species. Fifty-seven species of fishes belonging to 28 families, 15 species of crustaceans belonging to six families and 11 species of molluscs belonging to eight families were found to occur in the pokkali prawn filtration fields. Kaipad lands had more fish and shellfish species. Kaipad fields were found to have 74 species of fishes belonging to 34 families, 16 species of crustaceans belonging to seven families and nine species of molluscs belonging to six families. The details of species of fishes, crustaceans and molluscs encountered in these two ecosystems are provided in Table 3.1.

Table 3.1. Fishes, crustaceans and molluscs found in traditional prawn filtration fields.

Sl. No.	Scientific name	Common name in English	Family	Occurrence		IUCN Red List Status
				Pokkali fields	Kaipad fields	
A.	**Fishes**					
1.	*Oryzias setnai* (Kulkarni)	Malabar ricefish	Adrianichthyidae	X	✓	LC
2.	*Ambassis ambassis* (Lacepede)	Commerson's glassy perchlet	Ambassidae	✓	✓	LC
3.	*Ambassis gymnocephalus* (Lacepede)	Bald glassy perchlet	Ambassidae	✓	✓	LC
4.	*Parambassis dayi* (Bleeker)	Day's glassy perchlet	Ambassidae	✓	✓	LC
5.	*Parambassis thomassi* (Day)	Western Ghat glassy perchlet	Ambassidae	✓	✓	LC
6.	*Anguilla bengalensis* (Gray)	Indian mottled eel	Anguillidae	X	✓	NT
7.	*Anguilla bicolor* McClelland	Indonesian shortfin eel	Anguillidae	✓	X	NT
8.	*Aplocheilus blockii* Arnold	Green panchax	Aplocheilidae	✓	✓	LC
9.	*Aplocheilus lineatus* (Valenciennes)	Striped panchax	Aplocheilidae	✓	✓	LC
10.	*Arius maculates* (Thunberg)	Spotted catfish	Ariidae	✓	✓	NE
11.	*Arius subrostratus* (Valenciennes)	Shovelnose sea catfish	Ariidae	✓	✓	NE
12.	*Nemapteryx caelata* (Valenciennes)	Engraved catfish	Ariidae	✓	✓	NE
13.	*Arius arius* (Hamilton)	Threadfin sea catfish	Ariidae	X	✓	LC
14.	*Arius jella* Day	Blackfin sea catfish	Ariidae	✓	✓	NE
15.	*Horabagrus brachysoma* (Günther)	Günther's catfish	Bagridae	✓	✓	VU
16.	*Mystus gulio* (Hamilton)	Long whiskers catfish	Bagridae	✓	✓	LC
17.	*Mystus vittatus* (Bloch)	Striped dwarf catfish	Bagridae	X	✓	LC
18.	*Strongylura strongylurus* (van Hasselt)	Spottail needlefish	Belonidae	✓	✓	NE
19.	*Xenentodon cancila* (Hamilton)	Freshwater gar fish	Belonidae	✓	✓	LC
20.	*Carangoides malabaricus* (Bloch & Schneider)	Malabar trevally	Carangidae	✓	✓	LC
21.	*Caranx sexfasciatus* Quoy & Gaimard	Bigeye trevally	Carangidae	✓	✓	LC
22.	*Megalaspis cordyla* (Linnaeus)	Torpedo scad	Carangidae	✓	X	LC
23.	*Chanos chanos* (Forsskal)	Milk fish	Chanidae	✓	✓	LC

24.	*Etroplus maculatus* (Bloch)	Orange chromide	Cichlidae	✓	✓	LC
25.	*Etroplus suratensis* (Bloch)	Pearlspot	Cichlidae	✓	✓	LC
26.	*Oreochromis mossambicus* (Peters)	Mossambique tilapia	Cichlidae	✓	✓	NT
27.	*Anodontosoma chacunda* (Hamilton)	Chacunda gizzard shad	Clupeidae	✓	✓	LC
28.	*Dayella malabarica* (Day)	Day's round herring	Clupeidae	X	✓	LC
29.	*Ehirava fluviatilis* Deraniyagala	Malabar sprat	Clupeidae	X	✓	DD
30.	*Escualosa thoracata* (Valenciennes)	White sardine	Clupeidae	✓	✓	LC
31.	*Nematalosa nasus* (Bloch)	Bloch's gizzard shad	Clupeidae	✓	✓	LC
32.	*Cynoglossus macrostomus* Norman	Malabar tonguesole	Cynoglossidae	X	✓	NE
33.	*Amblypharyngodon mola* (Hamilton)	Mola carplet	Cyprinidae	✓	X	LC
34.	*Puntius amphibius* (Valenciennes)	Scarlet-banded barb	Cyprinidae	✓	X	DD
35.	*Dawkinsia filamentosa* (Valenciennes)	Blackspot barb	Cyprinidae	✓	✓	LC
36.	*Pethia ticto* (Hamilton)	Ticto barb	Cyprinidae	✓	✓	NE
37.	*Systomus sarana* (Hamilton)	Olive barb	Cyprinidae	✓	✓	LC
38.	*Puntius vittatus* Day	Greenstripe barb	Cyprinidae	✓	✓	LC
39.	*Rasbora daniconius* (Hamilton)	Slender rasbora	Cyprinidae	✓	✓	LC
40.	*Eleotris fusca* (Forster)	Dusky sleeper	Eleotridae	X	✓	LC
41.	*Elops machnata* (Forsskal)	Ten pounder	Elopidae	✓	✓	LC
42.	*Stolephorus indicus* (van Hasselt)	Indian anchovy	Engraulidae	✓	✓	LC
43.	*Thryssa malabarica* (Bloch)	Malabar thryssa	Engraulidae	✓	✓	DD
44.	*Gerres filamentosus* Cuvier	Whipfin silver- biddy	Gerridae	✓	✓	LC
45.	*Glossogobius giuris* (Hamilton- Buchanan)	Tank goby	Gobiidae	✓	✓	LC
46.	*Hyporhamphus xanthopterus* (Valenciennes)	Red- tipped halfbeak	Hemirhamphidae	✓	✓	VU
47.	*Hyporhamphus limbatus* (Valenciennes)	Congaturi halfbeak	Hemirhamphidae	X	✓	LC
48.	*Lates calcarifer* (Bloch)	Barramundi	Latidae	✓	✓	NE
49.	*Gazza minuta* (Bloch)	Toothpony	Leignognathidae	X	✓	LC
50.	*Leiognathus dussumieri* (Valenciennes)	Dussumier's pony fish	Leignognathidae	✓	✓	NE
51.	*Leiognathus equulus* (Forsskal)	Common pony fish	Leignognathidae	✓	✓	LC
52.	*Photopectoralis bindus* (Valenciennes)	Orangefin ponyfish	Leignognathidae	X	✓	NE
53.	*Lutjanus argentimaculatus* (Forsskal)	Mangrove red snapper	Lutjanidae	✓	✓	LC
54.	*Lutjanus johnii* (Bloch)	John's snapper	Lutjanidae	✓	✓	LC

55.	*Lutjanus russellii* (Bleeker)	Russell's snapper	Lutjanidae	✓	✓	LC
56.	*Lutjanus fulviflamma* (Forsskal)	Dory snapper	Lutjanidae	X	✓	LC
57.	*Megalops cyprinoides* (Broussonet)	Indo- Pacific Tarpon	Megalopidae	✓	✓	DD
58.	*Mene maculata* (Bloch & Schneider)	Moon fish	Menidae	✓	✓	NE
59.	*Liza parsia* (Hamilton)	Goldspot mullet	Mugilidae	✓	✓	NE
60.	*Planiliza subviridis* (Valenciennes)	Greenback mullet	Mugilidae	✓	✓	LC
61.	*Mugil cephalus* Linnaeus	Flathead grey mullet	Mugilidae	✓	✓	LC
62.	*Planiliza macrolepis* (Smith)	Largescale mullet	Mugilidae	✓	✓	LC
63.	*Rhinomugil corsula* (Hamilton)	Corsula	Mugilidae	✓	✓	LC
64.	*Pseudosphromenus cupanus* (Cuvier)	Spiketail paradise fish	Osphronemidae	✓	✓	LC
65.	*Eleutheronema tetradactylum* (Shaw)	Four finger threadfin	Polynemidae	X	✓	NE
66.	*Polydactylus sextarius* (Bloch & Schneider)	Blackspot threadfin	Polynemidae	X	✓	NE
67.	*Leptomelanosoma indicum* (Shaw)	Indian threadfin	Polynemidae	✓	X	NE
68.	*Scatophagus argus* (Linnaeus)	Spotted scat	Scatophagidae	✓	✓	LC
69.	*Johnius dussumieri* (Cuvier)	Sin croaker	Sciaenidae	✓	✓	NE
70.	*Johnius belangerii* (Cuvier)	Belanger's croaker	Sciaenidae	X	✓	NE
71.	*Johnius carutta* Bloch	Karut croaker	Sciaenidae	X	✓	NE
72.	*Protonibea diacanthus* (Lacepède)	Blackspotted croaker	Sciaenidae	✓	✓	NE
73.	*Epinephelus tauvina* (Forsskål)	Greasy grouper	Serranidae	X	✓	DD
74.	*Sillago sihama* (Forsskal)	Silver sillago	Sillaginidae	X	✓	LC
75.	*Sillago vincenti* McKay	Vincent's sillago	Sillaginidae	X	✓	NE
76.	*Brachirus orientalis* (Bloch & Schneider)	Oriental sole	Soleidae	X	✓	NE
77.	*Sphyraena jello* Cuvier	Pickhandle barracuda	Sphyraenidae	X	✓	NE
78.	*Terapon jarbua* (Forsskal)	Jarbua terapon	Terapontidae	✓	✓	LC
79.	*Dichotomyctere fluviatilis* (Hamilton)	Green pufferfish	Tetraodontidae	X	✓	LC
B.	**Crustaceans**					
1.	*Aphibalanus amphitrite* (Darwin)	Purple acorn barnacle	Balanidae	✓	✓	NE
2.	*Metopograpsus messor* (Forsskål)	Shore crab	Grapsidae	✓	✓	NE
3.	*Varuna litterata* (Fabricius)	Peregrine crab	Grapsidae	✓	✓	NE
4.	*Cranuca inversa* (Hoffmann)	Fiddler crab	Ocypodidae	✓	✓	NE

5.	*Gelasimus vocans (Linnaeus)*	Orange fiddler crab	Ocypodidae	✓	✓	NE
6.	*Macrobrachium rosenbergii* (de Man)	Giant river prawn	Palaemonidae	✓	X	LC
7.	*Macrobrachium idella* (Hilgendorf)	Slender river prawn	Palaemonidae	✓	✓	LC
8.	*Macrobrachium equidens* (Dana)	Rough river prawn	Palaemonidae	✓	✓	LC
9.	*Macrobrachium scabriculum* (Heller)	Goda river prawn	Palaemonidae	X	✓	LC
10.	*Penaeus indicus* H. Milne Edwards	Indian white prawn	Penaeidae	✓	✓	NE
11.	*Penaeus monodon* Fabricius	Giant tiger prawn	Penaeidae	✓	✓	NE
12.	*Penaeus semisulcatus* De Haan	Green tiger prawn	Penaeidae	✓	✓	NE
13.	*Metapenaeus monoceros* (Fabricius)	Speckled shrimp	Penaeidae	✓	✓	NE
14.	*Metapenaeus dobsoni* (Miers)	Flower tail prawn	Penaeidae	✓	✓	NE
15.	*Metapenaeus affinis* (H. Milne Edwards)	Brown shrimp	Penaeidae	✓	✓	NE
16.	*Scylla serrata* (Forsskål)	Mangrove crab	Portunidae	✓	✓	NE
17.	*Parasesarma plicatum* (Latreille)	---	Sesarmidae	X	✓	NE
C.	**Molluscs**					
1.	*Villorita cyprinoides* Gray	Black clam	Corbiculidae	✓	X	LC
2.	*Littoraria scabra* (Linnaeus)	Scabra periwinkle	Littorinidae	✓	✓	NE
3.	*Neripteron violaceum* (Gmelin)	---	Neritidae	✓	X	VU
4.	*Peronia verruculata* (Cuvier)	---	Onchidiidae	✓	✓	NE
5.	*Magallana bilineata* (Röding)	Indian backwater oyster	Ostreidae	✓	✓	NE
6.	*Saccostrea cuculata* (Born)	Hooded oyster	Ostreidae	✓	✓	NE
7.	*Pirenella cingulata* (Gmelin)	Girdled horn shell	Potamididae	✓	✓	NE
8.	*Telescopium telescopium* (Linnaeus	Telescope snail	Potamididae	✓	✓	LC
9.	*Melanoides tuberculata* (Muller)	Red-rimmed melania	Thiaridae	✓	✓	LC
10.	*Meretrix meretrix* (Linnaeus)	Asiatic hard clam	Veneridae	✓	✓	NE
11.	*Protapes gallus* (Gmelin)	Short neck clam	Veneridae	✓	✓	NE

The IUCN red list status (IUCN 2018) of various species of fishes, crustaceans and molluscs of pokkali fields is provided in Fig. 3.2, and that of the kaipad fields is provided in Fig. 3.3. A species alien to the country (*Oreochromis mossambicus*) found was abundant in the pokkali and kaipad prawn fields.

Species richness in different families of fishes in pokkali and kaipad prawn filtration fields is depicted in Fig. 3.4. Similarly, species richness in different families of crustacean in these fields is presented in Fig. 3.5 and that of molluscs in Fig. 3.6. Information on various indices of the diversity of fishes, crustaceans and molluscs in pokkali and kaipad prawn filtration fields are presented in Table 3.2. Lorenzs curves obtained by plotting the cumulative proportion of individuals (%) on the x-axis against corresponding cumulative proportions of species (%) on the y-axis concerning the pokkali and kaipad fields are presented in Fig. 3.7. Rank abundance curve of different species of fishes, crustaceans and molluscs in the traditional prawn filtration fields is depicted in Fig. 3.8. Indices of the diversity of fishes, crustaceans and molluscs in the pokkali prawn filtration fields in different months are presented in Table 3.3 and that of kaipad fields is presented in Table 3.4.

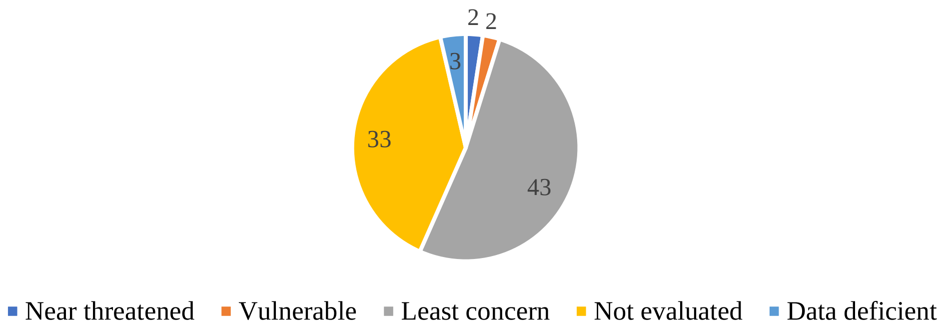


Figure 3.2. The IUCN red list status of various species of fishes and shellfishes of pokkali fields.

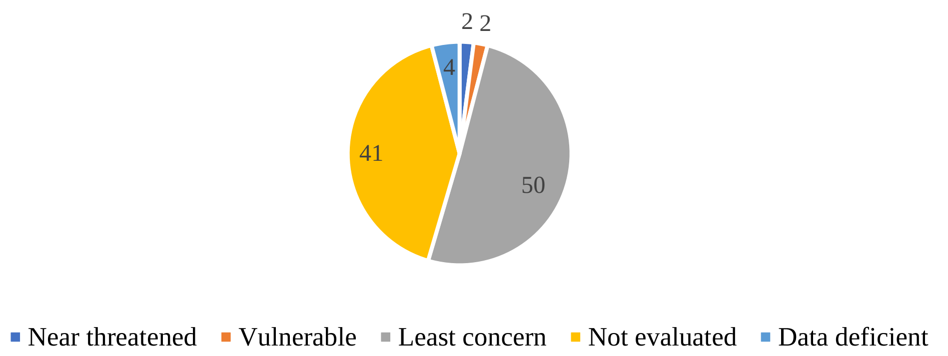


Figure 3.3. The IUCN red list status of various species of fishes and shellfishes of kaipad fields.

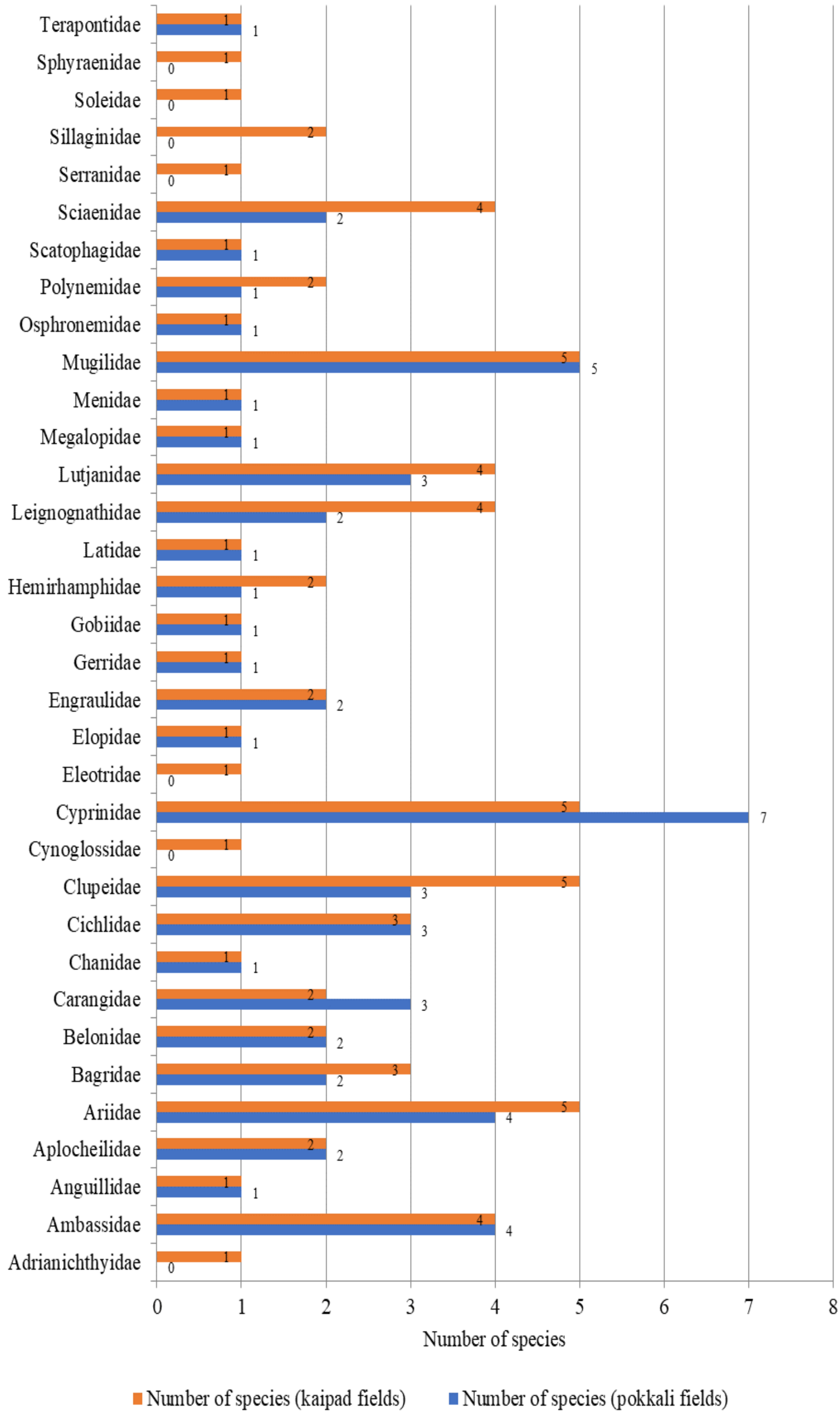


Figure 3.4. Species richness in different families of fishes in pokkali and kaipad prawn filtration fields.

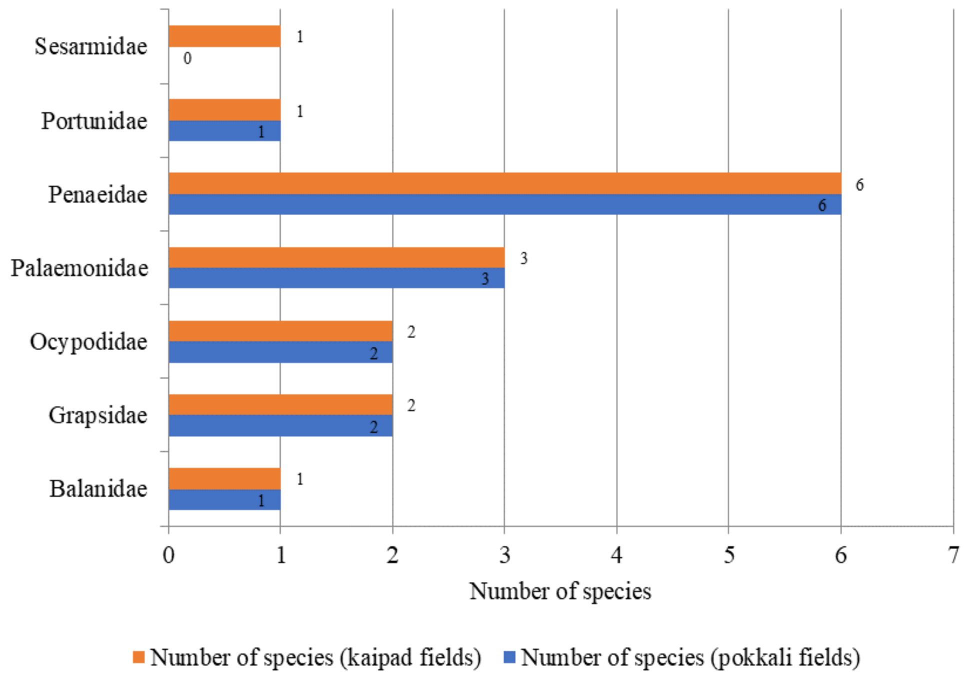


Figure 3.5. Species richness in different families of crustacea in pokkali and kaipad prawn filtration fields.

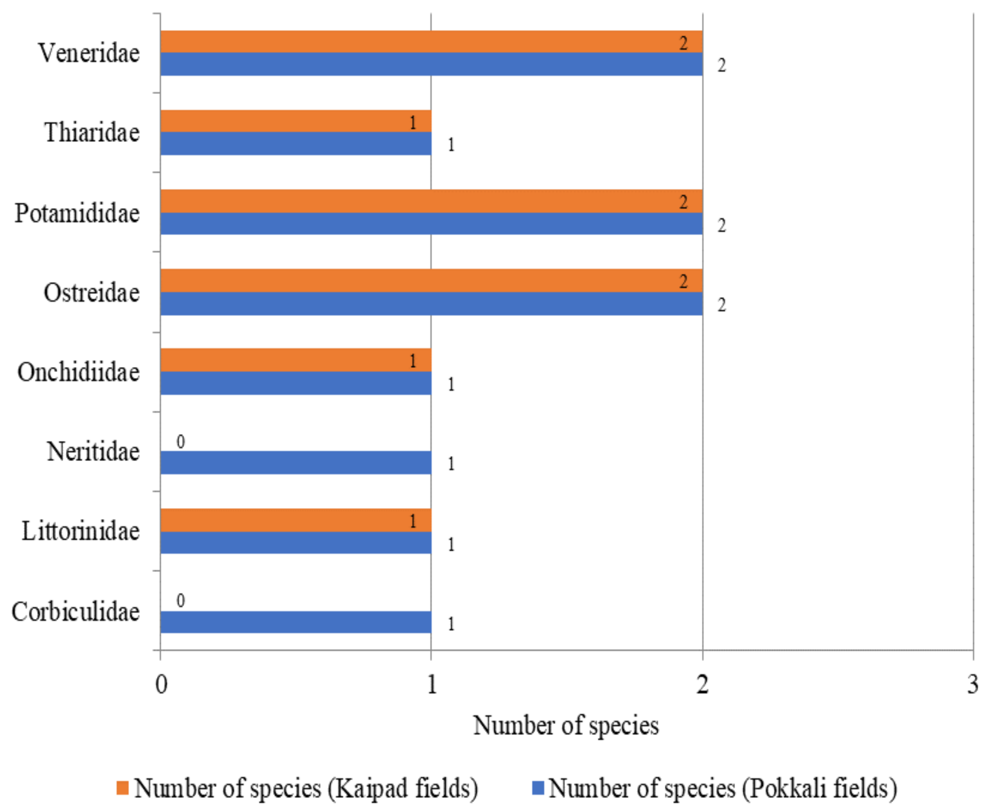


Figure 3.6. Species richness in different families of molluscs in pokkali and kaipad prawn filtration fields.

Table 3.2. Diversity indices of fishes, crustaceans and molluscs in traditional prawn filtration fields.

Fields	Margalef's diversity index	Shannon-Wiener diversity index	Simpson's index of diversity	Simpson's reciprocal index
Pokkali fields	6.11	3.14	0.926	13.40
Kaipad fields	7.55	3.22	0.929	14.12

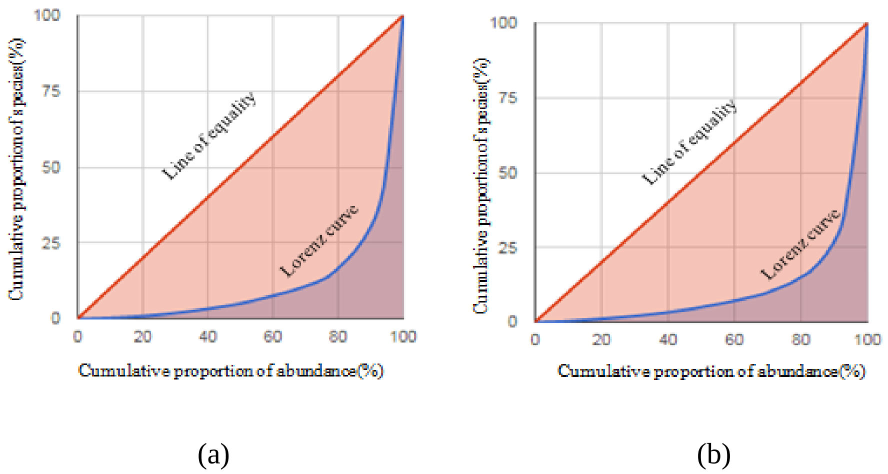


Figure 3.7. Lorenz curve for species evenness of traditional prawn filtration fields (a) pokkali fields (b) kaipad fields.

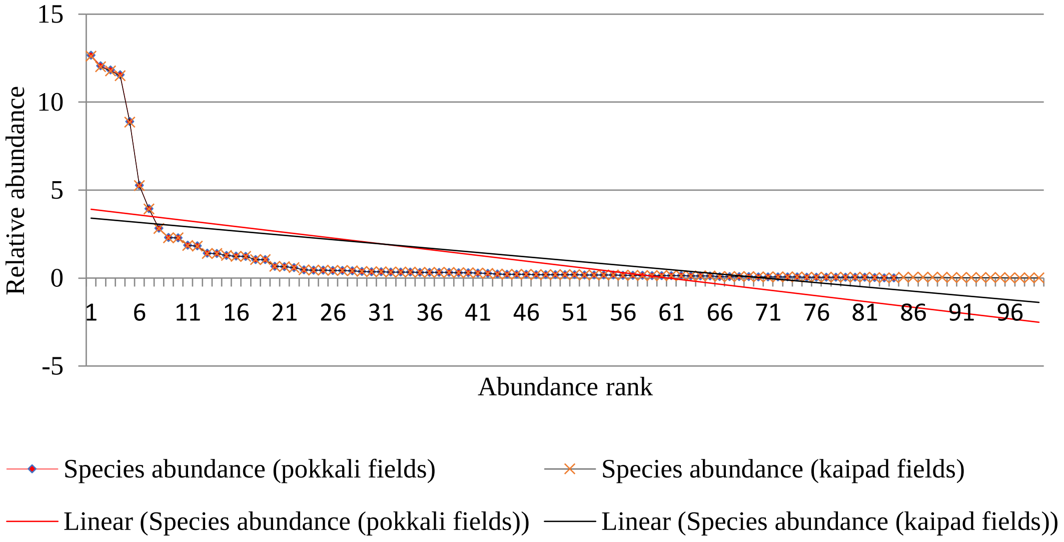


Figure 3.8. Rank abundance curve of different species of fishes, crustaceans and molluscs in the traditional prawn filtration fields.

Table 3.3. Indices of the diversity of fishes, crustaceans and molluscs in the pokkali prawn filtration fields in various months of the year.

Month	Margalef's diversity index	Shannon-Wiener diversity index	Simpson's index of diversity	Simpson's Reciprocal index
January	4.89	2.25	0.807	5.18
February	4.97	2.19	0.830	5.87
March	5.03	2.54	0.841	6.29
April	5.36	2.44	0.863	7.28
May	4.63	3.20	0.950	20.00
June	2.70	2.53	0.906	10.70
July	2.69	2.47	0.899	9.90
August	3.18	2.80	0.931	14.40
September	3.85	2.61	0.879	8.25
October	5.00	2.47	0.872	7.82
November	4.52	2.25	0.828	5.80
December	4.62	2.34	0.834	6.02

Table 3.4. Indices of the diversity of fishes, crustaceans and molluscs in the kaipad prawn filtration fields in various months of the year.

Month	Margalef's diversity index	Shannon-Wiener diversity index	Simpson's index of diversity	Simpson's Reciprocal index
January	5.43	3.03	0.917	12.10
February	5.15	2.43	0.859	7.08
March	5.96	2.85	0.888	8.95
April	5.57	2.58	0.871	7.73
May	4.60	3.15	0.945	18.10
June	3.16	2.89	0.939	16.30
July	4.29	3.14	0.952	20.70
August	4.10	1.78	0.585	2.41
September	4.80	2.35	0.786	4.68
October	5.51	2.85	0.902	10.20
November	5.09	2.42	0.838	6.17
December	5.18	2.67	0.879	8.30

Community similarity (what the communities have in common in terms of species) between pokkali and kaipad fields was assessed by employing Sorensen's Coefficient, which was found to be 0.824. The index of dissimilarity was found to be 0.176.

Species richness of fishes, crustaceans, and molluscs in different months of the year (2017) in pokkali prawn filtration fields is presented in Fig. 3.9, and that of kaipad fields is shown in Fig. 3.10. Lorenz curves for species evenness of pokkali prawn filtration fields in different months are depicted in Fig. 3.11 and 3.12. Lorenz curves for species evenness of kaipad prawn filtration fields in different months are displayed in Fig. 3.13, and 3.14.

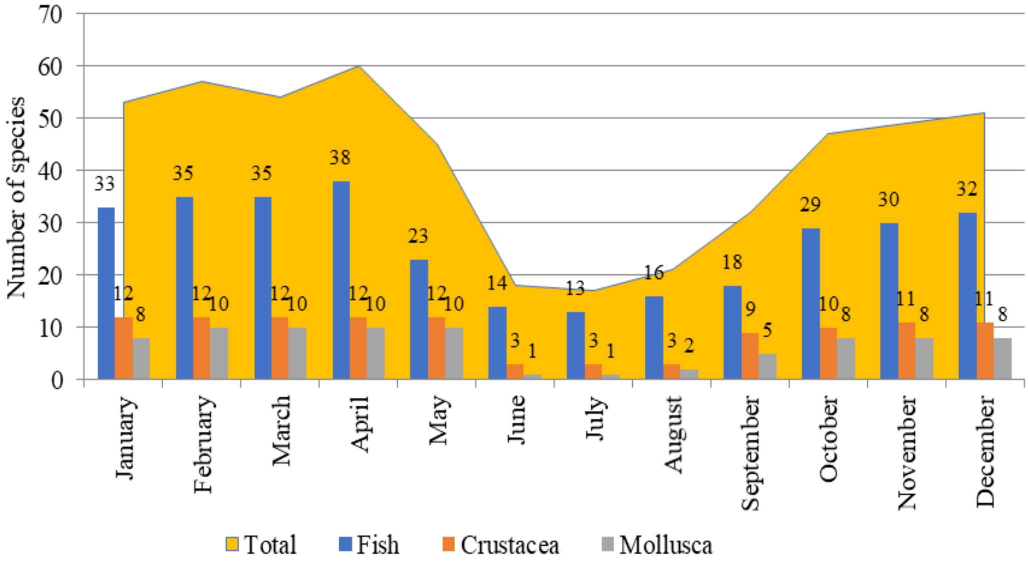


Figure 3.9. Species richness of fishes, crustaceans and molluscs in different months (2017) in pokkali prawn filtration fields.

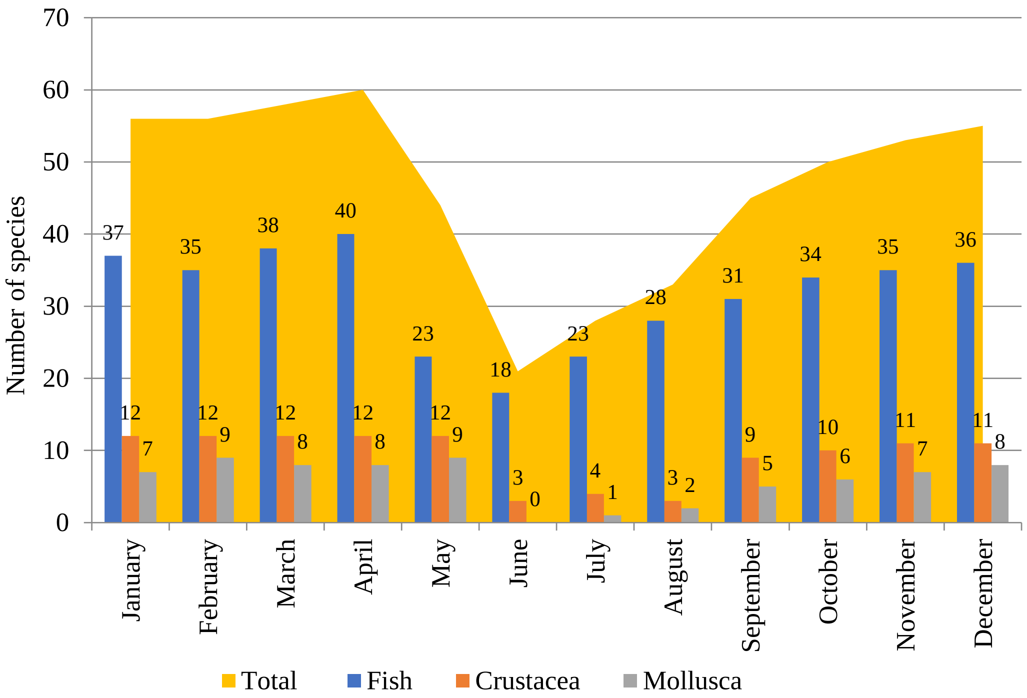


Figure 3.10. Species richness of fishes, crustaceans and molluscs in different months (2017) in kaipad prawn filtration fields.

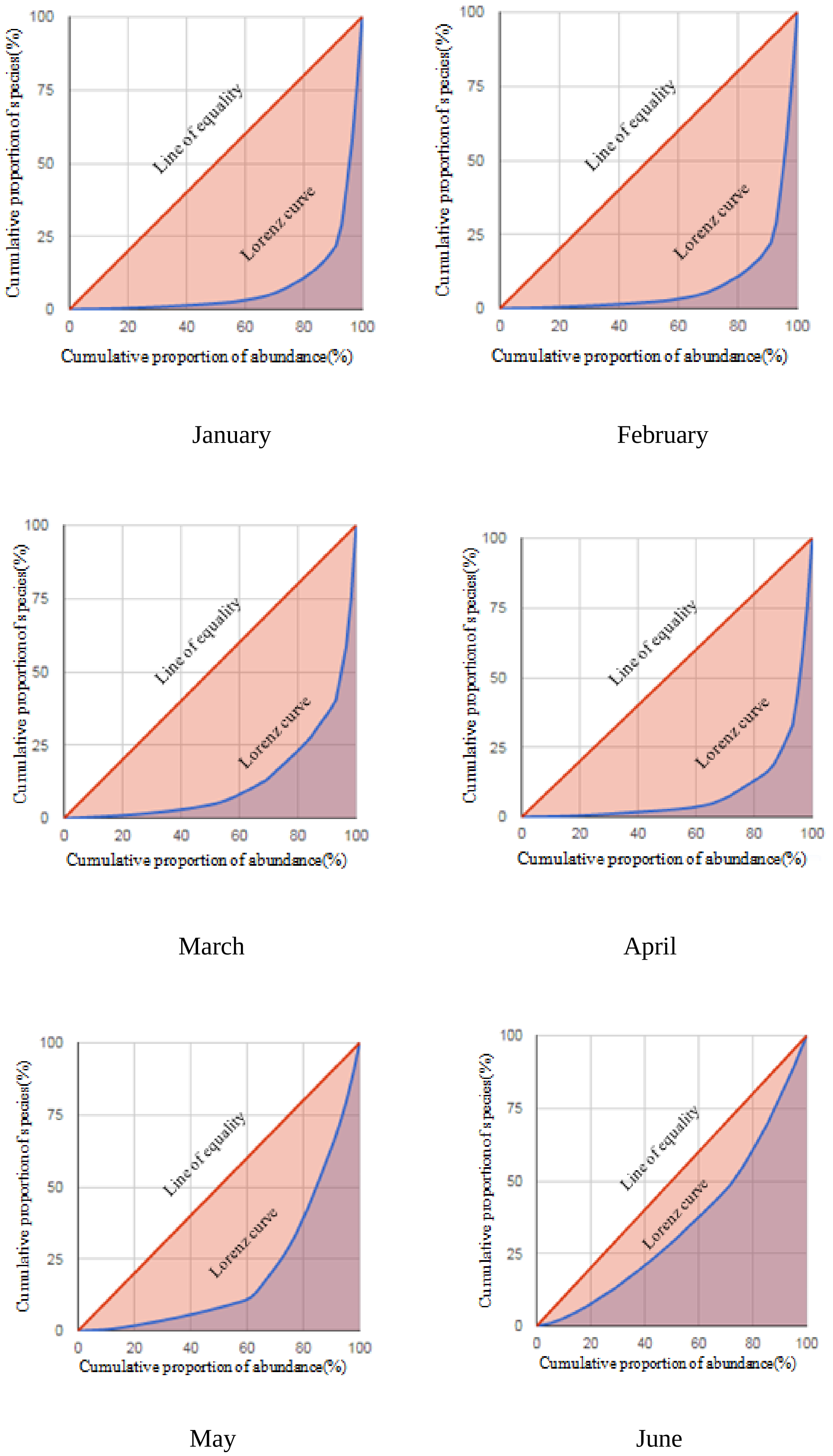
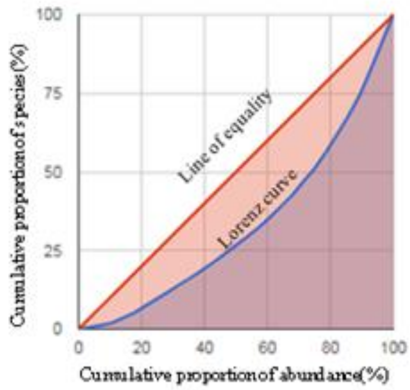
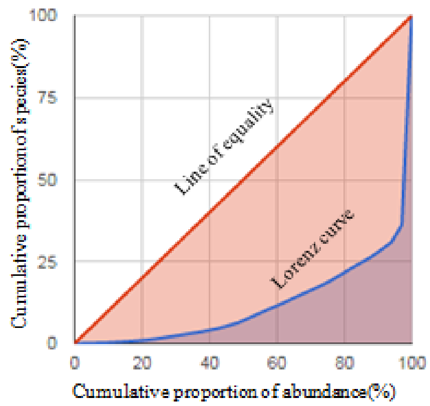


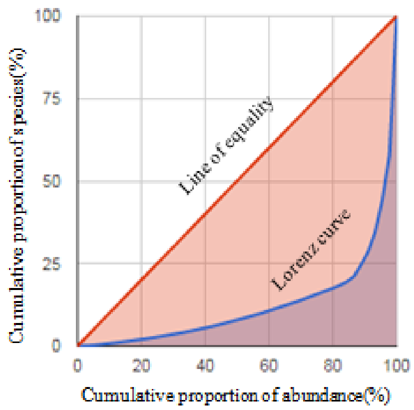
Figure 3.11. Lorenz curve for species evenness of pokkali prawn filtration fields in different months.



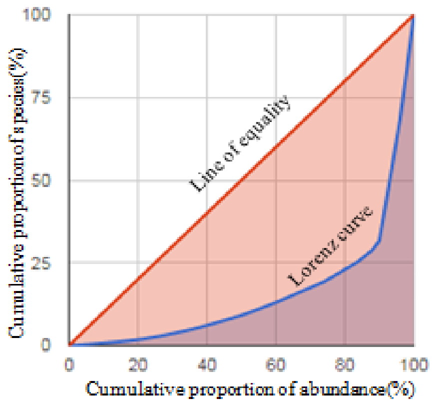
July



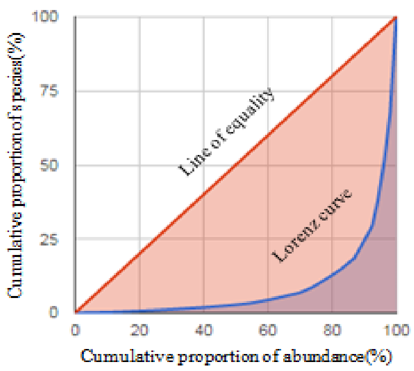
August



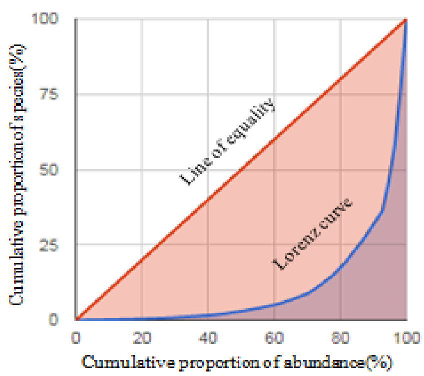
September



October

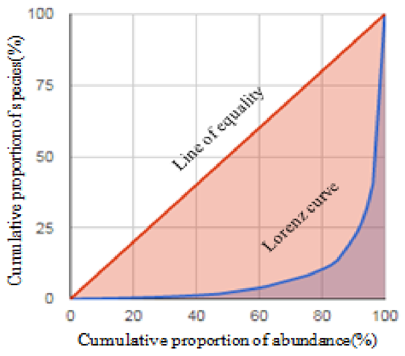


November

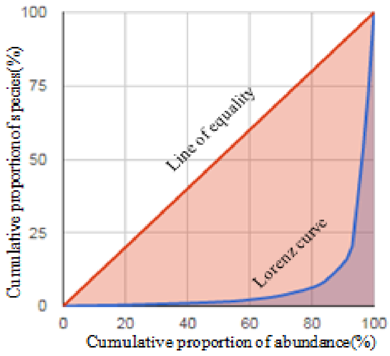


December

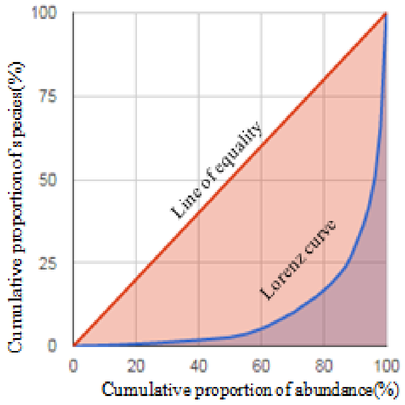
Figure 3.12. Lorenz curve for species evenness of pokkali prawn filtration fields in different months.



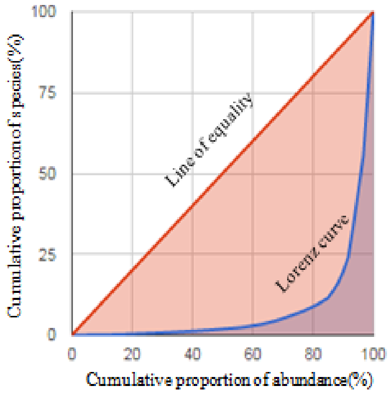
January



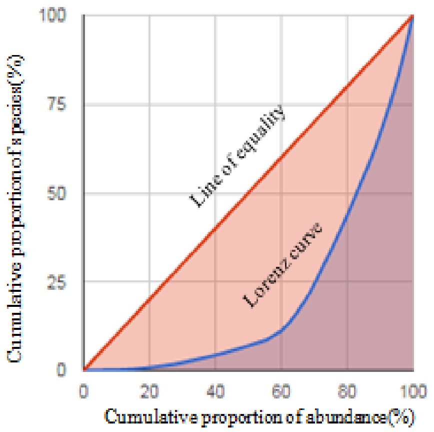
February



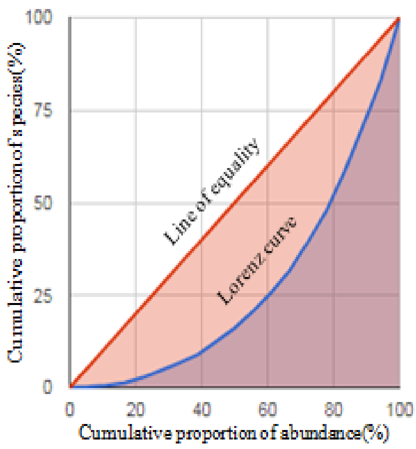
March



April



May



June

Figure 3.13. Lorenz curve for species evenness of kaipad prawn filtration fields in different months.

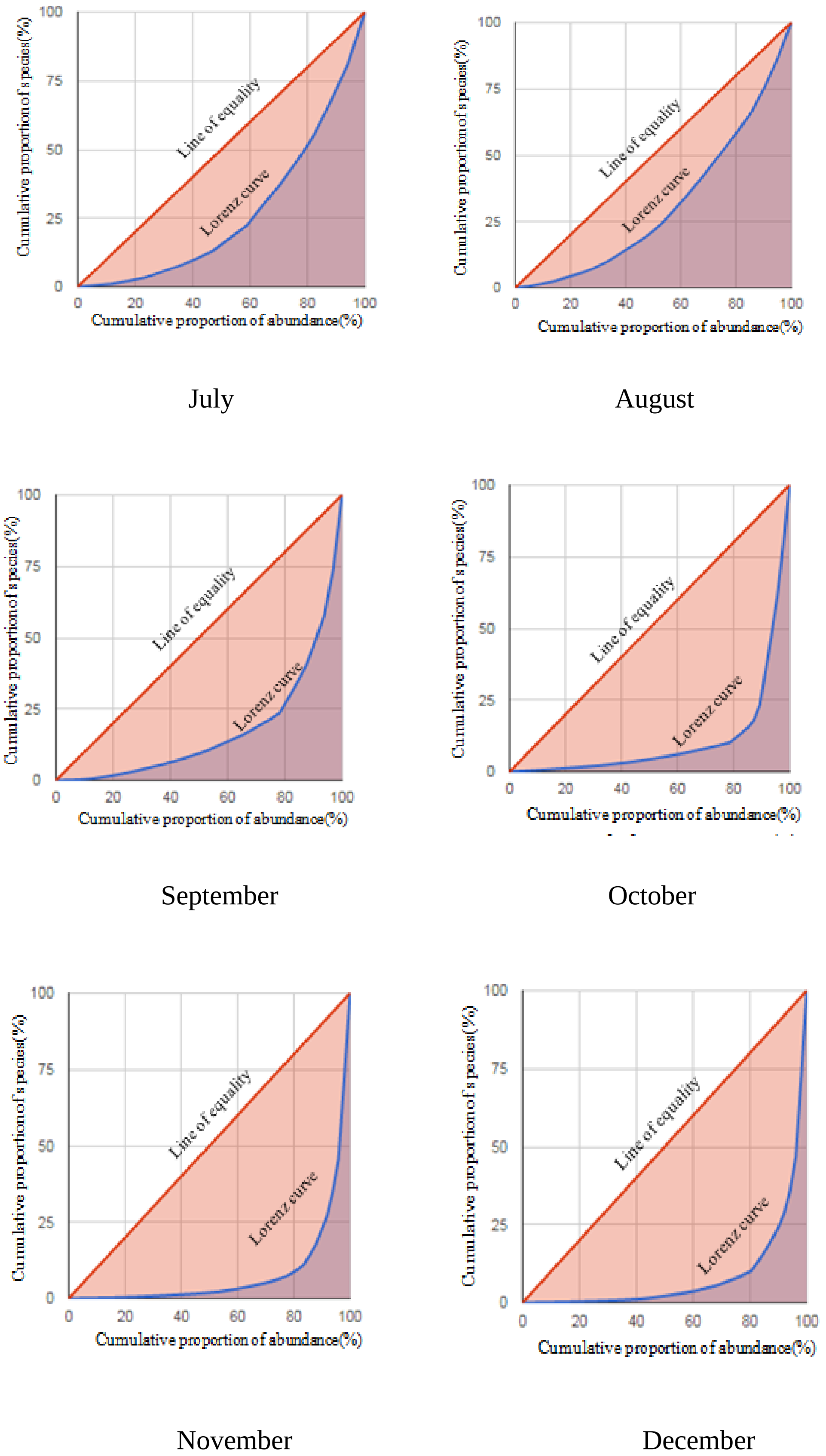


Figure 3. 14. Lorenz curve for species evenness of kaipad prawn filtration fields in different months.

3.5. Discussion

Traditional prawn filtration fields in Kerala are abundant in finfish and shellfish availability. Eighty-three species of fishes and shellfishes were found to occur in the pokkali prawn filtration fields. Kaipad fields are richer in fish and shellfish abundance and have 99 species of fishes and shellfishes. Analysis of the results showed that the species assemblages in these fields vary and include freshwater, brackish water and marine species. As per IUCN red list category, in pokkali fields, two species of fishes are threatened with global extinction. Two species of fish and one species of shellfish are vulnerable. In kaipad fields, two species are threatened, and two are vulnerable.

The list of finfishes in pokkali fields was dominated by the family Cyprinidae (7) followed by Mugilidae (5), Ambassidae (4), Ariidae (4), Carangidae (3), Clupeidae (3), Cichlidae (3), Lutjanidae (3), Aplocheilidae (2), Bagridae (2), Belonidae (2), Engraulidae (2), Leignognathidae (2), Sciaenidae (2), Anguillidae (1), Chanidae (1), Elopidae (1), Gerridae (1), Gobiidae (1), Hemirhamphidae (1), Latidae (1), Megalopidae (1), Menidae (1), Osphronemidae (1), Polynemeidae (1), Scatophagidae (1) and Terapontidae (1). These included intertidal fishes and diadromous fishes. The list had one species of fish exotic to the country, *viz.*, *O. mossambicus,* which was abundant in the catch. The list of crustaceans was dominated by the family Penaeidae (6), followed by Palaemonidae (3), Grapsidae (2), Ocypodidae (2), Balanidae (1)and Portunidae (1). The list of molluscs was dominated by family Ostreidae (2), Potamididae (2), Veneridae (2), Corbiculidae (1), Littorinidae (1), Neritidae (1), Onchidiidae (1), Thiaridae (1).

In kaipad fields, the highest number of species was found in Ariidae (5), Clupeidae (5), Cyprinidae (5) and Mugilidae (5) followed by Ambassidae (4), Leignognathidae (4), Lutjanidae (4), Sciaenidae (4), Bagridae (3), Cichlidae (3), Aplocheilidae (2), Belonidae (2), Carangidae (2), Engraulidae (2), Hemirhamphidae (2), Polynemidae (2), Sillaginidae (2), Adrianichthyidae (1), Anguillidae (1), Chanidae (1), Cynoglossidae (1), Eleotridae (1), Elopidae (1), Gerridae (1), Gobiidae (1), Latidae (1), Megalopidae (1), Menidae (1), Osphronemidae (1), Scatophagidae (1), Serranidae (1), Soleidae (1), Sphyraenidae (1), Terapontidae (1) and Tetraodontidae (1). As in pokkali fields, *O. mossambicus*, which is exotic to the country, was abundant in the catch. The list of crustaceans was dominated by the family Penaeidae (6), followed by Palaemonidae (3), Grapsidae (2), Ocypodidae (2), Balanidae (1), Portunidae (1) and Sesarmidae (1). The list of molluscs was dominated by the family Ostreidae (2), Potamididae (2), Veneridae (2), Littorinidae (1), Onchidiidae (1) and Thiaridae (1).

Many studies provide information on the species wise catch composition of the shrimp harvest of the traditional prawn filtration fields. Panikkar (1937), Hora (1943), Menon (1954), Gopinath (1956), Panikkar and Menon (1956), Kestevan and Job (1957), Raman and Menon (1963), George *et al.* (1968), George (1974), Muthu (1978), Nair *et al.* (1978); Kartha and Nair (1979), Gopalan *et al.* (1980), Gopinathan *et al.* (1982), Kurian and Sebastian (1982), Verghese *et al.* (1982), Unnithan (1985), Purushan (1986), Jose *et al.* (1987), Mathew and George (1987), Gopalakrishnan *et al.* (1988), Mathew (1988), Surendran (1988), Sathiadhas *et al.* (1989); Kurup *et al.* (1992), Nasser and Noble (1992), Pillai *et al.* (1997), Raju (1997), Pillai and Krishnan (1998), Chandramohan *et al.* (1999), Menon (2000), Nayak *et al.* (2000) and Chandramohanan and Mohanan (2012) are some works to mention. However, the information provided in these studies is on the commercially important finfish and/ or shellfish varieties and their catch contribution. Further, these studies are more or less restricted either to the rice farming season (*viz.*, May- September/ October) or to the prawn farming season (*viz.*, November to the following April/ May) alone and do not cover both the seasons.

There are few studies on the biodiversity of finfishes, crustaceans, and molluscs of Kerala's traditional prawn filtration fields covering all months of the year. Cheruvat (2005) reported 84 species of finfishes, 27 crustaceans and ten molluscs from the kaipad prawn filtration fields. However, apart from just enlisting the fishes, the author did not study other aspects of faunal diversity. In a study in the pokkali fields, Deepa (2014) reported 50 species of fishes belonging to 29 families and 11 orders. Among these, nine fish species were reported from the pokkali wetland area during the paddy cultivation period. Shellfishes were not noticed in the habitat during the paddy cultivation season.

The maximum abundance of fishes during paddy cultivation season was seen in June and minimum in August. Maximum diversity was noticed in October and minimum in September. The maximum richness of fishes during paddy cultivation season was noticed in July and the minimum in September. The dominant fish species noticed during this season was *E. maculatus.* Sudhan *et al.* (2016) studied the faunal diversity of fishes, crustaceans and molluscs of pokkali fields of Kerala. The authors reported six species of shrimps, three species of prawns, three species of crabs and 23 species of fishes from the pokkali fields of Kerala. However, the study was limited to prawn rearing months of the year only.

In general, the species composition of traditional prawn filtration fields is expected to be similar to that of the adjacent lake or backwaters, which feed water to the filtration fields. There are many reports on the finfish and shellfish availability of Vembanad lake and other lakes/ backwaters of Central and North Kerala, which serve as reservoirs of fishes and shellfishes of pokkali and kaipad fields. Kurup (1982) recorded 150 species of fishes belonging to 100 genera and 56 families from the Vembanad lake. Of this, 43 species were found to be resident species and were available throughout the year; 74 species were migrant species while 17, vagrant species. Kurup *et al.* (1993b) reported 115 species of fishes belonging to 84 genera, six species of penaeid prawns, four species of palaemonid prawns, and three species of crabs in Vembanad lake. Sreedharan (2004) reported 12 species of freshwater fishes and 47 species of brackish water fishes from the various water bodies of Kalliasseri Panchayat lying beside the Valapatnam River, which include many kaipad fields. Narayanan *et al.* (2005) conducted studies on the diversity of ichthyofauna of Aymanam panchayath in the Vembanad wetland. ATREE (2009) has reported 51 species of finfishes representing 26 families and 35 genera and 11 species of shellfishes belonging to six families and seven genera from the southern part of Vembanad. It included two critically endangered, four endangered and five vulnerable fish species. ZSI (2009) reported the faunal diversity of Vembanad lake. Harikrishnan *et al.* (2011) found thirty finfish species belonging to 18 families, six penaeid shrimp species, two palaemonid prawn species, two crab species and four bivalve species to contribute to the exploited fishery of the region. Krishnakumar and Ranjan (2012) have reported the results of the Vembanad fish count (2008-2011), in which the authors have recorded 67 species of fishes belonging to 46 genera and 34 families. The list included five species of fishes exotic to the lake. Nandan *et al.* (2012) investigated seasonal variation in fish diversity in the Kodungallur- Azhikode Estuary. The Authors reported 60 species of finfishes (belonging to 34 finfish families), six species of penaeid shrimps, two species of palaemonid prawns, two species of crabs (four crustacean families), six species of bivalves and two species of edible oysters (three molluscan families). Asha *et al.* (2014) have reported 80 species of finfishes, five species of penaeid shrimps, three species of palaemonid prawns, and two species of crabs in the lake, of which three species were classified as vulnerable. Mogalekar *et al.* (2015b) investigated the fish diversity and seasonal variation in their distribution in Vembanad lake at Panangad-Kumbalam backwater in Kochi. The authors found 39 species of finfishes belonging to 27 families, 11 orders and 31 genera. Fish abundance was high during the pre-monsoon season, whereas low during the post-monsoon season. They quantified the fish species diversity and species abundance. The indices of diversity included Shannon–Wiener diversity (H') ranged from 2.9 to 3.4, Margalef's species richness ('d') ranged between 4.8 and 7.05, Pielou's evenness (J') ranged between 0.95 and 0.97, taxonomic diversity (Δ) ranged between 86.8 and 91.4, average taxonomic distinctness index (Δ+) ranged between 91.8 and 92.6, and total phylogenetic diversity index (sPhi+) ranged between 1633 and 2300. The Bray-Curtis similarity found maximum between northeast monsoon and pre-monsoon was 78.9 %. Estimates from these indices indicated high fish species composition and richness. Mogalekar *et al.* (2015a) reported the biodiversity of the decapod crustacean in the Vembanad lake in the Panangad-Kumbalam region.

Sahadevan (2016c) studied the diversity of fishes crustaceans and molluscs of Puthuvypeen of Ernakulam district. This area includes a part of the pokkali prawn filtration fields. The author recorded 57 species of finfishes belonging to 27 families, 19 species of crustaceans belonging to seven families and 11 species of molluscs belonging to seven families. In the study, the author reported a species of fish that is near threatened (NT) *viz.*, *Anguilla bicolor* and one which is vulnerable (V) *viz.*, *Hyporhamphus xanthopterus*, as per IUCN (2018) red list category. Seventeen species belonged to the category of least concern (LC), two species belonged to the data deficient (DD) category and 36 species belonged to the not evaluated (NE) category. Of the crustaceans, three species belonged to LC and 16 species to the NE category. Four species belonged to LC and seven to NE categories among the molluscs. He observed that many stressors like habitat alterations, overexploitation, pollution, the introduction of exotic fishes etc., are responsible for a decline in abundance of species over time. Ansar (2017) reported 60 species of finfishes and shellfishes belonging to 13 orders, 31 families 43 genera and investigated the status of finfish and shellfish diversity and seasonal variation in their distribution and abundance in Vembanad lake in the Kumarakom region of the Kottayam district. He estimated values of biodiversity indices like Shannon- Wiener diversity index, Margalef richness index, Pielou's evenness index, taxonomic diversity index. Athira and Jaya (2020) investigated the fish diversity of the downstream part of the Anjarakandi river, which acts as a water source to many kaipad fields in the area. Krishnan *et al.* (2020) surveyed the species diversity of selected sites in Vembanad lake.

Many species reported from the lakes earlier are absent in the prawn filtration fields. It may be because the studies on the faunal diversity of the lake/ backwaters include a larger expanse of water bodies, including perennial freshwater areas. Further, the lacustrine environment is lentic. However, the present study is restricted to smaller water bodies that are more or less lotic. Further, it is saline most of the year and holds freshwater only during a short period. During this period of the year, the fields are primarily under rice cultivation or remain fallow. The change in species status of some fishes has also contributed to the observed difference in the number of fishes in the present study and earlier studies. For example, of the 84 species of finfishes reported by Cheruvat (2005) from kaipad fields, many species lost their independent species status subsequently, making the total number almost on par with the species number recorded in the present study.

Many stressors like habitat alteration, shrinkage of extent and depth of water bodies, overexploitation, pollution, the introduction of exotic fishes etc. might have also caused a decline in fisheries of lakes (Padmakumar *et al.* 2006; Krishnakumar *et al.* 2009, 2011; Asha *et al.* 2014) and adjacent water bodies including the prawn filtration fields and decline in abundance of particular species. However, the present author does not claim the local extinction of fish species. According to Knight (2010) and Knight and Remadevi (2010), any claim on local extinction of fish species should be cautiously verified before drawing any conclusions. Further, information on species diversity obtained in the present study cannot be compared with those obtained by earlier researchers because of the apparent difference in the study areas, sample size and study periods.

The species richness of fish, crustacean and molluscan fauna in traditional prawn filtration fields is mainly due to the high fertility and consequent productivity of the area because of alternate rice cultivation and proximity to mangrove areas. In these fields, while harvesting the paddy, only the panicles are cut, and the rest are left to decompose in the water, which in time becomes feed for the fishes and prawns brought in by the tides. Several rivers open into the lake, and in the monsoon period, when floodwater of rivers flow out into the sea through the lake, salinity goes down to as much as zero ppt. During this period, freshwater fishes inhabit the fields. In the summer months, the salinity increases to 30-35 ppt when many euryhaline species of brackish water and sea fishes reach the fields. The backwaters and the adjacent paddy fields are nursery grounds for many migratory freshwater and sea fishes. Productivity plays a vital role in fish and shellfish fauna in a community as it provides the primary source of food and shelter. The survival of many endemic species in a community or habitat warrants frequent monitoring of the ecological processes besides adopting appropriate conservation strategies to safeguard its rich genetic diversity (Mathew and Rahmatullah 1993).

Species richness and evenness are two important notions related to biodiversity. Generally speaking, the number of species per sample is a measure of richness and the more the species present in a sample, the 'richer' the sample is. It means that the kaipad ecosystem is richer in species than pokkali fields. Species richness as an index on its own gives no importance to the number of individuals of each species present. It gives as much weight to those species with very few individuals as those with many individuals. Evenness is a more subtle notion. It is the relative apportionment of abundances among the species present.

The various species and structural diversity investigated are meaningful because they describe the composition and structure of the two different traditional prawn filtration fields. Margalef's diversity index of pokkali (6.11) and kaipad fields (7.55) indicates that these ecosystems are species-rich, the latter being more prosperous than the former.

With an increasing number of species and a given number of species with increasing similarity of the species proportions, the Shannon-Wiener Index increases. In the present investigation, the maximum Shannon-Wiener Index that can theoretically be expected is ln (Number of species), which is 4.419 in pokkali fields and 4.595 in kaipad fields. However, the observed figures were 3.14 and 3.22, indicating high species richness and evenness in these two ecosystems. The Shannon-Wiener index is affected by the number of species and their equitability or evenness. Typical values generally range between 1.5 and 3.5 in most ecological studies, and the index is rarely greater than four (Seaby and Henderson 2006). The Shannon-Wiener index increases as both the richness and the evenness of the community increase. The fact that the Shannon-Wiener index incorporates both components of biodiversity may be considered as both strength and weakness. It is a strength because it gives a simple, synthetic summary, but it is a weakness because it makes it challenging to compare communities that differ significantly in richness. Owing to the confounding of richness and evenness in the Shannon-Wiener index, many biodiversity researchers favour adoption of two numbers for comparative studies, combining a direct estimate of species richness (the number of species in the community) with some measure of dominance or evenness. The most common dominance measure is the Simpson’s index. However, the Shannon-Wiener index is one of the oldest and more widely used diversity indices, although it has been severely criticised for its simplicity (May 1975; Magurran 2004; Leinster and Cobbold 2012).

Simpson's index provides the probability of any two individuals drawn at random from an infinitely large community belonging to different species**.** Simpson's Index of Diversity (1 – D) is a measure of diversity that considers both the number of species available and the relative abundance of each species. Simpson's Index of Diversity for pokkali and kaipad fields were 0.926 and 0.929, and Simpson's Reciprocal Index (1 / D) for these two ecosystems were 13.40 and 14.12, respectively. These observations further corroborate the inference mentioned above that both these ecosystems are species-rich, and the kaipad fields are richer in species abundance and higher in species equitability.

Species evenness refers to how close in numbers each species in an environment is. A Lorenz curve is the perfect representation for evenness ranking, independent of the number of species concerned (Taillie 1979 and Gosselin 2001). Since perfect equality would mean that 1/k of the species contain 1/k of the portion of the population, perfect equality on this graph was shown by a straight line with a slope of 1. This line was drawn on the graph as a point of reference, alongside the curved line representing the population's actual distribution. Any point on the curve can tell what percentage or portion of the species contains what percentage of the population abundance. The Lorenz curve would be identical to the 45 degrees 1/1 line in an entirely similar situation. The farther away from the 1/1 baseline a particular curve is, the more pronounced is the inequality (Gastwirth 1971). A comparison of the graphs reveals that the pokkali fields have a slightly more even species distribution than the kaipad fields.

The rank abundance curve visually depicts both species richness and species evenness. Species richness is viewed as the number of different species on the chart, *i.e.,* how many are ranked. Species evenness is reflected in the line slope that fits the graph (a linear, *i.e.,* logarithmic series, relationship). A steep gradient indicates low evenness as the high-ranking species have much higher abundances than the low-ranking species. A shallow gradient indicates high evenness as the abundances of different species is similar. Rank abundance curves of different species of fishes, crustaceans and molluscs of the traditional prawn filtration fields indicate that the kaipad fields have more species richness and high evenness than the pokkali fields. The latter has less number of species and has low evenness.

Sørensen's coefficient is a statistic used for comparing the similarity of two samples. It is one of the simplest but valuable indicators of community similarity. In the present context, it means what the communities of pokkali and kaipad fields have in common in terms of species. In the study, Sørensen's Coefficient was found to be 0.824 (index of dissimilarity: 0.176). It indicates that the communities of pokkali and kaipad fields have perfect overlap or similarity. It is also apparent from Table 3.1, which reveals in unambiguous terms that 75 species of fishes and shellfishes are common to pokkali and kaipad ecosystems.

The Sørensen's coefficient is mainly helpful for ecological community data (Looman and Campbell 1960). Rationale for its use is primarily empirical rather than theoretical, although it can be justified theoretically as the intersection of two fuzzy sets (Roberts 1986). Sørensen's distance retains sensitivity in more heterogeneous data sets and gives less weight to outliers (McCune *et al*. 2002).

It has been observed that there is pronounced temporal variation in the species richness of the traditional prawn filtration fields. In pokkali fields, the lowest number of species was noticed in July and the highest in April. A more or less pronounced trend in the increase in the number of species was discernible from July to April. After that, the number of species showed a declining trend and reached 45 in May and 18 in June. This trend was visible in the case of finfishes, crustaceans and molluscs. In kaipad fields, too, a similar trend was noticed. In the kaipad fields, the lowest number of species was noticed in June and the highest in April. After April, the number of species showed a declining trend and reached 21 in June. Here too, the observation was true in finfishes, crustaceans and molluscs, alike.

Traditional prawn filtration fields in Kerala are low lying coastal areas where seawater and freshwater mix. Salinity concentrations in rivers and canals that supply water to shrimp ponds are regulated by the proportions in which seawater and freshwater mix; during the wet season, river discharge increases and salinity declines in estuaries. Conversely, during the dry season, river discharge decreases and salinity increases. Through the backwaters/ lake or a network of canals, these estuarine waters with fishes and shellfishes reach the prawn filtration fields and determine the species spectrum.

Various reasons may be attributed to the observed trend in the species abundance in the traditional prawn filtration fields. The most important one is the change in salinity consequent to the prevailing monsoon rains. Kerala experiences two monsoons: the southwest monsoon (June- September) and the northeast monsoon (September- October). The former is very pronounced, which brings in freshwater conditions in the prawn farming areas. It starts at the end of May or the beginning of June and peaks by the end of June/ or the beginning of July. Most water bodies are flooded during the rainy season, and the water salinity decreases to zero. During this period of heavy rains, turbidity of the water also increases, which restricts the light penetration into the water, resulting in a decline of phytoplankton and benthic productivity.

Only freshwater species of fishes and shellfishes inhabit the area during the freshwater phase. By September – October, salinity starts to build up when many euryhaline species of fishes and shellfishes migrate to these waters. The backwaters, including the adjoining paddy fields and the adjacent mangrove areas, serve as nursery grounds for many marine fishes and shellfishes. After the northeast monsoon months, the water salinity steadily increases, during which the true freshwater fishes disappear, but most of the euryhaline species continue to remain. Further, a large number of true seawater fishes migrate to these waters. As a direct result, the number of species increases steadily during these months. However, farmers generally catch all the fishes and shellfishes left out in the fields by the middle of April. As a result, the number of species decreases by the beginning of May. By the end of May, southwest monsoon again sets in, making these waters fresh, leading to the disappearance of true seawater species and most of the euryhaline brackish water species leading to the decline of the species abundance. A similar species abundance associated with seawater ingress in Chilka lake of Orissa has been reported by Satapathy and Panda (2009).

Evaluation of Margalef's diversity index, Shannon Index, Simpson's Index and Lorenz curve of pokkali and kaipad fields during different months of the year further corroborates the trend in species richness and evenness observed above.

As has already been mentioned elsewhere, there is a complete lack of detailed studies on the diversity of fishes, crustaceans, and molluscs of Kerala's traditional prawn filtration fields. The few studies on the topic are limited just to listing the species of these fields. Comparing the results of studies on biodiversity of fishes and shellfishes obtained in the present study with earlier studies is not relevant in the context.

Biodiversity in species and structures has become a vital issue in fisheries management. This is in accordance with the convention on biological diversity (Anon 2007) and is essential for multi-functional fisheries. However, 'the all-encircling’ nature of biodiversity not only makes it a crucial concept but an extremely nebulous one also (McElhinny *et al.* 2005). In their work on the definition and measurement of forest and woodland structural complexity, McElhinny *et al.* (2005) concluded that at the stand level, structural attributes are more good surrogates for biodiversity than critical species or groups of species. They present many such stand structural attributes such as measures of abundance, richness, size variation and spatial variation of trees.

Many authors have criticised the concept of diversity (Hurlbert 1971; Peet 1974, 1975) because of equivocal meanings and explanations attached to it. The most possible reason for this confusion is that diversity is a concept with many aspects. Indices, such as Shannon-Wiener's or Simpson's, commonly used to measure diversity, combine in an unstandardised, intuitive way the two main sub-concepts: evenness and richness (Magurran 1991). As aresult, a thorough investigation of the mathematical background of functions used to measure diversity seems to be in order (Patil and Taillie 1982; Rousseau and Hecke 1999). Species richness as a simple concept is synonymous with the number of different species present in the community. It is the absolute number of species present in the population of interest. Two assumptions underlie the definition of richness (Marcon 2015). First that a classification of kinds exists and is known. If such a classification did not exist, any richness calculation would become difficult since it might not be apparent to which class or taxon any particular individual belongs. The second presumption is that each class is equally distinct so that no two classes are more or less homogenous than any others. In ecological contexts, enhanced richness has been shown to increase community functionality (*i.e.,* increase productivity) and stabilise it in the face of disturbances (Bell *et al.* 2005; Grman *et al.* 2010). Two mechanisms drive this effect (Hooper and Dukes 2004). The complementary mechanism assumes that different species use different resources, even slightly. Then communities with higher richness will make use more of available resources, thus improving their productivity. On the other hand, the selection mechanism assumes that different species contribute differently to the community's overall functionality, namely that some are more productive than others. Then richer communities are more likely to contain more productive species, enhancing community productivity.

Many relatively complex diversity indices are available in modern research literature. Such a large number of indices and their often discrepant behaviour has resulted in great confusion that some authors concluded that the very concept of diversity is incomprehensive. Even as far back as 1971, Hurlbert declared that "the term' species diversity now provides no information other than 'something to do with community structure'; species diversity has become a non-concept" (Hurlbert 1971), a criticism often continued for years. Although there is an important nuance in this criticism, it is also true that since then, the picture has only become busier, with the plethora of diversity indices already to be found in the literature being joined by new indices proposed every year.

Four broad reasons may be identified for this is. First and foremost, 'biodiversity' is such a general concept that it can and has been defined in very many different ways, depending on researchers' needs and specific requirements. These definitions may range from species or morphological diversity to functional or chemical diversity and any others in between. One review—published a couple of decades back—unearthed no fewer than 85 different definitions (De Long 1996). Thus biodiversity, as a general ecological concept, has been described (rather mildly) as "very confusing" (Ricotta 2005). It is also evident that different diversity indices can therefore measure patently different aspects of diversity. Quantifying biodiversity is still problematic because no single index can provide a suitable summary.

The second problem is that the concept of diversity is often confounded with the indices that measure it. Jost (2016) illustrated this problem with the example of a sphere: its radius can be used as a measure of its volume, but these two quantities are not equivalent. Similarly, the most commonly used diversity measure, the Shannon index, is a measure of entropy. Entropy refers to ambiguity in information: it is challenging to predict the existence of an individual (in terms of its species, functional group, or whichever biodiversity aspect is in consideration) in a very different system, whereas this prediction is less uncertain in a system with only a few types. Hence the former system has higher entropy than the latter. Entropy, therefore, shares significant conceptual similarities with diversity, and thus entropy and diversity measures also share many (but not all) of the characterising axioms. Without surprise, it may be seen that, entropic and other information-theoretic indices have a very long history of use in ecological investigations (MacArthur 1965; Pielou 1966) and have contributed significantly to the explosion in several ecological diversity indices. However, although entropy measures are reasonable and frequently used indices of diversity, this, of course, does not imply that entropy is the same as diversity. Similar arguments can be made regarding most other diversity indices, detailed discussion of which is beyond the scope of this manuscript.

Third, indices typically compress all relevant information about an ecosystem's diversity into a single actual number so that there are immeasurable many ways of computing such an index from the complex and extensive data on the ecosystem under consideration. Different indices give emphasis to different components of these data more strongly than others and entirely neglect some (Baumgärtner 2004). This freedom of formulation has resulted in the emergence of dozens of different indices, often providing wildly different estimates of evidently the same quantity.

The final confounding issue is relatedness but non-equivalence of the concept of diversity across different scientific disciplines. The apparent similarities between diversity measurement have resulted in the adoption of indices by one field from another, thus increasing their number without proper consideration of their conceptual differences.

It is essential to emphasise that none of the numerous diversity indices is wrong *per se*. On the contrary, each index has unique properties that are useful for specific applications. It is also important not to relate diversity as a unified concept. Since raw diversity indices display such a wide variety of mathematical behaviours, they cannot all give good results when directly inserted into any general equation or formula of diversity (Hurlbert 1971). Thus, it is very important to consider the purpose for which an index will be adopted while addressing how it is constructed mathematically and how it should be explained and interpreted ecologically.

The present work attempts to describe some aspects of the biodiversity of fishes, crustaceans, and molluscs in Kerala's traditional prawn filtration field. Pokkali and kaipad fields are ecologically and economically significant, providing critical habitat and refuge for many fishes and shellfishes and supporting a sizeable fishery locally. The water quality of the fields and the primary productivity are the primary factors affecting the community structure of aquatic species, including macroinvertebrates. Salinity is a significant environmental factor that significantly affects the other water quality variables and aquatic species. Seasonal changes in water salinity are directly affected by the salinity of the adjacent backwaters and the rate of evaporation which is a direct function of air temperature. The total number of fishes and shellfishes is an index of biomass, though extreme care has to be given in its interpretation than for diversity as the diversity is expected to be influenced significantly by the supplementary stocking, external feeding and use of artificial lights to attract the fishes and prawns to the fields.

More work is necessary in this regard, and further collections are essential for getting a detailed periodic estimate of the faunal diversity of finfishes and shellfishes in pokkali and kaipad prawn filtration fields. Ultimately, such work may lead to the development of standard monitoring procedures to ensure the sustainable development of these ecologically sensitive traditional prawn filtration fields, which could be of value in assessing their environmental stability.

Conservation of biodiversity implies knowledge of the number and distribution of the flora and fauna of any particular area. Because of the complexity of organisms and the number of species that have yet to be described, it is rarely possible to count individual species in a particular habitat. There is, therefore, a need for generalised models for biological diversity assessment, which can efficiently be utilised as reliable predictors of the number of species on a regional basis. Such generalised models for biological diversity assessment are advantageous because of the logistical and financial difficulties involved in comprehensive surveys.

As habitat degradation continues to accelerate globally, maintenance of species richness has become a central issue of conservation biology. This is particularly the case with the fish fauna of inland waters. There is a great diversity in the form and function of inland aquatic systems, presenting a wide range of habitats for fish. Unlike rivers and flood plains, natural lakes have relatively uniform habitats in a given area (Fernando and Holcık 1991). As environments change, the species composition of fish communities is reported to change (Cowx 1994). From the conservation point of view, studies on fish populations which focus on the static relationships between fish and their habitats are of particular importance because of their value in quantifying the effects of habitat supply limits, which by some means control the size and dynamics of fish populations.

Environmental changes are either due to natural causes or human activities. At present, most wetland ecosystems worldwide are used by people for multiple purposes such as fishing, waste disposal, industrial processes, transportation, recreation, etc. Thomas (1994) identified habitat alteration and destruction as the major causes for most of the fish extinctions. Fish communities are different in individual wetland ecosystems; hence site-specific management is vital in fishery biology and fish biodiversity conservation. Because of this, the abundance and community composition of fishes have long been subjects of interest in fishery ecology (Tonn *et al.* 1983; Marshall and Ryan 1987, Evans *et al.* 1987). Most available data from inland waters on almost all aspects ranging from morphometric and edaphic characteristics to biological characteristics such as the structure of biotic communities are insufficient in quality and quantity.

Simple models to describe inland fish diversity are essential tools in conserving and managing the biological diversity of inland water bodies. This is particularly important because inland fish biodiversity is one of the natural resources most vulnerable to environmental changes, including those caused by humankind.

The inter relationship between species diversity and ecosystem functioning is a central issue in ecology. Attempts to uncover the relationships between the taxonomic diversity, productivity and stability of ecosystems continue to produce indecisive, contradictory and controversial conclusions. New findings from recent studies support the hypothesis that species diversity enhances productivity and stability in some ecosystems but not others (Johnson *et al.* 1996). Appreciation is growing because particular ecosystem features, such as environmental variability and nutrient stress, can influence biotic interactions. Experimental approaches are evolving to test these hypotheses and elucidate the mechanisms underlying the functional role of species diversity.

3.6. Conclusion

Systematic biological inventories are prerequisites for understanding the ecological and survival requirements of individual species within any community. However, despite its importance, there is a general lack of scientific information regarding the faunal diversity of fish and shellfish species of Kerala's traditional prawn filtration fields. The present study was undertaken to address this insufficiency, for which information on the faunal diversity of fishes, crustaceans and molluscs of the traditional prawn filtration fields was collected and analysed.

The results showed that the traditional prawn filtration fields are rich in fish and shellfish species. Eighty-three species of fishes and shellfishes belonging to 42 families occur in the pokkali prawn filtration fields. These include 57 species of finfish (28 families), 15 species of crustacean (six families) and 11 species of mollusc (eight families). Kaipad fields harbour 99 species of fish and shellfish belonging to 47 families. These include 74 species of finfish (34 families), 16 species of crustacean (seven families) and nine species of mollusc (six families). The fish and shellfish assemblage of these fields includes freshwater, brackish water and marine species. In pokkali fields, as per IUCN red list category, two fish species are threatened with global extinction. Two species of fish and one species of shellfish are vulnerable. In kaipad fields, two species are threatened, and two are vulnerable. In both fields, a species of fish alien to the country is abundant in number.

Species richness and various indices of the diversity and evenness of fishes, crustaceans and molluscs in pokkali and kaipad prawn filtration fields were worked out separately, and community similarity between them was assessed. The index of dissimilarity was also estimated. Temporal variations in species richness and evenness of fishes and shellfishes were also computed.

The information collected in the present investigation throws significant light on the diversity of fishes and shellfishes of these ecologically sensitive aquatic ecosystems. The results will undoubtedly serve as baseline data for future studies on the biodiversity of the traditional prawn filtration fields and the adjacent backwaters. In addition to academic interest, the results provide valuable information for evolving management measures necessary for conserving the fishes and shellfishes of these fields and for the sustainable development of the resources.

Chapter 4

ECONOMICS OF SHRIMP FARMING

4.1. Introduction

Crustacean farming has made significant advances during the last couple of decades in many parts of the world, including India. With 9,400 thousand metric tonnes production, the crustaceans accounted for 11.45% of the farmed production of aquatic animals in the world in 2018 (FAO 2020). The main crustaceans cultivated globally include shrimps and prawns, craw fishes and crabs, of which shrimps and prawns accounted for more than 70% of the total. The growth of shrimp aquaculture in India has been impressive over the years, and the country produced 7,47,111metric tonnes of farmed shrimp in 2019-2020 (https://mpeda.gov.in/?page_id=651). However, despite the availability of rich and varied water resources and conducive climatic conditions for growth, the state of Kerala is yet to make any significant strides in the field of shrimp aquaculture (Sahadevan and Sureshkumar 2019).

To meet the increasing demand for shrimp, many countries have increased farming intensity by applying increased amounts of farm inputs to enhance productivity. Intensification of farming practices will undoubtedly increase production. However, the unbridled expansion of such a production system is expected to degrade the resource base, resulting in a massive outbreak of shrimp diseases and subsequent fall in shrimp production, as happened in most producing countries of the world in the 1990s. Thus, the sustainability of shrimp farming is emerging as an essential policy concern in the future development of shrimp aquaculture. The sustainability issues are interlaced with the environmental and social impacts of shrimp farming (Bhattacharya 2009). Of late, problems related to climate change has also emerged.

The sustainability of shrimp farming systems refers to ecological sustainability and economic sustainability, which is the capacity of the farming system to produce a positive income in the long run. Thus, the adoption of any aquaculture technology rests on its economic viability (Prasad 2006). If a shrimp farming system does not provide adequate income, farmers will not adopt it even if it is ecologically sustainable. The need to procure a stable return from shrimp farming, in the long run, assumes additional importance in the case of Kerala, where rural households invest their scarce resources into shrimp culture.

Many studies exist on the economics of prawn farming in Kerala and various other parts of the world. However, very few of these studies have judged the economics of the farming systems from a long-run perspective incorporating the negative externalities generated by such systems and the risks associated with them. Besides, the economic performance of shrimp culture practice is very much affected by the geographic location of the farm, the market demand for the produce, input cost, prevailing financial situation, price of shrimp, availability of substitutes to shrimp in the market etc., which vary significantly from place to place and from time to time. Hence studies on the economics of farming are to be revalidated regularly.

Further, in recent times owing principally to increased urbanisation and many other anthropogenic activities, the extent of shrimp farms in Kerala has come down drastically (https://mpeda.gov.in/?page_id=651). More and more farmers in Kerala are selling or converting their land for non-farming purposes and leave the avocation every year. In this context, there is a necessity to understand whether economic factors are responsible for the observed decline in interest of the farmers in prawn farming.

Thus, economic analysis is required to evaluate the viability of investment in the field, to determine the usefulness of resource allocation, to improve the existing management practices, to adopt new farming technology, to assess market potential and to delineate areas in which research success would have high potential payoff (Shang 1990). Such studies are also required to decide the intensity of farm management to be adopted and the species to be farmed.

Under these situations, the present study was taken up to analyse the economics of various shrimp culture systems of Kerala by incorporating the associated risks. Such analysis would help address how far the shrimp farming practices adopted by the small-scale shrimp farmers of the state is justifiable from a long term perspective and understand whether economic factors are responsible for the observed withdrawal of farmers from this avocation in Kerala.

4.2. Review of literature

Studies on the economics of shrimp farming in India are very few (Misra 2006) or fragmentary. However, there are many studies on the economics of inland fisheries in general. Some of the investigations covered riverine fisheries concerning the income of fishers and fishers' share in consumer's rupee.

Dhondy and Singh (1968) investigated the benefit-cost ratio in fish culture. Prasad (1968) attempted to examine the economic problems of inland fisheries development in Bihar. The author found that the economic issues of fisheries development arise from various factors, including a high degree of uncertainty and risks involved in the production, variation in fertility and weather conditions. According to the author, fishers have no settled rights over the farming areas, and there is insufficient investment in pond development. Srinivasan (1968) discussed economic aspects of fisheries development in the erstwhile Madras state paying importance on inland fisheries. He found that tanks suffer from a lack of care and attention from the owners. The author suggested Government intervention to initiate effective management. George (1974) studied the yield and economics of shrimp farming operations in seasonal and perennial fields of Vypeen island of Ernakulam district. Sinha (1976) investigated various costs and profitability of freshwater fish farming. CMFRI (1979) gave a detailed account of the economics of farming mussels in Kerala. Ghosh (1979) and Sharma *et al.* (1979) studied the costs and earnings of integrated fish farming practices. George (1980) further investigated the economics of traditional prawn culture practices in Kerala, noting the advantages of intensive prawn culture.

Gopalan *et al.* (1980) conducted case studies on the economics of improved paddy field shrimp culture methods in Vypeen island. Experimental studies on high-density, short-term farming of the Indian white shrimp in pokkali fields were conducted by Gopalan *et al.* (1982). These authors also examined the aspects of the economics of shrimp farming. Shang (1983a) surveyed the economics of marine shrimp farming. Shang (1983b) described the economic aspects of aquafarm construction and maintenance. According to Srivastava and Reddy (1983), one of the primary reasons for the unsatisfactory performance of the inland fisheries sector in India is the low availability of reliable economic data and standard terminologies necessary for comparison. Kumar (1984) made an economic analysis of fish farming financed by commercial banks in Sultanpur District of Uttar Pradesh. Singh and Gupta (1984) dealt with problems of fish farming related to the demand, supply, production, economics, marketing and distribution. Some studies on costs and earnings of integrated fish farming were also carried out in different parts of the country (Ghosh *et al.*1985).

Hirasawa (1985) analysed the economics of shrimp farming in Asia. With the help of cost forecast for cultured shrimp, he indicated that extensive and semi-intensive methods would dominate the Asian region. Unnithan (1985) presented the economics of scientific farming of shrimp in Kerala. Purushan (1986) discussed the economics of paddy cum fish culture operation. Ranadhir (1985) made a microeconomic analysis of composite fish culture operations in India, and Ranadhir (1986) reported the costs and earnings of traditional fish culture operations. Chattopadhyay (1987) discussed various institutional, technical and economic factors which were found detrimental to the smooth functioning of fish production. Kanittha (1987) made a financial analysis of the pond culture of giant freshwater prawn.

The book published by Misra (1987) attempted to analyse the economic aspects of freshwater fish farming in India, based on a micro-level study conducted among freshwater fish farmers in the Birbhum and Murshidabad districts of West Bengal. The author examined the ownership and operational features of ponds and tanks, productivity relationships, and different management strategies' impact on production. He observed that the new technology has failed to produce substantial results in the rural world. The author found the farmers circumscribed by factors like plurality of ownership of ponds and tanks, lack of quality fish seeds, shortage of finance, inadequate extension network, poaching, and inadequate organised marketing facilities.

Purushan (1987a) studied the economic aspects of shrimp culture in the pokkali fields of Kerala. Srivastava *et al.* (1987) examined the operations of brackish water fish culture in different states of India. The authors also performed a comparative analysis of the economics of intensive and traditional shrimp culture systems. The study showed that shrimp culture was highly profitable, and the average return on investment was 82%. The study also revealed that the gross revenue per hectare was the highest in intensive culture and the lowest in fields following shrimp filtration, due mainly to the differences in the variety and size of shrimps harvested. According to the study, significant constraints in brackish water shrimp culture are technical and managerial problems and conflict in the ownership of brackish water areas. These authors suggested provision for improved seeds, quality water, long-term land leasing policy, finance, technical assistance and extension services to accelerate the pace of development of shrimp culture.

Mathew (1988) presented the economic advantages of the integrated farming of fish with paddy in the context of the low return from paddy cultivation. Padmakumar (1988) examined the production trends, economics and feasibility of paddy fish culture in *punja* fields. Purushan (1988) analysed the economics of the traditional pawn farming operation in Vypeen island of Ernakulam district of Kerala. Chaudhury (1989) examined the economic conditions of the fishermen community adjacent to beeI in lower Assam.

Sathiadhas *et al.* (1989) studied the economic aspects of prawn culture in pokkali fields. Ajithkumar (1990) analysed the factor product relationship in prawn farming by resorting to a production function approach. Ghosh (1990) studied the investment pattern in an organised coastal fish culture system with clear brackish water and freshwater aquaculture phases. Panikkar (1990) studied the economics of prawn farming in the Orissa state of India. Shang (1990) presented various aspects of aquaculture economic analysis. Ali and Byerlee (1991) investigated the economic efficiency of small farmers in the changing world. Primavera (1991) studied the ecological, social and economic implications of intensive prawn farming. Neiland *et al.* (1991) published a review of the social and economic impact of aquaculture. Studies related to the cost of production, cost of operation, various cost factors and profit composition in freshwater fish culture were carried out by some researchers (Ranadhir and Tripathi 1991; Dalai and Das 1992; Suresh *et al.* 1992). Beena (1992) investigated the economics of traditional prawn farmers in the Ernakulam district. Chong (1992) discussed ways to improve the profitability of shrimp aquaculture. Nasser and Noble (1992) investigated the economics of prawn culture in Vypeen, Kerala. Viswakumar (1992) made technical and economic consultations for shrimp culture in Andhra Pradesh.

Ajithkumar and Panikkar (1993) presented a production function approach to analyse factor product relationships in prawn farming. The authors examined the economics of semi-intensive prawn farming being practised in Kerala based on a sample of farms selected from different villages in the Ernakulam district in Kerala. The model used for production function analysis was a general form of the Cobb-Douglas production function. These authors found that prawn farming is the main occupation of families involved. Most of them have traditionally been indulged in paddy-cum prawn culture. The average productivity in semi-intensive culture was also found to be higher than the state average, and farmers were found to earn excellent net farm surplus. The authors concluded that semi-intensive prawn farming could prosper very fast if farmers are given proper motivation through well-organised extension services, and financial constraints are removed by establishing links with rural funding agencies. It is also imperative to make available major inputs such as good quality seeds and feeds in adequate quantity in appropriate time to utilise these production factors to the optimum levels.

Iyer *et al.* (1993) conducted a detailed socio-economic baseline survey in five reservoir fishing communities of Kerala. Jayagopal and Sathiadhas (1993) studied the productivity and profitability of prawn farming practices. The authors assessed the productivity and profitability of different types of prawn culture practices and analysed the comparative economic efficiency of prawn farms based on their location, size and technique. They estimated the input-output relationship for prawn production in the semi-intensive culture system. Taege *et al.* (1993) published the results of the study on the economics of the cultivation of fingerlings of carps in pens at Malampuzha reservoir in Kerala. A study by Usharani *et al.* (1993) revealed that the semi-intensive system of farming shrimp is much profitable than the extensive and intensive systems.

Gupta and Rab (1994) studied the adoption and economics of silver barb (*Puntius gonionotus*) culture in seasonal waters. Jayaraman *et al.* (1994) discussed the economics of improved extensive shrimp farming in Vedarnyam in Tamil Nadu. Sureshwaran *et al.* (1994) studied the financial viability of *Penaeus setiferus* versus *Litopenaeus vannamei* with continuous live harvesting and one final harvest strategy. Funge-Smith and Aeron-Thomas (1995) studied the economic factors and risks influencing the sustainability of Thai intensive shrimp farms. Griffin (1995) studied the economic aspects of shrimp culture. Krishnan *et al.* (1995) studied the economics of cultivation of brackish water fishes in Krishna District of Andhra Pradesh. Singh *et al.* (1995) investigated the cost of production and profit composition in freshwater fish culture. Alam and Bashar (1996) conducted an economic analysis of financing and organising riverine fish production. The book published by Ghosh (1996) on scientific shrimp farming contained details of the economics of farming shrimp in Kerala. Rao (1996) studied the investment pattern and the economics of freshwater aquaculture. Sathiadhas *et al.* (1996) conducted an economic evaluation of composite culture practices of crab fattening and fish-shrimp farming in Kerala. Colwill (1997) presented the results of the financial analysis of shrimp farms and shrimp fisheries. Jayaraman (1997) made an economic analysis of carp culture in the Thanjavur district of Tamil Nadu, India.

Raju (1997) conducted detailed economic analyses of different aquaculture systems in Kerala. The author evaluated the practices of prawn and fish culture in Kerala by analysing the production and marketing aspects. He examined the production function, cost efficiency, economic viability and profitability of the different aquaculture systems. The study provided reliable and systematic economic information on the subject. Thongrak *et al.* (1997) conducted an economic evaluation of intensive shrimp production systems in Thailand. Agbbayani *et al* (1997) assessed aquaculture economics in Asia and the Pacific.

Coastal Resource Centre (1998) investigated the economic, environmental and social impacts of shrimp farming in Latin America. The study revealed the underlying causes of environmental and social problems in Latin America, which are complex and include poorly defined and insecure land tenure, open-access property rights for water and seed shrimp, inadequate institutional capacity and environmental regulations, unworkable legal frameworks, insufficient shrimp farm technical expertise, and inadequate understanding of coastal ecosystem conditions and trends. The multidimensional nature of the problem demands an integrated approach to coastal economic development and environmental management. Integrated coastal management was suggested as a governance framework for advancing sustainable shrimp aquaculture. Gupta *et al.* (1998) reported the feasibility and economic viability of integrating aquaculture with rice farming in Bangladesh.

Jose and Thomas (1998) studied the economic condition of the inland fisheries of the Kuttanad region of Kerala. They also investigated the problems and prospects of inland fisheries in the area. Rao and Raju (1998) studied the cost of production, cost of operation, various cost factors and profit composition in freshwater fish culture.

Shang *et al.* (1998) published results of comparative studies on the economics of various shrimp farming systems. They recorded the profitability of different culture systems under the boom period of shrimp farming in Andhra Pradesh. These authors reported that though the cost of production per kilogram of shrimp was the highest for semi-intensive system ($ 5.96) followed by intensive ($5.01) and extensive systems ($4.42), extensive system ranked first in terms of profit per kilogram of shrimp, followed by the intensive and semi-intensive system.

Andrew (1999) published a book on brackish water shrimp culture economics. The author attempted to analyse the economic aspects of shrimp culture in Andhra Pradesh. He observed that aquaculture, mainly brackish water shrimp, can bring about socio-economic uplift and rehabilitation of weaker sections in villages by providing income and employment. The average rate of return for all farm size groups was 60%. Even though the cost of production and net returns increased with farm size, no direct relationship was observed between the rate of return and the size of farms.

APRSAC (1999) studied the environmental management and monitoring of shrimp culture projects in the East Godavari District of Andhra Pradesh (India). Clayton and Brennan (1999) reviewed the economic issues for sustainable shrimp farming. Horstkotte-Wesseler (1999) conducted a detailed study on the economics of rice- aquaculture. James (1999) published an overview of environmental, socio-economic, legal and other implications of shrimp farming development in India. Pillai (1999) studied the economics of improved traditional and traditional shrimp farming in pokkali fields. Raghunanda (1999) conducted an economic analysis of shrimp aquaculture in the West Godavari District of Andhra Pradesh. Saju and Sukumaran (1999) studied the production and economics of extensive tiger and white shrimp culture. Talukder (1999) studied the financial profitability of the shrimp-based farming system in Bangladesh. The study analysed the comparative economic returns of alternate shrimp-crop farming and assessed the environmental and socio-economic impacts of shrimp farming in the coastal areas of Bangladesh.

Biswas *et al*. (2000) made an economic analysis of pond fish culture in some selected areas of Mymensingh district. Brennan *et al.* (2000) investigated the economic characteristics of extensive shrimp farms. Francis *et al.* (2000) discussed improving the profitability of small-scale farming by integrating fish culture into traditional rice farming in Kerala. Leung and Sharma (2000) examined the economics and management of shrimp and carp farming in Asia. Shingare and Shirgur (2000) studied the costs and earnings of integrated fish farming. Shah *et al.* (2000) studied the economics of bagda shrimp (*P. monodon*) farming in the coastal areas of Bangladesh.

Asokan *et al.* (2001) published the results of studies on the economics of the mussel farming operation in Kerala. Neiland *et al.* (2001) discussed the economic perspectives of shrimp culture for policy development. Pandey and Mishra (2001) studied the economic feasibility of fish culture in the Faizabad district of Uttar Pradesh in India. Salim and Biradar (2001) published a practical manual on fisheries project formulation and management. Tisdell (2001) published an overview of aquaculture economics and marketing. Valderrama and Engle (2001) analysed the risk of shrimp farming in Honduras.

Berg (2002) presented economic and ecological considerations of rice monoculture and rice-fish farming in the Mekong Delta of Vietnam. Brennan *et al.* (2002) evaluated rice shrimp farming systems. Jose *et al.* (2002) conducted a financial analysis of modified extensive shrimp farming. Katiha (2002) investigated the socio-economic aspects of culture-based fisheries. According to Pillai *et al.* (2002), the practice of pokkali shrimp farming in Kerala did not change over the years, except for introducing the component of the supplementary stocking. The system withstood the test of time. He observed it as a simple, low-cost system, which is easy to operate in tide affected low-lying areas. Though fluctuations are noticed, pokkali shrimp farming established itself as a sustainable system. According to the authors, farmers' principal social problem is that they are deprived of the entire culture period to carry out culture operations. The reduction in the culture period is because of the encroachment of cast net operators into the field before the expiry of the grow-out period, which forces the farmers to harvest shrimp before they grow to full size leading to economic loss to producers, pollution of neighbouring water bodies and social tension. The authors suggested enacting and implementing an aquaculture regulation act to solve the problem. These authors also recommended the introduction of innovative technologies to boost shrimp production.

Raju (2002) made a production function analysis of Kerala's semi-intensive shrimp farming system. He presented an analysis of the factor product relationship in a semi-intensive shrimp farming system. The study was based on data collected from shrimp farms in the Alapuzha, Ernakulam and Kasargod districts. Based on the analysis, the author concluded that the yield of farms under the system could be enhanced by changing the factor balances. It was estimated that semi-intensive farms in Kerala could improve the shrimp output fourfold through better resource management. According to the author semi-intensive system in the state is a promising area for profitable investment. The author recommended restrictions on stocking, reduction in the intensity of feeding to less than one-third of the present level, the substitution of costly food formulations with locally available low-cost feed, farm insurance, and technically qualified personnel to improve the techno-economic efficiency of the farming system.

Rashid (2002) conducted an economic study of shrimp farming. Faizbakhs (2003) investigated the economics of shrimp culture in Iran and presented future strategies for sustainable development. Pravin (2003) studied in detail the economics of traditional shrimp farming in Kerala. Singh (2003) examined the economic aspects of fish farming in northern Bihar. The study attempted to analyse the cost of production, returns and profitability of fish culture and identified the significant constraints faced by fish farmers. This investigation was based on primary data collected from fish farmers, fishers, and various market functionaries. Singh *et al.* (2003) also investigated the economics of fish production in Hasanpur block, Samastipur district of Bihar, India. Stanley (2003) investigated the economic impact of mariculture on the regional economy.

A detailed action report incorporating the economics of mussel farming in the backwaters of Kerala was prepared by Appukkuttan *et al.* (2004). Joseph (2004) made an economic analysis of the externalities in coastal mariculture. Mruthyunjaya (2004) studied the cost structure, returns and benefit-cost ratios of various aquafarming systems, including shrimp farming. Reddy (2004) made an economic analysis of shrimp aquaculture in the West Godavari district of Andhra Pradesh, India. Reddy *et al.* (2004) dealt with the ecological and financial aspects of shrimp farming. They also tried to understand the economic incentives and environmental compulsions associated with shrimp farming. Salim *et al.* (2004) published a book on the economic analysis of fisheries projects. Among other topics, it included some commercially viable aquaculture projects. Sathiadhas and Najmudeen (2004) investigated the economic efficiency of mud crab farming/fattening under different production systems.

Katiha *et al.* (2005) presented the economics of various inland aquaculture systems. They found that the return to capital in aquaculture is much higher than the return to labour due to the low labour input. Rao (2005) analysed the comparative economics of different aquaculture practices and their constraints. The author also attempted to review the available studies on the subject and to examine the comparative economics of small-scale aquaculture in India. De Ionno *et al*. (2006) presented the results of a bioeconomic evaluation of a commercial-scale recirculating finfish grow out system. Joseph and Sathiadhas (2006) studied the economics of selected aquaculture practices in Kerala, including various shrimp farming practices. Leung and Engle (2006) published a book on the global economics, trade, and markets for shrimp. Prasad (2006) made an economic analysis of the semi-intensive culture of tiger prawn. Velayudhan *et al.* (2006) investigated the profitability of farming green mussels in the Korapuzha estuary of Calicut. Alam *et al.* (2007) studied the economic return of disease-affected extensive shrimp farming. Chaudhari (2007) conducted an economic and marketing analysis of shrimp farming in some districts of the Konkan coast, Maharashtra. Ahmed *et al.* (2008) presented the results of a financial study of freshwater prawn, *Macrobrachium rosenbergii* farming.

Bhattacharya (2009) presented the results of a comparative study of traditional versus scientific shrimp farming. He examined the performance of alternative shrimp farming systems incorporating the cost of negative externalities caused by shrimp culture, the risk associated, and the possible variations in the international shrimp market in the economic analysis. The author analysed the economic viability of alternative shrimp farming systems from a long-term perspective in the context of household-level shrimp farming in West Bengal. Goswami *et al.* (2009) investigated the economic viability of rice-fish culture in Assam. Sanchez-Zazueta and Martinez-Cordero (2009) discussed aspects of economic risk assessment of semi-intensive shrimp farms.

Sathiadhas *et al.* (2009) made a break-even analysis and studied the profitability of various coastal aquaculture practices in India. They worked out break-even prices for different systems of coastal aquaculture and their net profitability. Net profitability per hectare of aquaculture is the highest for pearl culture and the lowest for the traditional system following paddy cum prawn filtration. Akter (2010) investigated the effect of financial and environmental variables on the production efficiency of white leg shrimp farms in Vietnam. Son *et al.* (2010) studied the production and economic efficiencies of intensive black tiger prawn (*P. monodon*) culture during different cropping seasons in the Mekong delta.

Rahman *et al.* (2011) discussed the economics and efficiencies in a 'blue-green revolution' combination of prawn, carp and rice farming. Sahu *et al.* (2012) conducted studies on econometric modelling of shrimp (*P. monodon*) farming in the Purba Medinipur district of West Bengal of India. Sadafule *et al.* (2013) conducted economic analyses of shrimp farming in the coastal districts of Maharashtra. The technical efficiency of farming was estimated using the Cobb Douglas production function. The results showed that the water spread area, stocking density, cost of seed, cost of feed, culture period, cost of medicines, and fertilizer used were the most critical factors for determining shrimp production in Maharashtra. The study suggested the need for concerted efforts for augmenting the production and realising a higher unit value for shrimp. Begum *et al.* (2015) studied the technical efficiency of shrimp and prawn farming. Estrada-*Pérez et al.* (2015) presented a bio-economic approach to analyse the role of alternative seeding-harvesting schedules, water quality, stocking density, and cultivation duration in semi-intensive shrimp production. Gammanpila (2015) investigated the economic viability of small-scale shrimp (*P. monodon*) farming in the North-Western province of Sri Lanka. Jagadeesh (2015) made a financial analysis of shrimp farming practices in Prakasam district, Andhra Pradesh. Navghan *et al.* (2015) presented the economics of shrimp aquaculture and factors associated with shrimp aquaculture in the Navsari District of Gujarat.

Dresdner and Estay (2016) analysed biosecurity versus profits and evolved a multi-objective model for the aquaculture industry. Of late, Kumar *et al.* (2016) made a detailed economic assessment of shrimp farming (*L. vannamei*) in the Gujarat state of India and found the farming as a profitable venture. Optimum use of potential areas and diversified farming practices have provided a tremendous opportunity to farmers residing along with coastal areas and brought them prosperity. Engle *et al.* (2017) discussed aspects of the economics of sustainable intensification of aquaculture and presented evidence from shrimp farms in Vietnam and Thailand. Nguyen and Jolly (2017) presented macro-economic and product challenges facing the Vietnamese pangasius industry. Rajarajan (2017) made an economic analysis of *L. vannamei* farming in Nagapattinam district of Tamil Nadu. Hartoyo *et al.* (2018) presented a risk and improvement strategy for shrimp production. Ranjith *et al.* (2018, 2019) investigated the economic and environmental aspects of pokkali rice- prawn production system in central Kerala. Shawon *et al.* (2018) investigated the financial profitability of small-scale shrimp farming in a coastal area of Bangladesh. Chaikaew (2019) studied the possibility of enhancing the ecological-economic efficiency of intensive shrimp farms through an in-out nutrient budget and feed conversion ratio. Shinji *et al.* (2019) conducted a bio-economic analysis of super-intensive closed shrimp farming and improved management plans. Durai *et al.* (2020) conducted an economic study of shrimp farming in the coastal districts of Tamil Nadu. The authors worked out the component-wise cost and the economics of shrimp farming practices. Nguyen *et al.* (2020) discussed the economic efficiency of extensive and intensive shrimp production under disease and natural disaster risks conditions. Nisar *et al.* (2021) made a comparative analysis of profitability and resource use efficiency between *P. monodon* and *L. vannamei* in India.

The review undoubtedly indicates that though there are studies on various aspects of the economics of farming shrimp under different conditions in different parts of the country and outside, very few of these studies have tried to evaluate the economics of the farming systems from a long-term perspective incorporating the negative externalities caused by such systems and the risks associated with them.

4.3. Material and Methods

The source of information for the present study was a survey carried out in the shrimp farming belt of Kerala *viz*., coastal areas of Thiruvananthapuram, Kollam, Alapuzha, Ernakulam, Thrissur, Malappuram, Kozhikkode, Kannur and Kasargod districts and the low-lying areas beside the Vembanad backwaters in Kottayam district.

Experience coupled with a preliminary survey revealed that two shrimp farming systems, *viz*., traditional shrimp farming (prawn filtration with or without supplementary stocking) and scientific farming, are in practice in Kerala. The traditional system of prawn farming is practised in the low lying coastal brackish water fields in Central Kerala and North Kerala. Scientific prawn farming is practised in all the districts mentioned above in the state. Data on the economics of farming were collected for each system separately. In scientific farming, data were collected separately for the three species *i.e.*, tiger prawn (*P. monodon*), Indian white prawn (*P. indicus*) and Pacific white prawn (*L. vannamei*)

A total of 162 farms undertaking traditional shrimp farming (prawn filtration farms with or without supplementary stocking) which formed 10.28% of the total traditional farms (with a water spread area of 845.32 ha.), and 58 farms undertaking scientific farming, which constituted 14.08% of the total scientific farms (with a water spread area of 268.45 ha) were selected. Data on aspects of interest were collected from the units chosen using an appropriately structured questionnaire which was pre-tested. The methodology adopted in the collection of data was discussed in detail in Chapter 2.

Data were collected for three consecutive crops from September 2015 to May 2018. Complete data were collected on various topics of interest in the present study by frequent visits and from the farm records. Before the beginning of collecting data on costs and returns, interviews were conducted with each farmer to determine their investment costs. Economics were worked out separately for traditional shrimp farming, scientific farming of tiger prawn (*P. monodon*), scientific farming of Indian white prawn (*P.indicus*) and scientific farming of Pacific white shrimp (*L. vannamei*).

Cost-return analysis, which is probably the most generally used method to understand the economic feasibility of aquafarming units, was adopted in the present study. It answers questions such as how much will it cost to start the farming, how much will it cost to operate the farm, what are the major cost items, is it profitable to invest in the aquaculture venture, what is the average cost of return to capital etc. as has been observed by Shang (1992).

The present study focused on the average costs and earnings for the farm units (for 1 ha) to determine the returns to capital. Profitability was examined from two points of view. First, return to the owner was arrived at by subtracting the fixed and operating costs from the owners' earnings and the balance treated as a return to owners' capital (Ovenden 1961). Second, the probable existence of pure profits (resource rents above all costs) was calculated by comparing returns to the capital with their respective opportunity costs (Panayotou 1981). This type of comparison reveals whether pure profits exist in the farming operation and whether there is scope to extend farming to redistribute the benefits. For example, if the returns to capital exceeds the opportunity costs of capital, it would be beneficial to increase the amount of capital employed in farming. If the inverse is found to be the case, the amount of capital in farming should be reduced, and the excess diverted to alternative buisinesses where they can earn more.

In the present study, annual depreciation on all items other than those like bird fencing material, harvesting nets, meshes, frames and sluice planks was calculated by the straight-line method considering the salvage value as zero and the useful life of the asset as ten years. The depreciation on items like bird fencing material, harvesting nets, meshes, frames and sluice planks was calculated at a 50% rate, as these items would stand only for two crops. The opportunity cost of capital for shrimp farming implies how much return the farmers would have gotten had they invested the money in some other alternative projects, *i.e.*, the forgone benefit that would have been derived from a business option not chosen. To arrive at a figure of the opportunity cost of capital is a difficult task. In the present study, the opportunity cost was computed as 7.5% per annum for the farming period (rate of interest for short term deposits in commercial banks at the study time). The survey showed that most farmers had taken loans from financial institutions and the loans are in various repayment stages. A decision was taken in the present study to include interest for the entire working capital in computing the profitability rather than the outstanding loan amount alone. The survey also showed that the farmers pay interest rates between 4 and 16% for the loan they took from the commercial banks and other financial institutions. So, in the present study, bank interest on borrowed capital was taken as 10%.

The rate of return was calculated by representing the residual return to the owner's capital as a percentage of the initial investment. The rate of return based on average investment costs to the present farming units was calculated as:

$$\text{Rate of return (\%)} = \frac{Residual\ return}{Investment} \text{X } 100$$

The economic viability of the scientific shrimp farming system was assessed by calculating the viability measures like Net Present Value (NPV) and Benefit-Cost Ratio (BCR). The costs and benefits were calculated per hectare basis and expressed in 2017 -2018 prices. The NPV and BCR were computed using the following formulae:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t}$$

Where B_t = Benefit in year t; C_t= Cost in year t; t = 1, 2, 3,……….., n; n= number of years and i= discount rate.

$$BCR = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+i)^t}}$$

In the present work, *n* is taken as 10 years.

The discount rate (*i*) is the rate of time preference. There have been many discussions related to the discount rate in the literature. India's current interest rate structure suggests that the interest rate of deposits (from 6 months to 2 years) in commercial banks ranges from 4.4% to 5%. Moreover, an estimation of social discount rate in the context of projects for agricultural development in India by Kula (Kula 2004) has suggested that a discount rate of 5.2% is appropriate for India. In most agricultural and livestock cost-benefit analyses, the Food and Agricultural Organization (FAO) adopted a discount rate varying from 8% to 15% (Acharya and Murray 1997; Shaw 2003). The opportunity cost of capital is often chosen as the discount rate for cost-benefit analysis (Farber 1993). In the context, in the present study, NPV and BCR were computed at both 5% and 8% discount rates, wherever applicable. The analysis primarily involved direct benefits of shrimp culture, *i.e.*, returns from shrimp culture in period *t*. However, in work, economic viability was judged with and without accounting for the imputed cost of production.

The internal rate of return (IRR) was also used to directly compare the various farming operations' profitability. The IRR is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis (De Ionno *et al.* 2006; Benninga 2008; Engle 2010). The IRR represents the maximum rate of interest that could be paid on all capital invested or the discount rate at which the annual return becomes zero or the farm breaks even. The algorithms available in the Excel software were used for calculating IRR.

Shrimp culture is subject to high financial risks. In general, it is believed that the higher the intensity, the higher would be the financial risk of shrimp farming (Bhattacharya 2009). The financial risk in shrimp culture stems from four main sources. They are - input factors (the price of postlarvae, water quality, availability of brood stock, credit, etc.), output factors (shrimp price, future supply to the market etc.), design factors (site selection, pond design etc.) and factors based in nature (naturally occurring risks such as shrimp diseases, typhoons, floods etc.) (World Bank 2000; Bhattacharya 2009; Gammanpila 2015). Among these factors, the decline in shrimp prices and the rise in the input cost is quite likely. In the present study, the risk was analysed by employing two methods, *i.e.*, sensitivity analysis and scenario analysis (Brigham and Houston 2004). Sensitivity analysis is used to understand the effect of changes in one input variable (for example, sale price of shrimp, fixed cost, variable cost or production quantity) at a time on the profitability of the farming. The present study attempted to accommodate such fluctuations assuming a 5, 10, 15 and 20% reduction in benefits (which can stem from a decrease in shrimp prices) and 5,10, 15 and 20% increase in production costs (fixed as well as variable costs). It also tried to identify the areas where a performance improvement may positively impact economic performance (Losordo and Westerman 1994). Such fluctuations were studied assuming a 5, 10, 15 and 20% increase in benefits and 5,10, 15 and 20% decrease in costs of production (fixed and variable costs). The sensitivity analysis results for principal costs and sale price were displayed on sensitivity plots, which plots the safety factor (NPVs) against the per cent change in the input variables (variable cost, fixed cost and sale price). It helps to understand the extent of the impact of fluctuations in costs and sales price on the profitability of different shrimp farming operations. On a sensitivity plot, the gradient of a curve for a parameter indicates the effect that parameter has on safety. Steeper (rising or falling) curves show a more significant influence on the factor of safety. A relatively "flat" curve indicates that a variable has little effect on the factor of safety. A completely flat curve shows that the variable has no impact on the safety factor (within the specified range of the variable).

The levels up to which the cost of production or the sale price can change so that the NPV remains positive were also estimated in the present work. The levels were computed by employing the Generalized Reduced Gradient (GRG) method. This method looks at the gradient or slope of the objective function as the input values (or decision variables) change. It determines that it has reached an optimum solution when the partial derivatives equal zero. The GRG method proposed by Lasdon *et al.* (1978) is one of the most popular methods to solve problems of nonlinear optimisation, as has been observed by Chapra and Canale (2009), requiring only that the objective function is differentiable. The principal objective of this method is to solve the nonlinear problems that deal with functional inequalities. The variables were separated into a set of basic (dependent) variables and non-basic (independent) variables. Then, the reduced gradient was computed to find the minimum in the direction of the search. This process was repeated until convergence was obtained (Venkataraman 2009).

The scenario analysis was used to evaluate the impact of changes in the input of more than one variable (variable cost, quantity of shrimp produced and the sale price of shrimp) while looking at the very optimistic, optimistic, normal, pessimistic and very pessimistic conditions. In sensitivity analysis, since variation in the fixed cost of production was found not to impact the profitability significantly, the fixed cost has not been evaluated in scenario analysis. The farming operations were evaluated under the different scenarios as given in Table 4.1. An attempt was made to develop scenarios in which the values of variables were internally consistent. The objective of such scenarios was to get an idea about what happens under the favourable or adverse configuration of key variables.

Table 4.1. Different scenarios for performance evaluation.

Scenario	Favourable/ adverse variables
Very optimistic scenario	10% increase in sales price, 10% increase in quantity of shrimp harvested and 10% decrease in variable cost.
Optimistic scenario	5% increase in sales price, 5% increase in quantity of shrimp harvested and 5% decrease in variable cost.
Base case scenario	Normal scenario
Pessimistic scenario	5% decrease in sales price, 5% decrease in quantity of shrimp harvested and 5% increase in variable cost.
Very pessimistic scenario	10% decrease in sales price, 10% decrease in quantity of shrimp harvested and 10% increase in variable cost.

The frequent outbreak of shrimp diseases is another source of financial risk in shrimp farming. The risk of disease outbreaks depends on the quality of shrimp seed used and the pond management practices. In the states like Kerala, there are many reasons for shrimp diseases. The main problem is that Kerala is dependent on other states for shrimp seed supply, and there is no proper mechanism to assure the quality of the seeds. Seeds have to undergo long-distance travel prior to stocking, which may make them weak and prone to diseases. Shrimp output should be adjusted with the incidence of disease occurrence in the analysis of the economic viability of shrimp farms. In the instant case, to account for the incidence of disease in the analysis of the economic viability of shrimp farms, shrimp output was adjusted as given below.

Let Yi be the shrimp output for the i^{th} shrimp farmer (i=162 for the traditional farming system and i= 58 for the scientific farming system). Pi is the probability of disease occurrence for the i^{th} shrimp farmer. Pi indicates the number of times of disease occurrence in the past five years. In the present study, it was calculated as the ratio of the number of years in which the shrimp farmer faced disease divided by five if the farmer had five or more years of experience.

In the case of the shrimp farmer who had less than five years' experience in shrimp farming, Pi was calculated as the number of incidences of disease occurrence out of total years of farmers' experience in shrimp culture. It is, in fact, the ratio of the number of years in which the shrimp farmer faced disease to the number of years of experience in farming. Thus, the i^{th} farmer's expected shrimp output is $Yi\ (1\text{-}Pi) + (1\text{-}\ a)\ Yi\ Pi$.

Where a is the proportion of loss of total shrimp output due to disease. The value of a could not be estimated precisely due to the lack of scientific data. As most scientific shrimp farmers have a single crop and a single harvest in a year, a was taken as one in the present study. This means a complete crop loss once the disease affects the pond.

In traditional farming, there are multiple cropping and harvesting systems depending on the tides. Thus, even if the disease loses one crop, a new crop can be initiated in the next high tide after disposing of the disease-affected shrimps and treating the pond soil and water. So, even if a farmer confronts a disease outbreak in a year, the entire yearly output would not be lost. It was assumed that a traditional shrimp farmer who had experienced a disease outbreak in a year lost 50% of the annual shrimp output (a= 0.5).

Following the framework mentioned above, the present research work also tried to judge the profitability of the various shrimp culture systems, in the long run, taking into account the most critical risk factor *viz.*, the risk of disease outbreak.

4.4. Results

Information on various aspects of the economics of traditional and scientific shrimp farming is provided below. In scientific farming, data were collected for tiger prawn, Indian white prawn and Pacific white prawn separately.

Data on the average initial investment required for traditional prawn farming is provided in Table 4.2. The details of the working capital requirement of traditional prawn farming are provided in Table 4.3, and those on annual costs and earnings are provided in Table 4.4. Details of average initial investment for scientific prawn farming is provided in Table 4.5, and those on working capital requirement are provided in Table 4.6. Information on annual costs and earnings of scientific prawn farming are provided in Table 4.7.

Table 4.2. Initial investment required for traditional shrimp farming (per hectare)[1].

Sl. No.	Items	Amount (Rs)[2]
1.	Machinery (diesel engine, pump)	20600
2.	Bird fencing	20100
3.	Meshes, frames, sluice planks, harvesting nets etc.	20400
	Total	**61100**

[1]Land cost not considered.
[2]Average rounded off to the nearest hundred Rupees.

Table 4.3. Working capital required for traditional shrimp farming (per hectare)[1].

Sl. No.	Items	Amount (Rs)[2]
1.	Lease rent	42000
2.	Pond renovation (Repair of bunds, sluice gates, temporary farm house etc.)	20100
3.	Annual license fee	500
4.	Lime and fertilizers	4800
5.	Cost of supplementary stocking of seed (including transportation and seed stocking expenses)	11000
6.	Supplementary feeds	30000
7.	Wages	90000
8.	Fuel/ electricity	6300
9.	Harvesting expenses	9900
10.	Miscellaneous	9200
	Total	**223800**

[1]Crop duration is six months
[2]Average rounded off to the nearest hundred Rupees

Table 4.4. Annual costs and earnings of traditional shrimp farming (per hectare)[1,2].

Sl. No.	Items	Amount (Rs)
A.	**Fixed cost**	
1.	Lease rent	42000
2.	Pond renovation (repair of bunds, sluice gates, temporary farm house etc.)	20100
3.	Depreciation	22310
4.	Annual license fee	500
5.	Interest expenses	11190
	Total fixed cost	96100
B.	**Variable cost**	
1.	Lime and fertilizers	4800
2.	Cost of supplementary stocking of seed (including transportation and seed stocking expenses)	11000
3.	Supplementary feeds	30000
4.	Wages	90000
5.	Fuel/ electricity	6300
5.	Harvesting expenses	9900
6.	Miscellaneous	9200
	Total variable cost	161200
C.	**Total cost of production**	257300
D	**Revenue**	
	Sale of 881.4 kg of shrimp, 216 kg of finfishes and 19.6 kg of crabs	259579
E.	**Residual return to owner's capital**	2279
F.	**Rate of return (%)**	**3.73**

[1]Land cost not included
[2]Crop duration is six months

Table 4.5. The initial investment for scientific shrimp farming (per hectare)[1].

Sl. No.	Items	Amount (Rs)[2]		
		Tiger prawn	Indian white prawn	Pacific white prawn
1	Pond construction	299600	240100	350400
2	Sluice gates, farm house	169800	147300	264500
3	Engine with pump	50400	25200	75100
4	Aerators	24300	-	103000
5	Generator	45000	-	76000
6	Cables, other accessories	21300	-	46100
7	Bird and crab fencing	44400	20200	74100
8	Sluice planks, meshes, check trays, cat walk harvesting nets etc.	30200	20700	35900
9	Miscellaneous	14600	5500	14900
	Total	**699600**	**459000**	**1040000**

[1]Land cost not included
[2]Average rounded off to the nearest hundred Rupees

Table 4.6. Working capital required for scientific shrimp farming (per hectare)[1].

Sl. No.	Items	Amount (Rs)[2]		
		Tiger prawn	Indian white prawn	Pacific white prawn
1.	Annual license fee	500	500	500
2.	Pond renovation (repair and maintenance of bunds, levelling, slopping of the pond bottom, tilling etc.)	10500	5700	15100
3.	Pond preparation (basal liming, fertilization, wash application, chlorination, eradication of weed and predatory fishes, water culture etc.)	21400	6100	28500
4.	Agriculture lime, dolomite, probiotics, zeolite, oxygen enhancer, minerals etc.	16100	7400	74300
5.	Seed and seeding (including testing of seed, transportation of seed etc)	25700	8100	166000
6.	Feed and feed supplements	146300	35200	622500
7.	Wages	75000	35000	120000
8.	Fuel	27800	6700	141000
9.	Harvesting	10500	9100	20800
10.	Miscellaneous	11100	5400	17600
	Total	**344900**	**119200**	**1206300**

[1]Crop duration is four months
[2]Average rounded off to the nearest hundred Rupees

Table 4.7. Annual costs and earnings of scientific shrimp farming (per hectare)[1,2].

Sl. No.	Items	Amount (Rs)		
		Tiger prawn	Indian white prawn	Pacific white prawn
A.	**Fixed cost**			
1.	Pond renovation (repair and maintenance of bunds, levelling, slopping of pond bottom, tilling etc.	10500	5700	15100
2.	Depreciation	99800	62260	148000
3.	Interest expense	11497	3973	40210
4.	License fee	500	500	500
	Total fixed cost	**122297**	**72433**	**203810**
B.	**Variable cost**			
1.	Pond preparation (basal liming, fertilization, application of wash, chlorination, eradication of weed and predatory fishes, water culture etc.)	21400	6100	28500
2.	Agriculture lime, dolomite, probiotics, zeolite, oxygen enhancer, minerals etc.	16100	7400	74300
3.	Seed and seeding (including testing of seed, transportation of seed etc)	25700	8100	166000

4.	Feed and feed supplements	146300	35200	622500
5.	Wages	75000	35000	120000
6.	Fuel	27800	6700	141000
7.	Harvesting	10500	9100	20800
8.	Miscellaneous	11100	5400	17600
	Total variable cost	333900	113000	1190700
C.	**Total cost of production**	**456197**	**185433**	**1394510**
D.	**Revenue**			
	Total revenue (Sale of shrimp)	512600	212200	1526600
E.	**Residual return to owner's capital**	**56403**	**26767**	**132090**
F.	**Rate of return (%)**	**8.06**	**5.83**	**12.70**

[1]Land cost not included
[2]Crop duration is four months

Returns to capital, opportunity cost and pure profit of traditional and scientific prawn farming units are presented in Fig. 4.1. Information on average costs (average fixed cost, average variable cost and average total cost) and revenue per kilogram of shrimp produced/ farm output in different shrimp farming systems are provided in Fig. 4.2. Since harvests of traditional shrimp farms consist of a mix of different species of finfishes and shellfishes average costs and revenue per kilogram of farm output represent those of shrimps, crabs and finfishes combined. In all other cases, they represent those of shrimp only. Net Present Value (NPV) and Benefit-Cost Ratio (BCR) of the different systems of shrimp farming are provided in Table 4.8 and 4.9, respectively. The Internal Rate of Return (IRR) of different systems of shrimp farming are provided in table 4.10. Sensitivity analyses of different variables on NPV of the different shrimp farming systems, with and without considering the opportunity cost (OC), are provided in Fig. 4.3, 4.4, 4.5, 4.6. 4.7. 4.8, 4.9 and 4.10.

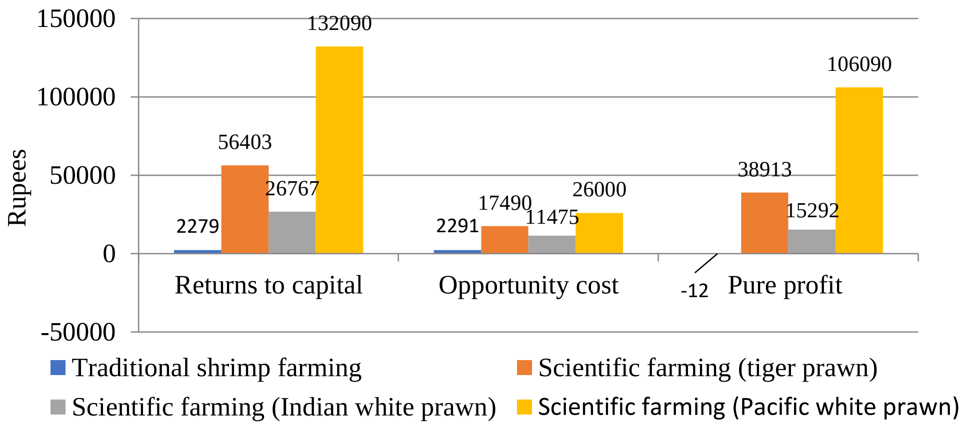


Figure 4.1. Returns to capital, opportunity cost and pure profit in different systems shrimp farming (per hectare).

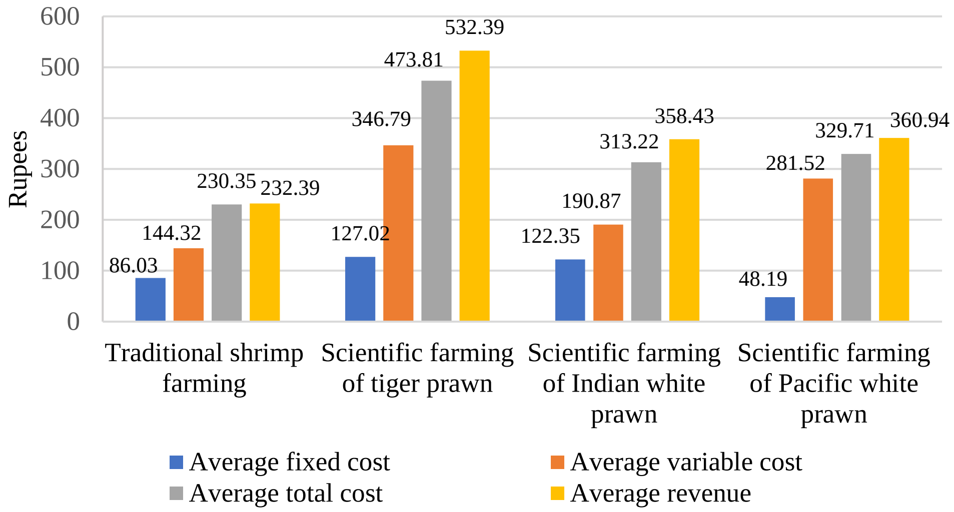


Figure 4.2. Average costs and revenue (per kilogram of shrimp produced / farm output) in different systems of shrimp farming.

Table 4.8. Net Present Value (NPV) of different systems of shrimp farming*.

System of shrimp farming	Net Present Value (NPV)			
	Excluding opportunity cost		Including opportunity cost	
	At 5% discount rate	At 8% discount rate	At 5% discount rate	At 8% discount rate
Traditional shrimp farming	1081.88	(-7999.50)	(-16608.62)	(-23372.30)
Scientific farming of tiger prawn	271360.27	142429.43	136307.13	25070.11
Scientific farming of Indian white prawn	99493.92	25379.60	10887.01	(-51618.58)
Scientific farming of Pacific white prawn	775974.20	535517.91	575209.09	361055.79

*Cash flows were summed up for ten years at 2017- 2018 prices.

Table 4.9. Benefit-Cost Ratio (BCR) of different systems of shrimp farming*.

System of shrimp farming	Benefit- Cost Ratio (BCR)			
	Excluding opportunity cost		Including opportunity cost	
	At 5% discount rate	At 8% discount rate	At 5% discount rate	At 8% discount rate
Traditional shrimp farming	1.02	0.87	0.73	0.62
Scientific farming of tiger prawn	1.39	1.20	1.19	1.04

Scientific farming of Indian white prawn	1.22	1.06	1.02	0.89
Scientific farming of Pacific white prawn	1.75	1.51	1.55	1.35

*Project duration considered was ten years.

Table 4.10. Internal Rate of Return (IRR) of different systems of shrimp farming.

System of shrimp farming	Internal Rate of Return (IRR) %	
	Excluding opportunity cost	Including opportunity cost
Traditional shrimp farming	5.32	(-0.03)
Scientific farming of tiger prawn	12.28	8.78
Scientific farming of Indian white prawn	9.20	5.48
Scientific farming of Pacific white prawn	18.35	15.14

* Project duration considered was years.

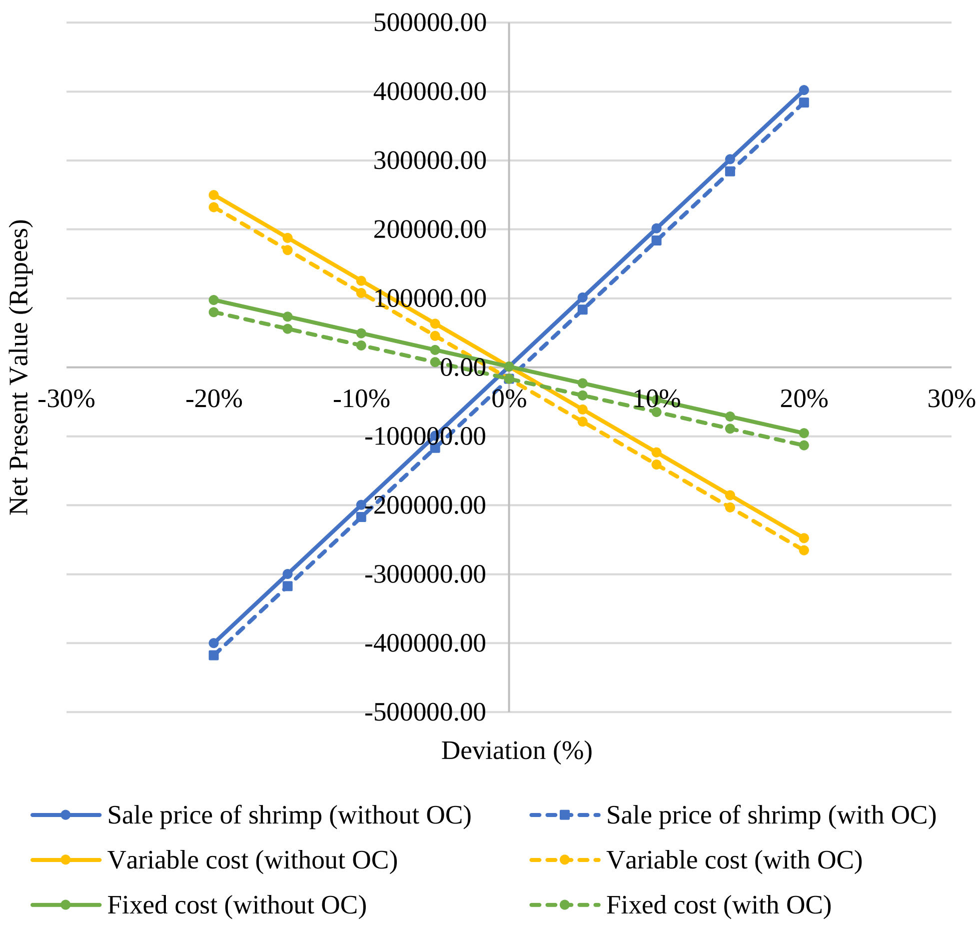


Figure 4.3. Sensitivity analysis of traditional shrimp farming (at 5% discount rate).

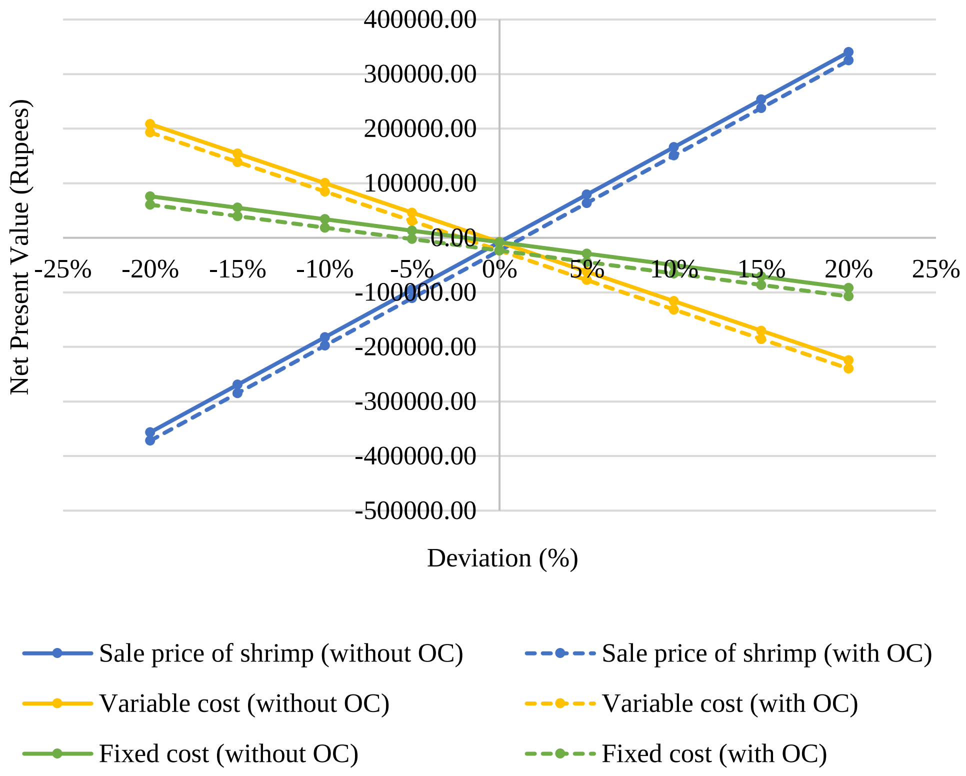


Figure 4.4. Sensitivity analysis of traditional shrimp farming (at 8% discount rate).

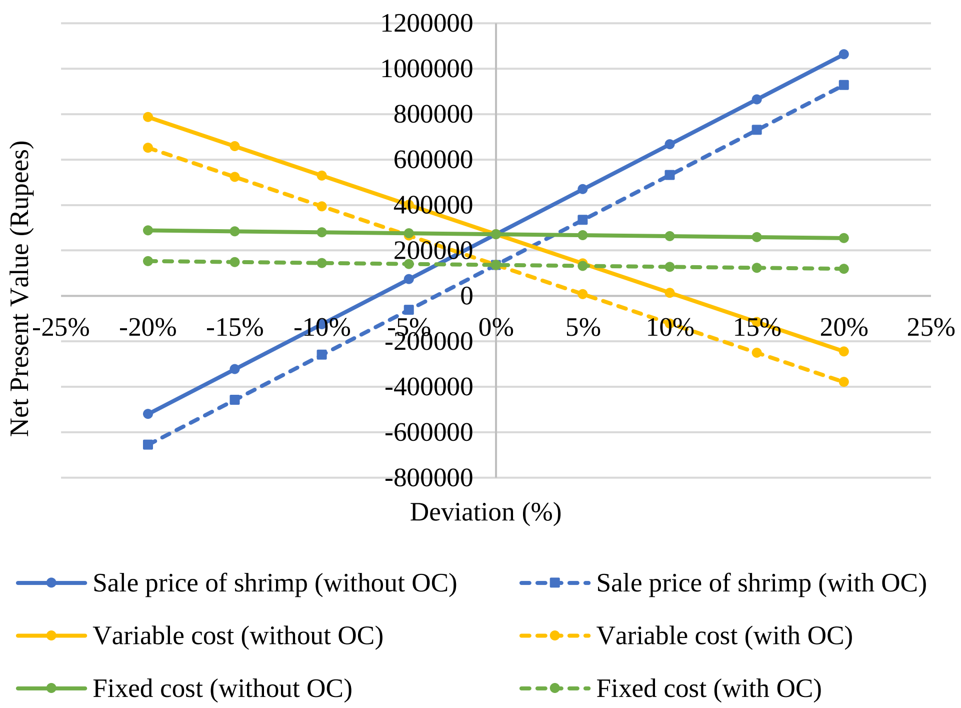


Figure 4.5. Sensitivity analysis of scientific farming of tiger prawn (at 5% discount rate).

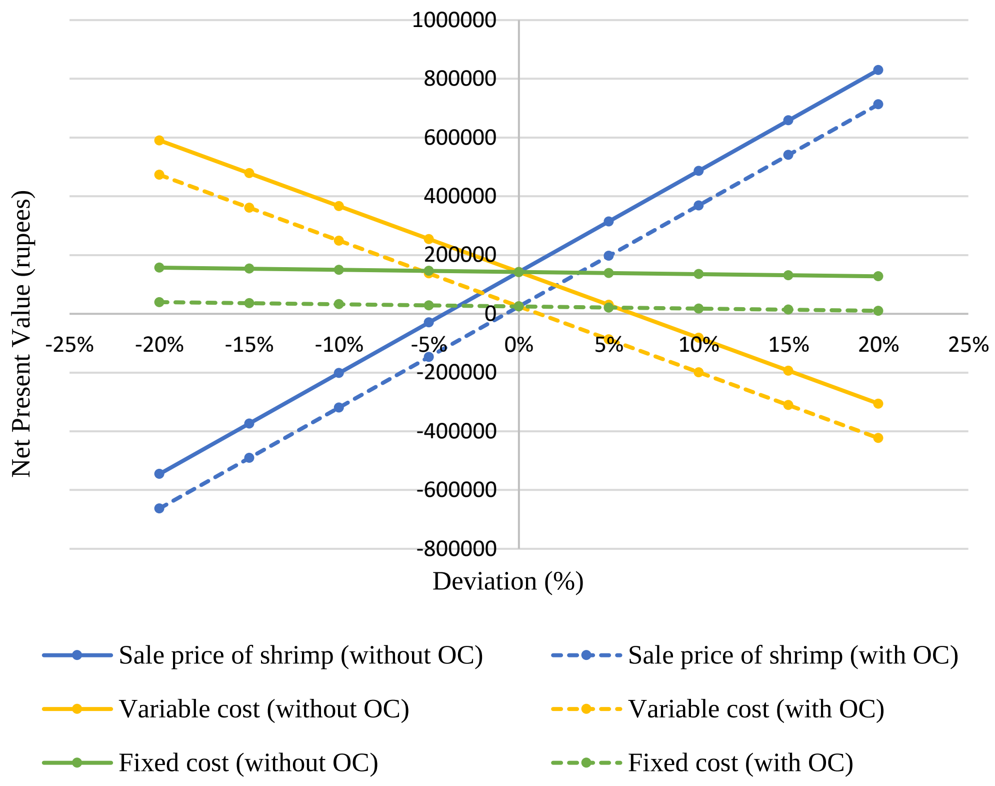


Figure 4.6. Sensitivity analysis of scientific farming of tiger prawn (at 8% discount rate).

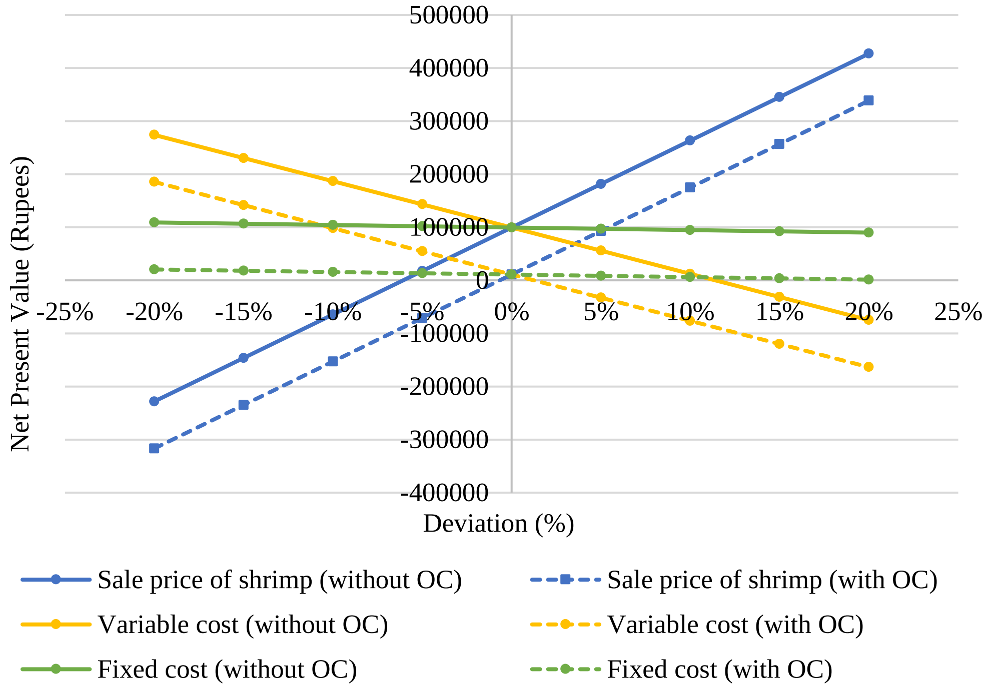


Figure 4.7. Sensitivity analysis of scientific farming of Indian white prawn (at 5% discount rate).

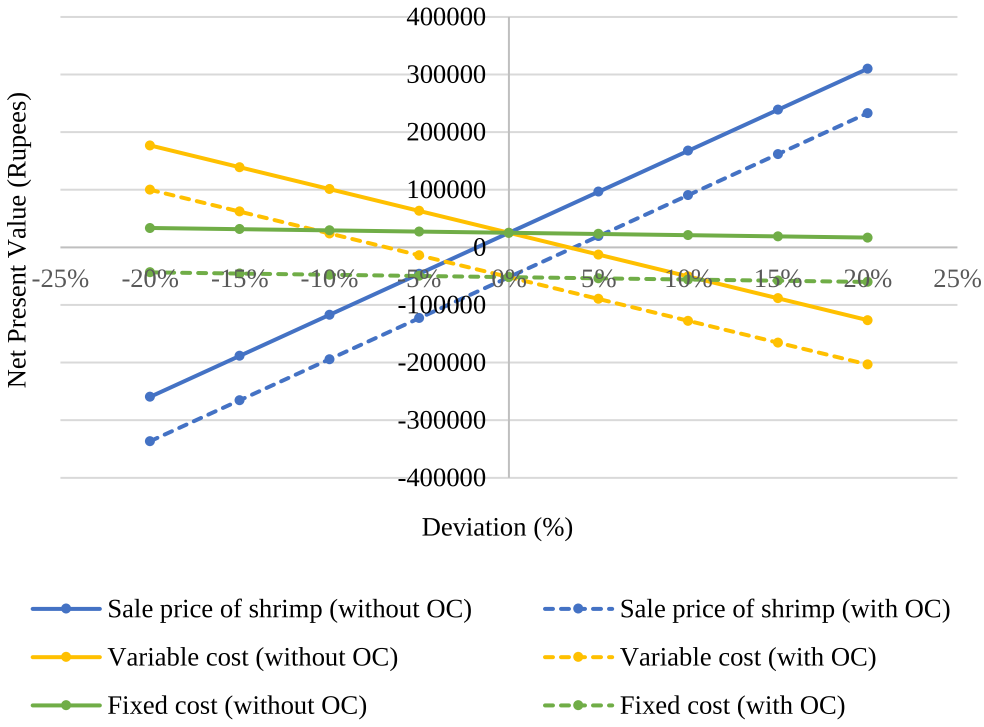


Figure 4.8. Sensitivity analysis of scientific farming of Indian white prawn (at 8% discount rate).

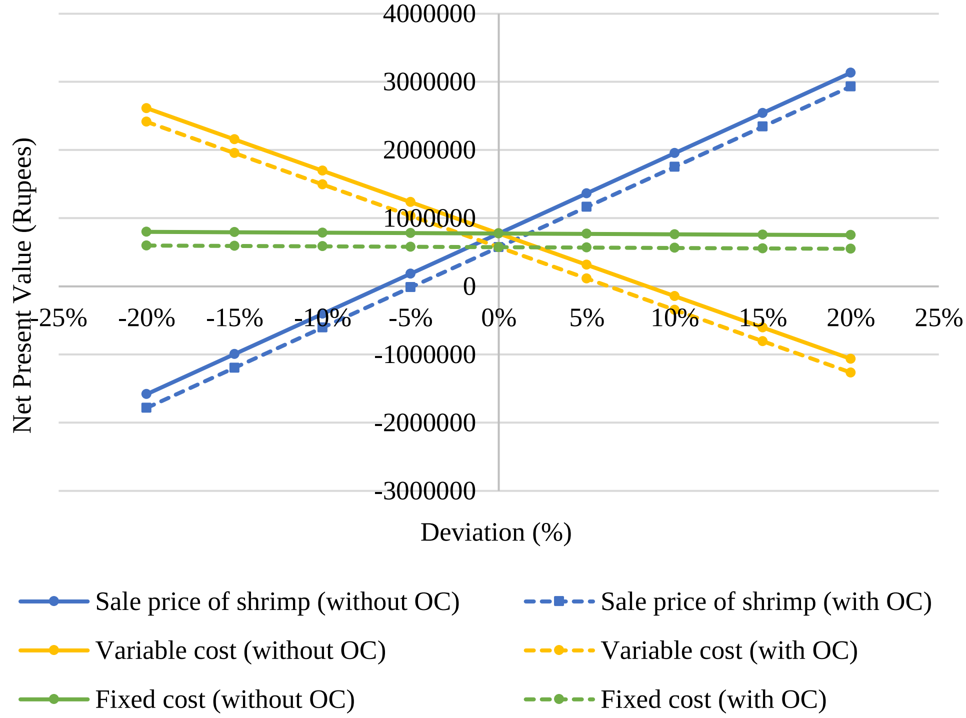


Figure 4.9. Sensitivity analysis of scientific farming of Pacific white prawn (at 5% discount rate).

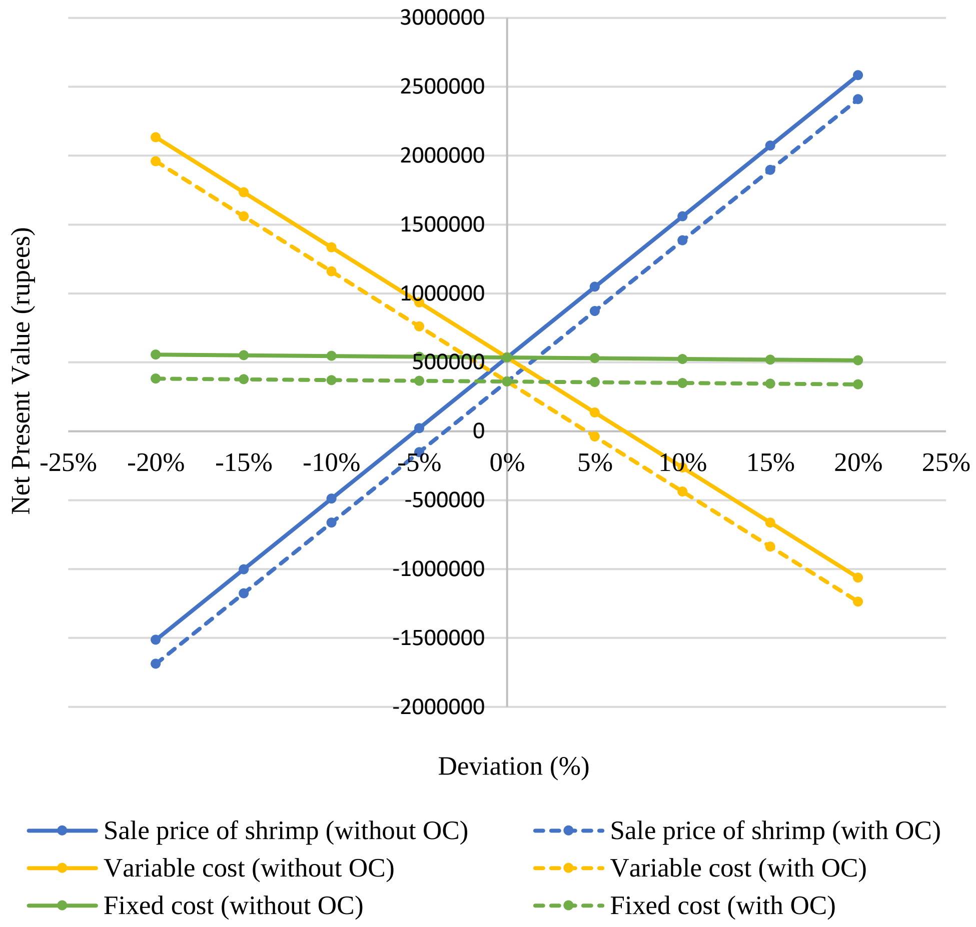


Figure 4.10. Sensitivity analysis of scientific farming of Pacific white prawn (at 8% discount rate).

Results of sensitivity analysis to estimate the per cent level up to which the sales price of shrimp and the cost of production can change while maintaining the NPV positive in different shrimp farming systems is provided in Table 4.11.

Table 4.11. Sensitivity analysis: the per cent level up to which the sales price and the costs of production of shrimp can change while maintaining the NPV positive in different systems of shrimp farming[1].

Situation	Level above which the Net Present Value (NPV) remains positive (%)			
	Excluding opportunity cost		Including opportunity cost	
	At 5% discount rate	At 8% discount rate	At 5% discount rate	At 8% discount rate
Traditional shrimp farming				
Sales price	(-0.05)	0.46	0.83	1.34

Variable cost	0.09	(-0.74)	(-1.33)	(-2.16)
Fixed costs	0.22	(-1.90)	(-3.44)	(-5.56)
Scientific farming of tiger prawn				
Sales price	(-6.86)	(-4.14)	(-3.44)	(-0.73)
Variable costs	10.52	6.36	5.29	1.12
Fixed costs	319.48	192.97	160.48	33.97
Scientific farming of Indian white prawn				
Sales price	(-6.07)	(-1.78)	(-0.66)	3.63
Variable costs	11.40	3.35	1.25	(-6.81)
Fixed costs	207.82	61.00	22.74	(-124.08)
Scientific farming of Pacific white prawn				
Sales price	(-6.58)	(-5.23)	(-4.88)	(-3.52)
Variable costs	8.44	6.70	6.26	4.52
Fixed costs	644.18	511.59	477.51	344.92

Different scenarios of variable cost, the quantity of shrimp produced and the sale price of shrimp and their impact on NPV in different shrimp farming systems are provided in Table 4.12. NPV of different shrimp farming systems considering disease adjusted output is presented in Table 4.13.

Table 4.12. Different scenarios of variable cost, the quantity of shrimp produced and the sale price of shrimp on Net Present Value (NPV) of different systems of shrimp farming.

	Scenario				
	Base case	Very optimistic	Optimistic	Pessimistic	Very pessimistic
Changing cells					
Variable cost	100%	90%	95%	105%	110%
Quantity of shrimp produced	100%	110%	105%	95%	90%
Sale price of shrimp	100%	110%	105%	95%	90%
Result cells					
Traditional shrimp farming					
Without opportunity cost (NPV in Rupees thousand)					
5% discount rate	1.08	546.48	268.77	(-256.58)	(-504.23)
8% discount rate	(-8.00)	465.94	224.62	(-231.91)	(-447.11)

With opportunity cost (NPV in Rupees thousand)					
5% discount rate	(-16.61)	528.79	251.08	(-274.27)	(-521.92)
8% discount rate	(-23.37)	450.57	209.25	(-247.28)	(-462.48)
Scientific farming of tiger prawn					
Without opportunity cost (NPV in Rupees thousand)					
5% discount rate	271.36	1360.40	805.99	(-243.47)	(-738.52)
8% discount rate	142.43	1088.79	607.01	(-304.96)	(-735.14)
With opportunity cost (NPV in Rupees thousand)					
5% discount rate	136.31	1225.35	670.93	(-378.53)	(-873.57)
8% discount rate	25.07	971.43	489.65	(-422.31)	(-852.50)
Scientific farming of Indian white prawn					
Without opportunity cost (NPV in Rupees thousand)					
5% discount rate	99.49	530.85	311.07	(-103.89)	(-299.09)
8% discount rate	25.38	400.22	209.24	(-151.36)	(-320.98)
With opportunity cost (NPV in Rupees thousand)					
5% discount rate	10.89	442.24	222.47	(-192.50)	(-387.69)
8% discount rate	(-51.62)	323.22	132.24	(-228.36)	(-397.98)
Scientific farming of Pacific white shrimp					
Without opportunity cost (NPV in Rupees thousand)					
5% discount rate	775.97	4170.88	2443.96	(-833.07)	(-2383.17)
8% discount rate	535.52	3485.65	1984.97	(-862.72)	(-2209.74)
With opportunity cost (NPV in Rupees thousand)					
5% discount rate	575.21	3970.12	2243.19	(-1033.83)	(-2583.94)
8% discount rate	361.06	3311.18	1810.51	(-1037.18)	(-2384.20)

[1] Project duration considered was ten years

Table 4.13. Net Present Value (NPV) of different systems of shrimp farming considering disease adjusted output[1,2].

System of shrimp farming	Net Present Value (NPV) in Rupees thousand			
	Excluding opportunity cost		Including opportunity cost	
	At 5% discount rate	At 8% discount rate	At 5% discount rate	At 8% discount rate
Traditional shrimp farming	(-491.40)	(-435.96)	(-509.09)	(-451.33)
Scientific farming of tiger prawn	(-1662.20)	(-1537.81)	(-1797.25)	(-1655.17)
Scientific farming of Indian white prawn	(-700.94)	(-670.19)	(-789.55)	(-747.18)
Scientific farming of Pacific white prawn	(-4982.46)	(-4468.49)	(-5183.23)	(-4642.95)

[1] Project duration considered was ten years.
[2]The probability of disease occurrence (*Pi*) was estimated as 0.4914 in the case of traditional shrimp farming and 0.4885 in the case of scientific shrimp farming.

4.5. Discussion

Entry into traditional shrimp farming requires a relatively low initial investment. On average, a one-hectare traditional farm unit requires Rs. 61,100 as the initial investment. Scientific shrimp farming (at the level of farm management intensity adopted in the state) requires higher initial investments (tiger prawn farming: Rs. 6,99,600 ha^{-1}, Indian white prawn farming: Rs. 4,59,000 ha^{-1} and Pacific white prawn farming: Rs. 10,40,000 ha^{-1}). Certain fixed costs are incurred whether the shrimp farms operate or not because they relate to "sunk" capital investment which cannot be regained without undue loss. In the case of traditional shrimp farming, fixed costs consist of lease rent (43.70%), depreciation of the farm assets (23.22%), pond renovation charges (20.92%), interest on working capital (11.64%) and the license fee (0.52%). In scientific shrimp farms, depreciation of the farm assets (tiger prawn farming: 81.60%, Indian white prawn farming: 85.96% and Pacific white prawn farming: 72.62%), interest on working capital (tiger prawn farming: 9.40%, Indian white prawn farming: 5.49% and Pacific white prawn farming: 19.73%), pond renovation charges (tiger prawn farming: 8.59%, Indian white prawn farming: 7.86% and Pacific white prawn farming: 7.41%), and the license fee (tiger prawn farming: 0.41%, Indian white prawn farming: 0.69% and Pacific white prawn farming: 0.25%) constituted the fixed costs. The average annual depreciation per hectare of traditional shrimp farming units was Rs. 22,310. In the case of scientific farming, depreciation amounted to Rs 99,800, 62,260 and 1,48,000 respectively for tiger prawn, Indian white prawn and Pacific white prawn. Depreciation is a decline in the value of an asset over time, due in particular to wear and tear. These amounts must be reserved for the eventual replacement of assets after they wear out. Earnings from farming must be high enough to cover the fixed costs in addition to the operating costs if farming is to sustain in the long run.

Operating costs such as pond preparation charges, cost of lime, fertilizers, seed, feed, fuel, wages, harvesting expenses and other cash costs vary with the level of output and are hence considered variable costs. It may be interesting to observe that the largest component of the variable cost in the case of traditional farming was wages to labourers (55.83%) followed in order by supplementary feed (18.61%), cost of seed (6.82%), harvesting expenses (6.14%), cost of fuel and electricity (3.91%) and cost of lime and fertilizers (2.98%). Miscellaneous expenditures accounted for 5.70%. In the case of scientific farming of tiger prawn, the various components of variable cost in the order of magnitude were cost of feed and feed supplements (43.82%), wages (22.46%), cost of fuel (8.32%), cost of seed and seeding (7.70%), pond preparation charges (6.41%), cost of agri-lime and related items (4.82%), and expenses for harvesting (3.14%). Miscellaneous expenditures accounted for 3.32%.

In the case of scientific farming of Indian white prawn, the various components of variable cost in the order of importance were cost of feed and feed supplements (31.15%), wages (30.97%), harvesting expenses (8.05%), cost of seed and seeding (7.17%), cost of agri-lime and related items (6.55%), cost of fuel (5.93%) and pond preparation charges (5.40%). Miscellaneous expenses accounted for 4.78%. In scientific farming of Pacific white prawn, the cost of feed and feed supplements accounted for more than half of total variable cost

(52.28%), followed by the cost of seed and seeding (13.94%), cost of fuel (11.84%), wages (10.08%), cost of agri-lime and related items (6.24%), pond preparation charges (2.39%) and expenses for harvesting (1.75%). (1.25%). Here miscellaneous expenditures accounted for 1.48%.

It is worth mentioning here that though the above information on cost components is valuable to understand the relative importance of each in a particular farming system, comparison of different costs among the different systems of farming is not relevant as the cost components and their relative magnitude vary very much depending upon the stocking density, level of management intensity and the final harvest intended.

It is necessary to deduct the total cost from the revenue to determine the annual residual return to the owner's capital. This averaged Rs. 2,279, Rs. 56,403, Rs. 26,767 and Rs. 1,32,090 for traditional shrimp farming and scientific farming of tiger prawn, Indian white prawn and Pacific white prawn, respectively. When the opportunity cost of capital was deducted from the residual return to capital, traditional prawn farming units were found to incur an average pure loss of Rs. 12. However, scientific farming of tiger prawn, Indian white prawn and Pacific white prawn registered a pure profit of Rs. 38,913, Rs. 15,292 and Rs. 1,06,090, respectively, after accounting for the opportunity cost. Though not incurred, opportunity costs are fundamental costs in economics and are used in computing the cost-benefit analysis of a project. Such costs are generally not recorded in the account books but are considered in financial decision making by calculating the cash outlays and their resulting profit or loss. It gives an idea about the gain or loss on investment for the farming period. Investment in economic activity may be justified only if it can generate sufficient income to offset its opportunity cost.

It may be interesting to observe that the average total cost for producing a unit weight (kilogram) of shrimp is the highest for tiger prawn followed in order by Pacific white prawn and Indian white prawn. It is the lowest for traditional farming. However, it must be remembered that in the case of traditional farming, the output consists of finfishes and crabs in addition to shrimps. The average fixed cost and average variable cost for producing a unit weight of shrimp are the highest in the case of tiger prawn. However, the higher cost is more than offset by the higher average price realised per kilogram of shrimp in the case of the tiger prawn. Another interesting observation is that in the case of Pacific white prawn, the average variable cost and total cost of production per kilogram of shrimp harvested is the second-highest while its average fixed cost per kilogram shrimp is the lowest of all; even less than that of traditional farming. On the other hand, in the case of the Indian white prawn, the average fixed cost per kilogram shrimp produced is the second-highest while its average total cost and average variable cost are the second-lowest.

The NPV of the traditional shrimp farming operation is positive at a 5% discount rate if the opportunity cost is not considered. However, at an 8% discount rate, the NPV is negative even when the opportunity cost of the initial investment is not considered. If the opportunity cost of initial investment is taken into account, even at a 5% discount rate, traditional shrimp farming results in a negative NPV. NPV are higher in the case of scientific prawn farming compared to traditional shrimp farming. In scientific farming, the highest NPV is noticed in the case of farming of Pacific white prawn followed in order by the tiger prawn and the Indian white prawn, at all rates of discount studied and with and without considering the opportunity cost. But it may be seen that the NPV of farming of Indian white prawn is negative when the opportunity cost is taken into account, at an 8% discount rate. It may be observed here that the computation of NPV in all cases is based on cash flows for 10 years.

Net Present Value is the present value of the cash flows at the required rate of return of the farming operation compared to the initial investment. In other words, it is the present value of future revenues minus the present value of future costs. In practical terms, it gives an idea about the return on investment or expenditure. It is an index of wealth creation relative to the discount rate. By looking at all of the money the farmer expects to make from the investment and translating those returns into today's money, he can decide whether farming is worthwhile to pursue. It also provides a concrete idea that farmers can adopt to easily compare an initial outlay of cash against the present value of the return. A negative NPV in farming means that the present value of the costs exceeds the present value of the revenues at the assumed discount rate.

So, it makes sense to bring down the cost of production, looking for opportunities to economize and increase the level of revenue seeking potential enhancements. It may be concluded that an investment with a negative NPV will result in a net loss. On the other hand, a positive net present value indicates that the projected earnings generated by the farming activity - in present money terms- exceeds the anticipated costs, also in present money terms. According to the net present value theory, investing in a farming activity that has a net present value greater than zero should logically increase the farmer's earnings. A farmer may also participate in a farming activity with neutral NPV when it is associated with future intangible and currently immeasurable benefits or where it enables ongoing investments to happen. Going by the theory mentioned above, it may be inferred that at the level of management intensity practised at present in Kerala, farming of pacific white prawn is the most profitable option for farmers, followed in order by the farming of tiger prawn and that of white prawn. However, it must be remembered that such a comparison may be approached with reservation as there is a huge difference in the intensity of farm management among the different systems of farming in Kerala. To be meaningful and fool proof, the comparison of results of farming of the different species at the same or similar level of management intensity is to be ensured. Before adopting a system, the difference in the level of initial investment required for the different farming systems is also to be reckoned with. Another inference that emerges is that traditional shrimp farming, though profitable at present, will be less so in the long run. It corroborates the precarious position of this farming activity which was already revealed based on the estimation of pure profit in the present work.

The BCR of traditional shrimp farming operation is above one only at 5% discount rates, when the opportunity cost is not considered. However, it is less than one at an 8% discount rate even when the opportunity cost is not included. Again, it is less than one even at a 5% rate of discount when the opportunity cost is taken into account. In general, BCRs are higher in the case of scientific shrimp farming at all rates of discount studied and with or without considering the opportunity cost, obviously because of the higher net profit realised. In scientific farming, the highest BCR was noticed in the case of farming of Pacific white prawn followed in order by the tiger prawn and the Indian white prawn, at all rates of discount studied and with and without considering the opportunity cost. But the BCR is less than one in the farming of Indian white prawn at an 8% discount rate when the opportunity cost is taken into account. A value of BCR above one indicates that the discounted benefits exceed the present value of the costs and investments. The general rule is that the higher the BCR, the greater the profit a farming option or project is expected to generate.

However, one must remember that apart from the benefit-cost ratio, there are other important quantitative and qualitative considerations to base upon rather than relying on the BCR only. The BCR is typically used for cost-benefit analyses, along with other measures such as the NPV, return on investment etc. The result of the NPV calculation is one single figure that represents the expected net value of all costs and benefits without giving an idea of the volume and the relation of the underlying gross cash flows. The BCR can be used to supplement this missing link of information. Representing the ratio of discounted benefits to discounted costs, it is a relative measure of whether and to what extent the present value of the benefits exceeds that of the investments and cost. For instance, a shrimp farmer could be working on a cost-benefit analysis of different farming options that may involve products or results with differences in their profit margins. While the NPV is based on the net amount of these margins, the BCR would be greater for a project with lower investments and costs and higher benefits and revenues, regardless of the net amounts. The ratio helps interpret the inherent risks of forecasted net cash flows and profitability. It considers the value of cash flows concerning the time of their occurrence. But one must consider the fact that BCR is subject to various assumptions for the discount rate, residual value and cash flow forecast. These assumptions can significantly affect the outcome of a benefit-cost analysis without considering the inherent insecurities of these parameters.

The Internal Rate of Return is a financial measure that helps estimate the profitability of an investment in farming. It is the discount rate that makes the net present value of the cash flows of the farm equal to zero. In other words, NPV equals zero. It is very widely used in discounted cash flow analysis. The IRR represents the interest rate at which capital could be borrowed for the farm or the interest that could be earned on capital (Siar *et al.* 2002; Gammanpila 2015). Farmers may use IRR to determine which farming system is more profitable to invest in. In other words, it evaluates investment returns. Since IRR is a percentage, it becomes easier to compare it with the farm's financing cost. And if the financing cost is lesser than the potential rate of return, the farming project is worth investing in. Usually, in theory, any project with a high IRR is considered for investment.

Based on the above, it may safely be concluded that the farming of Pacific white prawn is more attractive for investment followed in order by farming of tiger prawn and that of Indian white prawn both when the opportunity cost of investment is taken into account or not. As has already been pointed out earlier, traditional shrimp farming presents a fairly bleak picture.

Sensitivity analysis was conducted for variation in the sale price of shrimp (revenue) and fixed and variable production costs. It reflects the profitability of various farming systems under the risk of a fall in the sale price of shrimp/ fish and an increase in the production costs. The analysis results showed that the profitability of traditional shrimp farming is very sensitive to variations in the sale price and production costs. When the opportunity cost is not considered, if the sale price falls by 0.05% or more, traditional shrimp farming is no longer profitable at a 5% discount rate. Under NPV analysis, we have already seen that traditional shrimp farming is not profitable at an 8% discount rate before accounting for the opportunity cost.

Similarly, this farming system is unprofitable at all discount rates when we do not consider the opportunity cost. Additional valuable inferences that can be made from the sensitivity analysis are that traditional shrimp farming will be profitable when the sale price rises above 0.46% at an 8% discount rate without considering the opportunity cost, above 0.83% at 5% discount rate after accounting for the opportunity cost or above 1.34% at 8% discount rate after accounting for the opportunity cost. Similar observation can also be made in the case of change in variable cost of production. Before accounting for the opportunity cost, if the variable cost increases by 0.09% or more, traditional shrimp farming is no longer profitable at a 5% discount rate. However, this system of farming will cease to be unprofitable if the variable cost of production is reduced at least by 0.74% at an 8% discount rate without considering the opportunity cost, at least by 1.33% at a 5% discount rate after accounting for the opportunity cost and at least by 2.16% at 8% discount rate after accounting for the opportunity cost. Similarly, before accounting for the opportunity cost, if the fixed cost increases by 0.22% or more, traditional shrimp farming will cease to be profitable at a 5% discount rate. Thus, by contracting the fixed cost of production by 1.90% or more at an 8% discount rate without considering the opportunity cost, by 3.44% or more at a 5% discount rate after considering the opportunity cost or by 5.56% or more at 8% discount rate when we consider the opportunity cost, the traditional shrimp farming can be made profitable.

Based on the gradient of the sensitivity plot, it may be concluded that the profitability of scientific farming of tiger prawn is sensitive to variations in the sale price and less sensitive to changes in variable cost. Deviations in the fixed cost of production have little impact on profitability. When the opportunity cost is not considered, tiger prawn farming is profitable up to a 6.86% fall in the sale price at a 5% discount rate. The farming will remain profitable up to 4.14% fall in sale price at an 8% discount rate (without considering the opportunity cost), 3.44% fall in sale price at 5% discount rate (considering the opportunity cost) or 0.73% fall at 8% discount rate (considering the opportunity cost). Similarly, this system of farming will remain profitable so long as the variable cost does not increase beyond 10.52%, at a 5% discount rate when the opportunity cost is not considered, 6.36% at 8% discount rate when the opportunity cost is not taken into account, 5.29% at 5% discount rate when the opportunity cost is taken into account and 1.12% at 8% discount rate when the opportunity cost is taken into account. Change in fixed cost does not have a significant impact on the profitability of tiger shrimp farming. Thus, up to a 319.48% increase in the fixed cost of production, tiger shrimp farming is profitable (at a 5% discount rate when the opportunity cost is not taken into account). This farming will be profitable up to 192.97% (at an 8% discount rate when the opportunity cost is not taken into account), 160.48% (at 5% discount rate when the opportunity cost is taken into account) and 33.97% (at an 8% discount rate when the opportunity cost is taken into account) increase in fixed cost.

The profitability of scientific farming of Indian white prawn is sensitive to variations in the sales price and that in variable cost. Profitability does not seem to be significantly sensitive to changes in fixed cost. When the opportunity cost is not considered, Indian white prawn farming is profitable up to a 6.07% drop in the sale price at a 5% discount rate. The farming will remain profitable up to a 1.78% drop in sale price at an 8% discount rate (without considering the opportunity cost) and up to 0.66% drop in sale price at a 5% discount rate (considering the opportunity cost). Under the NPV analysis, it has already been seen that farming of Indian white prawn is not profitable at an 8% discount rate when the opportunity cost is considered. However, it will become profitable if the sale price increases above 3.63%.

Similarly, this system of farming is profitable up to 11.40% (at a 5% discount rate when the opportunity cost is not considered), 3.35% (at an 8% discount rate when the opportunity cost is not considered), and 1.25% (at a 5% discount rate when the opportunity cost is considered) rise in variable cost. At an 8% discount rate when the opportunity cost is taken into account, farming of Indian white prawn will be profitable only when the variable cost is decreased at least by 6.81%. Based on the gradient of the sensitivity plot, it may be seen that change in fixed cost does not profoundly impact the profitability of Indian white prawn farming. Thus, up to a 207.82% increase in the fixed cost, Indian white prawn farming is profitable (at a 5% discount rate when the opportunity cost is not taken into account). This farming will be profitable up to 61.00% (at an 8% discount rate when the opportunity cost is not taken into account) and 22.74% (at a 5% discount rate when the opportunity cost is taken into account) increase in the fixed cost. At an 8% discount rate when the opportunity cost is taken into account, farming of Indian white prawn will be profitable only if the fixed cost is reduced by 124.08%.

The profitability of scientific farming of Pacific white prawn is sensitive to variations in the sale price and variable cost but not sensitive to deviations in the fixed cost of production. Pacific white prawn farming is profitable up to a 6.58% fall in the sale price when the opportunity cost is not considered, at a 5% discount rate. The farming will remain profitable up to a 5.23% fall in sale price at an 8% discount rate (without considering the opportunity cost), 4.88% fall in sale price at a 5% discount rate (considering the opportunity cost), or 3.52% fall in sale price at 8% discount rate (considering the opportunity cost). Similarly, this system of farming will remain profitable so long as the variable cost does not increase beyond 8.44%, at a 5% discount rate when the opportunity cost is not considered, 6.70% at 8% discount rate when the opportunity cost is not taken into account, 6.26% at 5% discount rate when the opportunity cost is taken into account and 4.52% at 8% discount rate when the opportunity cost is taken into account. Change in fixed cost does not have a significant impact on the profitability of Pacific white shrimp farming. Thus, up to a 644.18% increase in the fixed cost of production Pacific white shrimp farming is profitable (at a 5% discount rate when the opportunity cost is not considered). This farming will be profitable up to 511.59% (at an 8% discount rate when the opportunity cost is not taken into account), 477.51% (at 5% discount rate when the opportunity cost is taken into account), and 344.92% (at 8% discount rate when the opportunity cost is taken into account) increase in fixed cost.

Three variable parameters, *i.e.,* the quantity of shrimp produced, sale price, and variable cost of production, were used for scenario analysis. In very pessimistic and pessimistic scenarios, all systems of shrimp farming were found to be unprofitable, indicating the precarious nature of the profitability status of the shrimp farming business. Even in a scenario of simultaneous 5% negative shift in the sale price, harvest quantity, and variable cost, all systems of shrimp farming yield negative profit.

The preceding discussion reveals that the traditional shrimp farms would not sustain their profit in the long run if the benefits drop or the cost escalates substantially from the present situation. Thus, the traditional shrimp farms are susceptible to the risk of even a marginal decline in price in the shrimp market or a marginal increase in the cost of production. It is worth noting that the traditional shrimp farming system will not remain profitable under the situations of distortions in the shrimp market when there is a fall in the prices and an escalation of the cost of production, even marginally.

Though slightly positioned better, the scientific shrimp farming of Indian white prawn at the intensity at which the farming is done cannot absorb many drops in the sale price or hike in the cost of production. On the other hand, the scientific farming of tiger prawn and pacific white prawn can be profitable under conditions of price drop and hike in the cost of production better. The decline in world shrimp prices is one of the critical issues facing shrimp producers. International market demand and prices are factors outside the control of an ordinary shrimp farmer. Funge-Smith and Aeron-Thomas (1995) performed a sensitivity analysis on Thai shrimp farming and found that shrimp price has the most significant effect on overall profitability, followed by production and feed price. There is a 10% reduction in sales price, changing profitability by 73% in his study, and it was a reduction of NPV by 50%. Shrimp production was the second most important factor and 10% reduction affecting profit by 47%, and it was 24% of NPV in the study. Shrimp prices vary with average size and quality differences, exchange rate fluctuation, export policies, the strength of the economy, consumer preferences (Engle 2010), and supply-demand interactions in the international market at the moment of harvest (Valderrama and Engle 2001). The prices fall when world supply expands faster than world demand, and costs rise as demand for inputs grows (Chong 1992). On the contrary, the price rises up when there is a shortage of supply.

Frequent disease outbreak is a source of financial risk which needs to be accommodated in the economic viability of shrimp farming in the long run. The values of NPV after adjusting the output with the risk of incidence of disease revealed that neither traditional nor scientific shrimp farming is profitable at the two discount rates studied. The probability of disease incidence has been calculated as the ratio of the number of years in which the shrimp farmers faced disease and the number of years of experience farmers had in cultivating shrimp. It may be observed that, on average, the traditional shrimp farms are likely to get affected by disease 491 times out of 1000. The probability of disease outbreak is 489 times out of 1000 in scientific shrimp farming. It reveals that the disease incidence is almost the same for traditional and scientific shrimp farming sectors. It is interesting to observe that the profitability of all shrimp farming systems in Kerala is likely to be affected by diseases in the long run. If ways to overcome/ manage diseases are not evolved, the shrimp farming industry will lose its attraction shortly, and more and more people will leave the avocation. The oft-recurring disease outbreak is the most critical reason for the shrinkage of the area under farming and the shrimp production in Kerala in the recent past, as is evident from the report published by MPEDA (https://mpeda.gov.in/?page_id=651).

The sustainability of shrimp culture systems is often discussed from technological and ecological points of view. However, such an approach reveals only a part of the picture. Ensuring economic sustainability, which is the capacity of the production system to produce a positive income in the long run, is a must if the sector is to survive and flourish. If a shrimp production system does not provide sufficient income, farmers will not adopt it, or they may altogether leave the avocation even if it scores high in terms of ecological sustainability. Thus, there is a necessity to ensure a stable return from shrimp farming in the long run if the system is to continue.

It must be remembered here that the present study is on the economics of small-scale or marginal shrimp farming, and hence care must be taken in generalizing the conclusions. Economies of scale apply to any farm or business entity in any industry and represent the cost-savings and competitive advantages larger farms have over smaller ones. The farms' size generally matters and has a direct bearing on the profitability of the operation. In general, the bigger the farm, the more the cost savings. Farms can achieve economies of scale by increasing production and lowering costs. It happens because costs are spread over more goods. Economies of scale may be both internal and external. The former is based on management decisions, while the latter involves outside factors. Further, it may be pointed out here that the present findings relate to the prevailing level of intensity of the various farming systems. Not all species are farmed at the same intensity level; hence, the production and profitability are different. Therefore, a direct comparison of the profit and income levels of different farming systems studied is to be approached with reservation.

A reasonably large number of studies have been carried out on the economics of various prawn farming systems in Kerala and other parts of the world at various points in time. These include George (1974, 1980), Gopalan *et al.* (1980, 1982), Hirasawa (1985), Unnithan (1985), Purushan, 1986, 1987a, 1988), Sathiadhas *et al.* (1989), Ajithkumar (1990), Panikkar (1990), Primavera (1991), Beena (1992), Nasser and Noble (1992), Ajithkumar and Panikkar

(1993), Jayagopal and Sathiadhas (1993), Sureshwaran *et al.* (1994), Funge-Smith and Aeron-Thomas (1995), Griffin (1995), Ghosh (1996), Colwill (1997), Raju (1997), Thongrak *et al.* (1997), Pillai (1999), Raghunanda (1999), Saju and Sukumaran (1999), Talukdar (1999), Leung and Sharma (2000), Shah *et al.* (2000), Krishnan *et al.* (2001), Valderrama and Engle (2001), Jose *et al.* (2002), Rashid (2002), Faizbakhs (2003), Pravin (2003), Reddy (2004), Alam *et al.* (2005), Prasad (2006), Chaudhari(2007), Sanchez-Zazueta and Martinez-Cordero (2009), Sathiadhas *et al.* (2009), Akter (2010), Son *et al.* (2010), Nguyen (2012), Sadafule *et al.* (2013), Begum *et al.* (2015), Navghan *et al.* (2015), Kumar *et al.* (2016), Engle *et al.* (2017), Shinji *et al.* (2019), Durai *et al.* (2020). A direct comparison of the profit levels reported by various earlier researchers with the present observation is not relevant because of the difference in the conditions of farming and the difference in the study's time frame. Commercial shrimp farming has many variables which cannot be predicted in advance or controlled. It may also be said here that most of the above-referred works deal with case studies based on a few farms. However, on the other hand, the present investigation is a sample survey based on a relatively very large number of farms for estimating the average costs and revenue and the economics of operations. The lack of time series data on financial aspects of prawn farming is a significant handicap to any serious analysis. Only with time-series data can trends be determined. The results of the present study on economic viability provides a snapshot of commercial shrimp farming at a particular point of time and is a valuable one because it allows conclusions drawn regarding the likely generation of benefits from the farming activity.

The profitability of different culture systems in major Asian countries was examined by Shang *et al.* (1998), who found that though the cost of production per kilogram of shrimp was the highest for semi-intensive systems followed by intensive and extensive systems, the extensive system ranks first in terms of profit per kilogram of shrimp, followed by intensive and semi-intensive systems. The author analysed the costs and returns of shrimp farming based on a farm performance survey conducted by the Asian Development Bank (ADB) and Network of Aquaculture Centers in Asia–Pacific (NACA). The survey indicated that the production cost per kilogram was US$ 4.56 in Sri Lanka.

Production costs in other Asian countries were: China (US$ 2.27), Vietnam (US$ 3.3), Indonesia (US$ 3.78), Philippines (US$ 4.0), Malaysia (US$ 5.5), and India (US$ 5.96) in 1994. For semi-intensive grow-out systems, Indonesia had the highest profit (US$ 3.05/kg), followed by Sri Lanka (US$ 3.00/kg), the Philippines (US$ 2.54), and Vietnam (US$ 2.29). Applying the resource cost ratio (RCR) approach to the Asian shrimp farming industry, Shang *et al.* (1998) indicated that Thailand, Indonesia, and Sri Lanka had a relative advantage in producing and exporting shrimp to markets like Japan and/or the United States of America compared to many other Asian countries. Gammanpila (2015) reported the declining profitability of shrimp farms in Sri Lanka from 1994 to 2014 despite a rise in the sale price of shrimp, obviously due to the rise in cost of production. He also indicated a gradual increase in the cost of chemicals in shrimp farming from 1994 onwards. Studies by Viswakumar (1992), Usharani (1993), Jayaraman *et al.* (1994) revealed that a semi-intensive system is more profitable than the other two systems. A study by Son *et al.* (2010) examined the production and economic efficiencies of tiger prawn farms in Vietnam. He obtained an average yield of 2,470 kg $ha^{-1}crop^{-1}$, and the net income received was 6,768 US$ $ha^{-1}crop^{-1}$ (US$ 2.3 kg^{-1}) after 150 culture days. Average production cost amounted to 3.4 US$ kg^{-1}, and feed, the largest operating cost item, accounted for 58% of the production cost. The total production cost reported was 3.4 US$ kg^{-1}. Nguyen (2012) published the result of studies on profitability and technical efficiency of black tiger shrimp (*P. monodon*) culture and white leg shrimp (*L. vannamei*) culture in Vietnam. Gammanpila (2015) evaluated the effect of varying economic variables on the profitability of shrimp farming. However, other biological, external, or technical aspects which are of importance to the economic viability of such investments were not evaluated in this analysis (Zuniga 2009). Cao (2012) indicated that disease outbreaks could cause only 12% to 36% crop reduction at the best or most probable cases and 78% crop reduction at the worst case in shrimp farming in China. However, under the worst-case scenario in his model, massive crop failure would produce zero to negative returns for intensive farming. The probability of yield loss was 15.6 times higher in the wet season than in the dry season, while the survival rate of the dry season crop (59%) was significantly higher.

Income is the primary indicator of the success of shrimp farming. The income reported in the present study is less compared to that reported by Naik *et al.* (2020). Naik *et al.* (2020) observed that the annual income of 49.15% of shrimp farms of the South Konkan region of Maharashtra was above 20 lakhs, and 25.42% of the farms were between 11 and 19 lakhs. The annual income of 25.42% of the farmers was between 6,00,000 and 10,00,000. Only 10.17% of shrimp farmers had a yearly income between Rs 1,00,000 and 5,00,000. Patil *et al.* (2019b) reported that the average annual income of shrimp framers of Palghar district, Maharashtra was Rs 5,00,000. The difference between the yearly income of shrimp farms of the states mentioned and that of Kerala is due to the difference in the farm management intensity and species farmed. However, the present study results are comparable with the results obtained by Dona *et al.* (2016), who reported that the annual income of shrimp farmers of Kerala was Rs. 2,00,000 per crop per hectare. Indeed, there are many studies conducted under different conditions. The results of various studies conducted in the past on income obtained from shrimp farming are not comparable because of the apparent difference in the intensity of farming, species farmed, and farming conditions and since they were conducted under different points of time.

Bhattacharya (2009) examined the profitability of different shrimp farming systems in West Bengal. He conducted NPV analysis with and without considering the opportunity cost. The estimates revealed that following the scientific method, shrimp culture is profitable at all discount rates when only paid-out costs are considered. The values of NPV for traditional shrimp farming showed that this farming system is also profitable for all the discount rates studied before accounting for the opportunity costs. A comparison of the NPVs of traditional and scientific shrimp farming revealed that in the long run, scientific shrimp farming generated approximately double the profit than that from traditional shrimp farming before accounting for the opportunity costs. The author also found that the BCRs for scientific shrimp farming are lower than traditional shrimp farming, implying that a given investment in traditional shrimp farming produces a relatively higher benefit than scientific shrimp farming. The sensitivity analysis reflected the profitability of shrimp farming under the risk of a decrease in the shrimp price and an increase in shrimp production costs. After assuming a reduction in benefits by 15% and an increase in costs by 15%, the study revealed that the scientific farming system would not be profitable if the farmers culture shrimp continuously. If the shrimp farmers follow the practice of crop rotations to minimise the degradation of on-farm environmental quality, scientific shrimp farming remains profitable even if benefits contract due to a drop in shrimp prices in the international market. However, even scientific shrimp farming with crop rotations will not remain profitable if there is a drop in the shrimp prices by 15% and an increase in the cost of production by 15% simultaneously. It was observed that the marginal scientific shrimp farmers could not sustain their profit in the long run if the benefits dropped by 15% from the present situation. The inclusion of opportunity costs of farming shrimp turns the NPV figures negative if there is a fall in prices and a rise in production costs by 15%. Bhattacharya (2009) further made an interesting observation that the traditional shrimp farming system qualifies as profitable under the situations of distortions in the shrimp market when there is a drop in prices and a rise in production costs. The author also found that the traditional farming system remains economically viable under these situations even after accounting for the opportunity cost. The sensitivity analysis showed that under the uncertain scenario of the international shrimp market, the scientific shrimp farming system would not be profitable, whereas the traditional shrimp farming system would be a profitable option. They attributed the differences observed among the different shrimp farming systems to the differences in the cost positions and the scale of farming operations. A relatively low cost might have helped the traditional shrimp farms to retain positive profits under the worse condition of price fall and escalation of the cost of production. On the other hand, a study by Hirasawa (1985), which assessed the economics of various shrimp culture systems in the Philippines, found that if the price of shrimp falls by 20%, intensive farming, extensive farming, and traditional farming cease to remain profitable with negative net present value. Only semi-intensive farming was found to be profitable in that case.

Bhattacharya (2009) also studied the NPV of shrimp culture considering the risk of disease outbreaks. The study revealed that scientific shrimp farming registered a negative NPV for all the discount rates. It is noteworthy that even if the incidence of disease was higher in traditional shrimp farms than that of the scientific shrimp farms, the loss of revenue due to disease was higher in the latter's case. In case of any outbreak of disease, the high magnitude of the gross value from scientific shrimp farming led to increased losses also. Thus, in the long run, considering the disease-adjusted output, the scientific shrimp farming was not profitable, whereas traditional shrimp farming qualified as a profitable option even after adjusting for the risk of disease outbreak taking all the farmers together.

However, the present study showed that traditional prawn farming, as practised today, is economically unattractive in the long run. In the context of very low-profit levels, along with the high risk associated with the recurrence of of viral diseases, pollution of water bodies, and the non-availability of good quality seeds, this traditional activity will become unappealing, and the area under cultivation is expected to contract in the years to come. At least in some cases, the farmers' commitment and inclination to continue the age-old tradition compel them to practice this farming avocation, even when the profit generated is negligible. However, they cannot carry on the farming buisiness for long if the economic situation does not improve. Indeed, not all traditional farming units are going to run at a loss or are at risk. Some traditional farms may be profitable because of their geographic proximity to the estuarine mouth, where the availability of prawn seed is more, and where the water quality is obviously better. Some farming units may also have been profitable owing to the Government financing/ subsidy provided at present. However, they may find it challenging to remain so when private financial institutions or commercial banks or own capital are the only means to finance the activity. With the available data, one can safely conclude that pure profit does not exist in traditional prawn farming. Although there are no concrete data to corroborate, it appears that this traditional farming activity will disappear in the future due to economic compulsions if no interventions are made to improve the situation.

It may be mentioned here that traditional shrimp farming is an example of organic farming of shrimp, as the minimal quantity of external inputs like feed, lime, fertilizers, disinfectants, and other chemicals are used. The factory-produced feeds are generally used in these systems only during the nursery rearing of seeds restricted to a few days. In most cases, either no feed is used (unfed) during the grow-out phase, or fresh feeds (mostly clam meat) alone are used. Lime is applied only to improve the pH. In prawn filtration fields, the use of fertilisers is also minimal. Similarly, in these farming systems, no disinfectants are used. Because it is a low input system, the chances of pollution are very minimum. Further, unlike in scientific farming, eradication of weed and predatory fishes is not done here. Thus, traditional prawn filtration fields also assume great importance from the fish conservation point of view. In this situation, there is an imperative necessity for governmental interventions to ensure that this traditional, ecologically sensitive and intricate agriculture-fishery system survives indigenously, as examples of local heritage and environment-friendly practice of shrimp culture.

Information collected during the prawn farming periods brought out some of the farmers' views regarding the ways and means for increasing production and making the traditional shrimp farming (prawn filtration) activity sustainable. Some farmers had an opinion to convert the shrimp filtration fields into scientific farms undertaking semi-intensive farming of *L. vannamei*.

But such a proposal may not be viable. For the semi-intensive farming of *L. vannamei*, the fields will have to be deepened to provide an adequate depth of 1.50 metre. However, most of these fields are situated in acid sulphate areas (Sahadevan 2012). Deepening acid sulphate areas may result in further lowering of pH values on exposure to air, making the fields unfavourable for prawn growth. High-density farming of *L. vannamei* also requires artificial aeration, for which availability of electricity is a prerequisite. However, many prawn filtration farms are located in areas that do not have electrical connectivity (Sahadevan and Sureshkumar 2020a).

Another suggestion put forth by the farmers was to stop paddy cultivation and undertake shrimp farming throughout the year in these fields instead of undertaking rice production for six months and prawn production for the next six months. However, perhaps this also may not be viable. Traditional shrimp farming is an integrated farming system in which paddy farming alternates with shrimp cultivation, benefitting each other. There is a favourable residual effect of paddy cultivation on the subsequent shrimp crop in that the straw and other left-outs of paddy on decay act as a nutrient source for plankton production. These also act as substrates for the growth of periphyton which acts as feed for the prawns. On the other hand, the excreta and the exuviae of the prawns serves as a good biofertilizer for the paddy. Thus, cessation of paddy cultivation would lead to a decline in nutrient release, which will result in a decline in food supply to the system, leading eventually to a decrease in prawn production. In addition, the state government's land utilization policy prohibits the conversion of paddy fields for raising other crops. Considering these aspects, it would appear that prawn culture round the year under the existing framework may not be a practical proposal.

Another view expressed by several farmers was on the desirability of extending the current date of ending of shrimp farming from mid-April to the end of May. The month-wise shrimp production in the present study (Chapter 2) showed that the production declined sharply after March. The yield trend indicates that prolonging the period beyond mid-April may not result in higher economic returns in prawn filtration fields. A comparable finding was also reported by Sathiadhas *et al.* (1989). In addition, there is an age-old custom in this part of the country where prawn fields become a common property resource after 15th April every year, conferring the local fishers the right to fish in the fields. In light of these, the proposal is not viable.

Many workers suggested supplementary stocking with seeds of fast-growing species of prawns like *P. indicus, P. monodon* etc. (Rao 1978; Muthu 1978; Unnithan 1985) for enhancing prawn production and higher value realization. The rationale behind supplementary stocking of tiny hatchery-produced seeds of shrimps in a system with no control over the entry of weed and predatory fishes may be questionable. There is always the presence of weed and predatory fishes in the field, which will take a great toll of seeds stocked supplementarily. However, the findings in the present study proved the contrary (Chapter 2). By stocking, the nursery reared advanced seeds, and by doing some modifications, higher production could be achieved. When high-yielding species are stocked, some changes would also be required in the present harvesting technique. Frequent harvesting, as is practised now, may have to be discontinued to provide more time for the added hatchery-produced seeds to grow. It is suggested to evolve a comprehensive technology package to enhance production, which will fit into the broad framework existing today.

To improve the final survival rate of stocked seeds, most farmers stock nursery reared juveniles instead of postlarvae directly in the grow-out ponds. Stages of postlarvae usually supplied in hatcheries in this part of the country range from 5 to 25 days old (PL 5 to PL 25). The objective of nursery rearing is to produce larger prawns that can escape from predatory and weed fishes. The aim is to make healthy, strong, and uniform juveniles with significant potential for compensatory growth after their transfer for final grow-out. This juvenile production phase occurs when the postlarval shrimp bodyweight reaches approximately 2 mg and can continue until the individual shrimp weighs 300 mg or more. Proper growth and development during the nursery phase help the animals manage the grow-out phase's challenges. Separate nursery facilities are increasingly being adopted by shrimp farmers due to their advantages both biologically and economically. The benefits of nursery rearing include control and biosecurity, efficient operation, and improved health and disease management. Many authors observed advantages of nursery rearing of seeds before grow-out socking in scientific farming of shrimp (Apud and Sheik 1978; Cholik 1978; Apud 1979, 1988; Fernandez 1979; Gabasa 1982; Hirono 1983; De la Pena and Prospero 1984; Unnithan 1985; SEAFDEC AQD 1989; Villalon 1991; Sturmer *et al.* 1992; Yta *et al.* 2004; Browdy *et al.* 2016, 2017). Incorporating a nursery phase into the production cycle is an effective management strategy implemented by many progressive shrimp farmers. Nursery systems with water conditions like hatchery avoids predators, provide greater water quality control, and improve feeding efficiency during the more critical initial life stages (Pretto 1983). Nursery rearing also results in larger and hardier shrimp at stocking into the grow-out pond. The use of nursery ponds also reduces culture time in the grow-out ponds and increases production.

Government must take strong measures to prevent unscientific fishing in the backwaters. Today, numerous gill nets, cast nets, Chinese nets, and stake nets operating in the backwaters prevent the free entry of prawn seedlings into the fields. Appropriate actions are required to limit the number and mesh size of gears and enforce the same strictly. There is also a need to prevent the operation of these gears during the high tides, prohibit the use of chemicals/ poisons for fishing, and clear weed chocking of water bodies that bring seeds to the prawn filtration fields. Of late, the reclamation of the backwaters for various purposes is also on the increase, which needs to be regulated to allow the free flow of water from the estuary to the fields. The generous support of the Government is also required to enhance profitability, which is indispensable for the survival of this very traditional agri- aquaculture system and its economic sustainability.

Another area where Government needs to act is the enforcement of laws to prevent pollution resulting from the discharge of effluents from the industrial units. Production and associated environmental factors must be regularly monitored for proper understanding of yield fluctuations which may facilitate the formulation of remedial measures, if need be, at the right time. A good information base would also help evolve suitable programmes for the sustainable management of the traditional shrimp farming practice.

Yet another option is to evolve a strategy for branding and marketing the shrimp harvested from the traditional farms as “organic shrimp,” which can help realize higher prices and improve the overall profitability. Organic aquaculture is a market-driven initiative, and organic products receive 10-40% higher prices than conventional products (INFOFISH 2011; Gammanpila 2015). The European Union (EU), United States of America and Japan are the major markets for organic/eco-labelled or certified food. Since most shrimp farms are small-scale and family-operated, Kerala has not widely adopted certification programmes.

To take the right actions and avoid financial losses due to the reduction of sales price of shrimp, it is necessary to closely monitor fluctuations of demand and sale prices in local/international markets. An important aspect that results in uncertainties in profitability is the recurrence of viral diseases resulting in the mass mortality of prawns (Sahadevan 2013). Provision of insurance coverage to traditional shrimp farms can go a long way in circumventing the situation. Further, the outer bunds, which are common to many small farms (shared facilities), may be strengthened or constructed by the Government agencies, reducing the risk involved in the cultivation and checking the expenses on the maintenance of bunds of traditional farms.

4.6. Conclusion

The present study attempted to make comparative economic analyses of traditional and scientific shrimp farming practices in Kerala by addressing the sustainability of the systems in the long run. The study tried to estimate the economic viability of the various farming systems employing viability measures like NPV, BCR and IRR by incorporating and not incorporating the opportunity costs and the risk of disease outbreak. It made a sensitivity analysis to understand the impact of different variables on the profitability of various shrimp farming systems. Scenario analysis was also conducted to evaluate changes in more than one variable under very pessimistic, pessimistic, optimistic and very optimistic situations. Assessment of the economic viability of shrimp farming showed that, on the whole, shrimp farming is a profitable option. A comparison of the NPVs of traditional and scientific shrimp farming revealed that scientific shrimp farming generated manifold profit in the long run than traditional shrimp farming before accounting for the opportunity costs.

The NPV estimates reveal that shrimp culture following the traditional system is profitable when only paid-out costs are considered. On the other hand, scientific shrimp farming of tiger prawn and that of the Pacific white prawn are profitable at all the discount rates if opportunity costs are considered or not. However, the scientific farming of the Indian white prawn is in a disadvantageous position in terms of profitability than its counterparts in scientific farming. In this context, in a state like Kerala, where the local supply of good quality shrimp seed and feed are limited, scientific farming of tiger prawn and pacific white prawn is more advisable. However, such a recommendation must be taken with reservations because economies of scale apply to any farm and represent the cost-savings and competitive advantages larger farms have over smaller ones. Further, the farms' management intensity greatly matters and directly impacts the operation's profitability. Thus, farming Indian white prawn at a higher stocking density and under a more rigid management regime may yield better financial results.

In unambiguous terms, the present study revealed that traditional prawn farming as practised now in the state is economically not attractive in the long run. Though the initial investment required is relatively low, traditional prawn farming generates only a meagre net profit. The present work attempted to analyse the economics of traditional prawn farming in various situations and scenarios, considering the generation of benefits that have important implications for the sustainable management of traditional prawn farming activity. In all unfavourable situations and scenarios, this system of farming showed unattractive financial results. The inclusion of opportunity costs in the analysis further deteriorated the situation. When the incidence of disease was accounted for in the analysis of the economic viability of shrimp farms, traditional shrimp farming was found to be unprofitable. In the context of very low-profit level coupled with the high risk associated with the frequent occurrence of viral diseases, pollution of water bodies, and the non-availability of good quality seeds, the activity is going to be unattractive, and the extent of areas under traditional prawn farming is expected to come down in the years to come if interventions to thwart the decline is not made. It does not mean that not all traditional farms are running on loss or present unappealing results. The fields which are nearer to the bar mouth may prove to be profitable and may attract the farmers for some more time. However, the overall prospects are unappealing. In this situation, there is a necessity for governmental interventions. Indeed, there is good scope for developing this form of shrimp farming by realising higher sale prices and reducing the cost of production. Branding and certification of the shrimp produced in this system as ‘organic shrimp’ is a way to improve the profitability of these farming systems.

On the other hand, scientific prawn farming, in general, is profitable. The higher NPV, BCR, and IRR of scientific shrimp farming than traditional shrimp farming suggests that emphasis must be made on the development of this sector in a meaningful way. Among all species, farming of Pacific white prawn is more profitable, followed by farming tiger prawn and Indian white prawn. However, not all sites are suitable for the adoption of scientific farming. In this context, there is a vital need to survey the brackish water areas available in the state and delineate them for farming of the different species of prawns. It is pointed out here that further analysis of NPVs in the context of distortions in the market showed that scientific farming, too, is sensitive to crash in the market price of shrimp and escalation of cost of production. It indicates the need to follow better management practices (BMP) in farming. It also reveals the need for the proper functioning of extension machinery to impart technology for prawn farming.

The sensitivity analysis also indicated that scientific shrimp farming would not remain profitable in adverse conditions of the disease outbreak. These results indicate the need to provide a comprehensive crop insurance scheme in the shrimp farming sector. Without proper risk covering facilities, the expansion of scientific shrimp farming may lead to undesirable situations. Introducing specific pathogen-free (SPF) and specific pathogen-resistant strains of shrimp, which are more disease-free/ resistant and grow faster than local strains (Lightner 2005), will help reduce the disease outbreaks. Most shrimp farmers have little knowledge about operational and management decisions for sustainable farming. As a result, the escalating cost of production becomes a critical factor determining farm profitability. Many shrimp farmers have had to produce and market their products without access to reliable or affordable input suppliers, production distribution chains with buyers, retailers, processors, financial, technical, or transport services, particularly towards improving biosecurity. Therefore, it is necessary to establish strong clusters to provide an opportunity to increase the competitiveness of the farming sector by strengthening the network among the stakeholders, including hatcheries, producers, collection agents and markets, traders, processing, exporters, and all other associated services like feed and chemical suppliers, consultant services, transportation, labour contractors and the government machinery. Scientific farming also needs relatively high capital investment, which has to be addressed because rural households are resource-constrained. Scientific shrimp farmers have reported that lack of financial resources was a significant problem for running shrimp farms. The household economy of small-scale farmers, who generally have few assets or savings, is not enough to implement shrimp farming. Farmers are reluctant to take bank loans because of high-interest rates. Because of high risks and production failures, banks are also unwilling to provide loans for shrimp farming. As a high level of initial investment is required for scientific shrimp farming, it is recommended to ensure low-interest loans by the government, perhaps on par with land-based agriculture.

It may be summarised that the farmers' profit or net income per unit of water area is mainly affected by production, the cost of production and marketing and the price received. Therefore, an increase in yield, reduction in costs and increase in price are the principal means of increasing profits. Biotechnical forces affect various production possibilities, and economic forces determine different levels of profitability. Many disciplines, including biology, genetics, nutrition, engineering, physiology etc. affect the economics of shrimp farming.

Various strategies to increase the production and profitability of shrimp farms in Kerala, which would help improve their profitability, have been discussed in Chapter 6.

Chapter 5

SOCIO-ECONOMIC STATUS OF SHRIMP FARMERS

5.1. Introduction

Fisheries and aquaculture are human activities that produce income and food and generate employment, all occurring in an ecological context. In the world, employment in the fisheries and aquaculture sector is growing faster than the world's population (FAO 2016). Globally, 59.51 million people were engaged in the primary sector of capture fisheries and aquaculture in 2018, with 20.53 million people engaged in aquaculture and 38.98 million people engaged in fisheries (FAO 2020). In India, fisheries and aquaculture provide a livelihood to about 28 million fishers and fish farmers at the primary level and twice the number along the value chain (GoI 2020a). Shrimp aquaculture provides direct employment to about 0.3 million people in the country, and ancillary units employ 0.6 – 0.7 million people (Yadava 2002). In Kerala, fisheries and aquaculture provide a livelihood to around 1.6 million people (DoF 2020). Most are small-scale, artisanal fishers and aqua farmers of those engaged in fishing and fish farming.

Shrimp farming has been identified as one of the most important income-generating activities that can bring about social and economic development, especially in rural areas. It can generate substantial job and income opportunities in rural areas and improve the socio-economic status of the rural population.

The socio-economic characteristics of demography means of production, investment, income and expenditure of people living in a particular area strongly influence their responses to technological changes and development schemes (Rahman 2005). The lack of reliable information on the socio-economic condition of the target group is one of the severe impediments to the successful implementation of developmental programmes.

Further, socio-economic data on shrimp farmers are a vital component of the scientific advice required for the evidence-based management of the sector. They are essential in formulating and implementing a management plan to understand livelihood contributions and evaluate the sector's performance to meet regional and international needs. The degree to which these objectives are achieved is ascertained using variables and indicators generated from data. A careful study of the socio-economic conditions of shrimp farmers is also helpful for the proper planning and successful implementation of Governments' developmental programmes in the sector.

Given all these reasons, the present study attempted to provide such information on the socio-economic dimensions of shrimp farming of Kerala through a survey and description of the shrimp farmers' absolute and relative socio-economic conditions. Information on the income generated from the farming activity combined with employment provides a key for understanding the sectors' contribution to livelihoods.

Socio-economic studies are considered necessary not only for their insights but also because improvements in the socio-economic conditions of farmers are considered an indirect means of increasing production and productivity. Socio-economic studies are expected to broaden the perspective of aquaculture development.

Socio-economic studies on these variables give an idea about the overall socio-economic conditions of the shrimp farmers and identify the constraints faced by them. Results of the study are expected to form the benchmark for future research on the topic and basis for policy formulation. It is perhaps the first comprehensive study on the socio-economic condition of the shrimp farmers of the State of Kerala.

Since aspects of the economics of shrimp farming formed part of chapter 4, they are not covered under the present chapter to avoid duplication.

5.2. Review of literature

Very few studies are known to exist on the socio-economic aspects of shrimp farmers of Kerala. However, though patchy and fragmentary, some studies exist on aqua farmers' socio-economic conditions in other parts of the world, within and outside the country. Despite the differing location-specific observations in these studies, some broad generalisations are discernible from them. Here, an attempt has been made to review the published literature on the topic.

Bhalerao and Charan (1968) discussed the role of fisheries co-operatives in fisheries development in India. They found a plurality of Ownership and interference of mediators as significant deterrents to the development of fisheries in a meaningful way. Chakravorty (1968) discussed problems of fish culture in West Bengal. Galgotia (1968) discussed the role of co-operatives in fisheries development in Maharashtra state. Sinha and Jha (1968) raised many socio-economic concerns in the development of fish culture and advocated government intervention.

Rajbanshi and Shrestha (1980) observed that the farmers got better incomes by resorting to integrated duck fish culture. Mondal (1981) discussed the role of marketing and co-operatives in rural aquaculture. Mammen (1984) pointed out the inadequate adoption of scientific farming methods and indicated the need for innovative techniques. Natarajan (1985) observed intersectoral competition between irrigation and pisciculture as one of the essential factors inhibiting the development of fish farming. Satheesh *et al.* 1985) found mixed duck and fish farming to yield higher income to farmers. Rahman and Ali (1986a; 1986b) investigated the credit and marketing aspects of pond fisheries in Bangladesh.

Chattopadyaya *et al.* (1987) discussed various institutional, technical and financial factors which were found detrimental to the smooth functioning of the fish culture units. These authors also pointed out inadequate extension activities in the field. Misra (1987) identified poaching as a critical constraint in aquaculture development. He also identified lack of proper transport facility, proper marketing management, absence of facilities for water and soil testing, an erratic and insufficient supply of fish seed and multiple Ownership of farms as the major factors inhibiting the development of fish farming. The author suggested the utilisation of canal irrigation, desilting of water bodies, long term lease arrangements, government legislation to evict multiple Ownership of ponds, development of region-specific technology for farming, organised marketing channels, and the practice of mixed farming as possible ways to ensure the development of the sector. According to the author, more village-based co-operatives should be set up, and more farmers must be encouraged to be part of the co-operatives. Balasubramaniam (1988) analysed technology transfer effectiveness in inland fish farming. Das *et al.* (1988) investigated variables contributing to the adoption of composite fish culture innovations. Sarma (1988) addressed some of the social issues in aquaculture based on a socio-economic study of fish farmers in the lower Sundarben delta. The study's central hypothesis was that income from fish culture is higher than that of agricultural operations. The study showed that the gross rate of return of fish farming was 35% higher than that of agriculture. It is also observed that the fish intake of fisheries households was much higher than in non-fishery families. A significant observation of the author was that even though aquaculture has a higher rate of return, people prefer agriculture to aquaculture because of the higher status in the society that agriculture confers. Chaudhury (1989) conducted an econometric analysis of the socio-economic status of the fishermen community in lower Assam. Krishnaiah (1989) studied the effectiveness of short-duration training programmes undertaken by FFDAs in Andhra Pradesh.

Bhaumick *et al.* (1990) investigated perceived problems and measures in the participation of fisherwomen in inland fisheries activities. Chaudhury (1990) observed that farmers' selection criteria in extension implementation programmes and selection of a suitable site for demonstration of aquaculture technology play critical roles in the diffusion of fish farming into rural areas and in the socio-economic uplift of the rural farmers. Panikkar (1990) conducted a socio-economic analysis of prawn farming in the Orissa state of India. He studied aspects like type of family, literacy rate, and occupational pattern of prawn farmers and identified their issues. Shang (1990) looked at the socio-economic constraints of aquaculture in Asia. Srivastava *et al.* (1990) made a detailed study on the socio-economics of fish farming to bring a large number of underutilised fallow water resources for fish production. The authors analysed the situation in detail and concluded that many institutional and technological factors are there to affect the production of fish adversely. The suggestion they made was to rationalise the leasing arrangements, provide subsidies and impart practical training to fish farmers, ensure a smooth supply of fish seeds at reasonable prices, and develop the marketing facilities. According to the authors, the plurality of ownership is also one of the most critical constraints in the development of fish culture. Srivastava *et al.* (1990)

also attempted to evaluate Fish Farmers Development Agency (FFDA) programme based on their performance. Based on the data collected from all FFDAs in the country, the study documented the operational features of FFDAs, impact on production, income and employment, their economic viability, marketing of the product etc.

Ganesan *et al.* (1991) highlighted the importance of integrated animal fish culture in the socio-economic uplift of fish farmers in rural areas. The authors observed that the farmers got better incomes by resorting to duck cum fish culture. Neilandl *et al.* (1991) discussed the social and economic impact of aquaculture. Primavera (1991) studied the ecological, social and economic implications of Intensive prawn farming in the Philippines. Beena (1992) investigated the socio-economic conditions of traditional prawn farmers of Ernakulam district. Srivastava (1992) discussed aspects of aquaculture marketing and economics in India. Ahmed *et al.* (1993) investigated the household socio-economics of fish farmers of two thane districts of Bangladesh. Stephen *et al.* (1993) examined the conflicts that arose from market guided unequal sharing of scarce shrimp resources in Cochin backwaters of Kerala among competing users. The authors opined that the state policy for promoting shrimp culture, with no proper planning and management mechanism, aggravated the conflicts. Jayagopal and Sathiadhas (1993) conducted a socio-economic analysis of prawn farming practices. Primavera (1993) further reported the environmental and socio-economic effects of shrimp farming.

Chimatiro and Janke (1994) assessed smallholder aquaculture farmers' socio-economic assessment. Singh and Bhattacharjee (1994) observed that ponds and tanks under common property regime had low fish productivity. The authors suggested the development of these water bodies under the co-operative sector and the extension of sufficient funds for the development of such water bodies. Marothia (1995) found that the multiple uses of common village ponds created conflicts and disorders among the fishers and village community.

Singh and Das (1994) discussed the prospects of fish culture in rural development. Verma (1994) conducted a socio-economic study of inland fish culture in Kosi division in Bihar state. Misra (1995, as cited in Misra 2006) identified constraints in developing inland fish culture with particular reference to West Bengal. Singh *et al.* (1995) conducted studies on the socio-economics of fish farming, emphasising the role of fish culture in the uplift of economically and socially backward sections of society. Tietze (1995) investigated the socio-economic aspects and the role of credit in fish marketing development.

Ahmad (1996) discussed aspects of integrated fish farming in social development. Hamid and Alauddin (1996) studied aspects of shrimp production and employment generation in Bangladesh and the changing role of women. Barraclough and Finger- Stich (1996) reported some ecological and social implications of commercial shrimp farming in Asia. Khan and Hossain (1996) reported the impact of shrimp culture on the coastal environment of Bangladesh. Kumar (1996) investigated the communication behaviour of fish farmers in Tamil Nadu. Molnar *et al*. (1996) studied the social, economic, and institutional impacts of aquaculture research on tilapia. Jha (1997) opined that short term leasing of public water bodies affects fish productivity. He observed that in short term leasing, the lessee would not invest much in fish production. Kumar (1997) discussed aspects of the status and scope of fisheries enhancement in large reservoirs. Primavera (1997) studied the socio-economic impacts of shrimp culture. Reddy (1997) investigated the entrepreneurial characteristics of fish farmers.

BBS (1998) conducted a household expenditure survey of aqua farmers. Bhaumik and Saha (1998) discussed the perception of fish farmers on the need for modification of composite fish culture technology. Deb (1998) discussed the environmental and socio-economic impacts of shrimp culture in the coastal areas of Bangladesh. Dutta (1998) studied the socio-economic status of fish culture in Assam. The author found that the social and economic dimensions of aquaculture have not been adequately understood in the past though much attention has been given to technical aspects of the use of these resources to produce fish. Tobey *et al.* (1998) investigated the economic, environmental and social impacts of shrimp farming in Latin America. The study revealed the underlying causes of ecological and social problems in Latin America, which are complex and include poorly defined and insecure land tenure, open-access property rights for water and seed shrimp, inadequate institutional capacity and environmental regulations, unworkable legal frameworks, insufficient shrimp farm technical expertise and inadequate understanding of coastal ecosystem conditions and trends. The multidimensional nature of the problem calls for an integrated approach to coastal economic development and environmental management. Integrated coastal management was suggested as a governance framework for advancing sustainable shrimp aquaculture.

Behera and Mahapatra (1998) studied small and marginal farmers' income and employment generation through integrated farming systems. Horstkotte-Wesseler (1999) investigated various aspects of the socio-economics of rice-aquaculture. Islam (1999) investigated the social and institutional aspects of shrimp-rice farming in Bangladesh. Kumar (1999) discussed the trickle-down system (TDS) of aquaculture extension for rural development. Meeran and Prince (1999) investigated the socio-personal and socio-economic and socio-psychological profile of shrimp farmers. Ponnusamy *et al.* (1999) conducted studies on cultural and economic aspects of farming practices and extension needs of farmers in Prakasam district of Andhra Pradesh. Sinha (1999) discussed various constraints and environmental issues faced by shrimp farmers. Prominent ones among them are lack of access to land and water bodies, difficulties in obtaining institutional credit, short duration of the lease of land and water bodies and lack of proper infrastructure for marketing aquaculture products. According to the author, rural aquaculture is also constrained by specific environmental issues. Main ecological issues are loss of productivity of land and water from freshwater ponds, loss of mangrove, loss of biodiversity, conversion of agricultural land, salinisation of potable water, nutrient loading etc. The author found rural aquaculture in India to significantly contribute to rural development. It has not only increased export earnings but also helped to increase per capita food consumption. Brummett and Williams (2000) studied aspects of the evolution of aquaculture in African rural and economic development. Goswami and Sathiadhas (2000) investigated aspects of fish farming through community participation in Assam. Islam and Wahab (2000) published a participatory rural appraisal (PRA) report of the socio-economic and environmental impact of shrimp farming in Bangladesh. Pillai (2000, as cited in Jha 2009) stated the need to strengthen the extension programmes in fisheries for the socio-economic uplift of fishers. Shyna and Joseph (2000) made a microanalysis of displaced women agricultural labourers' problems, emphasising the pokkali fields of Vypinkara of Ernakulam. Shaleesha and Stanley (2000) studied the involvement of rural women in aquaculture.

Braten (2001) studied the environmental impacts and socio-economic problems of shrimp farming in various countries. Bhatta (2001) discussed the socio-economics of freshwater fish farming in India. The report analysed the purchasing power, farm gate price of fish, wholesale and retail prices, price margins, price trends, and role of women in fish farming. Kumaran *et al.* (2001) examined aspects of diffusion and adoption of shrimp farming technologies. Nayak *et al.* (2001) investigated the significant constraints in adopting shrimp farming in the Balasore district of Odisha. Radheyshyam (2001) studied the relevance of the community-based aquaculture instituted on the principles of shared interest groups working together regardless of sex and age, which has been a valuable tool for implementing a scientific aquaculture programme in India. He used the SWOT analysis for the study. Selvam and Ramaswamy (2001) discussed the socio-economic and environmental impacts of shrimp farming.

Goswami *et al.* (2002) studied the socio-economic attributes of fish farmers in Assam in a case study of fish farming in two districts, Darrang and Nagoan, in Assam. The authors presented the characteristics representing the personnel and socio-economic attributes of the fish farmers. They found the socio-economic status of farmers in Assam to be relatively low. According to the authors, the socio-economic status of fish farmers has to be improved by bringing the modern concepts of fish farming to the doorstep of farmers. Katiha (2002) investigated the socio-economic aspects of culture-based fisheries. In the study, the author observed that the wide variety of social considerations might constrain the interventions in the management and institutionalisation of the water bodies. According to the author, it is necessary to consider the social aspects involving employment mobility, subsistence orientation of production and income distribution concerning the culture-based fisheries. Raju (2002) presented some elements of the socio-economic profile of the semi-intensive shrimp farmers of Kerala. Sinha and Katiha (2002) mentioned that in addition to the activities of Fish Farmers Development Agencies, aquaculture should be promoted with the necessary credit and technical support. They pointed out that preferential allotment of water bodies to production-oriented co-operatives would be an effective strategy for developing the sector. Turongruang and Demaine (2002) studied aspects of the participatory development of aquaculture extension materials and their effectiveness in transferring technology. Vimala (2002) investigated the training needs of shrimp farmers of Tamil Nadu. Islam *et al.* (2003) studied the impacts of shrimp farming on the socio-economic and environmental conditions in the coastal regions of Bangladesh.

Kumaran *et al.* (2003a) studied aspects of diffusion and adoption of shrimp farming technologies. Kumaran *et al.* (2003b) conducted a case study on the socio-economic consequences of shrimp farming in the East Godavari district of Andhra Pradesh, India. Sawant and Sawant (2003) studied the constraints in traditional shrimp farming in West Bengal. Singh (2003) explored the various socio-economic aspects of inland fish farming enterprises in Bihar. The study's specific objectives were to examine the cultural practices, costs, returns, labour, employment, marketing practices, and constraints in fish production. He identified institutional and technological constraints like low input use, the non-existence of fish nurseries, and lack of institutional credit. Trejos-Castillo *et al.* (2004) conducted a case study of small-scale aquaculture producers and discussed the role of aquaculture in income, food security and poverty reduction. Kumaran *et al.* (2004) studied the utilisation of information sources by shrimp farmers.

Mruthyunjaya (2004) investigated the socio-economic profile of the stakeholders of the inland fisheries sector. He also studied the socio-demographic profile of shrimp farmers of India. Pillai and Katiha (2004) gave a comprehensive account of the role of fisheries, both marine and inland, including fish culture, sector in the national economy, trend and structural changes in production, the profile of technology and research, the evolution of fishing and culture practices, socio-economic profile of fish farmers and fishers and other aspects of fisheries development in India. Chakraborty *et al.* 2005) conducted a socio-economic appraisal of fishery co-operatives in West Bengal. The study by Kumaran and Kalaimani (2005) examined the socio- personal profile of shrimp farmers in coastal districts of Tamil Nadu and its influence on the diffusion and adoption of technology at the farm level and training requirements of farmers. An analysis of the impact of the industry on the local society and constraints faced by farmers was also conducted. The study was conducted against the backdrop of the setback the industry suffered in the mid-1990s because of the viral disease outbreak. The damage caused by the outbreak of the disease made clear that farmers need timely advice and guidance about the maintenance of ideal pond and environmental conditions and management practices for the survival and growth of shrimp farming. The authors observed that most shrimp farmers were relatively young, had functional educational status and experienced up to 5 years in shrimp farming. Rao (2005) identified the various socio-economic and other constraints that hindered the progress of fish farming and suggested some remedial measures for betterment. The review revealed that small fish farmers under the private sector are at a disadvantage since they adopt traditional practices, use low-cost inputs, and sell their fish at low prices. According to the author, proper extension and management measures would go a long way in increasing the yield rates and bettering the socio-economics of small farmers. Rawool (2005) studied the efficacy and constraints in adopting improved aquaculture practices by shrimp farmers in the Thane district of Maharashtra. Swathilekshmi *et al.* (2005) investigated the socio-economic profile of shrimp farmers and its influence on the extent of adoption of culture technologies. These authors found that the extent of adoption of shrimp culture technologies by shrimp farmers of Nellore could be positively influenced by increasing their information-seeking behaviour, credit orientation and material possession. Similarly, the extent of adoption of shrimp culture technologies by shrimp farmers of Nagapattinam was found to be positively influenced by increasing their extension contact, risk orientation, annual income and farming experience and negatively impacted by the type of Ownership. Udo *et al.* (2005) reported improving aquaculture through increased fisheries extension research. Gawde *et al.* (2006) investigated aspects related to the adoption of improved aquaculture practices by shrimp farmers in the South Konkan region of Maharashtra. The authors observed that there was quite high extent of adoption for some of the practices such as use of feed check trays.

Kumaran (2006) investigated the role of farm opinion leaders and the transfer of aquaculture technology. Pandey and Dewan (2006) analysed constraints in fish farming practices in Uttar Pradesh. Thorpe *et al.* (2006) presented development and poverty reduction strategies for integrating fisheries into the development discourse. Datta and Kundu (2007) conducted a detailed socio-economic appraisal of culture-based fisheries in west Bengal. According to the authors, a great deal of direct and indirect employment potential is associated with inland fisheries in India if appropriately managed. The authors investigated the family income, family size, housing type, living conditions, sanitation facilities, living conditions, literacy rate and other socio-economic aspects of fish farming. They highlighted income inequalities among culture-based fishers of the study area.

Irz *et al*. (2007) discussed the equity and poverty impacts of Aquaculture. Singh (2007) studied the economics and determinants of fish production and its effects on family income inequality in the West Tripura district of Tripura. Ali *et al.* (2008) conducted a very detailed study to assess the livelihood status of fish farmers in some selected areas in the Rashashi district. Housing condition, health condition, income, size of ponds, age distribution and physical capital were studied. Pandey and Dewan (2008) investigated institutional support for freshwater aquaculture development. Rajan *et al.* (2008) discussed strengthening communities and institutions for sustainable management of Vembanad Backwaters, Kerala. Reddy *et al.* (2008) investigated the efficiency of shrimp (*Penaeus monodon*) farmers in Andhra Pradesh. Sathe (2008) studied the adoption of shrimp health management practices in the North Konkan region of Maharashtra. He reported the recurrence of disease as a major constraint faced by the shrimp farmers. Swathilekshmi *et al.* (2008) studied the information utilisation and constraint analysis among shrimp farmers.

Asadullah and Rahman (2009) studied the role of education in farm productivity and efficiency. Gawde *et al.* (2009) investigated constraints and improved techniques in shrimp farming. Hossain *et al.* (2009) studied the socio-economic condition of fishers in seasonal floodplain beels in Rajshahi District, Bangladesh. The authors considered educational status, age distribution, health and sanitary condition, housing condition, occupational pattern, fish consumption, family income, family size, living conditions, literacy rate and other socio-economic aspects of fish farmers. Jha (2009) investigated the socio-economics of fish farming in flood-prone areas of Bihar with particular reference to the Kosi river system. Kumar and Ananthan (2009) discussed extension strategies for the sustainable development of fisheries and aquaculture. Bhattacharya (2010) studied the role of shrimp farming in generating employment and income. Chandra *et al.* (2010) reported shrimp culture practices at the farmers level in Bagerhat District. According to FAO (2010), there should be an identification of social indicators and monitoring to promote integration with local communities and prevent conflicts with them. It also discussed measures to mitigate the negative socio-economic impacts of aquaculture. Ajayakumar (2011) investigated the socio-economic aspects of aquaculture development in Kerala. He also reviewed the studies conducted on the subject to date.

Swathilekshmi *et al.* (2011) investigated aspects of the diffusion of scientific shrimp farming through various stages of the adoption period. Goswami (2012) investigated the factors affecting the attitude of fish farmers towards scientific fish culture in West Bengal. Pandey and Upadhayay (2012) studied the socio-economic profile of fish farmers of an adopted model aquaculture village in West Tripura. Cyril *et al.* (2013) investigated the association of socio-economic attributes with adopting better management practices in shrimp farming in Karnataka, India. Khatun *et al.* (2013) investigated the socio-economic status of pond fish farmers of Charbata, Noakhali, Bangladesh. Megahed *et al.* (2013) studied the significant constraints facing the development of marine shrimp farming. Sheikh and Goswami (2013) investigated the socio-economic condition of fishers of Chandakhola wetland, Dhubri, Assam, India.

Das *et al.* (2014) investigated aspects of adopting improved aquaculture technologies in Tripura. Gupta and Dey (2014) studied the socio-economic and cultural profile of fish farmers in and around Lumding town, Nagaon district of Assam. Koteswari *et al.* (2014) reported the impact of aqua societies on shrimp farming in Andhra Pradesh. Nongmaithem and Ngangbam (2014) reviewed the investigations on the socio-economic conditions and cultural profile of the fishers in India, including the socio-economic conditions of fish farmers.

Pandey *et al*. (2014) investigated fish farmers' perceived constraints in the transfer of aquaculture technology in the Bishnupur district of Manipur, India. Peter and Susan (2014) investigated determinants of the adoption of pond fish farming innovations. Sahu *et al.* (2014) studied the adoption of better management practices (BMPs) and constraints in shrimp farming in selected districts of Odisha. Vadher and Manoj (2014) investigated the socio-economic profile of shrimp farmers of Gujarat State, India. Kumar *et al.* (2015) conducted studies for identifying socio-economic features of fish farmers of the Jammu district. The authors assessed the socio-economic characteristics, namely education, employment, income levels from aquaculture and other farm and non-farm activities of fish farmers, along with the status of fish farming and livelihood of the fish farmer. Nagamani and Vimala (2015) presented a socio-economic framework of fish farmers in Tamil Nadu. Orchard *et al.* (2015) discussed the impacts of aquaculture on social networks in the mangrove systems of northern Vietnam. Sen and Roy (2015) studied the socio-economic status of fish farmers in Tripura, India. Tokunaga *et al.* (2015) investigated the economics of small-scale commercial aquaponics.

Asif (2016) studied the socio-economic conditions of fish farmers of Bangladesh. Among other things, he investigated the livelihood status of the fish farmers in detail. Dona *et al.* (2016) investigated the occupational needs of shrimp farmers in Kerala. Haque and Dey (2016) discussed the impact of the community-based fish culture system on expenditure and inequality. Kumar *et al.* (2016) investigated the costs and risk of catfish split-pond systems. Parashar *et al.* (2016) assessed the socio-economic status of fisher communities of selected reach of River Narmada. Paul and Chakraborty (2016) made a detailed study on the impact of inland fish farming on the socio-economic development of Nadia District, West Bengal, India. Based on the analysis, the authors concluded that inland fish farming plays a vital role in the socio-economic improvement of developing countries like India. The authors opined that inland fish farming has immense potential as a source of livelihood, which can, at the same time, provide nutritional elements to society. Various impediments such as illiteracy and lack of knowledge regarding scientific fish farming hinder the all-round development of inland fish farming. Thus, to ensure satisfactory development of the sector, awareness of the concerned farmers should be enhanced, and the entrepreneurship of the local administration, State and the central government must be increased. Srinivas and Venkatrayalu (2016) studied the present problems and prospects of shrimp farming in the West Godavari district of Andhra Pradesh. They found disease one of the significant problems shrimp farmers of the area faced. Tammaroopa *et al.* (2016) studied the socio-economic factors influencing white shrimp production. Tandel *et al.* (2016) conducted a socio-economic survey of shrimp aquaculture practices in the Valsad district of Gujarat. According to these authors, the disease outbreak has become the most burning and threatening issue in shrimp farming. Chittem and Kunda (2017) conducted a constraint analysis of *Litopenaeus vannamei* culture in Prakasam District, Andhra Pradesh. Gautam *et al.* (2017) conducted an impact assessment study in Uttar Pradesh on Fish Farmers Development Agencies and farmers empowerment. Kumaran *et al.* (2017) made a comparative evaluation of the knowledge level of shrimp farmers of east and west coasts of India on better management practices (BMPs) of *L. vannamei* farming. Ogunmefun and Achike (2017) studied the socio-economic characteristics and constraints of pond fish farmers. Rajarajan (2017) investigated the constraints faced by shrimp farmers in Nagapattinam district, Tamil Nadu. Slater (2017) discussed the societal and economic impacts of aquaculture. Chittem and Kunda (2018) investigated the socio-economic condition of the shrimp (*L. vannamei*) farmers with the implementation of better management practices (BMP's) in Andhra Pradesh, India. Patil and Sharma (2018) assessed the training needs of shrimp farmers. Patil *et al.* (2018) investigated the emergence of shrimp farming and the profile of shrimp farmers in Palghar district, Maharashtra. They used discrepancy scores of importance and competency for designing training programmes for shrimp farmers. Salunkhe (2018) studied the efficacy and major constraints faced by shrimp farmers of the Palghar and Raigad district of Maharashtra. Baruah and Hazarika (2019) made a descriptive analysis of the socio-economic status of fishers of Assam. Khuman and Singh (2019) investigated fish farmers' perceived constraints and suggestions towards adopting scientific farming in the Valleys of Manipur. Patil and Sharma (2019a) examined the need for women-specific interventions for sustainable and equitable brackish water aquaculture development, and Patil and Sharma (2019b) studied the gender gap in the shrimp industry in India.

Alagappan and Kumaran (2020) studied the information sources and influence of socio-personal attributes on aqua farmers' information-seeking behaviour. Durai *et al.* 2020) conducted a socio-economic survey of shrimp farmers in the coastal districts of Tamil Nadu. The study revealed that 45.33% of shrimp farmers belonged to the middle age group, 44.67% were educated up to higher secondary level, 78.67% of the farmers were engaged in aquaculture alone for their livelihood, and 48.67% farmers had farming experience ranging from 5 to 10 years. The majority of the farmers (82%) belonged to the marginal (54.67%) and small (27.33%) category of farmers. Naik *et al.* (2020) investigated the socio-economic profile of shrimp farmers of the South Konkan region, Maharashtra, India. Patil and Sharma (2020) made an empirical analysis of constraints faced by shrimp farmers of Maharashtra and ranked the production, extension, financial, marketing and infrastructural constraints faced by them.

The review of the existing literature reveals in unambiguous terms that not many systematic studies have been conducted on the socio-economics of shrimp farming and the socio-economic condition of shrimp farmers in the country. Thus, there is a need for conducting a comprehensive study on both aspects. Ray *et al* (2021) investigated the role of shrimp farming in socio-economic elevation and professional satisfaction in coastal communities. The Authors investigated the shrimp farmers' financial and perceptual reactions to analyse shrimp farming's direct impact on their socio-economic status.

5.3. Material and methods

A detailed socio-economic survey collected the data for the present study. Simple random sampling and stratified random sampling are the standard methods employed in the socio-economic surveys (Shang 1981; Salim *et al.* 2005). However, according to Pinello *et al.* (2017), the stratified random sampling method (without replacement) is more appropriate to gather information of a broad nature. Conceptually, this sampling scheme is one of the most straightforward probability sampling techniques requiring no advanced statistical programmes. At the same time, it guarantees statistically sound and robust data (Pinello *et al.*, 2017). In this context, the stratified random sampling method (without replacement) was adopted in the present study.

The criterion for delineating the strata as homogeneously as possible was geographical consideration. As far as possible, the strata guaranteed that the shrimp farming units were homogeneous in terms of productive characteristics and socio-economic structure, as observed by Accadia and Franquesa (2006). Shrimp farming in Kerala is restricted to the nine coastal districts (Thiruvananthapuram, Kollam, Alapuzha, Ernakulam, Thrissur, Malappuram, Kozhikkode, Kannur and Kasargod) and the one inland district which lies beside the Vembanad Lake (Kottayam). In the present survey, each shrimp farming district formed the strata.

Since the sample survey and the knowledge of the estimation of the population parameters were not known or not well established, a "disproportionate allocation" sampling scheme (Sapsford and Jupp 2006) was adopted. This strategy allowed for keeping the sample as large as possible to have a higher coverage rate for the smaller-sized segments while minimising the variance among each stratum. In other words, the sample size in each stratum was inversely proportional to the stratum's population size (Pinello *et al* 2017), as provided in Table 5. 1. Based on the above, the sample size was fixed in each stratum. A large sample size was expected to ensure that the sample means and the standard deviation were approximately normally distributed about the population mean and standard deviation (Grafton *et al.* 2004). Details of the farms selected are provided in Table 5.1.

Table 5.1. Disproportionate allocation of the sample size.

Number of farmers per stratum	Sampling rate
<10	100%
10-20	50%
>20	10%

Two types of shrimp farming are in vogue in Kerala (Sahadevan 2013). They are traditional shrimp farming (prawn filtration with or without supplementary stocking) and scientific shrimp farming. Lists of farmers undertaking traditional and scientific farming in each shrimp farming district of Kerala were collected from the Fish Farmers' Development Agencies (FFDA) in various districts under the Department of Fisheries Kerala and the office of the Marine Products Export Development Authority (MPEDA). A consolidated list for each category was prepared by avoiding duplications. These lists formed the basis of the present study. A sample was selected from each list by employing a simple random sampling technique as suggested by Shang (1981), Goswami *et al.* (2002), Salim *et al.* (2005) and Pinello *et al.* (2017), and data on topics of interest were collected from the selected farmers. During the actual survey, if more than one farmer was found to be chosen from the same group, only one was surveyed, and the rest were replaced with those chosen afresh on a random basis from the list and information about them were collected.

Table 5.2. Details of shrimp farmers selected for the present study.

	Traditional farming	Scientific farming
Shrimp farmers enlisted	1473	684
Shrimp farmers selected for the study	221	102
Per cent of shrimp farmers selected for the study	15.00	14.91

For the collection of data, a questionnaire was developed, which was a modified version of the one proposed by Shang (1981), but incorporating more areas given by Ahmed *et al.* (1993), Goswami *et al.* (2002), Ali *et al.* (2008) and Pinello *et al.* (2017) and keeping in mind the requirement of the present study. The questionnaire developed was pre-tested in the field and was revised to suit the local conditions incorporating the field realities. The questionnaires employed in the present investigation were prepared in the local vernacular language (Malayalam). The survey was conducted between June 2017 and May 2018. The life cycle of the survey was as provided by Pinello *et al.* (2017) and is summarised in Fig. 5.1.

The questionnaire was divided into different parts that contained the variable groups, and the variables were listed in a rational sequence. The questions were delivered in the sequence presented because the explanations and responses build on the previous items. The order of the questions allowed the interview to begin with the less sensitive questions and build on the complexity of responses.

In the study, farmers' households were taken as the unit of analysis. Here household or family income from shrimp farming was defined as the return to family labour and assets owned after deducting current costs (excluding family labour and rent for own land and assets) from the gross value of production estimated using average prices of products recorded for individual households. The current cost was the cost incurred by individual households in purchasing farm inputs, hiring labour and renting services (Hossain 1990). The analysis of household income included returns from shrimp crop and non-farm income, including lease income, wages/ salaries and income from the petty business, petty trading and other occupations.

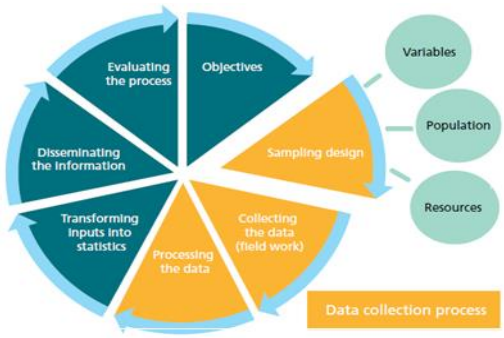


Figure 5.1. The life cycle of the survey.

The information collection process for the socio-economic survey is presented in Fig. 5.2.

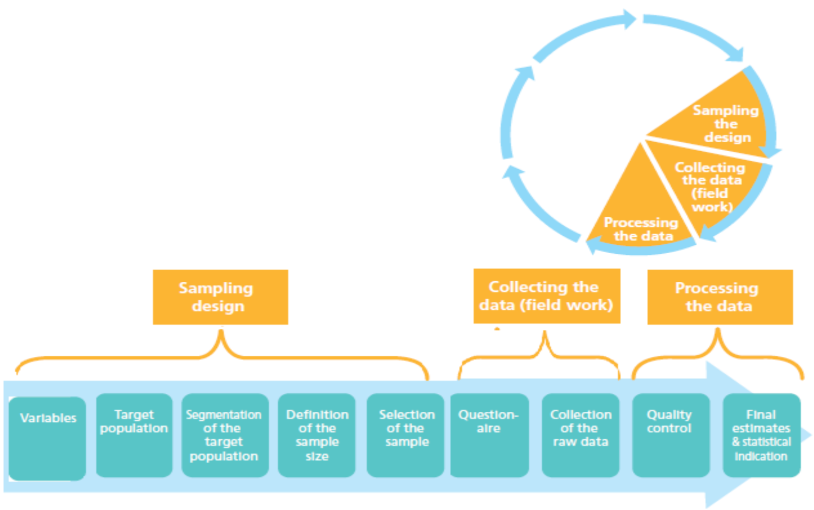


Figure 5.2. The information collection process for the socio-economic survey.

Socio-economic data were complementary to a broader data collection scheme where all information about the level of technology of farming, cost, revenue, profitability etc., of shrimp farming units of the State were collected.

5.4. Results

The data collected on various variables of interest in the present study are presented below.

5.4.1. Number of shrimp farmers

The number of shrimp farmers in the State was found to be 2157. Of this, 1473 farmers were engaged in traditional farming, and 684 in scientific shrimp farming.

5.4.2. Age distribution

Data on the age distribution of traditional and scientific shrimp farmers are presented in Table 5.3. The mean age of traditional and scientific shrimp farmers was 48.52 years and 45.69 years, respectively.

Table 5.3. Age distribution of shrimp farmers.

Age (years)	% distribution of farmers	
	Traditional shrimp farming	Scientific shrimp farming
20-30	2.71	4.90
30-40	14.03	17.65
40-50	39.37	46.08
50-60	33.03	28.43
Above 60	10.86	2.94

5.4.3. Type and size of family

Most of the shrimp farmers in the study area were found to live in nuclear families. The information collected in the present survey on the size of the family of shrimp farmers is provided in Table 5.4.

Table 5.4. Size of the family of shrimp farmers.

Size of the family (Number of members)	% distribution of families	
	Traditional shrimp farming	Scientific shrimp farming
4 or below	51.13	49.02
4-5	29.41	26.47
5-6	13.12	13.73
6-7	4.52	6.86
7-8	1.81	3.92

The family size of the shrimp farmers was divided into five categories according to the number of family members. The average family size of traditional shrimp farmers was 4.26, and that of the scientific shrimp farmers was 4.40.

5.4.4. Sex ratio

Shrimp farming activities were found to be virtually in the hands of males. The information on male-female participation in shrimp farming is provided in Table 5.5. Information on the sex ratio in the families of shrimp farmers is presented in Table 5.6.

Table 5.5. Male-female participation in shrimp farming.

Type of farmers	Male (%)	Females (%)
Traditional shrimp farmers	80.09	19.91
Scientific shrimp farmers	92.16	7.84

Table 5.6. Sex ratio of the family members of shrimp farmers.

Type of farmers	Number of females to 1000 males
Traditional shrimp farmers	1082
Scientific shrimp farmers	1079

5.4.5. Educational status

Information on the educational status of shrimp farmers is presented in Fig. 5.3.

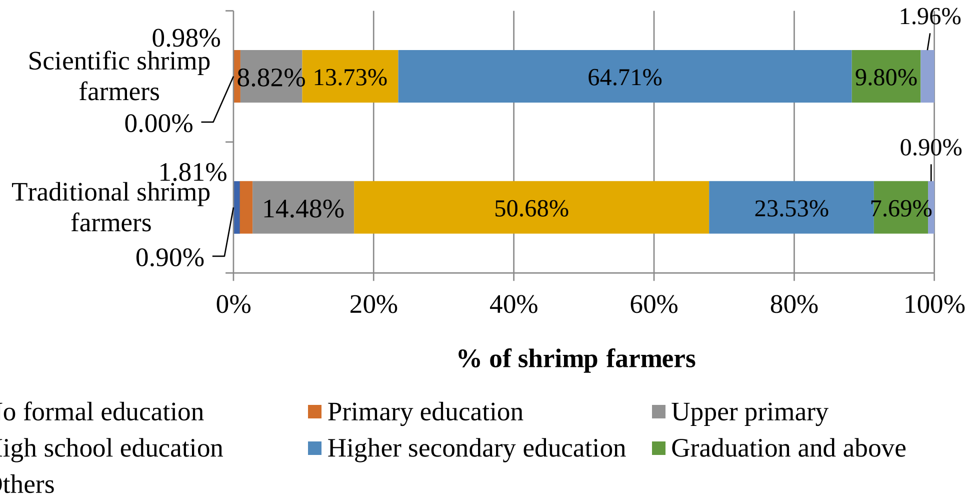


Figure 5.3. Educational status of shrimp farmers (percentage distribution).

Here' formal education' means school education, 'primary education' means up to four years of school education, 'upper primary education' means from 5 to 7 years of school education, 'high school education' means from 8 to 10 years of school education, 'higher secondary education' means from 11 to 12 years of education, 'graduation and above means' education above 12 years and includes professional and postgraduate courses and 'others' include qualifications like engineering diploma, Teacher Training Certificate (TTC), Industrial Training Institute (ITI) certificate etc.

5.4.6. Occupational pattern

The details of occupational patterns of shrimp farmers are presented in Fig. 5.4. Information on the principal avocation of the traditional and scientific shrimp farmers is provided in Fig. 5.5. and Fig. 5.6. respectively.

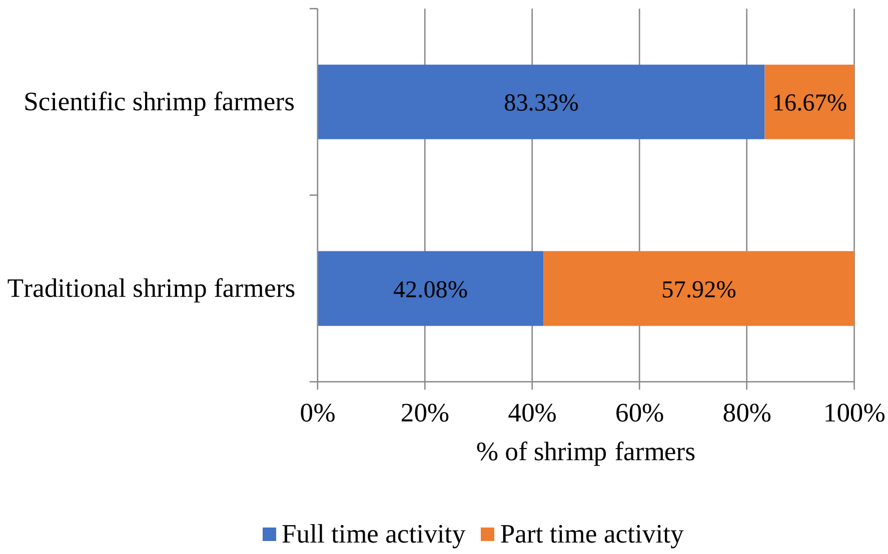


Figure 5.4. Occupational patterns of shrimp farmers (percentage distribution).

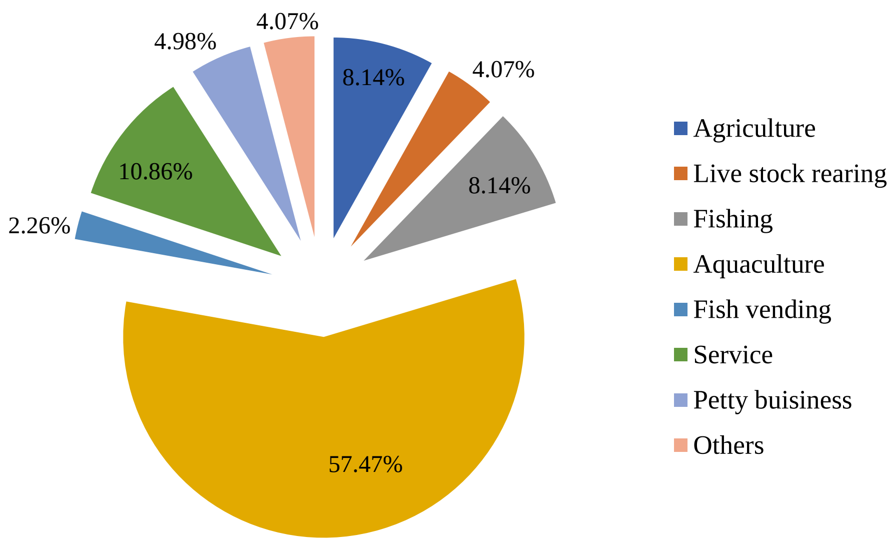


Figure 5.5. Principal avocation of traditional shrimp farmers (% of the total traditional farmers).

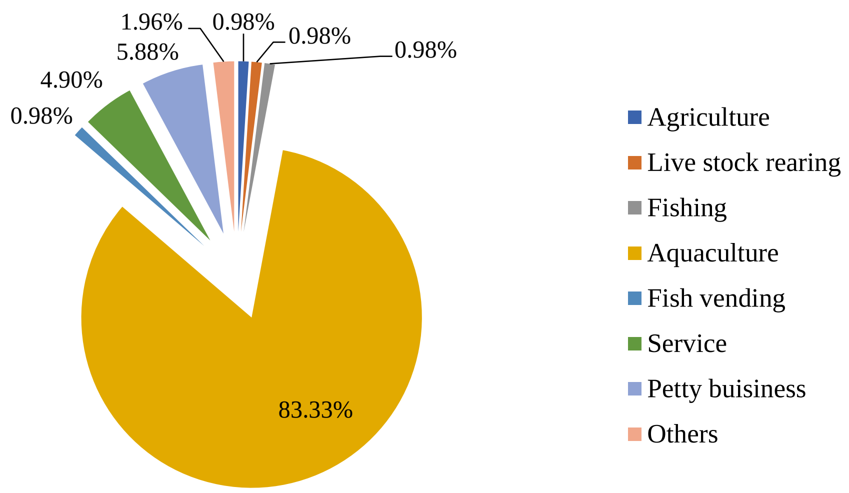


Figure 5.6. Principal avocation of scientific shrimp farmers (% of the total scientific farmers).

5.4.7. Type of houses

The details regarding the type of houses of shrimp farmers are presented in Table 5.7. Similarly, houses of 100% of the shrimp framers have sanitation facilities.

Table 5.7. Type of houses of shrimp farmers.

Type of farmers	% of farmers			
	Dilapidated houses	Good/ livable houses		
		Tiled	Concrete	Total
Traditional shrimp farmers	0.90	43.89	55.20	99.10
Scientific shrimp farmers	0.00	41.18	58.82	100.00

Dilapidated houses mean thatched or asbestos/ tile/plastic/ polythene roofed houses in which the living condition is bad.

5.4.8. Electrical connectivity

Houses of 98.19% of traditional and 100% of scientific shrimp farmers were electrified. Information on electrical connectivity to the shrimp farms is presented in Fig. 5.7.

5.4.9. Drinking water

Information on the drinking water source for shrimp farmers is presented in Fig. 5.8.

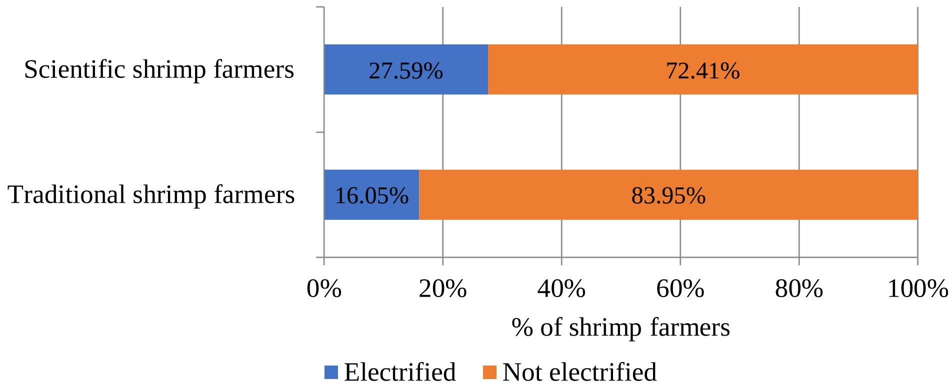


Figure 5.7. Shrimp farms having electrical connectivity (% of the total farms).

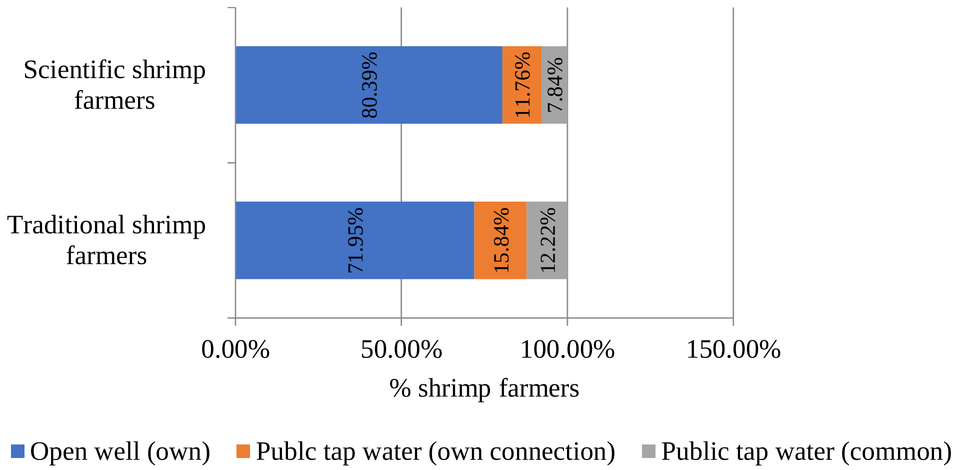


Figure 5.8. Source of drinking water to shrimp farmers (% of the total farmers).

5.4.10. Ownership of land

47.96% of traditional and 96.08% of scientific shrimp farmers were found to undertake shrimp farming in lands owned by them or by their family members. The rest undertake farming in lands taken on lease. In traditional shrimp farming, the lease period was generally for one crop season (6 months), though rarely extended to even 5 years (Fig. 5.9.). In the case of scientific farming, the lease period was from 3 to 5 years. The average extent of land owned by traditional shrimp farmers of the State was 0.94 ha, and that of the scientific shrimp six farmers was 1.55 ha. The mean size of farms operated (water spread area per farmer) by the traditional shrimp farmer was found to be 1.72 ha, and that by the scientific farmer was 0.92 ha.

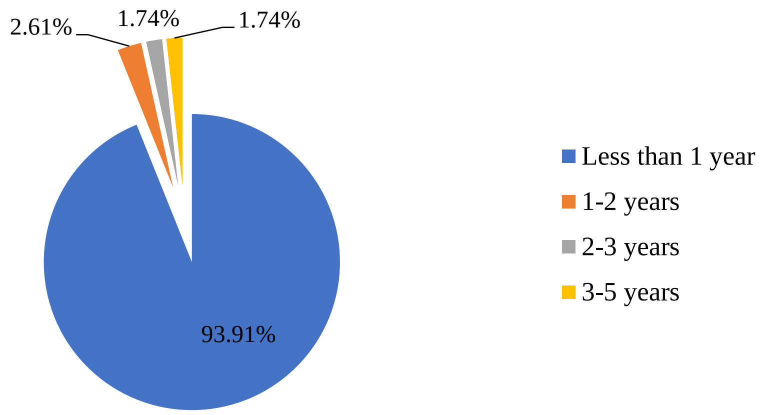


Figure 5.9. Lease period of traditional shrimp farms (% of farms on lease).

5.4.11. Household income

Information on the average annual household income of shrimp farmers is presented in Fig. 5.10.

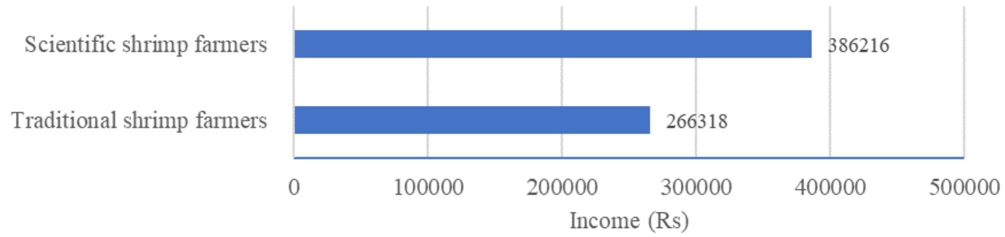


Figure 5.10. Average annual family income (Rupees) of shrimp farmers.

5.4.12. Income from shrimp farming

Information on the share of average income from shrimp farming in the total income of shrimp farmers is presented in Fig. 5.11.

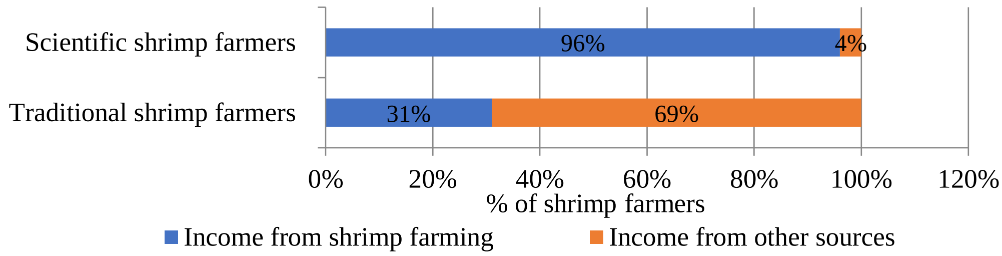


Figure 5.11. Share of income from shrimp farming in the total income of shrimp farmers.

5.4.13. Indebtedness

Information on the indebtedness of shrimp farmers is presented in Fig. 5.12. Data on the average loan amount and the source of loans taken are provided in Fig. 5.13 and Fig. 5.14, respectively.

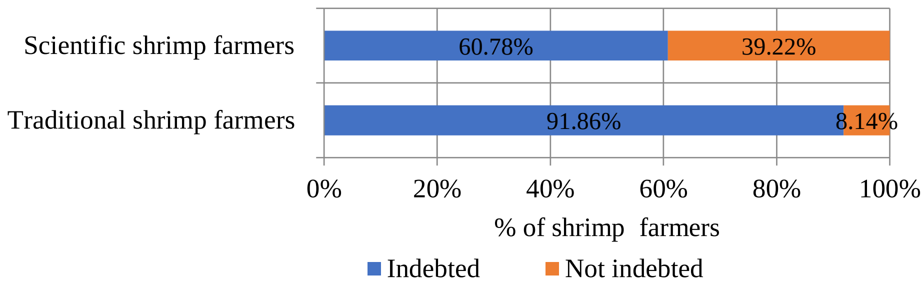


Figure 5.12. Indebted shrimp farmers (% of the total farmers).

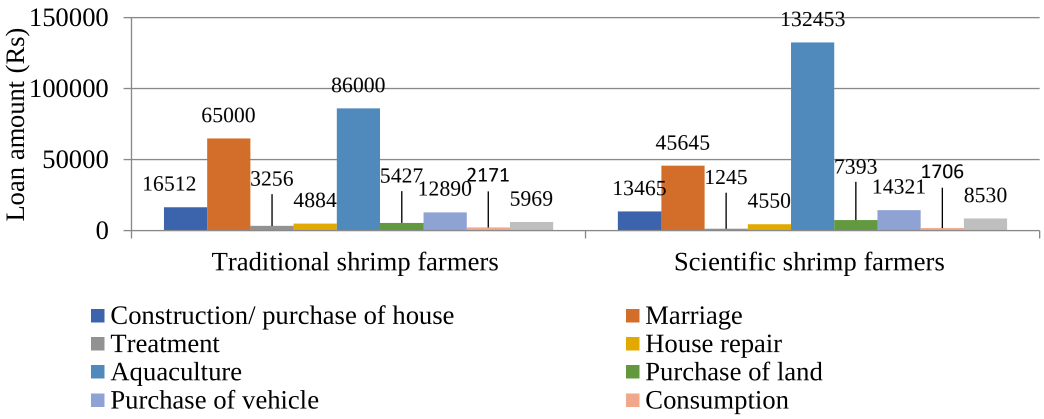


Figure 5.13. Average loan amount (in Rupees) for different purposes availed by shrimp farmers.

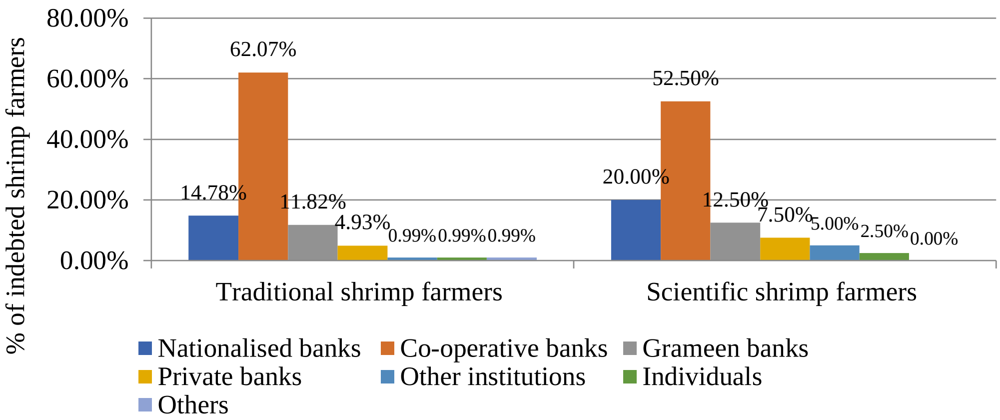


Figure 5.14. Source of loan availed by shrimp farmers.

5.4.14. Experience in shrimp farming

Most shrimp farmers had more than five years of experience in aqua farming. The details are provided in Table 5.8.

Table 5.8. Experience of the shrimp farmers in aquaculture.

Type of farmers	% of farmers					
	Experience (in years)					
	1-2	2-4	4-6	6-8	8-10	>10
Traditional shrimp farmers	0	4.07	7.69	32.13	36.20	19.91
Scientific shrimp farmers	0.98	8.82	25.49	49.02	7.84	7.84

5.4.15. Training in shrimp farming

Information on whether the shrimp farmers received any training in aquaculture is presented in Table 5.9.

Table 5.9. Training received by shrimp farmers.

Type shrimp farmers	% of farmers	
	Training received	No training received
Traditional shrimp farmers	80.09	19.91
Scientific shrimp farmers	83.33	16.67

5.4.16. Source of technical assistance

Most surveyed farmers received technical assistance (apart from training) from government sources like the State Department of Fisheries, Fish Farmers' Development Agency (FFDA), erstwhile Brackish water Fish Farmers' Development Agency (BFFDA), Marine Products Export Development Authority (MPEDA) and/or Agency for the Development of Aquaculture, Kerala (ADAK). Others depended on peer knowledge/ own knowledge in their current farming activities (Fig. 15). However, the technology had been diffused into the area initially through governmental projects like FFDA, erstwhile BFFDA or *Janakeeya Matsyakrishi, Matsya Keralam, Matsy Samrudhi* projects of the Department of Fisheries, Government of Kerala and/ or through the Marine Products Development Authority (MPEDA) working under the Government of India. Diffusion of information was effective because it was based on feasible, low-cost and straightforward ways.

5.4.17. Number of hours engaged by the farmer in farming

Data on the number of hours engaged by the farmers in shrimp farming is presented in Table 5.10.

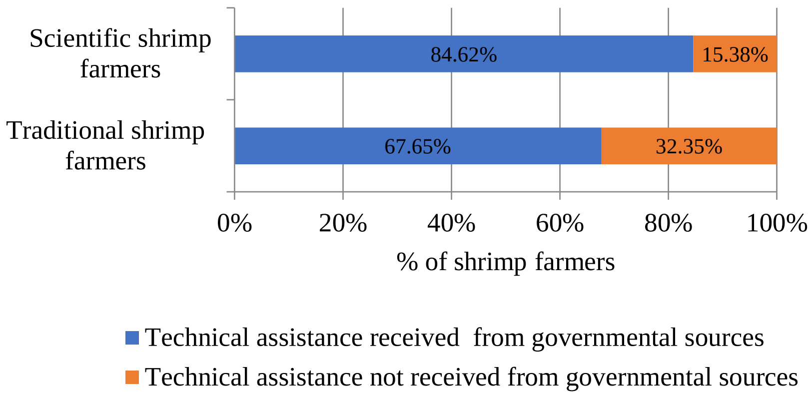


Figure 5.15. Technical assistance to shrimp farmers (other than training).

Table 5.10. The number of hours engaged by the farmers in shrimp farming.

Type of shrimp farmers	Hours engaged per day	Hours engaged during the crop period
Traditional shrimp farmers	10.50	1890
Scientific shrimp farmers	12.50	1687.50

5.4.18. Manpower employed

In the present study, 2006 workers were estimated to be employed in the traditional shrimp farming sector and 1586 workers in the scientific shrimp farming sector of the State of Kerala. This excludes the manpower utilised during the construction phase of the farm and the input of the farmers' labour. The number of person-days per hectare of shrimp farms, including the farmer's labour (during the farming period), is presented in Fig. 5.16.

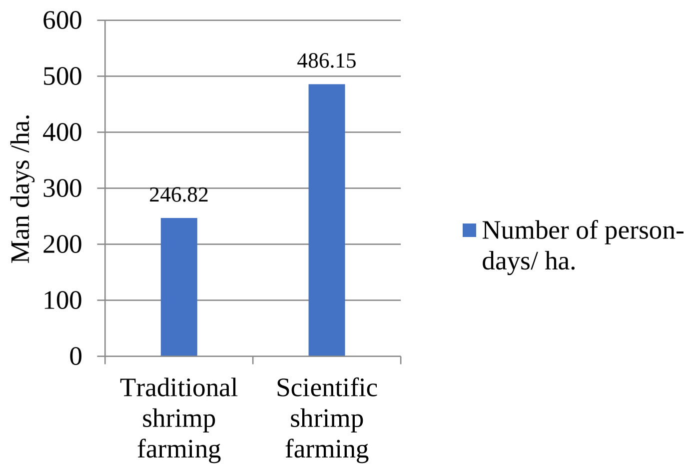


Figure 5.16. The number of person-days per hectare of the farm (during the farming period).

5.4.19. Family members engaged in shrimp farming

In many cases, the family members of the shrimp farmers were also found to assist in farming activities. Information on the number of family members regularly engaged in shrimp farming activities (who assisted the farmer in farming activities) is presented in Fig. 5.17.

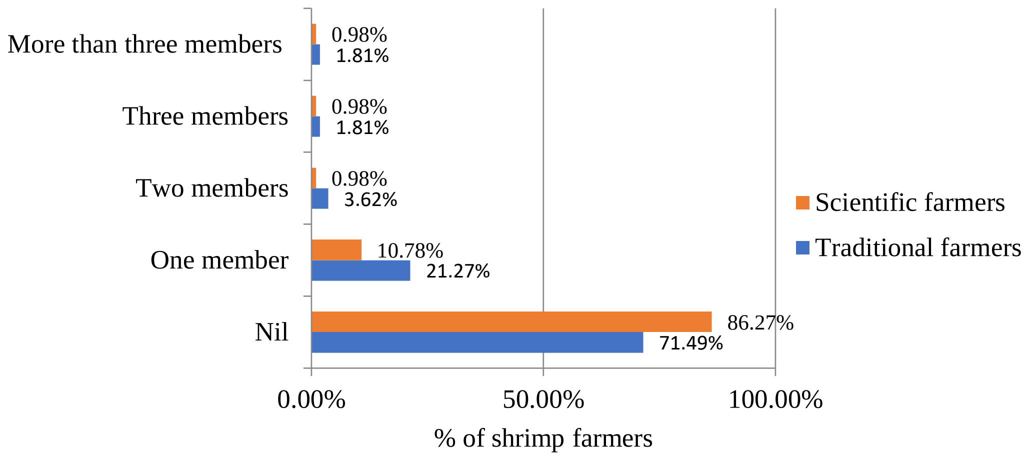


Figure 5.17. Involvement of members of the families of the farmers in shrimp farming.

5.4.20. Migrant labourers

The percentage distribution of migrant and native workers in the shrimp farming sector is provided in Fig. 5.18. Interestingly, these labourers consisted of only males, and female labourers were not employed in the farms.

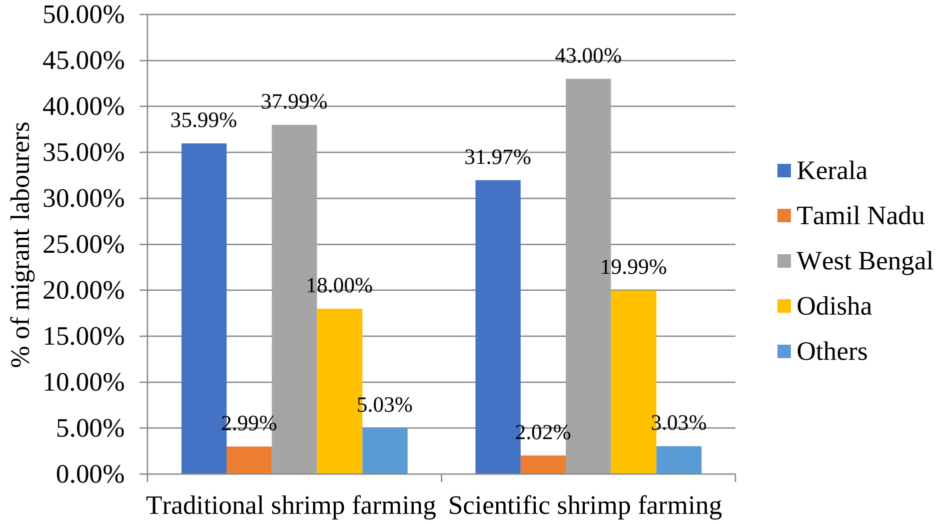


Figure 5.18. Migrant labourers employed in shrimp farms.

5.Discussion

The main objective of the present survey was to document the socio-economic conditions of the shrimp farmers of Kerala. Socio-economic studies are considered essential because improvements in the socio-economic conditions of shrimp farmers is an indirect means of increasing production and productivity. Though shrimp aquaculture is traditionally practised in Kerala, it is yet to make significant strides in the State. However, the sector can make important contributions in rural areas (Kutty *et al.* 2011; Sahadevan and Sureshkumar 2020a). Against the background of stagnation in the supply of fish from capture fisheries, recent advances in aquaculture technology have opened up alternate opportunities for increasing fish production. In the years to come, the popularisation of small-scale aquaculture is expected to play a vital role in increasing protein supply, income, and employment in rural areas.

Diffusion of aquaculture, like any new technology, would imply some form of reorganisation into the existing social pattern (Ahmed *et al.* 1993). Rural households generally engage themselves in various activities related to production and income. Limited farm resources are either used in farming or rented out to off-farm or non-farm uses. At the same time, farms draw on resources from outside through purchases, rentals and or sharing assignments. This may come through improving efficiency and/ or reallocation of farm resources and the supply of additional external inputs (Ahmed *et al.* 1993).

Studies on the socio-economic aspects of shrimp farmers are very few in India as a whole (Goswami *et al.* 2002). In Kerala, too, studies on the socio-economic conditions of shrimp farmers are few and fragmentary. In the absence of benchmark data, a direct comparison of the results obtained in the present study with those of other studies is not possible.

5.5.1. Estimate of number of farmers

The present study indicated that in Kerala, 2157 farmers were engaged in shrimp farming. Of this, 68.29% of farmers were engaged in traditional shrimp farming, where production and profitability were minimal. Only 31.71% of the farmers were involved in scientific shrimp farming. Besides, 3592 persons (traditional farming: 2006 persons and scientific farming: 1586 persons) were engaged as labourers in shrimp farms, most of whom were employed seasonally. Owing principally to the seasonal nature, farms generally do not employ workers permanently.

In the world, employment in the aquaculture sector has grown faster than the world's population (FAO 2016). In 2018, globally, 20.53 million people were reported to be engaged in aquaculture (FAO 2020). Fisheries and aquaculture provide a livelihood to about 28 million fishers and fish farmers at the primary level and twice the number along the value chain (GoI 2020a). Case studies carried out at a sea-based farm in the Nellore District of Andhra Pradesh showed an increase of 2–15% employment and 6–22% income for farm labourers following the establishment of shrimp farms (CIBA 1997). In the brackish water sector, hatcheries and feed mills are also providing many employment opportunities. It has been estimated that over 3,00,000 jobs have been generated in the main and supporting sectors of the shrimp farming sector in rural areas. However, no report of the number of people directly engaged in shrimp farming or those who earn a livelihood from the sector in the State of Kerala is available. Assuming that the labourers also have a family size similar to the average family size of farmers observed in the present study (*i.e.,* 4.3), it may safely be deduced that the State's shrimp farming sector provides livelihood 24,721 persons. However, it may be understood that the various types of work in this sector cannot be considered equal as the forms of employment or engagement vary from occasional to full-time and between seasonal, temporary and permanent occupations.

5.5.2. Demographic indicators

Most traditional shrimp farmers were between 24 and 74 years of age, the mean being 48.52 years. In scientific shrimp farmers, the age varied from 25 to 70 years, and the mean age was 45.69 years. Various authors made similar findings from different parts of the country. In a study conducted in six major fish farming Indian States (Andhra Pradesh, Haryana, Karnataka, Orissa, Uttar Pradesh and West Bengal), Bhatta (2003) reported the age of fish farmers ranging from 38 years in Andhra Pradesh to 58 years in Haryana, with a national average of 47 years. Vadher and Manoj (2014) observed that 56% of the shrimp farmers of Gujarat state were up to 40 years and only 44% of farmers were above

40 years of age. Nagamani and Vimala (2015) showed that 94% of fish farmers in Tamil Nadu belonged to the young and middle-aged group (20 to 49 years), and only 6% belonged to the old age group (>50 years). The authors indicated more involvement of middle and young age-group farmers in fish farming and inferred that fish farming practices fascinated the younger generation's attention. Chittem and Kunda (2018) reported that most (53.30%) of the *L. vannamei* farmers in Andhra Pradesh were in the middle age category. Patil *et al.* (2019b) made a similar finding and reported that most shrimp farmers in the Palghar district, Maharashtra were in the middle age group. Durai *et al.* 2020 found that most of the shrimp farmers in Tamil Nadu belonged to the middle age group (45.33%), followed by old (39.33%) and young (15.33%) age groups. Naik *et al.* (2020) revealed that most shrimp farmers of the South Konkan region of Maharashtra (52.54%) belonged to the 36–50-year group. Similar observations were also made by Kumaran *et al.* (2003b) in Andhra Pradesh, Swathilekshmi *et al.* (2005) in Tamil Nadu and Andhra Pradesh, Chaudhari (2007) in Maharashtra, Koteswari *et al.* (2014) in Andhra Pradesh, Sahu *et al.* (2014) in Odisha Tammaroopa *et al.* (2016) in Thailand, Ogunmefun and Achike (2017) in Nigeria, and Alagappan and Kumaran (2020) in Tamil Nadu and Andhra Pradesh. Ray *et al.* (2021) also found that a maximum percentage of shrimp farmers age groups comprised middle age.

Information about the age of shrimp farmers is one of the crucial factors in estimating the potential productive human resources (Hossain *et al.* 2009). Age is an issue that cannot be approached with cultural pre-occupations about the roles and needs of specific age groups. A better understanding of the role of age in determining economic and social participation levels may be of great importance when it comes to targeting interventions (Goswami *et al.* 2002). The age of farmers generally affects the perception of new technologies, adoption decisions and investment behaviour. Agbor (2007, as cited in Offem *et al.* 2010) stated that risk aversion increases with the advancement in age. According to Offem *et al.* (2010), investment in aquaculture which often has a long gestation period is usually avoided when the farmer's age advances. Durai *et al.* (2020) observed that age reveals the mental maturity of the aqua farmers while making decisions regarding their farming activities.

The present study results indicate that young or middle-aged people are primarily engaged in shrimp farming activities in this part of the country. The age of the farmers in the State also implies that people at both active (<60 years) and less active (>60 years) ages could be shrimp culturists. The increasing trend of younger farmers to adopt scientific farming techniques could be attributed to the high rate of returns, as observed by Adeogun *et al.* (1998).

Around 90% of the families of shrimp farmers of the State had less than six members. Further, most of the families of shrimp farmers live as nuclear families and only a small number as joint families. The size of the family has a bearing on its economic status. It also directly influences the expenditure and income pattern of the family and, thereby, the level of fish production (Goswami *et al.* 2002). Family size also reflects on the food consumption and socio-economic well-being of the family (Hossain *et al.* 2009).

In the present study, the average sizes of families of traditional and scientific shrimp farmers were found to be 4.26 and 4.40, respectively. The mean size of families observed in the present study is slightly less than the average size of families reported by (Beena 1992), who observed a family size of 5.5 among the small-scale traditional shrimp farmers of Ernakulam and (Aravindan 2006) for the general population of Kerala. According to Aravindan (2006), the average number of members in the families of Kerala (general population) is 5.6. Interestingly, the mean household size in Kerala as per the Government of India Census, 2011 (GoI 2011) was 4.2, which is on par with the observations made in the present study. The results obtained in the present study are also in concord with the findings of Nagamani and Vimala (2015), who reported that about 86% of fish farmers of Tamil Nadu lived as nuclear families and 14% as joint families. These authors found that 76% of the fish farmers had a small family consisting of 4 to 5 members. And the rest, 24%, had a large family size consisting of more than six members. Similar findings were also reported by Salunkhe (2018), wherein 73.58% of shrimp farmers belonged to nuclear families and 26.42% of the farmers belonged to the joint type of families in the North Konkan region of Maharashtra. Another study among the shrimp farmers of the South Konkan region (Naik *et al.* 2020) revealed that 59.32% of the farmers lived as nuclear families while 40.68% lived as joint families. Findings in the present study are also in agreement with the results obtained by Chaudhari (2007), Pandey and Upadhayay (2012), Cyril *et al.* (2013), Gupta and Dey (2014), Peter and Susan (2014), Kumar *et al.* (2016), Srinivas and Venkatrayalu (2016), Tammaroopa *et al.* (2016) and Chittem and Kunda (2018).

In the present study, shrimp farming activities were found to be dominated by males. The observation agrees with Nagamani and Vimala (2015), who observed that most of the fish farmers in Tamil Nadu were males (93%) while the females were only 7%. Patil *et al.* (2019b) reported that most of the shrimp farmers of Maharashtra were males. They also noted that though 6% of the total registered farms were in women's names, they were run by men. This is an indication that males participate in aquaculture more than females. Naik *et al.* (2020) also reported the dominance of males in the shrimp farming sector of the South Konkan region of Maharashtra, contributing almost 98.31%, whereas the share of females was only 1.69%. The present observation is also in agreement with the findings by USAID (2009) on the challenges facing women in Burkina Faso, which established that women were constrained in terms of access to land, control of production, decision making on the use of assets and control over household income. This observation can be justified by the assertion of Brummett *et al.* (2010) that men mostly dominate fisheries activities.

The observation is also in perfect concord with the situation prevailing in general sectors in the State. Mazumdar and Guruswamy (2006) observed that women's work participation in Kerala is generally lower than in other Indian states. According to the Government of India census 2011 (GoI 2011), the percentage of females in Kerala's total workforce (primary workers) is only 23.04%. The census also reveals that among the cultivators in Kerala, only 18.4% are females, whereas it is 31.11% in the county (India).

Kerala offers an exciting contradiction of social advancement and economic stagnation. Despite enjoying a better status and position than the women in other parts of the country, women in the State have low levels of participation in economic activity (Mazumdar and Guruswamy 2006). Regarded as a progressive state with a very high literacy rate and social sector indices matching even advanced countries and a high gender equality index, Kerala still lags behind most other Indian states in women's work participation. In contrast to 55.9% of rural males and 54.7% urban males employed in Kerala in 2004-05, the work participation rate of rural and urban female counterparts was only 25.6% and 20.0% in the same period.

Participation of women in economic activities outside the home has an important bearing on gender relations within the household. Inter-relationship exists among economic power, gender, and household variables. Dwyer and Bruce (1988) and Blumberg (1990) pointed out that the main factor that affects intra-household gender relations is the relative incomes of males and females. Women's economic power to control vital economic resources such as income, property and other means of production compared to men is posited as the most important dependent variable affecting gender relations at the household level (Elson and McGee 1995).

The social influences of women's work are also extensive. Job opportunities outside the home minimise women's economic reliance on men and, in turn, enhance her economic command within the family. Women's work outside the household would alter the concept of the male breadwinner. It would considerably reduce the societal biases regarding women's roles that are primarily responsible for underestimating women's work. Women's earning gives them access to and control over an independent income, which would make their economic contribution to the household visible and high (Basu 1996). This, in turn, improves their access to and control over household resources and would offer them better bargaining power (Dixon 1982). This bargaining power can strengthen their participation in and influence household decision-making, which is crucial to women's autonomy in the household.

Women's economic productivity is a critical factor, as the family's dependence on their contribution to household resources increases with the household's poverty status (Mahapatra 2002). Thus, it has been maintained that making women more productive and more effective income earners will reduce their dependency and enhance their status besides helping in reducing fertility and slowing down population growth, improving child health and nutrition status, bestowing greater decision-making power on the women, both inside as well as outside the household and increasing aggregate labour productivity and ensuring speedy growth in key economic sectors (Gopalan 1995). Social recognition and status hinge on economic empowerment (Mazumdar and Guruswamy 2006). It may be pointed out here that shrimp farming did not attract many women and had not contributed much to strengthening women's empowerment in Kerala.

Globally, inland fisheries and aquaculture can empower women and contribute to gender equity. The World Bank (2012) indicated that about 35 million of the estimated 60 million people engaged in global inland fisheries and their value chains – nearly half – are women. However, their role has largely been unrecognised (HLPE 2014). Women are strongly associated with the post-harvest sector, e.g., processing, sales, distribution and marketing. Income earned by women often has a more substantial, more beneficial impact on household incomes (Porter 2012). However, information on women in shrimp aquaculture is generally lacking.

However, there is considerable scope for the entry of large numbers of females into the aquaculture sector in Kerala, and there is substantial scope for expanding their role in shrimp production. Women can be trained for pond management (pond preparation, stocking, feeding, fertilisation, harvesting), handling, transport, and marketing- activities that do not involve highly sophisticated methods and techniques. In the State where female literacy rates are high and where women are aware of public services for infrastructure, credit, welfare, or extension, there is great potential to effectively increase the contribution of women to the development and promotion of shrimp aquaculture in a big way.

In general, females outnumber the males in the families of the shrimp farmers of the study area. The higher female to male ratio is in concord with the general population statistics of the State. It may be interesting to note that the Government of India Census of 2011 (GoI 2011) shows that the number of females to males in Kerala is 1084. This dominance in the number of females to males is also evident among the families of shrimp farmers. However, this figure is well above the sex ratio of the country's general population as a whole, which is 1000 males to 943 females.

A person's level of education directly impacts their earning ability, with higher earning power leading to more educational opportunities that increase future income potential. In the present study, 100% of the shrimp farmers of the State were found to be literate. 97.29% of traditional shrimp farmers and 99.02% of the scientific shrimp farmers were educated above the primary level, indicating a medium level of education. A good percentage had education beyond the high school level. It implies that literate persons were involved in shrimp culture practices. It is pretty interesting to observe that people with graduation and above qualifications were also participating in shrimp farming activities. It may be inferred that shrimp farming practices in the State succeeded in attracting the interests of educated persons.

Many earlier workers from various parts of the country reported similar observations on the relatively high literacy rate among the aqua farmers. Beena (1992) observed that 91.8% of the small and large traditional shrimp farmers of Ernakulam district were literates. Raju (2002) found that most of the semi-intensive shrimp farmers of Kerala were college-educated. Bhatta (2003) found the educational status of fish farmers of Andhra Pradesh, Haryana, Karnataka, Orissa, Uttar Pradesh and West Bengal to vary from 0 to10 years of schooling. Vadher and Manoj (2014) observed that 48.1% of the shrimp farmers of Gujarat State had studied up to SSLC, 30.2% of the farmers had completed graduation or post-graduation, 18.3% of the farmers had primary school level education, and 3.4% were illiterates. Nagamani and Vimala (2015) observed that 29% of the fish farmers in Tamil Nadu had primary education, 20% had high school level of education, 46% had higher secondary education, and 5% were undergraduates. Durai *et al.* (2020) found that 93.33% of shrimp farmers of Tamil Nadu were educated. He found that nearly half of the farmers (44.67%) were educated up to the higher secondary level followed by graduation and above level (22.67%), middle school level (12.00%) and primary school level (14.00%). Naik *et al.* (2020) observed that 40.68% of shrimp farmers of the south Konkan region of Maharashtra were educated up to the graduation level, 30.51% of farmers up to higher secondary and 8.47%, up to the secondary level of education. Around 11.86% of farmers were educated up to the primary level, and 3.39% of farmers were post-graduates. The percentage of illiterate shrimp farmers was 5.08% only. Similar observations were also reported by Patil *et al.* (2019b) in their study in Palghar district, Maharashtra, who found that 50.91% of the shrimp farmers were graduates and 29.09% educated up to higher secondary level. Findings in agreement with those of the present study were also made by Kumaran *et al.* (2004), Swathilekshmi *et al.* (2005), Chittem and Kunda (2018), Srinivas *et al.* 2019 and Alagappan and Kumaran (2020).

Education is an important socio-economic factor that has much bearing on performance in fish farming. There is a positive correlation between the level of education and farm production (Ofuoku *et al.* 2008). The level of education possessed by farmers influences the adoption rate of innovations (ADB 2005). The high rate of producers with secondary and post-secondary education in aqua farming could be attributed to the high economic gains, unemployment, underemployment among the educated, diversification of business enterprises and planning for retirement (Dey *et al*. 2000). Education and farming efficiency are interrelated, and education generally positively affects the productivity of farms. For the successful farming of shrimp, technical know-how is a prerequisite. Hence a shrimp farmer requires gathering and assimilating knowledge on better husbandry techniques, including management of diseases. In general, farmers with good educational backgrounds can quickly adopt scientific farming practices. The literacy rate of shrimp farmers plays a vital role in the efficient management and operation of farms and the successful raising of shrimp. An educated farmer is more likely to acquire new technology than an uneducated one (Meena *et al.* 2002; Chittem and Kunda 2018).

Kerala has the highest proportion of literate persons in the Indian States (State Planning Board, 2020). As per the Government of India Census 2011 (GoI 2011), the State of Kerala has a literacy rate of 94%. The literacy rate among the males in the State is 96.1%, and that among the females is 92.10%. It may be mentioned here that the literacy rate in the entire country (India) is only 73% as per the census. In Kerala, the level of education is also very high compared to other parts of the country. Adequate literacy skills and a higher level of education pave the way to more educational and employment opportunities. There are also linkages between literacy, education and health. The spread of literacy has played a significant role in the social and economic development of the State. Increased democratisation, rights consciousness and civic awareness in the State are highly correlated to the high level of literacy that has existed for decades.

It is evident from the present study that shrimp farming was a full-time avocation for only 42.08% of traditional farmers. In the case of others, shrimp farming was a part-time avocation. They were engaged in land-based agriculture, livestock rearing, fishing, fish vending, petty business or government or private services. They undertake shrimp farming in the traditional mode. Principally, because of the small pond holdings and the seasonal nature of traditional shrimp farming, these farmers do not undertake shrimp farming as their principal avocation. And in turn, this acts as one of the main reasons for the relatively low productivity of these units and the insignificant contribution of shrimp farming to the farmers' total income. These aspects have been discussed in detail in Chapter 2.

Further, it is observed that shrimp farming alone is insufficient for the traditional farmers to gain adequate means of livelihood. They were involved in other occupations like land-based agriculture, petty business, services, livestock rearing etc., to secure their livelihood year-round. Sarker (2004) and Nagamani and Vimala (2015) also made similar observations. Vadher and Manoj (2014) reported that about 65.70% of the shrimp farmers in the Gujarat state were engaged in business other than aquaculture, whereas 34.3% of shrimp farmers had depended only on aquaculture. Similarly, Naik *et al.* (2020) observed that most shrimp farmers (76.27%) of the South Konkan region practice other occupations along with shrimp farming. Only 20.34% practice shrimp farming alone. The results reported in the present study agree with those by Srinivas and Venkatrayalu (2016), who noted that 92% of shrimp farmers practised other occupations in addition to aquaculture, while only 8% of shrimp farmers depended on shrimp farming alone. Srinivas *et al.* (2019) also reported similar findings. From the above discussion, it can safely be concluded that most of the traditional shrimp farmers in Kerala undertake other occupations along with shrimp aquaculture. Alternative occupations provide financial security during crop failures and/ or when the price of the farm produce crashes. Further, these also add to the income of the shrimp farmers.

In the case of scientific shrimp farming, the situation is just the reverse. Here 83.33% of the farmers practised shrimp farming as their principal avocation, and the lion share of their income was derived from this activity. Raju (2002) found that majority of the semi-intensive shrimp farmers of Kerala were business people (42.86%), followed by professionals (23.81%) and agriculturists (19.05%). Chittem and Kunda (2018) found that 61.60% of the scientific shrimp farmers of Andhra Pradesh had the occupation of farming shrimp only, whereas 20.5% were involved in both shrimp culture as well as agriculture, and the remaining 12.2% were engaged in both shrimp and fish farming as their occupation. Durai *et al.* (2020) observed that about three-fourths (78.67%) of the scientific shrimp farmers of Tamil Nadu were engaged in aquaculture alone for their livelihood, and the rest (21.33%) had other professions as well, in addition to aquaculture. It was clear that shrimp aquaculture being a relatively risky farming activity, requires the farmer's full-time involvement and attention, as has been opined by Swathilekshmi *et al.* (2005), Kumaran *et al.* (2017) and Alagappan and Kumaran (2020).

5.5.3. Housing, sanitation, access to power and drinking water

The study found that 100% of the shrimp farmers had their own houses and the condition of their houses (except in the case of 0.90% of the traditional farmers) was also fairly good. Similarly, houses of all shrimp farmers (except those of 1.81% of the traditional farmers) were electrified. The majority of the houses of shrimp farmers had protected sources of drinking water mainly in the form of open wells, followed by their own tap water connection and public water taps. Similarly, houses of 100% of the shrimp framers have sanitation facilities.

The housing pattern is one of the most important indicators used to assess the economic well-being of any community. The findings in the present study are not in concord with the observations made by Beena (1992), who observed that most of the houses of marginal and small traditional shrimp farmers of Ernakulam district in Kerala were "kutcha" type with inadequate facilities. According to Beena (1992), 80% of the large traditional shrimp farmers of Ernakulam district had good quality houses. The observed difference is because the survey by the above author was conducted almost 28 years back. During the period, many projects were implemented by the government, exclusively focusing on providing houses to the houseless people. Besides, during the period, the economic status of the people of the State has increased many folds. Further, the above finding resulted from a survey that used a small sample of farmers residing in one of the most undeveloped villages of Ernakulam district. On the other hand, the present study relied on a large sample of shrimp farmers scattered throughout Kerala.

The study made it feasible to conclude that shrimp farmers generally have good houses to live in. The observations on the housing condition, electric connectivity and availability of sanitation facilities possessed by shrimp farmers in the present study agree with the situation prevailing in the State of Kerala in the case of the general population. According to Aravindan (2006), more than 95% of the people in Kerala own houses. As per the National Census 2011 (GoI 2011), more than 99.5 % of the people of Kerala own houses. The census reveals that in the coastal districts of Kerala, the housing condition is relatively good *viz.*, in Thiruvananthapuram (92.00%), Kollam (93.40%), Alapuzha (93.00%), Ernakulam (96.30%), Thrissur (95.60%), Malappuram (96.60%), Kozhikkode (95.40%), Kannur (96.40%) and Kasargod (94.20%), majority of the people live in good/ livable houses. A recent survey to identify houseless people in Kerala by Kudumbashree Community Development Societies (CDS) has found only 3195 homeless people in the State (State Planning Board 2020). The electrification of houses, sanitation facilities, etc., are also good compared with the case in many other parts of the country. The situation is due to the direct result of various housing, sanitation and electrification schemes implemented by the state government from the later years of the 1970s, mainly to those belonging to the lower echelons of the society (Aravindan 2006). The present observation is in agreement with that made by Chittem and Kunda (2018), who reported that 54.4% of the *L. vannamei* shrimp farmers of Andhra Pradesh had reinforced cement concrete (RCC) houses, 32.2% had tile-roofed houses, and only 13.3% had hut/shed type of houses.

Housing is a basic need and is recognised as a human right. Providing adequate shelter to all citizens is a welfare state's duty and a significant fiscal challenge to every government. The mean size, quality, and investment per house in

Kerala are better than in other parts of the country (State Planning Board 2020). Above two-thirds of all households (66.67%) in Kerala live in good quality houses (pucca houses with roof, wall etc.) where as the corresponding figure at the national level is 53.1%. 95% of houses in Kerala are electrified, while the national average is only 67% (State Planning Board 2020).

5.5.4. Ownership of land

The majority of the traditional shrimp farmers (52.04%) were found to undertake shrimp farming in leased land, and only 47.96% do farming in the land owned by them or their family members. The lease period was generally less than a year. Because of the short lease period, farmers normally do not undertake any significant investment in the farm for improving the physical facilities, production and productivity of the farm. The shorter lease period is one of the principal reasons for the low profitability/ performance of these farms. This aspect has been discussed in detail in Chapter 2.

However, 96.08% of the scientific farms were owned by the farmers themselves. Only 3.92% of the farmers were found to undertake farming in leased land. Here the leasing period was also long, *viz.*, 3-5 years. A similar observation was made by Raju (2002), who observed that only 7.52% of the semi-intensive shrimp farms in Kerala were in leased lands. The observations in the present study are in disagreement with those of Swathilekshmi *et al.* (2005), who found that 88.34% of farmers of Nellore district of Andhra Pradesh and 99.33% of farmers of Nagapattinam district of Tamil Nadu were undertaking farming in leased land. The observations were also not in concord with those by Naik *et al.* (2020), who found that the majority (64.41%) of the shrimp farmers of the south Konkan region of Maharashtra were operating in leased lands, whereas only 35.59% of shrimp farmers had owned their farms. According to these authors, capital investment is more if farmers have their own farms.

A fundamental reason for the lukewarm development of shrimp farming in Kerala is the lack of a land leasing policy for farming purposes. In this context, most of the public water bodies remain unutilised for farming. Indeed, some landowners lease their water bodies for a short period. However, in the absence of long-term leasing, farmers find it difficult to obtain financial assistance from banks or other institutions to develop the farms. This aspect has been highlighted by Kutty *et al.* (2011) and Sahadevan (2013).

The average extent of land owned by traditional shrimp farmers of the study area was 0.94 ha, and that of the scientific shrimp farmers was 1.55 ha. The mean size of farms (water spread area) operated by the traditional shrimp farmer was found to be 1.72 ha, and that of the scientific farmer was 0.92 ha. This means that the extent of land other than the farmers' farmlands is meagre and is in line with the size of land owned by the people of the general sector (State Planning Board 2020). The present observations are more or less in agreement with the findings of various authors from different parts of the country like Kumaran *et al.* (2003b), Swathilekshmi *et al.* (2005), Gawde *et al.* (2006), Mohite (2007), Randive (2008), Sahu *et al.* (2013), Vadher and Manoj (2014), Srinivas and Venkatrayalu (2016), Salunkhe (2018), Patil *et al.* (2019b), Srinivas *et al.* (2019) and Naik *et al.* (2020). The small landholding of the shrimp farmers is one reason for the dismal performance of the shrimp farms in the State of Kerala. Small farms may not permit mechanisation of the farming operation and crop diversification. Small farms will also have to incur a higher fixed cost per unit area, resulting in poor profitability and less attractive farming operation.

5.5.5. Household income and indebtedness

The average annual income of the traditional and scientific shrimp farmers was Rs. 2,66,318 and Rs 3,86,216, respectively. In traditional shrimp farming, the income level is slightly less than the per capita income of the general sector people of Kerala (State Planning Board 2020). But in the case of scientific farmers, the income is above the per capita income of the general sector. According to the (State Planning Board 2020), the per capita GSDP at constant prices in 2017-2018 of the State of Kerala is Rs. 1,48,927. At current prices, the corresponding figure is Rs. 1,99,101.

Another important observation was regarding the contribution of shrimp farming to the farmers' total income. The contribution of shrimp farming to total household income was only 31% in the case of traditional shrimp farmers. However, farming contributes substantially (96%) to the income of the scientific shrimp farmers owing principally to the higher profitability of the farming operation. It is because of the higher price obtained for the product in the latter case and because most farmers are engaged in farming as their principal avocation. As has already been mentioned, shrimp farming was a full-time avocation for only 42.08% of traditional farmers. In the case of others, shrimp farming was a part-time avocation. They were engaged in land-based agriculture, livestock rearing, fishing, fish vending, petty business or government or private service. They were found to undertake shrimp farming in the traditional mode. Principally on account of the small size of pond holdings, these farmers do undertake shrimp farming as their principal avocation. And in turn, this acts as one of the principal reasons for the relatively low revenue realisation by these farmers and the low contribution of shrimp farming to the total income of the farmers. In scientific shrimp farming, 83.33% of the farmers practised shrimp farming as their principal avocation, and the major part of their income was derived from the farming activity. Bhatta (2003) also made a similar observation in a study conducted in Andhra Pradesh, Haryana, Karnataka, Orissa, Uttar Pradesh and West Bengal. He found that fish farming, though a part-time activity, contributes a significant share of the income of farmers, ranging from 14.98% in Orissa to 95.26% in Andhra Pradesh, with an average of 79.66%.

Another important finding of the present study was that most shrimp farmers were indebted. Around 91.86% of the traditional shrimp farmers and 60.78% of the scientific farmers were financially indebted. Loans were availed for various purposes like shrimp farming, construction of the house, repair of house, marriage, treatment, purchase of land, purchase of vehicle, consumption, agriculture, livestock rearing etc. It is interesting to note that only around 42.55% of the loans were for shrimp farming purposes among traditional farmers. Among the scientific shrimp farmers, the corresponding figure was 57.76%. The source of loans was primarily commercial banks and not money lenders or middlemen or sources that charge exorbitant interest rates. Co-operative banks were the most common sources of loans, followed by nationalised banks, Grameen banks and private banks, obviously due to the easiness of getting loans.

At the farm level, income is perhaps the most critical factor for the choice of technology and enterprises. Small scale traditional farmers in the area face three interrelated problems, *i.e.,* maintaining an adequate income, securing a balanced diet for their families and preserving the natural resource base for future aquaculture production. The annual family income of traditional shrimp farmer households was relatively low. This low level of income is reflected in their relatively poor economic conditions. Their income was insufficient to maintain their normal livelihood, which explains their higher financial indebtedness for non-farming purposes. They cannot afford much for shrimp culture activities, too. This has made traditional shrimp farming less attractive. This aspect has been discussed in detail in Chapter 4.

However, the shrimp farmers' income is better than the general population in the State. According to (State Planning Board 2020), the primary breadwinner of 70.75% of the rural households in Kerala earns less than Rs. 5000 per month, while the corresponding share is 74.52% at all India level.

5.5.6. Experience in farming and source of knowledge

In general, the shrimp farmers of the State had a fairly good experience in aqua farming. It may be seen that 95.93% of the traditional farmers and 90.20% of the scientific farmers had more than four years of experience in shrimp farming. Similar observations were reported by many authors from different parts of the country. Vadher and Manoj (2014) observed that 74% of the farmers of Gujarat state had up to 5 years of experience in shrimp farming, and 26% had more than 5 years. Nagamani and Vimala (2015) made similar observations in the case of fish farmers and Durai *et al.* (2020) in the case of the shrimp farmers of Tamil Nadu. The latter authors found that nearly half of the shrimp farmers (48.67%) had farming experience between 5 and 10 years. Further, 27.33% of farmers had experience up to 5 years, while 24.00% had more than 10 years of experience. Similar results were also reported by Kumaran *et al.* (2017), who noted that 94.65% of the shrimp farmers of the east coast of India had more than 5 years of experience. Naik *et al.* (2020) observed that all shrimp farmers of the South Konkan region of Maharashtra were experienced, and around 49.15% of shrimp farmers had the experience of 6- 10 years, and 28.81% had experience up to 5 years. Based on their study in the Palghar district of Maharashtra, Patil *et al.*

(2019b) reported that 54.55% of shrimp farmers had the experience of 6-10 years in aquaculture. Findings similar to those made in the present study were also reported by (Kumaran *et al.* 2003b; Tammaroopa *et al.* 2016; Chittem and Kunda 2018 and Srinivas *et al.* 2019). Valid and longer experience is expected to help farmers get higher production, avert risks in farming and lower the cost of production. The farmers with longer years of experience are also likely to be able to forecast the market situation in advance and get a higher price for their produce.

A sizeable number of farmers in the area received training in aquaculture and technical assistance from government sources like the State Department of Fisheries, Fish Farmers' Development Agency (FFDA), erstwhile Brackishwater Fish Farmers' Development Agency (BFFDA), Agency for the Development of Aquaculture, Kerala (ADAK) and/ or Marine Products Export Development Authority (MPEDA). However, some depended on peer knowledge/ own knowledge or progressive farmers in the nearby areas in their current aqua farming activities. However, the technology had been diffused initially through governmental projects like FFDA, BFFDA, *Janakeeya Matsyakrishi*, *Matsya Keralam*, *Matsya Samrudhi* or other schemes implemented by the State Department of Fisheries and agencies under the Government of India. Diffusion of information was effective because it was based on feasible, low-cost and straightforward ways. Shrimp farming received the attention of the people partly because of the initiative of the governmental agencies in popularising shrimp farming as a foreign exchange earner and partly because of the awareness about the more profitable nature of the shrimp farming business.

Knowledge of modern farming techniques is an important aspect of success in shrimp farming. Training is an effective tool for the transfer of technology. Even though training programmes are being organised by the State Fisheries Department, FFDA, MPEDA, ADAK and other organisations, farmers were not willing to undergo frequent training for fear of wage loss, lack of time and lack of interest, as has been reported by Kumar (1996) and Goswami *et al.* (2002). Mohan *et al.* (2008), Patil *et al.* (2018) and Patil and Sharma (2020) also emphasised the importance of training in shrimp farming.

Naik *et al.* (2020) opined that technical information and the authenticity of the source of information are vital in achieving success in farming. Based on the study among shrimp farmers of the South Konkan region of Maharashtra, the above authors observed that progressive shrimp farmers were the primary source of information for 27.71% of shrimp farmers. Aqua company technicians (25.30%) were the second primary source of information, followed by internet/social media (17.47%). Similar results were also reported by Salunkhe (2018), who found that progressive shrimp farmers were the primary source of information for 50.94% of the shrimp farmers of the North Konkan region of Maharashtra. Similarly, Gawde (2004), in his study conducted in the South Konkan region, reported that 62.50% of shrimp farmers were dependent on progressive farmers for the information. Sathe (2008) said that 91.49% of the farmers had feed company technicians as their primary source of information in the North Konkan region of Maharashtra. Swathilekshmi *et al.* (2008) reported that 71.67% of farmers mainly depend on feed technicians and dealers.

5.5.7. Engagement in farming and labour requirement

During the periods of farming, traditional shrimp farmers and scientific shrimp farmers were engaged in farming activities on an average of 10.50 and 12.5 hours per day. Traditional shrimp farming required, on average, 246.82 person-days of labour, whereas scientific shrimp farming required 486.15 person-days of labour per ha of shrimp farm. The higher requirement of person-days for scientific farming than traditional farming is for seed stocking, feeding, monitoring water quality and security purposes.

In shrimp farming, the mean labour requirement has been estimated at 600 labour days per crop per hectare against 180 labour days per crop per hectare in paddy field cultivation by Rao and Ravichandran (2001). The person-days of labour reported by Sathiadhas *et al.* (1989) for pokkali prawn filtration is 90 days per ha. Begum *et al.* (2015) reported 116.79 person-days of work for scientific shrimp farming in Bangladesh. In a study conducted in Andhra Pradesh, Haryana, Karnataka, Orissa, Uttar Pradesh and West Bengal, Bhatta (2003) found a large percentage of the fish farmers practice aquaculture on a part-time basis with their engagement in the activity ranging from 17 person-days per annum in Karnataka to the highest of 75 person-days in West Bengal.

The observed huge difference in the requirement of person-days of work among the various studies mentioned above is because the farmer's labour input was also considered in some, whereas the farmers' contribution was not considered in others. Further, there is also variation in the intensity of farming. In general, the more intensive the farming is, the more the human resources requirement. The higher labour requirement would be for feeding, water quality management and harvesting.

In general, the family members of shrimp farmers are expected to be engaged in farming activities. However, contrary to the expectation, family members were not involved in shrimp farming activities to any significant level. In Kerala, it may be because demographic transition, high literacy rate, better education, and lack of professional and skilled jobs had forced Keralites to look for higher wages and skilled works outside the State and abroad. The young generation of the State, in general, is reluctant to pursue farming activities which were quite evident from the present study. This trend has led to a decline in the availability of the workforce in Kerala, especially in the unskilled job market and to a great extent, the migrant workforce fills the deficiency.

5.5.8. Source of the labour force

It is interesting that migrant workers from outside Kerala were the primary workforce in the shrimp farming sector. 64.01% of the total labourers of the traditional shrimp farms and 68.03% of the labourers of the scientific farms were migrant labourers. There were no female migrants found in the shrimp farming sector. The composition of native females was also insignificant because works in shrimp farms require physical strength, and the nature of work is more tedious.

Labour shortage in some segments had become a significant challenge of the labour market in Kerala since long back. Labour shortage occurs when the demand for a particular type of labour exceeds the supply at prevailing wage and working conditions of employment. At present, employers in Kerala found inter-state migrant workers as an alternative to their works due to the non-availability of natives for unskilled jobs in many fields like agriculture, food processing, construction, manufacturing, hotels, and the hospitality sector.

Employing migrant workers is cost-effective in many cases and a value-added to the organisations they are employed in terms of their productivity and performance (Reymen *et al.* 2015). It may also be mentioned here that many reports of migrant workers in construction, hotel, agriculture and industry exist in Kerala. A few studies also exist on the migrant labourers in the mechanised marine capture fisheries sector. However, no studies exist on the migrant labourers in the shrimp farming sector. Indeed, one can debate the pros and cons of engaging migrant workers, but it is a highly subjective decision to be made by farms. The process of hiring and managing migrant workers would also seem quite daunting.

5.6. Conclusion

In unambiguous terms, the preceding discussion indicates that shrimp farmers of the region are not homogenous. Several critical factors distinguish one group from another. Traditional shrimp farmers and scientific shrimp farmers lie in different socio-economic strata. The socio-economic conditions of traditional shrimp farmers are more or less similar to that of the State's general population. On the other hand, the socio-economic conditions of scientific shrimp farmers are slightly better than the general population. This is entirely justifiable because traditional farmers mostly use rudimentary techniques in farming which results in low revenue.

The socio-economic profile of shrimp farmers has a direct bearing on the adoption of technologies. Social and economic factors at various levels of social systems form an environment where people interact through roles and relationships defined by age, education, social participation, economic motivation and other socio-economic variables (Swathilekshmi *et al.* 2005). The socio-economic status of shrimp farmers also plays a vital role in productive activities. Parameters such as family size, age structure, education and living standards of shrimp farmers impact their response to new technology and participation in development schemes (Goswami *et al.* 2002). These also influence their willingness to take business risks.

Studies on various socio-economic variables attempted to explain the overall socio-economic conditions of shrimp farmers and delineate factors constraining the realisation of the full potential of shrimp farmers and the appropriate area for government interventions. Personal, psychological and situational factors always influence the earnings and the adoption of scientific shrimp farming techniques.

Livelihood outcomes can be considered as the inverse of poverty. Contributing to eradicating poverty and food insecurity depends on equitable access to disadvantaged groups to sufficient, safe and nutritionally adequate food (Scones 1988; Ali *et al.* 2008). Analysis of income levels of the shrimp farmer families in Kerala has brought out many exciting results, which are helpful for policymakers wishing to promote new diversification opportunities in the crop sector. Despite inadequate resources and intra-sectoral variants, scientific shrimp aquaculture is positive, and most of the farmers received reasonably good income. In general, employment and earnings are the twin decisive factors mainly used for determining the living standards of any community or region. Equitable distribution of income further strengthens the social harmony among the different societies of the population.

As has already been pointed out, in the absence of detailed studies on the socio-economic conditions of shrimp farmers in the study area or the nearby regions, a direct comparison of the results obtained is not possible. Comparing the socio-economic conditions of the shrimp farmers of the study area with those of other geographically distant regions is also not relevant because socio-economic conditions vary according to geographical locations and time. However, the present study results are expected to serve as benchmarks for future studies.

Chapter 6

A MANAGEMENT PLAN FOR SUSTAINABLE DEVELOPMENT

6.1. Introduction

Kerala has been an important state contributing to farmed shrimp production in India. The state has 65,214 hectares (ha) of water area amenable to brackish water aquaculture (ADAK 1991). Besides, it has 12,873 ha of prawn filtration fields utilised for paddy cum shrimp farming (ADAK 1991). The state also has a long tradition of farming shrimp. Despite having rich and varied water resources and a long tradition in farming, shrimp aquaculture is yet to develop meaningfully in Kerala (Sahadevan 2013). The farmed shrimp production in the state is declining year after year (https://mpeda.gov.in/?page_id=651). The productivity of shrimp farms (*viz.*, the weight of shrimp harvested per unit area per year) in Kerala is also the lowest among all shrimp farming Indian states. As per the Marine Products Export Development Authority (https://mpeda.gov.in/?page_id=651), in 2019-20, the productivity of shrimp farms in India is 4.70 t ha^{-1} $year^{-1}$ whereas that of Kerala is only 0.67 t ha^{-1} $year^{-1}$. The present study also corroborates the reported low production and productivity of shrimp farms in the state (Chapter 2).

While the production and productivity of shrimp farms in the country and most shrimp farming states increased manifold over the last four decades, those in Kerala are declining, indicating the extreme need to identify the reasons and evolve a plan for sustainable development of the sector.

A reasonably large number of studies exist on various aspects of prawn farming in Kerala. However, very few studies (Sahadevan 2012, 2013) investigated the reasons for the lacklustre performance of the shrimp farming sector in the state and suggested strategies for developing it in a meaningful manner.

Based on the information collected in the present study and the published literature on the subject, the current chapter attempts to identify the reasons for the low production and productivity of shrimp farms in Kerala and to put forward a management plan for the sustainable development of the sector. In addition to academic interest, the present chapter will provide valuable practical information that would throw light on the reasons for the lukewarm development of the shrimp farming sector and identify ways to increase the shrimp production of the state. It would also reveal areas that deserve immediate attention from the planners and administrators in the field.

6.2. Reasons for the low production of farmed shrimp in Kerala

The principal reasons for the observed low production of shrimp (and fall in shrimp production in recent times) in Kerala can broadly be considered under the following heads.

6.2.1. Under-utilisation of brackish water areas

As has already been pointed out, Kerala has a 65,214 ha water spread area amenable to brackish water farming. In addition, it has 12,873 ha of prawn filtration fields which have been in use traditionally for paddy-shrimp farming. However, the present study revealed that shrimp farming is practised only in 3,167.72 ha, representing only 4.06% of the total area available. GoI (2019) reported the area under shrimp farming in Kerala as 3,196 ha and the Marine Products Development Authority as 3061 ha in 2019-20 (https://mpeda.gov.in/?page_id=651). It means that a significant part of the brackish water area available for shrimp aquaculture in Kerala remains unutilised.

6.2.2. Decline in the area under cultivation

One of the reasons for the fall in shrimp production in Kerala during the last decade is the sharp decline in the area under cultivation. A perusal of the statistics published by the Marine Products Development Authority (https://mpeda.gov.in/?page_id=651) reveals in unambiguous terms that the area under shrimp farming in the state of Kerala decreases year after year resulting in a progressive reduction in production (Fig. 6.1). Many reasons could be attributed to the decline in areas under shrimp farming. However, the principal causes may be increasing risk consequent to the recurrence of diseases (Chapter 2) and decreasing profitability (Chapter 4) of shrimp farming.

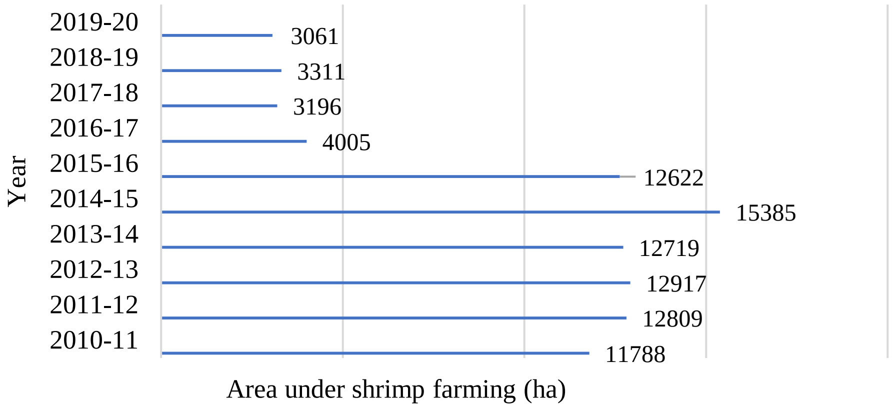


Figure 6.1. The area under shrimp farming in Kerala.

6.2.3. Low shrimp productivity

Productivity of shrimp farms refers to the average weight of shrimp harvested per unit area per year. The productivity of shrimp farms in Kerala is the lowest among all shrimp farming states (Table 6.1). The mean productivity of shrimp farms in Kerala estimated in the present study was 0.932 t. ha^{-1}. $year^{-1}$ (Chapter 2), which corroborates the low productivity figures reported by other agencies.

Table 6.1. Productivity of shrimp farms in Kerala.

States	Productivity of shrimp farms (t ha^{-1} $year^{-1}$)	
	GoI[1]	MPEDA[2]
West Bengal	1.30	1.03
Odisha	3.58	3.65
Andhra Pradesh	7.15	7.93
Tamil Nadu	4.93	5.36
Kerala	0.54	0.67
Karnataka	2.17	1.08
Goa	2.44	
Maharashtra	4.70	4.24
Gujarat	7.28	7.61
India	4.46	4.70

[1]GoI (2019); the productivity figures relate to 2017-2018.
[2] (https://mpeda.gov.in/?page_id=651); the productivity figures relate to 2019-2020.

From the observations made in the present study, the following are the principal reasons for the low productivity of shrimp farms in Kerala.

6.2.3.1. Reliance on the traditional mode of farming

One of the important reasons for the low productivity of shrimp farms in Kerala is that most farms undertake a traditional mode of farming. The present study revealed that around 80% (both in terms of number and water spread area) of the shrimp farms in Kerala are undertaking traditional modes of farming. Traditional shrimp farming units are low input systems doing subsistence farming and are tide-fed, wherein production and profitability are low.

In the traditional system, the shrimp harvest consists of a mix of commercially important and less important species of prawns. In these systems, since the prawns trapped inside do not get sufficient time to grow, the catch generally contains many undersized prawns, which fetch a low price in the market. Predatory fishes and shellfishes entering the field along with the incoming tidal water eat away a good number of prawns. Further, since the stocking depends entirely on nature, no control over the stocking density is possible, and the fields may either be over-stocked or under-stocked. Because of competition for food and space, over-stocking leads to the poor growth of prawns. On the other hand, under-stocking results in underutilisation of the field. Both over-stocking and under-stocking lead to lower productivity of farms.

6.2.3.2. Fragmentation of aquacultural fields/ small aquacultural holdings

The small farm landholding is one of the principal causes of the low productivity of shrimp farms in Kerala. The term aquacultural holding indicates the size of aquaculture land held by shrimp farmers. The present study revealed that most shrimp farmers in the state own small parcels of aquacultural land. Thus 48.76% of the traditional farms and 70.69% of the scientific farms have less than 2 ha. Marginal, small, and medium land holdings account for the major share of the farmed areas. The average size of traditional farms in the state is 1.61 ha, and that of scientific farms is 1.53 ha. In small landholdings, mechanisation and intensification of farming operations are difficult to achieve. Farmers with small landholdings also often face problems due to inefficiencies in transporting the produce, increasing their dependence on intermediaries. Therefore, there is a loss of income which becomes the middle men's commission and reduces the net farm revenue making the farming activity less lucrative.

6.2.3.3. Lack of species diversity

Brackish water shrimp farming in Kerala is confined to a single species, *i.e.*, the tiger prawn (*Penaeus monodon*), and to a minimal extent to the Indian white prawn (*P. indicus*) and the Pacific white shrimp (*Litpenaeus vannamei*). In the current investigation, it has been found that 95.17% of the traditional farms which undertake supplementary stocking used hatchery-produced seeds of the black tiger prawn. Others stocked the seeds of either Indian white prawn or Pacific white shrimp. In terms of extent, the corresponding figures were 95.57%, 1.25%, and 3.18%, respectively. Among the scientific farms, 91.38% cultured *P. monodon*, 5.17% cultured *P. indicus*, and 3.45% cultured *L. vannamei*. In scientific farming, in terms of area, the corresponding figures were 90.42%, 1.15%, and 8.43%, respectively.

As per the statistics published by the Government of India (GoI 2019), *L. vannamei* is farmed in 61.27% of the total area under shrimp farming in India. Further, except in Kerala and to some extent in West Bengal (7.47%), in all other states, *L. vannamei* occupies most of the areas under shrimp farming. *L. vannamei* is farmed in 97.07% of the total area under shrimp farming in Andhra Pradesh, 99.28% in Gujarat, 99.89% in Tamil Nadu, 100% in Maharashtra, 77.15% in Odisha, 100 % in Goa, and 56.92% in Karnataka, in the year 2017-2018. Kerala is the only state in India that relies almost entirely on *P. monodon*.

The reluctance of the state of Kerala to shift from *P. monodon* to *L. vannamei* is one of the important causes for the low productivity of the shrimp farms. *L. vannamei* is generally cultured at high density resulting in higher productivity. It may be mentioned here that modern prawn farming is a dynamic process in which optimum per unit area production depends on the highly manipulatable population density adjustable with the quantity of feed and the food conversion ratio of the species concerned (Sahadevan 2012).

6.2.3.4. Improper site selection

All shrimp farms studied in Kerala were found to be situated in low-lying brackish water areas. Traditional farms are tide-fed, and around 92% were not fully drainable, except perhaps during the periods of the lowest low tide. About 57% of the scientific shrimp farms were also not fully drainable. These farms cannot be drained fully and dried as and when required, inhibiting the mineralisation of organic matter in the pond bottom, leading to lower primary productivity and unhealthy pond bottom conditions. As a consequence, maximum growth of shrimp cannot be achieved in these farms in most cases. This also offers a limitation on enhancing stocking density beyond certain level.

The shrimp culture site must be free from pollution in order to ensure success. The present survey indicated that the majority of the traditional farms (75.93%) and a sizeable portion of the scientific farms (34.48%) are located in areas that are either polluted or are under the constant threat of pollution owing to periodic discharge of pollutants from industrial, agricultural, hospital, sewage and/ or other sources.

A few farms (traditional farms: 11.73% and scientific farms: 1.72%) were also found to be located in coconut retting areas containing a high concentration of hydrogen sulphide, which is lethal to shrimp. Hydrogen sulphide is a by-product of the decomposition of coconut husk. This gas accumulates on the pond bottom and turns the soil black. The pH regulates the distribution of total sulphides among its forms (H_2S, HS-, S- -). Unionised hydrogen sulphide is toxic to aquatic organisms (Krishnani *et al.* 2010). Heavy accumulation of hydrogen sulphide results in oxygen depletion leading to mortality of prawns.

Pollution of water acts as a significant deterrent to improving the productivity of shrimp farms in the state of Kerala. Industrial pollution, coconut retting, domestic and city sewage, hospital wastes, pesticides from agriculture fields, etc., are all critical pollutants of inland water bodies that inhibit the growth of shrimp and reduce the productivity of ponds. Sahadevan (2012) observed that pollution of the water body is a grave issue in some parts of Kerala. According to the author, areas that were well known for prawn production a couple of years back have, of late, become unsuitable for shrimp farming in most parts of the year.

Information collected in the present study on the soil pH of shrimp farms in Kerala indicated that the soil in most farms is acidic, the pH ranging between 3.3 and 6.8. 83.95% of the traditional shrimp farming units and 75.86% of the scientific farming units were in acid sulphate/ low pH areas (less than 6).

Before selecting a site for shrimp farming, soil quality should invariably be ascertained for pH. Soil with low pH (below 5) should not be selected. The ideal soil pH for shrimp farms varies from 7 to 8 (Unnithan 1985). Soils with extremely low pH and acid sulphate areas are not suitable for shrimp farming as they lead to escalation of cost of cultivation and may take a more prolonged period for giving the expected level of shrimp production. The fact that a large number of the shrimp farms in Kerala are situated in acid sulphate soils or low pH areas is one of the reasons for their poor performance. Ponds situated in acid sulphate soils cannot be drained and dried and may not be amenable to scientific management as drying will lower the pH value due to capillary action in the soil.

6.2.3.5. Insufficient depth of ponds

For successful farming of shrimp (tiger prawn and Indian white prawn), the preferred water depth is around 1.2 m. For Pacific white prawn a slightly deeper ponds (1.5 m) are ideal. Water depth has a direct influence on the production capacity of ponds. The present study revealed that most shrimp ponds in Kerala (traditional farms: 79.63% and scientific farms: 81.04%) have effective water depths of less than 1.2 m. From a biological point of view, an aquaculture pond should have a depth of 2 m (Sinha and Srivastava 1983; Jhingran 1991). Depth of ponds has a direct influence on the physical and chemical qualities of water. On it, but varying with water turbidity, depends the limit of sunlight penetration, which, in turn, determines the temperature and circulation patterns of the water and the extent of photosynthetic activity (Jhingran 1991). In shallow ponds, sunlight penetrates up to the bottom, warms up the water, and facilitates the growth of algal mats at the bottom. Uncontrolled growth of algae upsets the dissolved oxygen balance of the pond and has a deleterious effect on the survival and growth of shrimp. In tropical areas like Kerala, ponds shallower than one metre get heated up in the summer, leading to the Decline of the survival rate.

6.2.3.6. Inadequate pond preparation

Pond preparation is an essential measure in improving the productivity of shrimp ponds. As the first step in this direction, draining the pond and drying and tilling the pond bottom assumes great importance. In the present study, it was found that all the traditional farms and a part of the scientific farms do not drain the ponds completely, dry, and till the pond bottom as a pre-stocking management measure. Only 39.66% of the total scientific farms (46% of the scientific farms that drain and dry the pond) plough the pond bottom.

In shrimp culture, as a general rule, pond bottoms should be allowed to dry and crack, primarily to oxidise the organic matter left from the previous culture cycle. Drying and tilling the pond bottom also facilitate greater penetration of sunlight and loosen the soil (Apud 1988). Mineralisation of the organic matter liberates nutrients that will enhance primary productivity, mainly phytoplankters, during the ensuing culture cycle. Proper drying also enhances the oxidation of hydrogen sulphide in anaerobic sediment. The presence of hydrogen sulphide not only retards primary productivity but may reach levels during the following culture cycle sufficient to inhibit the healthy growth of shrimp. Drying the pond bottom also eliminates fish eggs, crab larvae, and potential predators in humid and wet areas, which has a role in reducing final survival rate and decreasing shrimp production. Many authors emphasised the importance of drying pond bottom (Apud 1988; Wang and Fast 1992; Galib *et al.* 2013; CIBA 2015; Sahadevan and Sureshkumar 2019). Carrying capacity of a shrimp pond will decrease if organic matter is allowed to accumulate on the pond bottom (Nagesh *et al.* 2009; Galib *et al.* 2013). Silt removal is essential in farms where stocking densities are more than six postlarvae per square metre and those that experienced diseases during previous crop (Nagesh *et al.* 2009).

6.2.3.7. Inadequate lime application

Many shrimp farmers undertake liming as a measure of pond preparation to correct the soil pH and improve the total alkalinity. However, the dose of lime application is less than the recommended dose. In general, farmers believe that lime is applied to correct the acidity of the pond soil and water, and the quantity of lime is limited to serve that objective. However, the lime application performs many other functions in an aquaculture pond. Lime has been considered a fertiliser because it supplies calcium, one of the essential nutrients for shrimp growth. Lime accelerates the decomposition of organic matter, releasing carbon dioxide from the bottom sediments. It raises bicarbonate content, and the lack of carbon dioxide will not become a limiting factor for photosynthesis. Liming a pond establishes a powerful pH buffer system. Lime counteracts the toxic effect of excess amount of magnesium, potassium and sodium ions. It also fixes harmful acids such as humic acids and inorganic acids. The calcium content of lime displaces certain other fertilisers from the organic colloidal system, making available more quantities of such ions as K^+ and PO_4^- when they are applied as manure. Lime treatment is also done to sterilise the soil, control diseases, and neutralise disease conditions (Apud 1988). Lime kills bacteria and parasites in their various life-history stages by its toxic and caustic action. Thus, the inadequate lime application has a direct effect on lowering the production and productivity of shrimp farms.

6.2.3.8. Non acclimatisation of seed

In shrimp farming the relevance of acclimatisation of seed before stocking cannot be overemphasised. Probably proper acclimatisation is one of the most critical management tools for enhancing shrimp productivity. The appropriate time for seed stocking is early morning or late evening.

The seed should not be stocked when the water temperature is high. To avoid any sudden change in water quality and temperature, the seed to be stocked should be kept in the transporting medium in a container to which the pond water should gradually be added. Aeration may also be preferably provided during acclimatisation. The container should then be slowly dipped and tilted in the pond so that the seed is free to swim out of the container. As a general rule, adjusting salinity by about two parts per thousand (ppt) per hour is recommended. For maximum results, seeds are distributed throughout the area when released into the pond.

In the present study, 72.22% of the traditional farms and 44.83% of the scientific farms did not undertake adequate acclimatisation before stocking. 89.66% of the scientific farms were found not to evaluate stocking mortality for 48 hours. Further, none of the traditional farms was found to adopt such measures. In this circumstance, it is expected that a sizeable number of seeds might be dying on the day of stocking or the days that follow immediately. However, due to the seed's small size, the mortality may go unnoticed, resulting in a lower yield. Inadequate acclimatization of seed is one of the reasons for the observed low productivity of shrimp ponds in Kerala (Sahadevan 2012).

6.2.3.9. Use of poor-quality seed

Use of good quality seed is a prerequisite to ensure success in shrimp farming. Most farmers in Kerala do not have a dependable local source of good quality shrimp seeds. Many also do not have mechanisms to ensure the quality of seeds. Long-distance transportation, poor handling and failure to ensure the quality of seeds undoubtedly result in a lower survival rate and poor yield at harvest.

In the present study, it has been seen that 59.79% of the traditional farms that undertook supplementary stocking and 72.41% of the scientific farms depended on the seeds produced outside the state of Kerala. The rest of the farms relied on hatcheries functioning inside the state for their seed requirement. 43.59% of the traditional farms that depended on seeds from hatcheries operating outside Kerala received seeds through seed supply agents. The rest procured the seeds directly from the seed production centres. Similarly, 38.10% of the scientific farms that depended on seeds from hatcheries functioning outside the state got the seeds through seed supply agents. The rest procured the seeds directly from the hatcheries. 54.32% of the traditional farms and 87.93% of the scientific farms were found to check the quality of seeds before stocking. 77.27% of the former and 94.12% of the latter were seen to undertake PCR (polymerase chain reaction) tests, but others were satisfied with visual observations and/ or stress tests. Further, 41.18% of the traditional farms and 91.67% of the scientific farms that undertook PCR tests were found to get the test done by them. Others depended on the test results provided by the hatchery operators/supply agents. 51.85% of the traditional farms and 67.24% of the scientific farms used seeds 20 days or less in age.

The age of seed has a direct bearing on shrimp productivity. While in the case of white prawn (*P. indicus*), it may be proper to stock seeds from PL 5 to PL 10, PL 20 is the ideal stage for black tiger prawn (*P. monodon*). Lesser aged seeds may not be able to tolerate the grow-out pond conditions. The use of over-aged seeds usually will lead to heavy mortality during transportation and stocking. Because of the acute shortage of seed, especially during the peak periods of farming, farmers in Kerala often have to be content with lesser/ over aged seed leading to lower shrimp production.

6.2.3.10. Unscientific stocking density

Adopting optimum seed stocking density is one of the most crucial management measures to achieve higher production in shrimp farming. Both sub-optimum and supra optimum stocking densities lead to a drop in shrimp harvest. In Kerala, the stocking densities adopted by traditional farms were found to vary from 3,000 to 50,000 seeds ha^{-1}. Here the average stocking density in the farming of *P. monodon*, *P. indicus*, and *L. vannamei* was found to be 12,500, 3,5000, and 42,000 seeds ha^{-1}, respectively. The scientific shrimp farms in the state were found to adopt stocking densities anywhere between 40,000 and 3,50,000 seeds ha^{-1}, the average in the case of *P. monodon*, *P. indicus* and *L. vannamei* farming being 57,100, 75,900, and 3,20,000 seeds ha^{-1} respectively.

The stocking density depends on the species farmed and the intensity of the culture operation, quality and quantity of food provided, and water management efficiency. In the case of tiger prawn, recommended stocking densities in extensive operations may vary from 20,000 to 80,000 ha^{-1}. Stocking densities for semi-intensive and intensive systems range from 1,00,000 to 4,00,000 ha^{-1} with an optimum of 1,50,000-2,50,000 ha^{-1}. Higher densities may be adopted for white prawns (*P. indicus* and *L. vannamei*). *L. vannamei* is amenable to the farming at very high stocking densities of up to 150 m^{-2} in pond culture and even as high as 400 m^{-2} in controlled recirculated tank culture (Briggs *et al.* 2004). Although such intensive culture systems require a much higher intensity of management and control over environmental parameters, it enables the production of high numbers of shrimp in limited areas, resulting in higher productivity than that currently achievable with *P. monodon*. However, *P. monodon* can be aggressive, has high protein requirement, and may be more demanding of high-water quality, making it difficult to culture as intensively as *L. vannamei*.

As has been already mentioned, stocking density plays a vital role in deciding the growth and survival of shrimp and, hence, productivity. Other things being constant, the more the stocking density, the more the shrimp productivity will be. In Kerala, shrimp farms generally adopt stocking densities lower than the scientifically recommended levels, and hence the productivity achieved is lower.

6.2.3.11. Poor dissolved oxygen management

Dissolved oxygen is the most important critical factor in any system of aquaculture. In addition to the direct effect on survival, low dissolved oxygen inhibits shrimp growth and increases the susceptibility to diseases and toxic gases like carbon dioxide, ammonia, and hydrogen sulphide.

The volume of oxygen dissolved in water depends on its temperature and the concentration of dissolved salts. Under a given set of conditions, there is a non-linear inverse relationship between water temperature and dissolved oxygen, the latter always tending to maintain a normal value towards the saturation point (Welch 1952). There is also an inverse relationship between the water salinity and the dissolved oxygen content (Boyd 1989).

In the present study, it was observed that only 19.75% of the traditional farms and 65.52% of the scientific farms had facilities to measure dissolved oxygen at the farm level. No traditional farms had aerators. 48.28% of the scientific farms used aerators for artificial aeration; others used no aerators. Only 1.72% of the farms operated aerators for more than 12 hours per day.

For shrimp farming, the dissolved oxygen level should not go below 3.5 ml l^{-1} (Suseelan 1978). The ideal level of dissolved oxygen for the farming of *P. monodon* is 5-7 ppm (CAA 2006). Mandal and Dubey (2015) recommended a dissolved oxygen content of more than 5 ppm for *P. monodon* farming. According to Boyd (1982), less than 1 mg l^{-1} is lethal to shrimp if exposure continues for more than a few hours. Growth will be less if exposure to low dissolved oxygen (1-5 mg l^{-1}) is prolonged. The best condition for growth occurs when dissolved oxygen concentration is between 5 mg l^{-1} and saturation.

The present study showed that the dissolved oxygen level observed in many farms is below the optimum level required for the best growth and survival, especially during the third and fourth months of rearing, when the shrimp biomass and the consequent oxygen demand are relatively very high. The dissolved oxygen concentration in shrimp ponds can fall so low that shrimps in ponds are killed. However, more often, adverse effects of low dissolved oxygen are expressed as retarded growth and greater disease susceptibility. In ponds with chronically low dissolved oxygen concentrations, shrimp will eat less, and they will not convert food to flesh as efficiently as in ponds with normal dissolved oxygen concentrations.

6.2.3.12. Poor water exchange

Maintaining a good quality of the rearing medium is very important to elicit optimum growth and survival in aquaculture systems. In the present study, many scientific farms were found not to practice good water exchange. Traditional farms generally were at the benevolence of tides for water exchange.

Except in instances of 'zero-water exchange systems,' water exchange is required for maintaining the quality of the rearing medium. It is also required in the case of traditional farms where incoming water is the principal source of shrimp seeds. Water exchange ensures replenishment of dissolved oxygen, removal of accumulated organic wastes, and correction of turbidity. Proper water exchange ensures the healthy growth of the animals and helps avoid diseases. In Kerala, many shrimp farms are tide-fed, and they cannot exchange water at the required time. Inadequate water exchange has a role in the observed lower shrimp productivity in these farms.

6.2.3.13. Inadequate feeding and feed monitoring

Except for a few, most of the traditional farms in the state were found not to use any good quality formulated feed. Many were found to use farm-made feed, the composition of which is determined more by economic consideration rather than nutritional. Groundnut oil cake, dry fish, dry clam meat, rice bran, wheat flour were the principal raw materials for making farm-made feeds. Groundnut oil cake, which was abundantly used in farm-made shrimp feeds until a couple of years ago, was not seen widely used during the study period because of its higher price. Coconut oil cake which has lower nutritional value for shrimp (Sahadevan 2012), had replaced it, at least in some instances. Most scientific farms were found to use factory-produced feeds, and a few farms used farm-made feeds.

In the present study, only 16.67% of the traditional farms and 87.93% of the scientific farms were found to assess the demand for feed with the help of feed check trays. The rest of the farms were found to fix the quantity of feed based on wild assumptions or previous experience rather than on any scientific assessment of the demand for feed. Traditional farms were not generally able to ascertain the quantity of feed to be offered daily, as they could not estimate the biomass of shrimp and finfish available in the pond. The amount of feed to be offered to shrimp is to be ascertained based on the average body weight (ABW) and the assessed survival rate of prawns estimated by regular sampling. The quantity of feed to be given varies according to the nutritional composition, the prevailing environmental conditions, including the water temperature, dissolved oxygen content and the intensity of the pond managenment adopted. However, periodic sampling of prawns was not regularly practised in most cases. Regular sampling is a prerequisite for scientific feed management and to know whether the shrimps are growing on desired lines. This also helps to reduce the cost in connection with feed and feeding and to maintain good water quality. In the present study the quantity of feed offered was also found to be insufficient in many cases which has a direct influnence on the growth and survival of prawns.

6.2.3.14. Inadequate management of plankton growth

Adequate plankton production is an important management measure to be ensured before seed stocking and during the culture period. It may be ascertained by observation of watercolour supported by Secchi disc reading. In the present study, it has been found that most of the shrimp farms (100% of the traditional farms and 60.34% of the scientific farms) were not seen paying adequate attention to ensure sufficient plankton growth and maintenance of healthy watercolour in shrimp ponds, before stocking. In most shrimp ponds, watercolour was not seen developed before seed stocking, indicating insufficient phytoplankton growth.

Experienced shrimp farmers worldwide who had to face repeated mass mortalities relate shrimp mortality to clear water and lack of 'watercolour' in their ponds. The watercolour of a shrimp pond is regarded as an essential feature that reflects the pond water quality and indicates good management skills.

Although the actual function and benefit of one colour over another are difficult to tell, the intensity and liveliness of the colour, indicating the condition of phytoplankton growth, are thought to be more crucial than the variety of colours per se. The appearance of light and lively watercolour indicates the phytoplankton cells to be young and actively growing, while the dull and dark colour reflects aged cells with slow growth. A greyish tint in any colour indicates an inactive phytoplankton population or a mixture of decayed uneaten feeds or suspension of bottom mud.

Healthy phytoplankton functions as a nutrient sponge soaking up dissolved ammonia, amines, urea, nitrite, nitrate, phosphate, other metabolic wastes from shrimp, and toxic substances such as heavy metals and pesticides. Furthermore, phytoplankters producing abundant oxygen under sunlight are efficient aerators. The healthy growth of phytoplankton also reduces light penetration, making the shrimp feel more pleasant in the well-shaded pond bottom. Another important benefit of phytoplankton growth is to prevent the excessive development of 'lab-lab' in the pond bottom, which will ultimately lead to dissolved oxygen depletion in the pond.

Despite the importance, farmers in Kerala, in general, are not paying sufficient attention to developing and managing plankton growth and maintaining healthy watercolour in shrimp ponds. In most aged shrimp ponds, watercolour is not seen developed during the start-up stage of farming, indicating insufficient phytoplankton growth. Watercolour is a direct function of fertilisation and feeding.

6.2.3.15. Recurrence of diseases

Another principal reason for the low productivity of shrimp farms in Kerala is the oft-recurring disease outbreak. White Spot Syndrome (WSS) is perhaps the most important cause of massive shrimp mortality. Infectious Hypodermal and Haematopoietic Necrosis (IHHN) virus is also common in some areas, which results in retardation of shrimp growth. The absence of a shrimp seed quality certification system enhances the chances of outbreaks of diseases in the state. Because of fear of disease outbreaks, farmers now take only one shrimp crop per year, even in areas suitable for two crops otherwise. Thus, the fields are mostly underutilised during most part of the year leading to lower production and productivity.

The frequency of incidence of diseases in farms during the last five years was taken as an index to assess the risk associated with disease in the present study.

It may be very interesting to see at least one disease incidence in 95.06% of the traditional farms and 93.10% of the scientific farms during the last five years. There were disease incidences four or more times in the previous five years in 9.88% of the traditional farms and 24.13% of the scientific farms. Almost all these diseases were reported to be due to viral aetiology.

The frequent incidence of diseases is one of the most important reasons for the low profitability of shrimp farms in Kerala. It explains the decline in interest of farmers in taking up shrimp farming as a reliable avocation and the observed sharp drop in farmed areas in recent years.

6.2.3.16. Poaching

One of the most important reasons for the low survival rate and productivity in shrimp farming is poaching. Poaching is a social issue and can be avoided only by creating awareness among the local people. In the present study, 40.12% of the traditional farms and 51.72% of the scientific farms reported poaching as a significant constraint.

6.2.3.17. Traditional customary rights over water resources

Customary rights refer to established traditional patterns of norms observed within a particular socio-cultural setting (Thompson1991). In some parts of Kerala say, for example, the traditional prawn filtration fields of Ernakulam district (where the most traditional shrimp farms of the state are located), the owner of the field has the right over the crop only up to April 15 (effectively from November to April 15). After April 15, local inhabitants can enter the field and catch whatever fish is available in the field *viz.*, it becomes a common property resource. This acts as an deterent for prolonging the crop beyond the date, at least in some areas. The farmers are compelled to harvest their crops before the date mentioned above, resulting in lower productivity.

6.2.3.18. Shortage of labourers

One of the most critical issues reported by the shrimp farmers was the shortage of labourers in the present study. The issue exists in other agriculture sectors, too. In the study, 43.83% of the traditional farms and 41.38% of the scientific farms reported a shortage of labourers as a significant constraint they faced.

Shrimp farms need continuous and close surveillance for the best results. However, due to the acute shortage of labour force in the state, many farms remain 'unmanned'. Thus 'corrective measures' cannot be done on time, and poaching cannot be avoided, and the situation leads to a decrease in shrimp productivity.

6.2.3.19. Discontinuance of paddy farming

Shrimp farming in Kerala is traditionally practised in pokkali fields (Central Kerala) and kaipad areas (North Kerala). Here shrimp farming alternates with paddy farming. The varieties of paddy cultivated are flood resistant and salt resistant, which requires no fertiliser or pesticide application. This type of paddy-shrimp farming benefits both paddy and shrimp in many ways and reduces the cost of cultivation.

The decayed organic wastes of paddy increase the fertility of the fields, which helps improve shrimp growth. Similarly, the excreta of the shrimp and the uneaten feed act as fertilisers to the paddy. However, of late, obviously due to the noticeable decline in profitability of paddy cultivation, many farmers discontinued it, which has an apparent adverse effect on shrimp production and productivity.

6.2.3.20. Failure in year-round utilisation of ponds

Year-round utilisation of ponds is one of the ways to improve the productivity and profitability of farming operations. Generally, shrimp farmers in Kerala take only one crop in a year. The present study indicated that no farm was utilised for shrimp farming year-round. The study revealed that 93.21% of traditional shrimp farms used the fields for shrimp farming for less than 180 days in a year. Similarly, 87.93% of the scientific farms did shrimp farming for less than 140 days in a year. During the rest of the periods, the fields remained idle. It means that the fields are grossly underutilised during most of the year.

6.2.4. Inadequate physical and/ or electric connectivity

Areas suitable for shrimp farming in Kerala generally lie in remote locations. Many of these areas do not have physical and/ or electrical connectivity. In such places, only low-intensity farming is possible. Electrical connectivity is needed to provide artificial aeration to shrimp ponds which can enhance the carrying capacity of the ponds manifold.

The present study found that only 16.05% of the traditional farms and 27.59% of the scientific farms have electric power connectivity (service connection from Kerala State Electricity Board). Others do not have access to electric power. In the absence of connectivity to chap power, intensification of farming operations is difficult. Similarly, only 35.80% of the traditional farms and 51.72% of the scientific farms have road connectivity. Lack of power connection and road facility deter new entrepreneurs from venturing into shrimp farming. It also poses hurdles to the existing farmers in species diversification and improving productivity.

6.2.5. High financial risk and lack of adequate insurance coverage

Shrimp culture is one of the riskiest farming ventures. This is especially so in the context of oft-recurring disease outbreaks and subsequent crop loss. Natural calamities like floods, cyclones, etc, also often hit the sector. On the other hand, there is no adequate insurance coverage for the crop. Insurance coverage, wherever available, is not attractive because of the high premium levied. In this circumstance, many entrepreneurs are reluctant to invest in the sector.

6.2.6. High social risks

Shrimp aquaculture, in general, involves a high level of social responsibility, and at times it acts as a deterrent in the development of the sector. Social risks in aquafarming are challenges posed by society to the sector, industry, company, or farm practices over the perceived or actual impacts of these practices on issues related to human welfare (Bueno 2008). The "polluter pays" principle demonstrates this definition. A farmer compensates society through a tax or a license fee for the cost of repairing damage that results from the pollution caused by him , or he assumes the cost by investing in a system to prevent his operation from causing pollution. Otherwise, the farm could become the target of challenges from the affected community or other stakeholder groups that perceive the harm and act on behalf of the community. For instance, the government could impose a penalty, or an activist group could file a legal action.

This also suggests three spheres of social responsibility: internal, external, and global. The internal sphere would encompass responsibilities to the farmers, their family and the farmworkers; the external sphere would include the commitment to the community in which it operates, other users of community resources, and the most proximate players in the value chain such as suppliers, buyers, and processors; and the global sphere would include the responsibility to the rest of the stakeholders, especially consumers. A glaring example of this responsibility includes the obligation to supply antibiotic-free shrimps in the international markets.

6.2.7. Inadequate capital inflow

Shrimp aquaculture in general is capital intensive. It is also often considered a high-risk business venture. This is more so in recent times due to the oft-recurring disease outbreak, leading to total loss of the crop. As a result, financial institutions are generally reluctant to extend capital support for shrimp farming ventures. Inadequate availability of capital makes the rapid development of the sector difficult.

6.2.8. Lower financial return

At the level of the intensity of farming practised in Kerala, shrimp aquaculture is fast becoming less and less attractive in terms of financial gain over the relatively high capital invested, as is evident from the findings on the economics of farming discussed in Chapter 4. Many people are leaving the field because of the lower economic returns and the high risk involved. This applies to traditional farming and the more evolved and restrictive scientific farming. As a direct result, the shrimp production of the state has come down drastically in recent years.

6.3. A management plan for the sustainable development

The state of Kerala has immense potential for the development of shrimp aquaculture. However, the water resources in the state have not been adequately utilised for the purpose to date. Shrimp aquaculture, which offered great scope for development, witnessed a near-total collapse towards the end of the 1990s due to a large-scale outbreak of viral diseases. While the shrimp farming sector in other states of the country, which were similarly placed then, witnessed a revival in the last decade, the sector is still groping in the wilderness for various reasons in Kerala. There is an imperative need to take adequate steps to revive the sector in this context.

A three-pronged approach is required to develop brackish water shrimp aquaculture in Kerala. They are 1. Extension of shrimp farming to new areas 2. Improvement of the productivity of existing farming units, and 3. Adoption of non-conventional technologies and species for farming. The development of shrimp aquaculture on a sustainable basis would require interventions and support at different levels. These include policies, research, and farmers' initiatives. Some approaches which are expected to catapult the development of the shrimp aquaculture sector and enhancement of shrimp production manifold in Kerala are discussed below.

6.3.1. Aquaculture policy for the state

The government of Kerala has adopted a fisheries development and management policy in the year 1994 (DoF 1994). However, the policy is primarily concerned with the development of capture fisheries, the conservation of fish resources, and the welfare of fishers. The government recently published a fisheries policy for the state in 2019, which includes marine capture fisheries, inland capture fisheries, aquaculture, fish marketing and trade, fisherfolk development, fisheries extension, human resource development, and fisheries administration. Because of the fast-increasing importance of aquaculture as a provider of inexpensive protein-rich food to the masses, a vital source of foreign exchange, and employment provider in rural areas, the state may evolve a vibrant policy exclusively for the development of aquaculture with emphasis on shrimp farming. Such a step will help set the direction for shrimp culture development and highlight the areas where the extreme focus is to be given. Such a policy will also accelerate the momentum for development of the sector.

6.3.2. Survey of cultivable areas suitable for aquaculture

Various agencies have reported the extent of water bodies available in Kerala. However, the extent of areas available which are amenable to scientific shrimp culture is not known with certainty. Agency for Development of Aquaculture, Kerala (ADAK) conducted a detailed survey of brackish water areas which may be harnessed for shrimp farming during 1989-1991 (ADAK 1991). According to the survey, Kerala has a 65, 212.96 ha brackish water area. Besides, it has 12,873 ha of prawn filtration fields traditionally utilised for paddy cum shrimp farming (ADAK 1991). The brackish water area reported includes the backwaters and canals whose total extent is 46,128 ha. It may be seen that, though some of these areas are suitable for pen and cage culture, most cannot be utilised for aquaculture purposes directly.

Further, a substantial portion of the reported water bodies have been reclaimed for non- aquaculture purposes and are now unavailable for farming. Thus, the data on water bodies available for shrimp farming need to be ascertained afresh and earmarked for the shrimp farming/ aquafarming purpose by enacting appropriate laws to avoid the decline in farmed areas. Reliable data on sites suitable for various aquaculture systems (*i.e.*, traditional farming, scientific farming, cage culture, pen culture etc.) is an essential prerequisite for planning shrimp aquaculture development in the state. Hence, a detailed survey aided by remote sensing techniques is required to delineate areas suitable for various systems of brackish water farming and conserve them.

6.3.3. Policy for the leasing of water bodies for aqua farming

A perusal of the available data on the ownership pattern of water bodies in Kerala indicates that a sizeable portion of the water bodies is owned either by the state government or by the local bodies (Kutty *et al.* 2011). This ownership pattern acts as a significant impediment to the development of shrimp aquaculture. In the absence of a suitable leasing policy that allows utilising public water resources for production purposes, most of these water bodies would remain idle. In this circumstance, there is an imperative need for evolving a policy for long-term leasing of water bodies for aquaculture and resource enhancement purposes, ensuring ecological and economic sustainability. The Government of Kerala constituted an expert committee to formulate a draft policy for the leasing of water bodies in 2009. The committee submitted its detailed report to the state government in March 2011. The committee recommended leasing water bodies for aquaculture purposes intending to meet nutritional security needs, generate gainful employment in rural areas, improve the socio-economic condition of the target groups and increase export earnings. However, the government is yet to adopt it. The development of appropriate leasing policies is necessary to further expand shrimp farming in the state on a sustainable basis.

6.3.4. Improving the productivity of existing shrimp farms

As has already been discussed, among Indian states, Kerala has the lowest shrimp productivity. The reasons for the low shrimp productivity in Kerala have been discussed in detail under section 6.2.3. By properly selecting sites, scientifically designing farms, adopting scientific management practices, diversification of species, increasing the number of crops, ensuring crop rotation, and intensifying farming activities the productivity of shrimp aquaculture units in the state can be improved perceptibly.

6.3.5. Species diversification

Brackish water aquaculture in Kerala is more or less restricted to the tiger prawn and to a minimal extent to the Indian white prawn and the Pacific white prawn. Brackish water finfish farming has also not become popular in the state. In this context, there exists a necessity to diversify species. Shrimp species that tolerate high density, such as *L. vannamei*, may be popularised in areas suitable for its farming. It is mentioned here that *L. vannamei* is the prime species cultured in all shrimp farming states of the country except in Kerala. Other non-conventional species of shrimp may also be farmed in appropriate places with distinct benefits.

Further, farming of brackish water finfishes may be encouraged during the off-season period for shrimp. Indeed, in the absence of hatcheries, there is a shortage of seed of the pearl spot, milkfish, mullets, sea bass, and the white-legged prawn in the state, indicating the need for setting up commercial hatcheries for the seed production of these fishes. Fine-tuning technology for the commercial seed production of milkfish, grey mullets, sea bass, and crab is also required for private entrepreneurs to adopt the technology developed by research organisations in the country.

Species diversification is also advocated as a tool for risk management. Farm planning is done with diversified species to reduce income variability. The viability of shrimp culture will be more with diversification, mitigating the risks associated with the dependence on a couple of high-value species (Ravisankar *et al.* 2005). Species diversification is mainly considered a risk management strategy that involves performing more than one species at any time. It facilitates mitigating price risk as well as production risk of falling output. As recognised half a century ago by Abel (1971) and Swingle (1972), the choice of aquaculture species and production systems will be driven by economic and business realities reflected in the decisions made by individual entrepreneurs who manage the businesses.

Based on the present study, both system diversification and species diversification are recommended to enhance the farmed shrimp production of Kerala. Three main strategies may be adopted for shrimp aquaculture diversification: increase the number of farmed species, increase the evenness of farmed species, and increase the diversity within currently farmed species by developing new strains. Indeed, the primary drivers of diversification are market demand (including export potential), financing opportunities, competition, climate change and other environmental and social factors. Diversification of species and farming systems and a more even product distribution could provide resilience in the face of a changing climate and other external drivers and offer economic, social, and ecological insurance to shrimp farming units. However, diversification is not without risks and may not always be viable to increase shrimp production. In addition to purely economic costs, there will be associated development costs, including evaluating and mitigating environmental and social impacts and establishing species-specific biosecurity frameworks (Harvey *et al.* 2017). The state must identify general principles that can help guide diversification in shrimp aquaculture- both system and species diversification.

Identifying and developing new species for brackish water farming is an ongoing process, driven by perceived market opportunities or other evaluation of need or opportunities. This may include the potential for food production, the potential for production of other products for human use, revitalisation of threatened wild populations, use in the ornamental trade or scientific research, or individual interest (Carolsfeld *et al.* 2017).

6.3.6. Year-round utilisation of brackish water ponds

The majority of shrimp farms in Kerala remain idle for the most part of the year. The present study indicated that no shrimp farms are being utilised for aquafarming year-round in the state. Ponds, where two shrimp crops in a year are possible, are also being used to raise only one crop. A cropping system that allows year-round utilisation of the ponds for raising shrimps must be popularised to increase shrimp production, productivity and profitability of farming operations. Farming brackish water finfishes when shrimps are not grown will also improve shrimp farms' profitability.

6.3.7. Crop rotation

One of the most important impediments to aquaculture development in Kerala is the oft-recurring disease outbreaks. Treatment of diseases of aquatic animals is rather tricky and/ or cost-prohibitive. Crop rotation is one of the ways to control the outbreak of diseases. Many pathogens of aquatic animals are host-specific, and crop rotation helps avoid diseases to a great extent. A crop of shrimp (invertebrate) followed by a crop of finfish (vertebrate) is an excellent example to emulate. Such a step will undoubtedly improve the profitability of shrimp farming units and make them financially more attractive.

6.3.8. Popularisation of non-conventional systems of farming shrimp

In Kerala, shrimp farming is more or less restricted to farming in earthen ponds. Non-conventional shrimp farming systems like cage farming, pen farming, substrate-based farming, recirculatory aquaculture and bio-floc farming in suitable areas will help increase shrimp production and productivity.

Cages and pens are water-based aqua-ecosystems in which there is a continuous exchange of water with the surrounding environment. Cages are mostly floating or suspended enclosures with water exchange through the sides and bottom. Pens are fenced areas of shallow water bodies with sediments forming the bottom of the pen with water exchange through the sides of the enclosure. Cages and pens may be located in natural aquatic systems such as lakes, backwaters, estuaries, etc. Indeed, site requirements are usually more demanding than ponds because of the competitive uses of aquatic environments. Kerala, the land of rivers, lakes, and backwaters, has excellent scope for the development of cage farming. However, cage farming in Kerala is still in the infant stage.

In substrate-based aquaculture, submerged substrates are provided for the growth of periphyton which serves as feed for the cultured aquatic animals. Periphyton is the total assemblage of attached aquatic fauna and flora that shrimp more easily consume. In recent years, the concept of periphyton-based aquaculture has been tested and applied with varying degrees of dependence on periphyton as food or substrates or as shelters for farmed animals. For finfish, the reported increases in production due to substrates have ranged from 30 to 210 %, depending on the amounts and kinds of substrates employed, cultured species, nature of ponds, feeding and fertilisation practices, and other management aspects. Many research findings indicate that production in substrate-based ponds is higher than in ponds without substrates. This could be accounted for by the additional feed provided by the periphyton surfaces (Azim *et al.* 2002a; 2002b). In traditional ponds, as in the case of substrate-free control, the pond bottom presents the only substrate for benthic algae to grow (Azim and Wahab 2003). This produces less food to meet the nutritional requirements of cultured species. However, additional substrates provide more algae and benthos, offering natural food for increased shrimp yield. However, there is a need to fine-tune the shrimp culture in periphyton-based systems further.

Raceways or running water ponds have brick or concrete sides and bottom and they have relatively fast-flowing water. Shrimps are stocked at high density and fed complete diets in these systems.

Recirculating shrimp aquaculture systems rear shrimp at high densities in indoor tanks with a rigidly 'monitored' environment. Recirculating systems filter and clean the water for recycling through shrimp culture tanks.

Biofloc-based farming is an innovative and cost-effective way of farming shrimp in which toxic materials such as nitrate, nitrite, and ammonia are converted to a useful product, *i.e.,* proteinaceous feed. It is the technology used in aquaculture systems with limited or zero water exchange under high stocking density, vigorous aeration, and biota formed by biofloc. Biofloc is a heterogeneous aggregate of suspended particles and various microorganisms associated with extracellular polymeric substances. It is composed of bacteria, algae, fungi, invertebrates, detritus, etc. It is a protein-rich live feed formed due to converting unconsumed feed and excreta into a natural food in a culture system on exposure to sunlight. Each floc is held together in a loose matrix of mucus secreted by bacteria and bound by filamentous microorganisms or electrostatic attraction. Biofloc farming enhances survival rate, growth performance, and feed conversion in shrimp culture systems.

6.3.9. Popularisation of integrated agri- fish farming/ fish- livestock farming

Integration of shrimp farming with agriculture and/or livestock is one of the important ways to increase the production of shrimp and agri/ animal crops. It also helps to bring down the cost of production of both crops. Crop integration also enhances the profitability of shrimp farming operations and its acceptability in rural areas. However, except for the alternate culture of rice and shrimp in pokkali and kaipad areas, no worthwhile attempts were made to integrate agriculture and/ or livestock with shrimp farming. There should be a new and concerted effort for popularising integrated agri and/ or livestock rearing with shrimp culture.

6.3.10. Adoption of climate intelligent technologies

Changes in climate are expected to profoundly impact coastal ecosystems and shrimp aquaculture. Shrimp aquaculture is threatened by changes in temperature, precipitation, drought and extreme climatic events (cyclones, storms, floods), inundation of low-lying lands that affect infrastructure and livelihoods. Adaptations for likely impacts of climate change are reachable through better management practices in site selection, pond construction and preparation, selection of postlarvae for stocking, pond management, bottom sediment management and disease management together with reducing non-climate stressors such as pollution, conservation of sensitive ecosystems and adoption of dynamic management policies. Climate-smart approaches in shrimp farming address three key objectives. The first objective is connected to the overarching goal of achieving sustainable food systems and encompasses the environmental, social and economic aspects of shrimp culture. The second objective focuses on the necessity to reduce the susceptibility of the sector to the impacts of climate change and build the sector's resilience so that it can accommodate the impacts of climate variability and climate change and with natural disasters caused by an enhanced incidence of severe weather episodes. The third objective is to enable the sector, where possible, to contribute to the mitigation of greenhouse gases emissions during the production stages and throughout the entire value chain. Climate-smart approaches in shrimp farming sector are connected with most, if not all, of the major cross-cutting themes of sustainable development. As in other sectors, several issues need to be recognised and reconciled for climate-smart approaches to become the default pathway for the development of shrimp aquaculture.

For shrimp aquaculture, the primary emphasis is on sustainably intensifying production, using more fully integrated systems, improving the productivity of farmed strains, making feeding more efficient and reducing losses from disease. All these must be accomplished without compromising the nutritional quality and safety of the product. It is also increasingly likely that shrimp aquaculture development will face constraints related to the availability of land and water resources in coastal areas. These constraints are the outcome of increased competition from other sectors and changing agro-ecological conditions. Aquaponics presents a potential option for improving efficiency to address existing constraints within the aquaculture subsector.

6.3.11. Consolidation of shrimp farms

In the context of fragmentation of farm holding, to ensure farmer-centric shrimp aquaculture development, land consolidation efforts may be undertaken. Co-operative farming is a method wherein farmers pool their resources in some regions of farming activity for mutual benefits. Contract farming and collaborative farming may also be resorted to in appropriate areas. Though contract farming does not directly help prevent fragmentation, contractual requirements can be a tool for farmers. Associations of farmers or farmer co-operatives and the extension wing of the Department of Fisheries may educate farmers on the benefits of land consolidation, which will reap the benefits of scaling up their operations and increasing profitability. Kerala has a robust and effective panchayati raj system that can function as an institutional forum for aquaculture development projects. Projects structured and monitored by the panchayats can be undertaken at various grama panchayat levels.

6.3.12. Development of species-specific feeds

The nutrient requirement of various species of shrimps varies very much. The nutrient need may also vary according to the farming intensity and life-history stage. However, in Kerala, commercial feeds meant for extensive/ semi-intensive farming of black tiger shrimp and pacific white shrimp only are available in the market. In farming other species (*e.g., P. indicus*), any one of the feeds mentioned above or the conventional dried clam meat and trash fish are used by shrimp farms. As a direct result, maximum growth cannot be elicited in many cases making the farming operation uneconomical. Availability of species-specific feeds is relevant to elicit maximum growth and bring down the cost of production.

6.3.13. Setting up of hatcheries, seed banks, and quarantine units

An important reason for the low-profile development of shrimp aquaculture in Kerala is the insufficient availability of quality seeds at the appropriate time. As per the official statistics, the state has ten registered shrimp hatcheries with a total production capacity of 175 million seeds per annum (Kerala State Fish Seed Centre, *Pers. Communi*.) The actual production of shrimp seed in these hatcheries is around 70 million in 2018-2019. In addition to these, there are around ten unregistered shrimp seed hatcheries with a capacity of about 100 million seeds per annum. Besides, many seed distributors scattered throughout the state buy seeds from hatcheries functioning outside Kerala. Some of these distributors are mere agents between the hatcheries operating outside Kerala and the farmers and have no facilities to hold the seeds even for a short period. Seed produced in the hatcheries inside Kerala is grossly inadequate to meet the shrimp seed requirement of the state. A rough estimate indicates that only 35% of the seed requirement of the state is met by the seed production centres functioning inside the state, and the balance is met by units working in Andhra Pradesh and Tamil Nadu (Sahadevan 2013). Seed brought from distant places is often weak due to stress caused by handling and transportation, which will result in lower shrimp production levels. In this context, there is a need to increase the seed production capacity of the state by setting up more hatcheries, seed distribution centres and seed banks. It may be incidentally pointed out here that the seed production in all important shrimp farming states in India has increased manifold during the last decade. But during the period, shrimp seed production of Kerala has more or less stagnated. An adequate number of quarantine centres may also be set up to ensure the availability of disease-free seeds to shrimp farmers.

6.3.14. Seed certification and accreditation agency

Good quality seed is an essential prerequisite for the success of any shrimp farming venture. The saying that 'well begun is half done is very much relevant in the case of shrimp aquaculture, too, as in other business ventures. A sustainable shrimp production system requires good quality seed to ensure the economic viability of the operation. To ensure seed quality and sustainability in its production process, the hatcheries must use broodstock, breeding, and husbandry practices as per scientific norms. Similarly, it needs to be ensured that hatcheries use nauplii obtained from reliable sources that follow quality and sustainability norms. The essential elements of an accreditation and certification system are an independent body consisting of experts from the fish seed production sector and a series of laboratories to test the quality of fish seed. Though Kerala has enacted the fish seed act and constituted a state fish seed committee, it is yet to start functions in this direction in a meaningful way. It is crucial to note that the production and trade of shrimp in India is a highly dispersed and unorganised activity that operates at various social, economic, and geographical scales.

Notwithstanding the need to make shrimp seed production environmentally sustainable and socially equitable, it is a stupendous task to bring the whole range of seed production activities under the accreditation and certification regime. This is to be accomplished in a phased manner after taking all stakeholders into confidence. Equally important is the need to launch a campaign to build awareness among shrimp seed producers, distributors, and farmers to produce shrimp seed sustainably.

6.3.15. Disease diagnostic laboratories

The disease is a significant problem affecting the production and profitability of shrimp farms. In this context, providing a full-fledged system for disease diagnosis, treatment, and health management is essential. However, Kerala does not have an elaborate system for these. Aquatic animal health management includes preventing, diagnosing, and treating diseases in fish and other aquatic organisms, including shrimps. The facilities envisaged may contain a State Referral Laboratory and a network of laboratories in all shrimp farming districts. Besides undertaking disease surveillance in the natural water bodies, it is expected to cater to the shrimp farmers' diagnostic needs. The lab should have state-of-the-art diagnostic facilities to undertake advanced diagnosis of diseases in farmed fishes and shellfishes.

6.3.16. Development of road and power connectivity

As has already been pointed out, many shrimp farming units in Kerala are situated in remote areas with little road access and electrical connectivity. Inadequate road and power connectivity makes the intensification of farming systems difficult and increases the cost of production. Aeration is undoubtedly one of the most important ways to improve shrimp production from any aquaculture system. In the absence of electrical connectivity, most farms do not use aerators to enhance the dissolved oxygen content of the rearing water.

Thus, the farms have to restrict to low stocking density, resulting in low production. In the absence of facilities for aeration, shift to species that tolerate high density like *L. vannamei* is also difficult. The provision of road and electrical connectivity will undoubtedly improve the productivity and profitability of shrimp farming systems. It also enhances the quality of the end product as refrigerated trucks can reach the farm premises, and the harvested material can be loaded in the trucks immediately on washing. Subsidised power tariffs to aqua farmers can also be considered in this context. Recognising aquaculture on par with land-based agriculture and the provision of electricity at a subsidised rate applicable to paddy cultivation are long pending demands of the shrimp farmers of the state, which can go a long way in enhancing shrimp production and profitability of the farming operation.

6.3.17. Sustainable development of mariculture

India has an Exclusive Economic Zone (EEZ) of 2.02 million square kilometres. Of this, 36,000 square kilometres is adjacent to the Kerala coast. The territorial waters, where the state has the exclusive right for fishing, extend to 22 kilometres from the baseline. Besides the territorial waters, Kerala could utilise areas in the EEZ for farming suitable species by formulating appropriate policies and adopting the right technologies. This is especially significant in the light of the newly evolved technologies for open ocean aquaculture of many species of finfishes like cobias, pompanos, groupers, sea bass, etc.

6.3.18. Integration with ornamental fish trade

Traditional shrimp farms are important sources of finfishes that have tremendous demand in the ornamental fish market. The present study revealed that the pokkali fields have 57 species of finfishes belonging to 28 families. *Kaipad* fields have more fish species. These fields were found to have 74 species of finfishes belonging to 34 families (Chapter 3). Many of these fishes like *Ambassis gymnocephalus, A. ambassis, Anguilla bengalensis*, *A. bicolor, Aplocheilus blockii*, *A. lineatus*, *Arius jella, Glossogobius giuris*, *Etroplus maculatus, E. suratensis*, *Gerres filamentosus*, *Horabagrus brachysoma, Mystus gulio*, *M. vittatus*, *Puntius amphibius*, *P. vittatus, Scatophagus argus*, *Terapon jarbua* etc. have very high value as ornamental fishes. At present, these fishes either go as wastes or are sold as 'trash fishes' fetching nominal price. However, if the farmers can collect these fishes live and undamaged, they can be sold as ornamental fishes in the aquarium trade. Such an arrangement will undoubtedly improve the farm's revenue, making the farming operation more profitable. The farms where scientific prawn farming is carried out may also be utilised for the low-intensity farming of brackish water ornamental fishes after the shrimp harvest, which facilitates year-round utilisation of these farms and enhances the net farm revenue.

6.3.19. Liberal finance for aquaculture

One of the principal reasons for the lukewarm development of the shrimp aquaculture sector in Kerala is inadequate capital infusion. As evident from the information presented in Chapter 4, shrimp aquaculture, in general, is capital intensive and prone to a high level of risks. Because of these, financial institutions in the state are reluctant to extend capital support for shrimp aquaculture units. Consequently, new entrepreneurs find it difficult to start new ventures. Considering the sector's importance in ensuring nutritional security, as a source of foreign exchange and as a provider of employment in the rural areas, there is an urgent need to ensure the availability of easy and low-interest finance to shrimp farming on liberal terms. A revolving fund may also be constituted to meet the working capital requirement.

6.3.20. Assistance for creation of common facilities

The shrimp farming areas of the state, like the pokkali and kaipad lands, are low lying which lie adjacent to backwaters and lower reaches of the rivers. In these areas, strong common peripheral bunds are required to prevent water incursion and protect the crop. Large common sluice gates may also be required in some areas. The construction of solid peripheral bunds and large sluice gates requires enormous capital investment. Individual farmers cannot afford to construct such facilities. As a result, a large extent of such areas remains idle. In this context, to bring such areas under farming the government may provide such facilities free of cost, which will help accelerate the development the sector in a big way.

6.3.21. Insurance coverage for aqua farming

Because of the recurring diseases, insurance companies, in general, are not willing to provide coverage to shrimp farmers in Kerala, as in other parts of the country. This acts as a significant obstacle in the development of shrimp aquaculture. The shrimp farmers, in general, also could not insure their crops on account of stringent conditions put forth by the insurance company. The government may make the insurance companies simplify the norms and provide financial assistance to farmers to meet at least part of the premium for insuring their crops.

6.3.22. Creation of awareness

A principal reason for the low pace of development of shrimp aquaculture in Kerala is the inadequate awareness among the general public about the potential of the sector. In this context, concerted efforts are required to organise periodic awareness programmes on shrimp farming especially meant to the general public and the potential farmers.

6.3.23. Application of biotechnology

Genetic engineering plays a significant role in developing disease-resistant and fast-growing strains of fishes and shellfishes and improving their nutritional quality. GET Excel Tilapia (Genetically Enhanced Tilapia with Excellent qualities) developed in the Philippines and GIFT (Genetically Improved Farmed Tilapia) developed under the Genetic Improvement of Farmed Tilapia Project in Malaysia are luring examples to mention. Genetic manipulation may also help in producing mono-sex fishes. Apart from tilapia and scampi (in whose case it is well documented), mono-sex culture has relevance in farming many shellfish species, including shrimp. For example, females grow faster than males in penaeid prawns like *P. monodon* and *L.vannamei*. The exploitation of this trait may help improve the productivity of penaeid prawn farming units.

Specific Pathogen Free (SPF) and Specific Pathogen Resistant (SPR) seeds of cultivable species of shrimps may also be of great importance in improving the productivity and profitability of shrimp farms. SPF shrimps are the particular stock of shrimps kept in specific pathogen-free facilities under a rigorously monitored environment , which are subjected to sensitive and precise diagnostic methods. The animals are repeatedly reproduced under controlled conditions to ensure their freedom from specific pathogens, and the SPF designation itself is tested regularly over an extended period. The SPF shrimps are not innately resistant to the specified pathogens or infections, although they can be developed as SPR strains. They are not intended to provide either superior genetic stock or improved culturing attributes such as faster growth. However, these attributes can be incorporated into SPF stock to increase their commercial value.

Specific Pathogen Free seeds of *L. vannamei* and *P. monodon* readily are available, though to a limited extent. To ensure uninterrupted availability, some of the hatcheries of the Department of Fisheries or agencies under it may be converted into centres exclusively for the production and distribution of SPF seeds. Efforts are also required to make available the SPF seeds of *P. indicus* in adequate numbers. Similarly, steps are also needed to ensure the availability of sufficient numbers of SPR seeds of *L. vannamei, P. monodon, and P. indicus*.

6.3.24. Application of nanotechnology

Another technological advancement that can revolutionise the shrimp aquaculture sector is nanotechnology. Nanotechnology is an innovative formulation of nano-sized particles which are qualitatively and quantitatively different from their original counterparts. It is applied as tools, devices, machines, etc., through the regulated process of modulating the structure and properties of matter at the nano level. Nano-sized particles, which can be manufactured from inorganic, plant, animal, or microbial sources, are attributed to unique properties influencing the behaviour and activities of all the strata of life. Nano aquaculture incorporates nanotechnology in shrimp farming to increase growth and productivity and modulate the culture system management. Possible applications of nanotechnology in shrimp aquaculture can be numerous, and they cover pond management, shrimp nutrition, reproduction of shrimps, health management, water quality management, and molecular biology (Sarkar 2010).

6.3.25. Use of artificial intelligence

Artificial intelligence (AI) is the ability of a digital computer or computer-controlled machine to perform tasks commonly associated with intelligent beings. The term is very frequently applied to systems endowed with the intellectual processes characteristic of humans, such as the ability to think, discover meaning, generalise, or learn from experience. Artificial intelligence is already making considerable improvements to the efficiency and sustainability of global aquaculture. Artificial intelligence-based machines can optimise feeding regimes, manage the disease, reduce human resources, reduce pollution and enhance production and profitability.

Fine-tuning feeding regimes is crucial because shrimp stocks fed too little lose valuable weight while overfeeding wastes money and pollutes the pond water. Before they happen, programs can predict disease outbreaks by annotating collected data, presenting it, and applying preventive measures. Through

Artificial intelligence, farmers can remotely switch pumps, motors, aerators or diffusers on or off. Production and demand can be forecasted by altering program parameters, thus improving farm efficiency and monitoring ability manifold. Even optimising economics during harvesting, which most farmers gauge based on educated guesswork, can be dictated by the machines. Artificial intelligence can help detect underwater pollution and alert farmers before the environment harms the shrimp stocks. AI-based automation can significantly produce more shrimp while reducing the cost of aquaculture operations and environmental footprint.

6.3.26. Setting up of a labour bank

One of the critical problems faced by the shrimp farmers of Kerala is the inadequate availability of a trained labour force. In this context, the government/ local bodies may set up a labour bank with a workforce trained in shrimp farm operations. The labour bank will function as a platform or forum where youth interested in shrimp farming can register their names. In addition to acting as a ready source of labourers to shrimp farms, the labour bank will increase the livelihood opportunities of the local unemployed people. The bank will help ensure gainful employment and fair wages to them. Besides, to help augmentation of income, it also helps enhance the sense of dignity of the labourers. Labour bank may function under the Department of Fisheries or the local bodies concerned.

Training in shrimp farm management and developing business acumen should be extended to the registered youth. Skill development should also be ensured through the labour bank. Periodic refresher training may also be provided to them. Labour bank should have a business management cell to manage its business and accounts.

6.3. 27. Processing, value addition and marketing

One of the ways to improve the profitability of shrimp farming is to realise higher market prices for the shrimp harvested which may be achieved by improving the marketing and adding value. Simply put, value-added marketing refers to the enhancement brought to shrimp by the farmer or the processor. Sometimes value-addition is as simple as putting a brand name on the shrimp.

Adding value to farmed shrimp is very important as it provides consumers with an incentive to make purchases, thus increasing a farm's revenue. It makes the service better than the alternative and worth the buyer's money.

Shrimp processing and marketing has become competitive worldwide, and exporters are switching to value addition to increase profit. Value addition is vital because of the possibility of better realisation of foreign exchange earnings and high unit value. The processing of value-added products requires improved harvest and post-harvest technology.

A shrimp farmer can differentiate his products from those of other producers and present a greater variety to buyers to gain value. The various product presentations offer labour-saving ways to purchase a product for restaurants, retail outlets, and consumer kitchens.

Value-adding is traditionally thought of as processing outside straight commodity sales. Farmers or processors can gain extra income by further processing shrimp and supplying specific markets with targeted product forms. To generate added value, a product can also be differentiated by its means of culture, such as "chemical-free" or "organic". Shrimps that are chemical-free, all-natural, or organic are increasingly in demand, especially in the United States of America and European markets. Fish and shrimp harvested from the traditional prawn fields of Kerala (pokkali and kaipad fields) may easily qualify to be sold as organic if certified by a certifying body. Giving a brand name for pokkali and kaipad produce, including rice, fish and shrimp, to ensure availability of this nutritionally rich naturally organic produce in its original quality is a glaring example. These products can be marketed as premium products fetching higher prices, under a common brand name. It ensures more remuneration to the farmers by ensuring the sustainability of this traditional and world-renowned farming system.

6.3.28. Training in shrimp farming

Farmers must be given periodic training in improving shrimp production and productivity. The training program will allow the farmers to strengthen those farming skills that they need to improve. It will bring them to a higher level that will help improve productivity and revenue. The training programme may include aspects like pre-stocking, stocking, and post-stocking management of shrimp farms. They may be particularly given exposure to field diagnosis of disease conditions and measures to keep the diseases at bay. The training must also provide knowledge of climate change, disaster management and mitigation measures to tide over the situations. Farmers generally believe the farmers more than scientists or extension workers. Hence, all training programmes may preferably be organised in farmers' fields.

6.3. 29. Enforcement of law

Shrimp aquaculture raises legal and institutional issues because it is an activity that affects natural resources and matters central to most legal regimes. Shrimp farming interacts with the environment, being dependent on land, water and aquatic species ultenvironmental changes. It also must produce a product secure for human consumption in domestic or overseas markets. Therefore, the development and management of shrimp aquaculture fall within the scope of various pieces of legislation and the expertise of multiple institutions.

Apart from the general acts like the Water (Prevention and Control of Pollution) Act 1974, the Environment (Protection) Act 1986, the Wildlife (Protection) Act 1972, a shrimp farmer in Kerala is expected to comply principally with the provisions of three Acts specifically meant to regulate aquaculture and the Rules framed under them. They are Coastal Aquaculture Authority (CAA) Act 2005, Kerala Inland Fisheries and Aquaculture Act 2010 and Kerala Fish Seed Act 2014.

Any belief that imposition of legal restriction on unacceptable action will solve an ecological concern is erroneous. The use of law to promote sustainable aquafarming is not an easy task, and law is only one of several mechanisms required to secure this objective. Confronted with an environmental challenge, it involves multi-disciplinary and inter-disciplinary approaches.

In the context of increasing difficulty in regulating aquaculture because of the diverse interests involved, the diverseness of natural resources used, and the variety of institutions concerned, increasing importance and recognition are given to issues such as local and private aquaculture management, sustainable aquaculture management, use and planning, improved design and awarding of aquaculture leases, adoption of codes of practices, guidelines or other soft law instruments and involvement of a wider range of stakeholders from both public and private sectors.

Aquafarming activities need to be carefully monitored and controlled. There is also a need to recognise that compliance is in the collective self-interest of all members of the shrimp aquaculture sector. Space should also be provided for various individual or collective "self-regulation" mechanisms.

6.3.30. Strengthening of Agency for Development of Aquaculture, Kerala

Another important reason for the slow pace of development of aquaculture in Kerala is the inadequate attention being paid by the government agencies to the development of the sector. The Department of Fisheries is the nodal agency for promoting aquaculture in Kerala, as in other states of the country. However, the Department is very often loaded with schemes meant for the welfare and development of fisherfolk. In the chorus of its work, it could give perhaps very little attention to aquaculture development. In this context, an independent agency under the name 'Agency for Development of Aquaculture, Kerala (ADAK)' was set up in Kerala in 1989. However, the agency grossly failed to achieve the goal for which it was set up. In this circumstance, there is a strongly felt need for revamping the agency. It should also be provided with adequate budgetary support and the mission to focus on aquaculture development intensely.

6.4. Conclusion

Despite having rich and varied water resources and a long tradition in farming, Kerala could not make any significant progress in shrimp aquaculture. Based on the observations made in the present study and the already published literature on the subject, an attempt has been made in the current chapter to identify the reasons for the low production and productivity of shrimp farms in the state and to put forward a management plan for the sustainable development of the sector. Under-utilisation of brackish water areas, the decline in the area under cultivation, low productivity of shrimp farms, inadequate infrastructure facilities, inadequate capital infusion, declining profitability, the high financial risk involved, adequate insurance coverage, high social risks etc are found to be the principal reasons for the colourless performance of the shrimp aquaculture sector in Kerala. The reasons for the low shrimp productivity include reliance on the traditional mode of farming, fragmentation of aquacultural fields (small aquacultural holdings), lack of species diversity, improper site selection, insufficient depth of ponds, inadequate pond preparation, inadequate lime application, use of the poor quality seed, non-acclimatisation of seed, unscientific stocking density, poor dissolved oxygen management, poor water exchange, insufficient feeding and feed monitoring, inadequate plankton growth management, recurrence of diseases, poaching, the existence of traditional customary rights over water resources, shortage of labourers, discontinuance of paddy farming, failure in year-round utilisation of ponds were found to be the reasons for the low productivity of shrimp farms in the state.

In the context of good performance of the shrimp farming sector in other states in the country, Kerala has immense scope for development if appropriate corrective measures are adopted. A three-pronged approach is required to reverse the degeneration trend and develop the sector positively. They are 1. Extension of shrimp farming to new areas 2. Improvement of the productivity of existing farming units, and 3. Adoption of non-conventional technologies and species for farming. The development of shrimp aquaculture on a sustainable basis would require interventions and support at different levels. These include policies, research, and farmers' initiatives. Some strategies which are expected to accelerate the development of the shrimp aquaculture sector in Kerala include formation of an aquaculture policy for the state, survey of cultivable areas suitable for farming, adoption of a policy for the leasing of public water bodies for aqua farming, improving the productivity of existing shrimp farms, species diversification, year-round utilisation of brackish water ponds, crop rotation, popularisation of non-conventional systems of farming (like biofloc culture, substrate based culture, recirculatory culture, cage farming etc.), popularisation of integrated agri- livestock and shrimp farming systems, adoption of climate intelligent technologies, consolidation of shrimp farms, development of species-specific feeds, setting up of multispecies seed production and distribution centres, setting up of quarantine units, formation of seed certification and accreditation agencies , establishment of disease diagnostic laboratories, ensuring road and power connectivity to the farming sites, integration with ornamental fish trade, ensuring liberal finance, assistance for creation of shared facilities, providing insurance coverage, awareness creation, application of biotechnology, application of nanotechnology, use of artificial intelligence, setting up of labour banks, improvement of processing, value addition and marketing facilities, imparting training in shrimp farming, enforcement of law, strengthening of institutions etc.

SUMMARY AND CONCLUSION

Summary of findings

The context and the significant research findings of the present study are summarised below.

1. Aquaculture of shrimps and prawns has made significant advances during the last couple of decades in many parts of the world, including India. With 9400 thousand metric tonnes production, the crustaceans accounted for 11.45% of the world's farmed food fish production in 2018. The growth of shrimp aquaculture in India has been quite impressive over the years, and the country produced 843.36 thousand metric tonnes of farmed shrimp in 2020-2021. However, despite the availability of rich and varied water resources and conducive climatic conditions for growth, the state of Kerala is yet to make any significant strides in the field of shrimp aquaculture.
2. The present study was meant to assess the status of shrimp aquaculture and identify the reasons for its slow pace of growth with particular reference to the technology, production, productivity and economics of farming. The study also aimed to understand the diversity of fishes, crustaceans, and molluscs in the traditional prawn filtration fields and shrimp farmers' socio-economic conditions. Based on the findings of the present work and the results of already published literature on the subject, an attempt was also made to present a management plan for the sustainable development of shrimp aquaculture in Kerala.
3. The study was conducted in the shrimp farming belt of Kerala *viz.*, coastal areas of Thiruvananthapuram, Kollam, Alapuzha, Ernakulam, Thrissur, Malappuram, Kozhikkode, Kannur and Kasargod districts and the low-lying brackish water areas lying adjacent to the Vembanad backwaters in Kottayam district. The various studies were conducted between September 2015 and May 2018. Before starting the primary investigation, a preliminary study was conducted from January 2015 to December 2015 to understand the physicochemical parameters of the water bodies that form the sources of water to the existing prawn farming units and those that may come up in the future.

4. For the study, both primary and, to a minimal extent, secondary data were employed. Information on the extent and type of water bodies suitable for inland aquaculture and areas amenable to brackish water aquaculture/ shrimp farming in different districts of Kerala was collected from secondary sources. All other information was collected from primary sources.
5. Experience coupled with a preliminary survey revealed that two types of farming are in practice in Kerala. They are traditional prawn farming (prawn filtration with or without supplementary stocking) and scientific prawn farming. Data on shrimp farming was collected for each category separately.
6. For the study, lists of all shrimp farms/ farmers belonging to each of the above categories were collected from the Fish Farmers' Development Agencies (FFDA) functioning in various districts under the Department of Fisheries, Kerala and the Marine Products Export Development Authority (MPEDA). A consolidated list for each category was prepared. Samples were selected from each list by employing an appropriate random sampling procedure, and data on topics of interest were collected.
7. In the study on the status of shrimp aquaculture, information on the extent of areas suitable for inland fish production, brackish water areas amenable to shrimp farming, species farmed, size of farms, site selection (topography, tidal flow, pollution, temperature, salinity, source of water, soil texture, soil nutrients, soil pH and potential acidity and access to power and road), farm design and construction (size of ponds, shape of ponds, depth of ponds, water intake, distribution and discharge facilities, intake reservoirs, effluent treatment ponds and aeration system), pond management (pre-stocking, stocking and post-stocking management), harvesting, post-harvest management (post-harvest handling of shrimp, marketing and marketing channels), farm performance (growth, survival, production, productivity and food conversion ratio), crop failures, crop duration, crop rotation, constraints faced, awareness of farmers on the impact of farming on the environment, understanding of farmers on climate change, extent of legal compliance etc. were collected and analysed. Under pre-stocking management, data were collected on pond preparation, including draining, drying, liming, eradicating weed and predatory fishes, fertilisation, plankton

production, pond disinfection, and probiotic use. Grow-out stocking included seed source, seed transportation, seed age, seed quality, acclimatisation, and stocking density. The post-stocking management included aspects of water quality management (temperature, dissolved oxygen, water pH, total alkalinity, total hardness, water salinity, turbidity, water exchange), feed management (type of feed, method of feeding, assessment of feed demand, frequency of feeding, feed ration, nutritional composition of feed, feed handling and storage), biomass assessment, management of predatory birds and disease management (frequency of incidence of disease, treatment of disease and use of antibiotics). A critical evaluation showed that most shrimp farms in Kerala adopt a sub-optimum level of pond management.

8. The extent of areas under shrimp farming in Kerala was estimated to be 3,167.72 hectares (ha). It includes 2,537.36 ha under traditional farming and 630.36 ha under scientific farming. A perusal of published historical data indicates that the area under shrimp farming in Kerala is diminishing year after year. It decreased from 12,917 ha (2012-2013) to 3,167.72 ha (2017-2018).
9. Most of the shrimp farming units in Kerala are under traditional farming (79.28% in number, 79.54% in registered area, and 80.10% in water spread area), wherein production and profitability are low. These farm units fall under the subsistence farming system, are located in tidal areas, and are tide-fed.
10. In the study, it has been found that only 10.49% of the traditional farms are engaged in the original 'trapping and holding' system of farming. 89.51% of the traditional shrimp farms resort to supplementary stocking to increase their production and income. Most farms (95.17%) that undertake supplemental stocking use hatchery-produced tiger prawn seeds (*Penaeus monodon*). Others stock the seeds of white prawns, *viz.*, Indian white prawn *P. indicus* and Pacific white prawn (*Litopenaeus vannamei*).
11. In the scientific farming sector, 91.38% of the farms culture *P. monodon*, 5.17% culture *P. indicus* and 3.45% culture *L. vannamei*. In terms of area, the corresponding figures are 90.42%, 1.15% and 8.43%, respectively. It

reveals that shrimp culture in Kerala is more or less restricted to a single species, *i.e.*, the tiger prawn (*P. monodon*) and a minimal extent to the Indian white prawn (*P. indicus*) and the Pacific white shrimp (*L. vannamei*).

12. The study revealed that most shrimp farming units in Kerala are tiny or small-scale units whose water spread area is limited. The mean size (water spread area) of traditional shrimp farms is 1.61 ha, and that of the scientific farms, 1.53 ha. 72.84% of the traditional farms are less than 5 ha in area. On the other hand, 70.69% of the scientific farms are less than 2 ha in extent.
13. The farmed shrimp production of Kerala is estimated to be 2,952.56 metric tonnes (t) in 2017-2018. Of this, the contribution of the traditional farming sector is 2,174.80 t (73.66%), and that of the scientific farming sector is 777.76 t (26.34%). The contribution of different species to total shrimp production are as follows. *P. monodon*: 1457.32 t (49.36%), *P. indicus*: 372.95 t (12.63%), *L. vannamei*: 242.78 t (8.22%), *M. monoceros*: 71.28 t (2.41%), *M. dobsoni*: 794.94 t (26.92%) and others: 13.29 t (0.45%).
14. Farmed shrimp production of Kerala is only 0.35% of the total farmed shrimp production of the country. A perusal of published historical data on farmed shrimp production indicates that the farmed shrimp production of Kerala is diminishing year after year. It fell down to 2,952.56 metric t in 2017-2018 from 8,075 t in 2010-2011.
15. The study revealed that, in prawn filtration fields in which supplementary stocking is practiced, *P. monodon* (41.77%), *Metapenaeus dobsoni* (36.55%), *P. indicus* (16.95%), *M. monoceros* (3.28%), and *L. vannamei* (0.83%) are the predominant species harvested. *P. semisulcatus* and *M. affinis* are also harvested, though minimal. A noteworthy observation in the study is the presence of *L. vannamei*, a species exotic to the country in the harvest from the traditional farms.
16. It may be seen that the productivity of shrimp farms in Kerala is low. The overall productivity of shrimp farms in Kerala (traditional and scientific farms) is 932.08 kg ha^{-1} $year^{-1}$. Productivity has also been calculated for various other situations (system and species) like traditional farms (with supplementary stocking): 881.40 kg ha^{-1} $year^{-1}$; traditional farms (without supplementary stocking): 605.46 kg ha^{-1} $year^{-1}$; scientific farms (overall):

1,233.83 kg ha^{-1} $year^{-1}$; P. *monodon* (traditional and scientific): 468.99 kg ha^{-1} $year^{-1}$; *P. indicus* (traditional and scientific): 146.56 kg ha^{-1} $year^{-1}$ and *L.vannamei* (traditional and scientific): 1916.02 kg ha^{-1} $year^{-1}$. Comparison with the shrimp productivity figures already published indicates that among the Indian states, Kerala has the lowest productivity of shrimp farms.

17. In the study, the feed conversion ratio obtained by traditional farms fed with factory-made feeds varied from 0.8 to 2.2, averaging 1.28. In the case of farms that used farm-made wet feed, the feed conversion ratio ranged between 1.4 and 2.5, the average being 1.8. A significant part of the traditional farms (around 29%) is non-fed. In the case of scientific farms that used factory-produced feeds, the FCRs obtained varied between 1.2 and 1.9 (average: 1.51). In the case of scientific farms employing farm-made feed, the FCRs obtained ranged from 3.2 to 4.0 (average: 3.40).
18. Fishes/ shrimps harvested from the farms are marketed principally through seven channels. Fishes and small shrimps from traditional farms are marketed through three channels locally. Large shrimps from traditional farms and all shrimp from scientific farms are exported in frozen form (two channels). A part of the tiny shrimps, especially during the periods of good harvest from traditional farms, are marketed after drying through two channels. Farmed shrimp/ fish marketing is generally characterised by shorter channels than the marketing channels prevalent in the capture fisheries sector.
19. Shrimp farming is a risky business, and crop failure from disease is quite common. It may be worth mentioning that 100% of the traditional farms and 82.76% of the scientific shrimp farms met with crop failures at least once during the last 10 years. Crop losses in shrimp farming may be due to natural disasters, water pollution, disease outbreak, or other reasons like depletion of dissolved oxygen, unfavourable physicochemical water quality parameters, damage to farm structures etc. However, most crop losses are caused by pathogens that can invade shrimp under environmental stress.
20. Because of fear of disease outbreaks, shrimp farmers in Kerala take only one crop in a year, even in areas suitable for two crops. The study indicated that no farms are being utilised for aqua farming year-round in the state.

93.21% of traditional farms use the fields for shrimp farming for less than 180 days in a year. Similarly, 87.93% of the scientific farms undertake shrimp farming for less than 140 days in a year. During the rest of the periods, the fields remain idle, which means that the fields are grossly underutilised.

21. Shrimp farmers of the state face various constraints in various degrees. The significant constraints which the farmers face include reduction in tidal flow, water pollution, scarcity of quality seed, increasing cost of production, fluctuating shrimp price, shortage of labourers, disease outbreak, difficulty in getting power connection, insufficient road access, inadequate insurance coverage, insufficient extension machinery, lack of leasing policy, insufficient credit availability, poaching, competition for land use etc. in varying degrees.
22. The present study showed that 61.73% of the traditional farms and 77.59% of scientific farms are aware of the possible adverse effects of shrimp farming on the surrounding environment. However, generally, they do not adopt any remedial measures to rectify the potential negative impact. Legal compliance in the sector is weak. It has been observed that shrimp farmers generally have only preliminary awareness of climate change and its implications on shrimp farming, indicating the urgent need to create awareness among them on this crucial subject and urge them to take adaptation and/ or mitigation measures to ensure the sustainable development of the sector.
23. Traditional prawn filtration fields in Kerala have an impressive richness of fish and shellfish species. Fifty-seven species of fishes belonging to 28 families, 15 species of crustaceans belonging to six families and 11 species of molluscs belonging to eight families were found to occur in the pokkali prawn filtration fields. Kaipad lands had more fish and shellfish species. Kaipad fields were found to have 74 species of fishes belonging to 34 families, 16 species of crustaceans belonging to seven families and nine species of molluscs belonging to six families.
24. As per the IUCN (2018) lists of endangered species, in pokkali fields, among the finfishes, two species each belonged to Near Threatened (NT)

and Vulnerable (VU) categories. Forty-three species belonged to the Least Concern (LC) category, and 33 species to the Not Evaluated (NE) category. Three species belonged to the Data Deficient (DD) category. A species alien to the country, *i.e.,* tilapia (*Oreochromis mossambicus*) was abundant in the pokkali filtration fields.

25. As per the IUCN (2018) lists of endangered species, in kaipad fields, two species each belonged to the NT and VU categories among the finfishes. Fifty species belonged to the LC, and 41 species to the NE category. Four species belonged to the DD category. As observed in pokkali fields, tilapia (*Oreochromis mossambicus*) was abundant in the kaipad fields.
26. Species richness and various indices of the diversity and evenness of fishes, crustaceans and molluscs in pokkali and kaipad prawn fields like Margalef's diversity index, Shannon-Wiener diversity index, Simpson's index of diversity and Simpson's reciprocal index were worked out. Community similarity (what the communities have in common in terms of species) between pokkali and kaipad fields was assessed by employing Sorensen's Coefficient. Temporal variations in species richness and evenness of fishes, crustaceans and molluscs of these fields were also computed. Lorenz curves for representing evenness ranking and Rank abundance curve were also constructed.
27. To evaluate the economic feasibility of various systems of shrimp farming, cost-return analysis was adopted. Profitability was examined from two points of view. First, return to the owner was calculated by subtracting fixed and operating costs from the owners' earnings and the residual treated as a return to the owners' capital. Second, the possible existence of pure profits (resource rents above all costs) was calculated by comparing returns to the capital with their respective opportunity costs. This type of comparison revealed whether pure profits exist in operation and whether there is room to expand farming to redistribute the benefits. The rate of return was calculated by representing the residual return to the owner's capital as a percentage of the initial investment.
28. The economic viability of the scientific shrimp farming system was assessed by calculating the viability measures like Net Present Value (NPV) and

Benefit-Cost Ratio (BCR). The internal rate of return (IRR) was also used to directly compare the various farming operations' profitability. In the study, the risk was analysed by employing two methods, *i.e.*, sensitivity analysis and scenario analysis. Sensitivity analysis was used to see the effect of changes in one input variable at a time on the profitability of the farming. The present work also estimated the levels up to which the cost of production or the sale price can change so that the NPV remains positive. The scenario analysis was used to evaluate the impact of changes in the input of more than one variable (variable cost, quantity of shrimp produced and the sale price of shrimp) while looking at the very optimistic, optimistic, normal, pessimistic and very pessimistic situations.

29. Entry into traditional shrimp farming requires a relatively low initial investment. On average, a one-hectare traditional farm unit requires Rs. 61,100 as the initial investment. Scientific shrimp farming (at the level of farm management intensity practised in the state) requires higher initial investments (tiger prawn farming: Rs. 6,99,600 ha^{-1}, Indian white prawn farming: Rs. 4,59,000 ha^{-1} and Pacific white prawn farming: Rs. 10,40,000 ha^{-1}).
30. The annual residual return to the owner's capital averaged Rs. 2,279, Rs. 56,403, Rs. 26,767 and Rs. 1,32,090 for traditional shrimp farming and scientific farming of tiger prawn, Indian white prawn and Pacific white prawn, respectively. When the opportunity cost of capital was deducted from the residual return to capital, traditional prawn farming units were found to incur an average pure loss of Rs. 12. However, scientific farming of tiger prawn, Indian white prawn and Pacific white prawn registered a pure profit of Rs. 38,913, Rs. 15,292 and Rs. 1,06,090, respectively, after accounting for the opportunity cost.
31. The average total cost for producing a unit weight (kilogram) of shrimp is the highest in tiger prawn farming, followed in order by Pacific white prawn and Indian white prawn farming. It is the lowest for traditional farming.
32. The average fixed cost and average variable cost for producing a unit weight of shrimp are the highest in the case of tiger prawn farming. However, the higher cost is more than offset by the higher average price realised. In the

case of Pacific white prawn, the average variable cost of production per kilogram of shrimp harvested is the second-highest, while its average fixed cost per kilogram shrimp is the lowest of all; even less than that of traditional farming. On the other hand, in the case of the Indian white prawn, the average fixed cost per kilogram shrimp produced is the second-highest while its average variable cost is the second-lowest. Indian white prawn and Pacific white prawn fetch a relatively low price in the market.

33. The NPV of the traditional shrimp farming operation is positive at a 5% discount rate if the opportunity cost is not considered. However, at an 8% discount rate, the NPV is negative even when the opportunity cost of the initial investment is not considered. If the opportunity cost of initial investment is taken into account, even at a 5% discount rate, traditional shrimp farming results in a negative NPV. NPV are higher in the case of scientific prawn farming compared to traditional shrimp farming. In scientific farming, the highest NPV is noticed in the case of farming of Pacific white prawn followed in order by the tiger prawn and the Indian white prawn, at all rates of discount studied and with and without considering the opportunity cost. But it may be seen that the NPV of farming of Indian white prawn is negative when the opportunity cost is taken into account, at an 8% discount rate.
34. The BCR of traditional shrimp farming operations is above one at a 5% discount rate when the opportunity cost is not considered. However, it is less than one at an 8% discount rate even when the opportunity cost is not included. Again, it is less than one even at a 5% rate of discount when the opportunity cost is taken into account. In general, BCRs are higher in the case of scientific shrimp farming at all rates of discount studied and with or without considering the opportunity cost, obviously because of the higher net profit realised. In scientific farming, the highest BCR is noticed in the case of farming of Pacific white prawn followed in order by the tiger prawn and the Indian white prawn, at all rates of discount studied and with and without considering the opportunity cost. But the BCR is less than one in the farming of Indian white prawn at an 8% discount rate when the opportunity cost is taken into account.

35. It may safely be concluded that the farming of Pacific white prawn is more attractive for investment followed in order by farming of tiger prawn and that of Indian white prawn both when the opportunity cost of investment is taken into account or not. As has already been pointed out earlier, traditional shrimp farming presents a fairly bleak picture in terms of net profit realised.
36. Sensitivity analysis results showed that the profitability of traditional shrimp farming is very sensitive to variations in the sale price and production costs. When the opportunity cost is not considered, if the sale price falls by 0.05% or more or if the variable cost increases by 0.09% or more or if the fixed cost increases by 0.22% or more, traditional shrimp farming is not profitable at a 5% discount rate. It reveals the precarious nature of the traditional mode of shrimp farming practised.
37. Based on the gradient of the sensitivity plot, it may be concluded that the profitability of scientific farming of tiger prawn is sensitive to variations in the sale price and less sensitive to changes in variable cost. Deviations in the fixed cost of production have little impact on profitability. The profitability of scientific farming of Indian white prawn is sensitive to variations in the sales price and that in variable cost. Profitability does not seem to be significantly sensitive to changes in fixed cost. The profitability of scientific farming of Pacific white prawn is sensitive to variations in the sale price and variable cost but not sensitive to deviations in the fixed cost of production.
38. Three variable parameters, *i.e.*, the quantity of shrimp produced, sale price, and variable cost of production, were used for scenario analysis. In very pessimistic and pessimistic scenarios, all shrimp farming systems were found to be unprofitable, indicating the financial risk involved in the shrimp farming business. Even in a scenario of simultaneous 5% negative shift in the sale price, harvest quantity and variable cost, all systems of shrimp farming yield negative profit.
39. Traditional shrimp farms will not sustain their profit in the long run if the benefits drop or the cost escalates substantially from the present situation. It is worth noting that the traditional shrimp farming system will not remain profitable under the conditions of distortions in the shrimp market when

there is a drop in the prices and an escalation of the cost of production, even marginally.

40. Though slightly positioned better, the scientific shrimp farming of Indian white prawn at the intensity at which the farming is done at present cannot absorb any drops in the sale price or hike in the cost of production. On the other hand, the scientific farming of tiger prawn and pacific white prawn can be profitable under conditions of price drop and hike in the cost of production, comparatively better.
41. Frequent disease outbreak is a source of financial risk which needs to be accommodated in the economic viability of shrimp farming in the long run. The estimates of NPV after adjusting the output with the risk of disease incidence revealed that neither traditional nor scientific shrimp farming is profitable at the two discount rates studied. The observation holds good in the case of Indian white prawn, Pacific white shrimp and the tiger prawn.
42. The NPV estimates reveal that shrimp culture following the traditional system is profitable when only paid-out costs are considered. On the other hand, scientific shrimp farming of tiger prawn and that of the Pacific white prawn are profitable at all the discount rates if opportunity costs are considered or not. However, the scientific farming of the Indian white prawn is in a disadvantageous position in terms of profitability than its counterparts in scientific farming. In this context, in a state like Kerala, where good quality shrimp seed and feed are limited, scientific farming of tiger prawn and pacific white prawn is more advisable.
43. In unambiguous terms, the present study revealed that traditional prawn farming as practised now in the state is economically not attractive in the long run. Though the initial investment required is pretty low, traditional prawn farming generates only a meagre net profit. It answers why the area under traditional shrimp farming in Kerala shrinks year after year.
44. On the other hand, scientific prawn farming, in general, is profitable. The higher NPV, BCR and IRR of scientific shrimp farming than traditional shrimp farming suggests that emphasis must be made on the development of the sector in a meaningful way. Farming of Pacific white shrimp is more profitable, followed by farming of tiger prawn and Indian white prawn.

45. The sensitivity analysis also indicated that scientific shrimp farming would not remain profitable in adverse conditions of the disease outbreak. These results indicate the need to provide a comprehensive crop insurance scheme in the shrimp farming sector. Without proper crop insurance and risk covering facilities, the expansion of scientific shrimp farming may lead to undesirable situations. Farmers are reluctant to take bank loans because of high-interest rates. Because of high risks and production failures, banks are also unwilling to provide loans for shrimp farming. As a high level of initial investment is required for scientific shrimp farming, it is recommended to provide loan/financial support by the government at the micro-level with low-interest rates, perhaps on par with land-based agriculture.
46. Studies on the socio-economic condition of shrimp farmers included aspects like age distribution, size and type of family, sex ratio, educational status, occupational pattern, type of houses, electrical connectivity, drinking water, ownership of land, household income, income from shrimp farming, indebtedness, experience in shrimp farming, training in shrimp farming, source of technical assistance, number of hours engaged by the farmer in farming, human resources employed, family members involved in shrimp farming and employment of migrant labourers.
47. The study indicated that 2,157 farmers are engaged in shrimp farming in Kerala. Of this, 68.29% of farmers are in traditional shrimp farming, where production and profitability are minimal. Only 31.71% of the farmers are involved in scientific shrimp farming.
48. The shrimp farmers of the state of Kerala are not homogenous. Several critical factors distinguish one group from another. Traditional shrimp farmers and scientific shrimp farmers lie in different socio-economic strata. The socio-economic conditions of traditional shrimp farmers are more or less similar to that of the general population. On the other hand, the socio-economic conditions of scientific shrimp farmers are slightly better than the general population.
49. Kerala offers an interesting paradox of social advancement and economic stagnation. Regarded as a progressive state with a very high literacy rate and social sector indices matching even advanced countries and a high gender

equality index, Kerala still lags behind most other Indian states in women's work participation. Despite enjoying better status and position compared to other parts of the country, women in the state have low levels of participation in shrimp farming.

50. There is considerable scope for the entry of large numbers of females into the shrimp aquaculture sector in Kerala, and there is substantial scope for expanding their role in production. Women can be trained for pond management (pond preparation, stocking, feeding, fertilisation, harvesting), handling, transport, pre-processing, value addition and marketing. In the state where female literacy rates are high and where women are aware of public services for infrastructure, credit, welfare, or extension, there is great potential to effectively increase the contribution of women to the development and promotion of aquaculture.
51. It is interesting to note that migrant workers from outside Kerala are the main workforce in the shrimp farming sector. 64% of the total labourers of the traditional shrimp farms and 68% of the labourers of the scientific farms are migrant labourers. There are no female migrants found in the shrimp farming sector. Demographic transition, high literacy rate, better education and lack of professional and skilled jobs had forced Keralites to look for higher wages and skilled works outside the state and abroad, resulting in a net deficit of labour force in the state.
52. Based on the study results, an attempt was made to delineate the reasons for the low production and productivity of shrimp farms in Kerala. The traditional mode of farming, lack of species diversification, improper site selection, insufficient tidal flow, water pollution, lack of engineering design in farm construction, lack of electrical connectivity, inadequate depth of ponds, lack of aeration facility, failure to dry the pond bottom, failure in the eradication of predatory and weed fishes, insufficient/ absence of lime application, inadequate fertilisation, poor quality of seed, inadequate acclimatisation of seed, unscientific stocking density, poor dissolved oxygen management, poor water exchange, inadequate feeding, failure in growth assessment, ineffective management of plankton growth, water pollution, the prevalence of diseases, poaching, shortage of labourers,

discontinuance of paddy farming, failure in year-round utilisation of ponds, absence of crop rotation and large scale destruction of mangroves were identified as the principal reasons for the low productivity of shrimp farms in Kerala.

53. An attempt was also made to present a management plan for the sustainable development of the shrimp farming sector in Kerala based on the observations made in the present study and the published literature on the subject. The management plan highlighted aspects like formulation of an aquaculture policy for the state, survey and delineation of areas suitable for aquaculture, making a dependable data base, formulation of a policy for the leasing of water bodies for aqua farming, improving the productivity of existing shrimp farms, species diversification, year-round utilisation of brackish water ponds, crop rotation, popularisation of non-conventional systems of farming shrimp, popularisation of integrated agri- fish farming/ fish- livestock farming, adoption of climate intelligent technologies, consolidation of shrimp farms, development and use of species-specific feeds, setting up of hatcheries, establishing seed banks, setting up of quarantine units, setting up of seed certification and accreditation agencies; encouraging the use of specific pathogen free (SPF) and specific pathogen resistant (SPR) seeds, setting up of disease diagnostic laboratories, popularising the use of immuno- stimulants and pro-biotics, provision of road and power connectivity, sustainable development of mariculture, integration with ornamental fish trade, ensuring of liberal finance for aquaculture, provision of assistance for creation of shared facilities, insurance coverage, creation of awareness among general public, application of biotechnology, application of nanotechnology, use of artificial intelligence, setting up of labour banks, adoption of better processing facilities, value addition and marketing, providing training in shrimp farming, enforcement of law and strengthening of institutions.

Conclusion

The focus of the present research work was to understand the status of shrimp aquaculture in Kerala with particular reference to the level of technology, production, productivity, profitability and identify the reasons for its current poor state. An attempt was also made to investigate whether economic and social factors are responsible for the lacklustre performance of the shrimp farming sector.

The study found that reliance on the traditional mode of farming, the failure to diversify to other species, inadequate pond design and construction, inadequate pond management measures, recurrent disease outbreak, insufficient support from the government and degradation of the environment are the principal reasons for the low production, productivity and profitability of shrimp farming units in the state.

A comparative economic analysis of traditional and scientific shrimp farming practices by addressing the systems' sustainability revealed that scientific shrimp farming generated manifold profit than traditional shrimp farming. The present study revealed that traditional prawn farming as practised now in the state is economically not attractive in the long run. Though the initial investment required is low, traditional prawn farming generates only a meagre net profit. In the context of fragile profit level coupled with the high risks involved, the extent of areas under traditional prawn farming is expected to come down shortly if interventions to thwart the decline is not initiated.

In scientific culture, farming of Pacific white prawn is more profitable, followed by farming of tiger prawn and Indian white prawn. Indeed, not all sites are suitable for the adoption of scientific farming. In this context, there is a vital need to survey the brackish water areas available in the state and delineate them for different farming systems.

Scientific farming is sensitive to crashes in the shrimp market price and escalation of production cost. Further, scientific farming would also not remain profitable in adverse conditions of the disease outbreak. These indicate the need to follow better management practices (BMP) in farming. It also reveals the need for the proper functioning of extension machinery to impart training in modern farming methods and the need to introduce a comprehensive crop insurance scheme.

The study also tried to understand the diversity of fishes, crustaceans, and molluscs in Kerala's traditional shrimp farming fields (pokkali and kaipad fields). It also computed various indices of the diversity and evenness of fishes, crustaceans and molluscs in pokkali and kaipad prawn filtration fields. The results showed that the traditional prawn filtration fields are rich in fish and shellfish species. Eighty-three species of fishes and shellfishes belonging to 42 families occur in the pokkali prawn filtration fields. Kaipad fields harbour 99 species of fishes and shellfishes belonging to 47 families. In pokkali fields, as per IUCN red list category, two species of fish are threatened with global extinction. Two species of fish and one species of shellfish are vulnerable. In kaipad fields, two species are threatened, and two are vulnerable. In both areas, a species of fish alien to the country is abundant.

In the end, a management plan was suggested for the sustainable development of the shrimp farming sector based on the results of the study and the already available literature on the subject. The plan is based on a three-pronged approach *i.e.*, the extension of shrimp farming to new areas, improvement of the productivity of existing farming units, and adoption of non-conventional technologies and species for farming. The development of shrimp aquaculture on a sustainable basis would require interventions and support at different levels, which include policies, research, and farmers' initiatives.

REFERENCES

Abel RB (1971) Keynote address: the future of aquaculture—A manic-depressive view. *Proceedings of the World Mariculture Society* **2,** 13-19.

Abesamis Jr GC (1989) Philippine shrimp grow-out practices. In: 'Proceedings of the Southeast Asia shrimp farm management workshop' (Ed. DM Akiyama). pp. 93-101. (American Soybean Association: Singapore)

Abraham TJ, Sasmal D (2009) Influence of salinity and management practices on the shrimp (*Penaeus monodon*) production and bacterial counts of modified extensive brackishwater ponds. *Turkish Journal of Fisheries and Aquatic Sciences* **9**, 91-98.

Accadia P, Franquesa R (2006) The operational units' approach for fisheries management in the Mediterranean Sea: Studies and reviews. General Fisheries Commission for the Mediterranean no. 80. Food and Agriculture Organisation of the United Nations (FAO), Rome, Italy. Available at: https://www.fao.org/3/a0846e/a0846e00.htm [Verified 18 January 2022]

Acharya AK, Murray CL (1997) Economic appraisal of eradication programs: The question of infinite benefit. In 'The eradication of infectious diseases: Report of Dahlem workshop'. (Eds WR Dowle, DR Hapkins) pp. 75-90. (Jhon Willey and Sons: Berlin, UK)

ADAK (1991) 'Kerala Fisheries: Brackishwater Resource Survey-1991 at a Glance.' (Agency for Development of Aquaculture, Kerala (ADAK): Thiruvananthapuram, Kerala, India)

ADB (2005) 'An evaluation of small-scale freshwater rural aquaculture development for poverty reduction.' (Operations Evaluation Department, Asian Development Bank: Manila, Phillipines)

Adeogun OA, Ayinla OA, Ajao EA, Ajana AM (1998) Economic impact assessment of hybrid catfish in Nigeria. World Bank technical report, World Bank, Washington DC, USA.

Agbayani RF, Belleza ET, Agbayani EC (1997) Aquaculture economics in Asia and the Pacific: A regional assessment. In 'Aquaculture economics in developing countries: regional assessments and an annotated bibliography.' (Eds. AT Charles, RF Agbayani, EC Agbayani, M Agüero, ET Belleza, E González, B Stomal, J-Y Weigel) pp. 35-80. (Food and Agriculture Organization: Rome) Available at https://www.fao.org/3/w7387e/W7387E04.htm [Verified 21 December 2021]

Ahmad SH (1996) 'Development of fisheries in Bihar, situation, progress problems and strategy" (Department of Institutional Finance and Programme Implementation, Government of Bihar: Patna, India)

Ahmed M (1999) Policy issues deriving from the scope, determinants of growth, and changing structure of supply of fish and fishery products in developing countries. In 'ICLARM conference proceedings on fisheries policy research in developing countries: Issues, priorities and needs'. (Eds M Ahmed, C Delgado, Sverdrup-Jensen S, RAV Santos) pp. 37-57. (International Center for Living Aquatic Resources Management (ICLARM): Manila, Philippines)

Ahmed M, Rab MA, Bimbao MAP (1993) Household socioeconomics, resource use and fish marketing in two Thanas of Bangladesh. ICLARM technical report no. 40, International Center for Living Aquatic Resources Management (ICLARM): Manila, Philippines.

Ahmed N, Ahammed F, van Brakel M(2008) An economic analysis of fresh water prawn, *Macrobrachium rosenbergii* farming in Mymensingh, Bangladesh. *Journal of the World Aquaculture Society* **39** (1), 37-50.

Ahmed N, Allison EH, Muir JF (2010) Rice fields to prawn farms: a blue revolution in southwest Bangladesh? *Aquaculture International* **18**, 555-574.

Ahmed SU, Ali MS, Islam MS, Roy PK (2000) Study on the effect of culture management and stocking density on the production of shrimp (*Penaeus monodon*) in semi-intensive farming system. *Pakistan Journal of Biological Sciences* **3**, 436-439. doi: 10.3923/pjbs.2000.436.439

Ajayakumar C (2011) Socio- economic aspects of development of aquaculture in Kerala. PhD thesis (Mahatma Gandhi University: Kottayam, India)

Ajithkumar V (1990) An Analysis of factor product relationship in prawn farming - A production function approach. MSc dissertation (Cochin University of Science and Technology: Cochin, India)

Ajithkumar V, Panikkar KKP (1993) An analysis of factor product relationship in prawn farming: A production function approach. 'Mariculture research under the postgraduate programme in mariculture' Part 4 CMFRI special publication no. 54. (Eds K Rengarajan, A Noble, P Rohit, V Kripa, N Sridhar, M Zakhriah) pp.85-93. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Akiyama DM (1992) Future considerations for shrimp nutrition and the aquaculture feed industry. In 'Proceedings special session on shrimp farming'. pp. 198-204. (The World Aquaculture Society: USA)

Akiyama DM (1993) 'Semi-extensive shrimp farm management'. ASA technical bulletin, MITA (P) no. 518/12/92. Vol. AQ 38 1993/3. (American Soybean Association: Singapore)

Akiyama DM, Dominy WG, Lawrence AL (1991) Penaeid shrimp nutrition for the commercial feed industry (Revised). MITA/ (P) 93/1/91. Vol. AQ 32 1991-8. (American Soybean Association, Singapore)

Akiyama DM, Dominy WG, Lawrence AL (1992) Penaeid shrimp nutrition. In 'Marine shrimp culture: Principles and practices.' (Eds AW Fast, LJ Lester) pp. 535-568. (Elsevier Science Publishers BV: Amsterdam)

Akter S (2010) Effect of financial and environmental variables on the production efficiency of white leg shrimp farms in Khanh Hoa Province, Vietnam. Master's thesis (University of Tromso: Norway and Nha Trang University: Vietnam)

Alagappan M, Kumaran M (2020) A study on the information sources and influence of socio-personal attributes on information seeking behavior of aqua farmers. *International Journal of Farm Sciences* **10** (2), 5-12. doi: 10.5958/2250-0499.2020.00026.9

Alagarswami K (1978) Prospects for coastal aquaculture in India. In 'Proceedings of seminar on the role of small-scale fisheries and coastal aquaculture in integrated rural development'. pp. 83-92. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Alagarswami K, Ali SA (2000) Indigenous feeds for shrimp farming – development and assessment in comparison with imported feeds. In 'Aquaculture feed and health' (Eds G John, AS Ninawe) pp. 56-66 (Biotech Consortium India Limited: New Delhi)

Alam MF, Bashar MA (1996) An economic analysis of financing and organizing riverine fish production in Bangladesh. Department of Agricultural Finance, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Alam SMN, Lin CK, Yakupitiyage A, Demaine H, Philipps M (2005) Compliance of Bangladesh shrimp culture with FAO code of conduct for responsible fisheries. *Ocean & Coastal Management* **48** (2),177-188. doi: 10.1016/j.ocecoaman.2005.01.001

Alam SMN, Pokrant B, Yakupitiyage A, Phillips MJ (2007) Economic returns of disease-affected extensive shrimp farming in southwest Bangladesh. *Aquaculture International* **15**, 363–370. doi: 10.1007/s10499-007-9100-7

Alauddin M, Hamid MA (1996) Shrimp culture in Bangladesh, sustainable and research issues. Paper presented in the NACA and ACIAR workshop on key researchable issues in sustainable shrimp aquaculture. 28-31 October 1996, Songkhla, Thailand. Network of Aquaculture Centres in Asia-Pacific (NACA) and Australian Centre for International Agricultural Research (ACIAR): Bangkok, Thailand.

Alava VR, Lim C (1983) The quantitative dietary protein requirements of *Penaeus monodon* juveniles in a controlled environment. *Aquaculture* **30,** 53-61. doi: 10.1016/0044-8486(83)90151-5

Ali M, Byerlee D (1991) Economic efficiency of small farmers in a changing world: A survey of recent evidence. *Journal of International Development* **3**, 1-27. doi: https://doi.org/10.1002/jid.4010030102

Ali MH, Hossain MD, Hasan ANGM, Bashar MA (2008) Assessment of the livelihood status of the fish farmers in some selected areas of Bagmara Upazila under Rajshahi district. *Journal of Bangladesh Agricultural University* **6** (2), 367-374.

Ali SA (1982) Relative efficiencies of pelletized feeds compounded with different animal proteins and the effect of protein level on the growth of the prawn *Penaeus indicus*. 'Proceedings of the symposium on coastal aquaculture Part 1'. 12-18 January 1980, Cochin. (Eds EG Silas, PV Rao, PVR Nair, K Alagarswami, T Jacob, KC George, K Rengarajan, PP

Pillai, KJ Mathew, VK PiIIai, AG Ponniah) pp. 321-328. (Marine Biological Association of India: Cochin, India)

Ali SA (1988) Studies on the evaluation of different sources of proteins, carbohydrates and mineral requirements for juvenile penaeid prawn *Penaeus indicus* H. Milne Edwards. PhD thesis (Cochin University of Science and Technology: Cochin, India)

Ali SA (1996) Carbohydrate nutrition under different dietary conditions in prawn *Penaeus indicus*. *Journal of Aquaculture in the Tropics* **11** (1), 13-26.

Alikunhi KH (1957) 'Fish culture in India'. Farm bulletin no. 20 (Indian Council of Agricultural Research: New Delhi)

Alikunhi KH (1978) Shrimp farming in India- present status and future prospects. Paper presented in the first national symposium on shrimp farming. 16-18 August 1978, Bombay. Marine Products Export Development Authority, Cochin, India.

Alikunhi KH (1988) Freshwater aquaculture in Kerala. In ‘Proceedings of seminar on problems and prospects of freshwater aquaculture in Kerala'. pp. 45-60. (Kerala Agriculture University Union and Students' Union, College of Fisheries: Cochin, India)

Alikunhi KH, Choudhary H, Ramachandran V (1955) On the mortality of carp fiy in nursery ponds and role of plankton in their survival and growth. *Indian Journal of Fisheries* **2** (2), 257-313.

Allan GL, Magiure GB (1992). Effect of pH and salinity on survival, growth and osmoregulation in *Penaeus monodon* Fabricius. *Aquaculture* **107,** 33-47. doi: https://doi.org/10.1016/0044-8486(92)90048-P

Allan GL, Moriarty DJW, Maguire GB (1995) Effects of pond preparation and feeding rate on production of *Penaeus monodon* Fabricius, water quality, bacteria and benthos in model farming ponds. *Aquaculture* **130**, 329-349. doi: https://doi.org/10.1016/0044-8486(94)00316-G

Almazan G, Boyd CE (1978) 'Water quality management for pond fish culture.' Fisheries and Allied Aquacultures Department, Alabama Agricultural Experiment Station, Auburn University, Alabama (Birmingham Publishing Company: New York, USA)

American Marketing Association (1960) ‘Marketing definitions: A glossary of marketing terms.’ (American Marketing Association: Chicago, USA)

Anand PEV (2019) The fish farming industry of India. Global Aquaculture Advocate, Global Aquaculture Alliance, 21 October 2019. Available at https://www.aquaculturealliance.org/advocate/the-fish-farming-industry-of-india/ [Verified 13 August 2021]

Anand PSS, Kumar S, Deo AD (2013) Provision for biosecurity in shrimp farm. In 'NFDB sponsored training manual on BMP in shrimp farming with special reference to West Bengal' CIBA Special Publication No. 67. (Eds AD Deo, PSS Anand, P Ravichandran) pp. 29-33. (Kakdwip Research Centre of Central Institute of Brackishwater Aquaculture (CIBA): Kakdwip, West Bengal, India)

Anand PSS, Panigrahi A, Ravichandran P, Kumar S, Dayal JS, Deo AD, Ponniah AG, Pillai SM (2015) Growth performance of black tiger shrimp (*Penaeus monodon*) in substrate based zero water exchange system. *Indian Journal of Geo-Marine Sciences* **44** (10) 1495-1503.

Anderson JL, Valderrama D, Jory DE (2016) Global shrimp survey: GOAL 2016. The Responsible Seafood Advocate, Global Seafood Alliance's (GSA), 10 October 2016. Available at https://www.globalseafood.org/advocate/global-shrimp-survey-goal-2016/ [Verified 9 December 2021]

Anderson JL, Valderrama D, Jory DE (2017) GOAL 2017: Global shrimp production review and forecast. Global Aquaculture Advocate, Global Aquaculture Alliance, 21 October 2017. Available at https://www.globalseafood.org/advocate/goal-2017-shrimpproduction-survey/ [Verified 13 November 2021]

Andrew P (1999) 'Economics of brackish water shrimp culture'. (Daya Publishing House, Delhi, India)

Andrews JW, Murai T, Gibbons G (1973) The influence of dissolved oxygen on the growth of channel catfish. *Transactions of the American Fisheries Society* **102**, 835–838. doi: https://doi.org/10.1577/1548-8659(1973)102<835: TIODOO>2.0.CO;2

Andrews JW, Sick LV, Baptist GJ (1972) The influence of dietary protein and energy levels on growth and survival of penaeid shrimp. *Aquaculture* **1**, 341-347.

Anilakumari KS, Azis PKA (1992) Water quality of the Poonthura estuary, Thiruvananthapuram. *Mahasagar* **25**, 1-9.

Anon (1996) Pollution potential of industries in coastal areas of India. Coastal pollution control series: Central Pollution Control Board report. COPOCS /9/1995-96, Central Pollution Control Board, Government of India, Delhi. India

Anon (1998) NEERI - Carrying capacity based developmental planning of Greater Kochi Region. Phase I report, CSIR-National Environmental Engineering Research Institute, Nagpur, India.

Anon (2006) Master plan for aquaculture development, Kerala. Submitted to the Government of Kerala, Directorate of Fisheries, Thiruvananthapuram, Kerala, India.

Anon (2007) 'Convention on Biological Diversity 2007.' Available at https://www.cbd.int/ibd/2007/ [Verified 17 December 2021]

Ansar CP, Mogalekar HS, Sudhan C, Chauhan DL, Golandaj A, Canciyal J (2017) Finfish and shellfish diversity of Vembanad Lake. *Journal of Entomology and Zoology Studies* **5** (2), 351-357.

Antony A, Mercy TVA, Shaju SS (2014) Effect of rotational pokkali cultivation and shrimp farming on the soil characteristics of two different pokkali fields at Chellanam and Kadamakudi, Kochi, Kerala, India. *International Research Journal of Environment Sciences* **3** (9), 61-64. Available at: www.isca.in, www.isca.me [Verified 22 February 2022]

Antony J, Sandeep KP, Aravind R, Panigrahi A, Balasubramanian CP (2019) Growth, survival, and osmoregulation of Indian white shrimp *Penaeus indicus* juveniles reared in low salinity amended inland saline groundwater and seawater. *Journal of Coastal Research* **86,** 21-31. doi: 10.2112/SI86-004.1

Antunes CRN, Ledo CAS, Periera CM, dos Santos J (2018) Evaluation of feeding rates in the production of *Litopenaeus vannamei* shrimp using artificial substrates. *Ciencia Animal Brasileira* **19,** 1-11.

Anzari ZA (1977) Macrobenthos of the Cochin backwater. *Mahasagar- Bulletin of the National Institute of Oceanography* **10** (3&4),169-171.

AOAC (1980) 'Official Methods of Analysis of the Association of Official Analytical Chemists.' 13th edn. (Association of Official Analytical Chemists (AOAC): Washington, USA).

Appelbaum S, Garada J, Mishra JK (2002) Growth and survival of the white leg shrimp (*Litopenaeus vannamei*) reared intensively in the brackish water of the Israeli Negev desert. *The Israeli Journal of Aquaculture-* (*Bamidgeh*), **54** (1), 41-48.

Appukuttan KK, Sreenath K, Sahadevan P, Surendran PP, Shamsuddin PV (2004) Action plan on green mussel culture in backwaters of Kerala. Submitted to the Government of Kerala, India.

APRSAC (1999) 'Environmental management and monitoring of shrimp culture project, East Godavari District, Andhra Pradesh – land use/land cover'. Vol. 51. (Andhra Pradesh Remote Sensing Application Centre (APRSAC): Hyderabad, India)

Apud FD (1979) Effects of water movement and aeration systems on the survival and growth of hatchery-bred sugpo (*Penaeus monodon* Fabricius) in earthen nursery ponds. MS thesis (University of the Philippines: Metro Manila, Philippines)

Apud FD (1985) Extensive and semi-intensive culture of prawn and shrimp in the Philippines. In 'Proceedings of the first international conference on the culture of penaeid prawns/ shrimps' (Eds Y Taki, JH Primavara, JA Llobrera) pp. 105-113. (Aquaculture Department, Southeast Asian Fisheries Development Center (SEAFDEC): Iloilo City, Philippines)

Apud FD (1988) Prawn grow-out practices in the Philippines. In 'Biology and culture of *Penaeus monodon*.' pp. 89-118. (Brackishwater Aquaculture Information System, Aquaculture Department, South East Asian Fisheries Development Centre: Tigbauan, Iloilo, Philippines)

Apud FD, Gonzales K, Deatras N (1981) Survival, growth and production of *Penaeus monodon* Fabricius at different stocking densities in the earthen ponds with flowthrough system and supplemental feeding. *Fisheries Research Journal of the Philippines* 6, 1-9.

Apud FD, Primavera JH, Torres PLJr (1983) 'Farming of prawns and shrimps'. Extension manual no. 5. 3rd edn. (Aquaculture Department, Southeast Asian Fisheries Development Center (SEAFDEC): Iloilo City, Philippines)

Apud FD, Sheik MA (1978) Design and construction of a prawn nursery pond system. In 'Pond culture and management; selected readings.' Training materials series, no. 2. 97-105. (Aquaculture Department, South East Asian Fisheries Development Centre (SEAFDEC): Tigbauan, Iloilo, Philippines)

AQUACOP (1977) Reproduction in captivity and growth of *Penaeus monodon* Fabricius in Polynesia. *Proceedings of the World Mariculture Society* **8**: 927–945.

Aquaculture Authority (1999) 'Guidelines–adopting improved technology for production and productivity in traditional and improved traditional system of shrimp farming.' (Aquaculture Authority: Chennai, India)

Aravindakshan PN, Balasubramanian T, Devi CBL, Nair KKC, Gopalakrishnan TC, Jayalakshmi KV, Kutty MK (1992). Benthos and substratum characteristics of prawn culture fields in and around the Cochin backwater. *Journal of the Marine Biological Association of India* **34 (**1&2), 203-217.

Aravindan KP (2006) 'Kerala Padanam: Keralam Engane Jeevikkunnu? Keralam Engane Chinthikkunnu?' (Kerala Sastra Sahitya Parishad: Kozhikkode)

Arun AU (1996) A study of environmental and hydrographical parameters and its influence on primary production in a pokkali field. MSc dissertation (Cochin University of Science and Technology: Kochi, India)

Aryalekshmi V (2016) Silicon availability of tropical soils with respect to rice nutrition. M Sc (Ag) thesis (Kerala Agricultural University: Thrissur, Kerala, India)

Asadullah MN, Rahman S (2009) Farm productivity and efficiency in rural Bangladesh: the role of education revisited. *Applied Economics* **41** (1), 17-33.

Asha CV, Suson PS, Cletus RI, Nandan SB (2014) Decline in diversity and production of exploited fishery resources in Vembanad wetland system: strategies for better management and conservation. *Open Journal of Marine Science* **4,** 344-357. doi: 10.4236/ojms.2014.44031

Asif AL (2016) Study on the socio-economic condition of fish farmer of Jhikargachha upazila in Jessore district, Bangladesh, MS thesis (Bangladesh Agricultural University: Mymensingh, Bangladesh)

Asokan PK, Vipinkumar VP, Appukuttan KK, Surendran VG, Sivadasan MP (2001) Mussel culture in backwaters of Kasargod district, Kerala. *Marine Fisheries Information Service T & E Series* **169**, 9-11.

Aswathi VB, Saranya A, Sankar, Sekharan NM (2020) Impact of deluge on cage culture systems in two districts of the South Indian State, Kerala. In 'Book of abstracts, Climfishcon 2020: International conference on impact of climate change on hydrological cycle, ecosystem, fisheries and food security'. 11-14 February 2020, Cochin. (Eds BM Kurup, MR Boopendranath, M Harikrishnan, AV Shibu, VPAncy, NM Sekharan, S

Sabu, M Sileesh, R Radhika, HS Harisankar, OK Sreedevi, S Sreelakshmi, S Reshma, P Anju, Sariga) pp. 108-109. (Cochin University of Science and Technology: Cochin, India)

Athira N, Jaya DS (2020) Fish diversity of Anjarakandy River in Kerala, South India. *Journal of Aquatic Biology and Fisheries* **8** (S),19-25.

ATREE (2009) Vembanad fish count report (2009) Report of the participatory fish resources survey of the Vembanad Lake, Kerala. Community Environmental Resource Centre (CERC), Ashoka Trust for Research in Ecology and the Environment (ATREE), Alappuzha.

Ayyappan S, Gopalakrishnan A, Kumar B (2009) Species diversification in aquaculture and domestic fish marketing in India. In 'MPEDA Souvenir Indaqua 2009'. pp. 13-22. (Marine Products Export Development Authority: Cochin, India)

Ayyappan S, Jena JK (2003) Grow-out production of carps in India. *Journal of Applied Aquaculture* **13** (3), 251-282.

Ayyappan S, Krishnan M (2004) Indian fisheries: dimensions of development. *Indian Journal of Agricultural Economics* **59** (3), 391-412.

Azim ME, Milstein A, Wahab MA, Verdegem MCJ (2003) Periphyton-water quality relationships in fertilized fish ponds with artificial substrates. *Aquaculture* **228,** 169-187. doi: 10.1016/S0044-8486(03)00319-3

Azim ME, Verdegema MCJ, Rahmanb MM, Wahabb MA, van Dam AA, Beveridge MCM (2002a) Evaluation of polyculture of Indian major carps in periphyton-based ponds. *Aquaculture* **213,** 131-149. doi: 10.1016/S0044-8486(02)00029-7

Azim ME, Wahab MA, Verdegema MCJ, van Dam AA, van Rooij JM, Beveridge MCM (2002b) The effects of artificial substrates on freshwater pond productivity and water quality and the implications for periphyton-base aquaculture. *Aquatic Living Resources* **15** (4), 231-241. doi: 10.1016/S0990-7440(02)01179-8

Bages M, Sloane L (1981) Effects of dietary protein and starch levels on growth and survival of *Penaeus monodon* (Fabricius) postlarvae. *Aquaculture* **25,** 117-128.

Balachandran KK (2007) Ecosystem modeling of the Vembanad Lake (Cochin backwaters). In 'Proceedings of the workshop on Indian estuaries. pp. 16-18. (National Institute of Oceanography: Goa, India).

Balakrishnan G, Peyail S, Ramachandran K, Theivasigamani A, Savji KA, Chokkaiah M, Natarajan P (2011) Growth of cultured white leg shrimp *Litopenaeus vannamei* (Boone 1931) in different stocking densities. *Advances in Applied Science Research* **2** (3), 107.

Balasubramaniam S (1988) Analysis of technology transfer effectiveness in inland fish farming. PhD thesis (Tamil Nadu Agricultural University: Coimbatore, India)

Balasubramanian T, Viswakumar M, Venugopal P (1995) Ecological evaluation of two prawn culture fields in the Cochin Backwater based on premonsoon diurnal observations. *Journal of Marine Boilogical Association of India* **37** (1-2), 212-220.

Barraclough S, Finger-Stich A (1996) Some ecological and social implications of commercial shrimp farming in Asia. UNRISD discussion paper no. 74. United Nations Research Institute for Social Development (UNRISD), Geneva, Switzerland and World-Wide Fund for Nature WWF-International, Gland, Switzerland

Baruah PB, Hazarika PJ (2019) Socio-economic status of fishermen of Assam: A descriptive Analysis. *International Journal of Fisheries and Aquatic Studies* **7** (4), 34-39

Basu AM (1996) Women's economic roles and child health: An overview. In 'Population and women.' pp. 312-321. (Department for Economic and Social Information and Policy Analysis, Population Division, United Nations: New York).

Baticados MCL (1988) Typical prawn diseases- causes, prevention and treatment. In 'Technical considerations for the management and operation of intensive prawn farms.' (Eds YN Chiu, LM Santos, RO Juliano) pp. 134-143 (University of the Phiippines Aquaculture Society: Iloilo City, Philippines)

Baticados MCL, Coloso RM, Duremdez RC (1986) Studies on the chronic softshell syndrome in the tiger prawn *Penaeus monodon* Fabricius, from brackish water ponds. *Aquaculture* **56**, 271-285.

Baticados MCL, Cruz-Lacierda ER, de la Cruz M, Duremdez-Fernandez RC, Gacutan RQ, Lavilla-Pitogo CR, Lio-po GD (1990). 'Diseases of penaeid shrimps in the Philippines'. (Aquaculture Department, Southeast Asian Fisheries Development Center (SEAFDEC): Iloilo City, Philippines)

Baumgärtner S (2004) 'Measuring the diversity of what? And for what purpose? A conceptual comparison of ecological and economic measures of biodiversity' (Interdisciplinary Institute for Environmental Economics: Heidelberg, Germany)

Bautista MN (1986) The response of *Penaeus monodon* juveniles to varying protein/energy ratios in test diets. Aquaculture **53** (3-4), 229-242. doi: 10.1016/0044-8486(86)90353-4

BBS (1998) Report of household expenditure survey 1995-96. Bangladesh Bureau of Statistics, Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhakka.

Beena KB (1992) Socio- economic study of prawn farmers in Ernakulam district MSc (Mariculture) dissertation (Cochin University of Science and Technology: Cochin, India)

Begum MEA, Hossain MI, Papnagiotou E (2013) Technical efficiency of shrimp farming in Bangladesh: An application of the stochastic production frontier approach. *Journal of the World Aquaculture Society* **44** (5), 641-654.

Begum MEA, Hossain MI, Tsiouni M, Papanagiotou E (2015) Technical efficiency of shrimp and prawn farming: Evidence from coastal region of Bangladesh. In 'Proceedings of the 7th international conference on information and communication technologies in agriculture, food and environment (HAICTA 2015)' 17-20 September 2015, Kavala, Greece. (Eds. Andreopoulou Z, Bochtis D) pp. 842-857. (Hellenic Association for Information and Communication Technologies in Agriculture, Food and Environment (HAICTA): Greece)

Behera UK, Mahapatra IC (1998) Income and employment generation for small and marginal farmers through integrated farming systems. *Indian Farming* **48** (3): 16-28.

Behera UK, Mahapatra IC (1999) Income and employment generation of small and marginal farmers through integrated farming systems. *Indian Journal of Agronomy* **44** (3): 431-439.

Bell JD, Ganachaud A, Gehrke PC, Griffiths SP, Hobday AJ, Hoegh-Guldberg O, Johnson JE, Borgne RL, Lehodey P, Lough JM, Matear RJ, Pickering TD, Pratchett MS, Gupta AS, Senina I, Waycott M (2013) Mixed responses of tropical Pacific fisheries and aquaculture to climate change. *Nature Climate Change* **3** (6), 591-599. doi: https://doi.org/10.1038/nclimate1838

Bell T, Newman JA, Silverman BW, Turner SL, Lilley AK (2005) The contribution of species richness and composition to bacterial services. *Nature* **436,** 1157–1160. doi: 10.1038/nature03891

Benninga S (2008) 'Financial modelling.' 3rd edn (The MIT Press: Cambridge, MA 02142, USA)

Berg H (2002) Rice monoculture and rice-fish farming in the Mekong Delta, Vietnam – Economic and ecological considerations. *Ecological Economics* **41**, 95-107. doi: 10.1016/S0921-8009(02)00027-7

Bhadran G (1997) Heavy metal pollution in Ashtamudi estuarine system. PhD thesis (University of Kerala: Thiruvananthapuram, India)

Bhalerao MM, Charan K (1968) Fisheries co-operatives in India. *Indian Journal of Agricultural Research* **23** (4), 210-219.

Bhasker T (1982) Nutritional requirement of postlarvae of *Penaeus indicus*. MSc dissertation (University of Cochin: Cochin, India).

Bhatta R (2001) Production, accessibility and consumption patterns of aquaculture products in India FAO fisheries circular no. 973. (Food and Agriculture Organisation of the United Nations: Rome,Italy). Available at https://www.fao.org/3/Y2876E/y2876e0w.htm# [Verified 26 December 2021]

Bhatta R (2003) Socio-economic issues in fisheries sector in India. In 'A profile of people, technologies and policies in fisheries sector in India.' (Eds A Kumar, PK Katiha, PK Joshi). pp. 17-42. (National Centre for Agricultural Economics and Policy Research: New Delhi, India)

Bhattacharya D, Rahman M, Khatun F (1999) Environmental consequences of structural adjustment: Towards sustainable shrimp culture in

Bangladesh. CPD working paper 2 (Centre for Policy Dialogue: Bangladesh).

Bhattacharya P (2009) 'Economics of shrimp farming: A comparative study of traditional vs. scientific shrimp farming in West Bengal.' (Institute for Social and Economic Change (ISEC): Bengaluru, India)

Bhattacharya P (2010) Role of shrimp farming in generating employment and income: A study of small- scale shrimp farming in West Bengal, India. In 'Proceedings of the fifteenth biennial conference of the International Institute of Fisheries Economics & Trade' July13-16 2010, Montpellier, France. pp. 476-485. (International Institute of Fisheries Economics and Trade (IIFET): Corvallis, Oregon, USA).

Bhaumick U, Pandit PK, Chatterjee JG (1990) Participation of fisherwomen in inland fisheries activities-Perceived problems and measures. *Environment and Ecology* **8** (2), 713-716.

Bhaumik U, Saha SK (1998) Need for modification of composite fish culture technology in West Bengal as perceived by the fish farmers. In 'Current and Emerging trends in aquaculture.' (Ed. PC Thomas) pp. 348-354. (Daya Publishing House: New Delhi, India).

Biddle GN (1977) The nutrition of *Macrobrachium* species. In 'Shrimp and prawn farming in the western hemisphere.' (Eds JA Hanson, HL Goodwin) pp. 272-291. (Dowden, Hutchison and Ross Inc.: Pennsylvania).

Bijulal PS, Kumar BM (2003) Different harvesting techniques of *Macrobrachium rosenbergii* in the culture systems of Kerala, India. In 'Freshwater prawns 2003: Advances in biology, aquaculture and marketing'. (Eds CM Nair, DD Nambudiri) pp. 274-277. (Allied Publishers Pvt Ltd: New Delhi)

Biswas A (1996) Experimental monoculture of *Penaeus monodon* (Fabricius, 1879) in freshwater ponds at beel Kodalia, Mollahat, Bagerhat. Bachelor thesis (Khulna University: Khulna, Bangladesh)

Biswas SS, Hossain, MI, Mazumder MS, Akteruzzaman M (2000) An economic analysis of pond fish culture of BRAC in some selected areas of Mymensingh district. *Progressive Agriculture* **11**(1-2), 243-249.

Blumberg RL (1990) 'Gender, family and economy: The triple overlap.' 1st edn. (SAGE Publications Inc: Newbury Park, United States)

BOBP (1992) Feeds for artisanal shrimp culture in India - Their development and evaluation. BOBP/REP/52, Bay of Bengal Programme, Madras, India.

Bohle HG, Downing TE, Watts MJ (1994) Climate change and social vulnerability. *Global Environmental Change* **4,** 37–48. doi: https://doi.org/10.1016/0959-3780(94)90020-5

Bower SM, McGladdery SE, Price IM (1994) Synopsis of infectious diseases and parasites of commercially exploited shellfish. *Annual Review of Fish Diseases* **4**, 1–199.

Boyd CE (1973) Summer algal communities and primary productivity in fish ponds. *Hydrobiologia* **41**, 357-390.

Boyd CE (1981) 'Water quality in warm water fish ponds.' 2nd edition, Craftmaster, Printers Inc.: Auburn)

Boyd CE (1982) 'Water quality management for pond fish culture'. Developments in aquaculture and fisheries sciences 9. (Elsevier Science Publishing Company: Amsterdam)

Boyd CE (1987) Evaluation of water quality and water quality management techniques for brackish water aquaculture in ponds in Thailand. Report for the Asian Development Bank, Manila, The Philippines.

Boyd CE (1989) Water quality management and aeration in shrimp farming. Fisheries and Allied Aquacultures Department series no. 2, Alabama Agricultural Experiment Station, Auburn University, Alabama (Birmingham Publishing Company: New York)

Boyd CE (1990) 'Water quality in aquaculture ponds.' (Agriculture Experiment Station, Auburn University: Alabama, USA)

Boyd CE (2019) Shrimp pond preparation crucial for production, disease prevention. Global Aquaculture Advocate, Global Aquaculture Alliance, March 2019. Available at https://www.aquaculturealliance.org/advocate/ shrimp-pond-preparation-crucial-production-disease-prevention/ [Verified 16 August 2021]

Boyd CE, Fast AW (1992) Pond monitoring and Management. In 'Marine shrimp culture: Principles and practices.' (Eds AW Fast, LJ Lester) pp. 497-513. (Elsevier Science Publishers BV: Amsterdam)

Boyd CE, Tucker CS (1998) 'Pond aquaculture water quality management.' (Kluwer Academic Publishers: Boston, USA)

Branford JR (1981) Sediment and distribution of penaeid shrimp in the Sudanese Red Sea. Estuarine. *Coastal and Shelf Science* **13** (3), 349-354. doi: https://doi.org/10.1016/S0302-3524(81)80032-1

Braten B (2001) Environmental impacts and socio-economic problems of shrimp farming in various countries. In 'Proceedings of the workshop on environmental and socioeconomic impacts of shrimp farming in Bangladesh'. (Bangladesh Agricultural University: Mymensingh, Bangladesh)

Bray WA, Lawrence, AL, Leung-Trujillo JR (1994) The effect of salinity on growth and survival of *Litopenaeus vannamei,* with observation on the interaction of IHHN virus and salinity. *Aquaculture* **123,** 133-146. Available at https://www.ecowin.org/pdf/documents/Bray%201994%20vannamei%20salinity%20growth.pdf [Verified 16 August 2021]

Bray WA, Moya M, Lawrence AL, Collins CA (1999) Brood stock culture of *Litopenaeus vannamei* in low salinity desert groundwater of 2.3 ppt): Summary of growth and sperm development. In: Book of abstracts, World Aquaculture Society Annual Conference'. p. 101. (World Aquaculture Society: Sydney, Australia).

Bray WA, Moya M, Lawrence AL, Collins CA (2000) Reproduction of *Litopenaeus vannamei* following low salinity (2.2 ppt) culture in desert groundwater in the southern U.S. In 'Book of abstracts, World Aquaculture Society Annual Conference'. p.9. (World Aquaculture Society: Nice, France)

Brennan D, Clayton H, BE TT (2000) Economic characteristics of extensive shrimp farms in the Mekong Delta. *Aquaculture Economics and Management* **4** (3-4), 127-139. doi: 10.1080/13657300009380265

Brennan D, Preston N, Clayton H, Be TT (2002) An evaluation of rice-shrimp farming systems in the Mekong delta. Report prepared under the World Bank, NACA, WWF and FAO consortium program on shrimp farming and the environment. Work in progress for public discussion. World Bank, NACA, WWF and FAO consortium. Available at http://www.enaca.org/ shrimp [Verified 21 December 2021]

Brett JR (1979) Environmental factors and growth. In 'Fish Physiology', Vol. VIII. (Eds WS Hoar, DJ Randall, JR Brett) pp. 599-675. (Academic Press: New York, USA)

Briggs M, Funge-Smith S, Subasinghe RP, Phillips M (2004) Introductions and movement of *Penaeus vannamei* and *Penaeus stylirostris* in Asia and the Pacific. FAO technical paper 476, Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, Bangkok. Available at http://www.fao.org/3/a0086e /A0086E00.htm [Verified 11 September 2021]

Brigham EF, Houston JF (2004) 'Fundamentals of financial management.' 11th edn. (Thomson South-Western: USA)

Browdy C, Wyk PV, Stock C, Zeigler TR, Lee R (2016) Shrimp nursery technology: system design and management for cost-effective results Part 1. Design considerations. *Aqua Culture Asia Pacific Magazine* **12**, 39-43.

Browdy C, Wyk PV, Stock C, Zeigler TR, Lee R, Flores D (2017) Building a better shrimp nursery Part 1: Benefits and design considerations for these important production tools. Global Aquaculture Advocate, Global Aquaculture Alliance, 24 April 2017. Available at https://www. aquaculturealliance.org/advocate/building-better-shrimp-nursery-part-1/ [Verified 17 September 2021]

Brummett RE, Williams MJ (2000) The evolution of aquaculture in African rural and economic development. *Ecological Economics* **33** (2), 193-203.

Brummett RE, Youaleu JLN, Tiani, AM, Kenmegne MM (2010) Women's traditional fishery and alternative aquatic resource livelihood strategies in the Southern Cameroonian rainforest. *Fisheries Management and Ecology* **17**, 221-230. doi: 10.1111/j.1365-2400.2009. 00702.x

Bueno PB (2008) Social risks in aquaculture. In 'Understanding and applying risk analysis in aquaculture.' FAO fisheries and aquaculture technical paper no. 519. (Eds MG Bondad-Reantaso, JR Arthur, RP Subasinghe) pp. 209-228. (Food and Agriculture Organisation of the United Nations: Rome, Italy)

Bukhari FA, Jones DA, Salvina AJ (1994) Optimal salinities for the culture of *Penaeus indicus* from the Red sea. In 'Proceedings of first international symposium on aquaculture technology and investment opportunities' 11-14 April 1993, Riyadh. pp. 379-389. (KAU Scientific Publishing Center: Riyadh, Saudi Arabia)

Bundell K, Maybin E (1996) After the prawn rush: the human and environmental costs of commercial prawn farming. Christian Aid Report, London, UK.

CAA (2006) 'Coastal Aquaculture Authority - Compendium of act, rules, guidelines and notifications'. (Coastal Aquaculture Authority, Government of India: Chennai, India). Available at http://caa.gov.in/publications.html [Verified 11 September 2021]

CAA (2014) 'Coastal Aquaculture Authority- Compendium of act, rules, guidelines, regulations and other notifications' Updated- March 2014. (Coastal Aquaculture Authority, Government of India: Chennai, India). Available at http://caa.gov.in/uploaded/doc/COMPUPD2014.pdf [Verified 11 September 2021]

Cao L (2012) Farming shrimp for the future: Sustainability analysis of shrimp farming in China. PhD thesis (University of Michigan: Michigan, USA)

Carolsfeld J, Faría MA, Dean G (2017) Pathways for aquaculture diversification. In 'Planning for aquaculture diversification: the importance of climate change and other drivers. Proceedings of FAO technical workshop'. 23–25 June 2016. FAO fisheries and aquaculture proceedings no. 47. (Eds B Harvey, D Soto, J Carolsfeld, M Beveridge, DM Bartley). pp. 135154 ((Food and Agriculture Organisation of the United Nations: Rome, Italy)

Chaikaew P, Rugkarn N, Pongpipatwattana V, Kanokkantapong V (2019) Enhancing ecological-economic efficiency of intensive shrimp farm through in-out nutrient budget and feed conversion ratio. *Sustainable Environment Research* **29** (28). doi: https://doi.org/10.1186/s42834-019-0029-0

Chakraborti RK, Halder DD, Das NK, Mandal SK, Bhowmik ML (1986) Growth of *Penaeus monodon* Fabricius under different environmental conditions. *Aquaculture* **51**, 189-194.

Chakraborty C, Dutta S, Katiha P (2005) Fishery co-operatives in West Bengal: A socio-economic appraisal. *Environment and Ecology* **23**, 50-57.

Chakravorty SK (1968) Some problems of fish culture in West Bengal- A case study. *Indian Journal of Agricultural Research* **23** (4), 228-235.

Chamberlain G (2003) World shrimp farming: Progress and trends. In: World Shrimp Farming 2003.' (Ed. B Rosenberry) p. 5. (Shrimp News International, San Diego)

Chamberlain GW (1988) Rethinking shrimp pond management. *Coastal Aquaculture* **5** (2), 1–20.

Chandra KJ, Chowdhary AR, Das DR (2010) Shrimp culture practices at farmers level in Bagerhat District. *Progressive Agriculture* **21** (1-2), 173-185.

Chandramohan K, Benakappa S, Anjanayyappa HN (1999) Pokkali fisheries of Kerala- Boon or ban? *Seafood Export Joumal* **30** (3), 13-15.

Chandramohanan KT, Mohanan KV (2012) Kaipad rice farming in North Kerala- an indigenous saline resistant organic farming system. *Indian Journal of Traditional Knowledge* **11** (1), 185-189.

Chapra SC, Canale RP (2010) 'Numerical methods for engineers.' 6th edn. (McGraw-Hill: New York, USA)

Chattopadhyay GN, Biswas CR, Ghosh A, Chakraborti PK, Bandopadhyay AK (1987) A study on rice fish culture in coastal saline soils. *Journal of the Indian Society of Coastal Agricultural Research* **5** (1), 245-249.

Chaudhari KJ (2007) Economics and marketing analysis of shrimp farming in some districts of Konkan coast Maharashtra. PhD thesis (College of Fisheries: Ratnagiri, India)

Chaudhuri H (1960) Contributions to the techniques of pond fish culture in India. D. Phil thesis (University of Calcutta: Calcutta, India)

Chaudhury M (1989) An econometric study on the socio-economic status of the fishermen community in lower Assam. *Journal of Inland Fisheries Society of India*, **2** (1): 7-13.

Chen HC (1985) Water quality criteria for farming the grass shrimp, *Penaeus monodon* (abstract). In 'Proceedings of the first international conference on the culture of penaeid prawns/ shrimps' (Eds Y Taki, JH Primavara, JA Llobrera), 4-7 December 1984, Iloilo City, Philippines. pp. 165. (Aquaculture Department, Southeast Asian Fisheries Development Center (SEAFDEC): Iloilo City, Philippines)

Chen LC (1990) 'Aquaculture in Taiwan' (Fishing News Books: Oxford, UK)

Cheruvat D (2005) Ecological studies on kaipad: A traditional system of farming in North Malabar. PhD thesis (University of Calicut: Calicut, India)

Chhabra TN, Grover SK (2003) 'Marketing management'. 3rd edn. (Dhanpat Rai & Co. Pvt Ltd: Nai Sarak, Delhi, India).

Chimatiro SK, Janke A (1994) Socio economic assessment of small holder aquaculture: a case study of small holder farmers in Mwanza and Zamba districts (extended abstract). In 'Proceedings of aquaculture policy options for integrated resource management in sub-Saharan Africa: ICLARM conference proceedings no. 46' (Ed. RE Brummett) pp. 10-11. (International Center for Living Aquatic Resources Management (ICLARM): Manila, Philippines)

Chittem PB, Kunda SK (2017) Constraint analysis of *Litopenaeus vannamei* culture in Prakasam District, Andhra Pradesh, India. *International Journal of Research Studies in Biosciences* **5** (10), 10-17.

Chittem PB, Kunda SK (2018) Socio-economic condition of the *Litopenaeus vannamei* farmers with implementation of better management practices (BMP's) in Andhra Pradesh, India. *International Journal of Fisheries Aquatic Studies* **6** (6 Part E), 325-331.

Chittleborough RG (1975) Environmental factors affecting growth and survival of juvenile western rock lobsters *Panulirus longiceps* (Milne- Edwards). *Australian Journal of Marine and Freshwater Research* **26**, 177-196. doi: https://doi.org/10.1071/MF9750177

Chiu YN (1988) Prawn nutrition and feeding. In 'Technical considerations for the management and operation of intensive prawn farms.' (Eds YN Chiu, LM Santos, RO Juliano) pp. 86-101 (University of the Phiippines Aquaculture Society: Iloilo City, Philippines)

Cholik F (1978) Study on the effects of different densities of artificial shelters on the survival and growth of sugpo fry (*Penaeus monodon* Fabricius) in nursery pond. MS thesis (University of the Philippines: Metro Manila, Philippines)

Chong KC (1992) Improving profitability of shrimp aquaculture. In 'Proceedings of shrimp 92, Third global conference on the shrimp industry'. (Eds. H De Saram, T Singh) pp. 81-98 (INFOFISH: Honkong)

Choudhary BN (1990) Technologies for inland fisheries development In 'Lab to Land Programme' pp. 209-211 (Indian Council of Agricultural Research: New Delhi, India)

Chuang JL (1990) Nutrient requirements, feeding and culturing practices of *Penaeus monodon*: a review. In 'The nutrition of prawns' (F. Hoffmann-La Roche Ltd Vitamin and Fine Chemicals Division, Animal Nutrition and Health: Basel, Switzerland)

Chuntapa B, Piyatirativorakul S, Nitithamyong C, Viyakaran V, Menasveta P (1999) Optimal lipid: carbohydrate and protein: energy ratios in semi–purified diets for juvenile black tiger prawn *Penaeus monodon* Fabricius. *Aquaculture Research* **30**, 825.

CIBA (1997) Assessment of ground realities regarding the impact of shrimp farming activities on environment in coastal areas of Andhra Pradesh and Tamil Nadu: Final report. Central Institute of Brackishwater Aquaculture (CIBA), Madras, India.

CIBA (1998) 'Chlorination in brackishwater aquaculture' CIBA extension series no.5. (Central Institute of Brackishwater Aquaculture (CIBA), Madras, India)

CIBA (2001) 'Soil and water quality management in brackishwater aquaculture.' CIBA special publication no. 13. (Central Institute of Brackishwater Aquaculture (CIBA): Channai, India)

CIBA (2002) 'Training manual on shrimp and fish nutrition and feed management.' CIBA special bulletin no.15. (Central Institute of Brackishwater Aquaculture (CIBA): Channai, India)

CIBA (2013) 'NFDB sponsored training manual on BMP in shrimp farming with special reference to West Bengal.' CIBA special publication no. 67.

(Central Institute of Brackishwater Aquaculture (CIBA): Chennai, India)

CIBA (2015) 'Training manual on aquatic animal health management in brackish water aquaculture.' (Central Institute of Brackishwater Aquaculture (CIBA): Chennai, India)

CIBA (2017) Culture demonstration of Indian white shrimp, *Penaeus indicus* in different geographical locations. CIBA news, January- June 2017. 3, 4-6. Available at http://www.ciba.res.in/Books/CIBANEWSJanJun2017 .pdf [Verified 20 December 2021)

CIBA (2019) 'Soil and water quality management for shrimp farming'. AAHED Advisory 2019. (Central Institute of Brackishwater Aquaculture (CIBA): Madras, India)

CICFRI (1991) 'Methodology for collection and estimation of inland fisheries statistics in India.' (Central Inland Capture Fisheries Research Institute, Indian Council of Agricultural Research: Barrackpore, West Bengal, India)

CIFE/CIBA (1997) Assessment of ground realities regarding the impact of shrimp farming activities on environment in coastal areas of Andhra Pradesh and Tamil Nadu: Final report (Mimeo). Central Institute of Brackishwater Aquaculture (CIBA), Madras, India and Central Institute of Fisheries Education (CIFE), Mumbai, India

Clayton H, Brennan DC (1999) A review of economic issues for sustainable shrimp farming in the Mekong Delta, Vietnam. Paper presented in the 43rd conference of the Australian Agricultural and Resource Economics Society. 20-22 January 1999, Christchurch, New Zealand. Australian Agricultural and Resource Economics Society, Mitcham North Victoria, Australia. Available at https://ageconsearch.umn.edu/record/123794 /files/ Clayton.pdf [Verified 20 December 2021)

Clifford HC III (1985) Semi-intensive shrimp farming. In 'Texas shrimp farming manual, an update on current technology' (Eds GW Chamberlain, MG Haby, RJ Miget) pp. 13-40. (Texas A&M University: College Station, Texas, USA)

CMFRI (1979) ‘Mussel farming: Lab to land transfer of technology’. Lab to land Series. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Coastal Resources Center (1998) ‘The economic, environmental and social impacts of shrimp farming in Latin America’ (Coastal Resources Center, University of Rhode Island: USA)

Coche AG, Muir JF, Laughlin TL (1996) ‘Management for freshwater fish culture, fish stocks, and farm management.’ Vol. 1. FAO training series no. 21/1, (Food and Agriculture Organization of the United Nations: Rome, Italy)

Cole BA, Boyd CE (1986) Feeding rate, water quality, and channel catfish production in ponds. *The Progressive Fish-Culturist* **81,** 25-29.

Colvin LB (1985) Intensive grow out systems for shrimp. In ‘Texas shrimp farming manual: An update on current technology’ (Eds GW Chamberlain, MG Haby, RJ Miget) pp. IV-1-IV-12. (Texas A&M University: College Station, Texas, USA)

Colvin LB, Brand CW (1977) The protein requirement of penaeid shrimp at various life cycle statges in controlled environment systems. *Proceedings of the World Mariculture Society* **8**: 821-840. doi: https://doi.org/10.1111 /j.1749- 7345. 1977.tb00164.x

Colvin PM (1976) Nutritional studies on penaeid prawns: protein requirements in compounded diets for juvenile *Penaeus indicus* (Milne Edwards) *Aquaculture* **7**, 315-326. doi: https://doi.org/10.1016/0044-8486(76)90128-9

Colwill T (1997) Shrimp farms and shrimp fishery-an economic analysis. PhD thesis (University of Guelph: Canada)

Cook HL, Pongsuwana U, Wechasitt S (1984) Recommendations for construction and management of brackishwater aquaculture ponds in areas with acid-sulphate soils. In 'Malaysia: Coastal aquaculture development', FAO field document 2, FI: DP/MAL/77/008. pp. 243-259. (Food and Agriculture Organisation of the United Nations: Rome)

Corsin F, Hao NV, Madhusudhan M, Mohan CV, Morgan KL, Padiyar PA, Thakur PC, Turnbull JF (2003) Relationship between white spot syndrome virus and indicators of quality in *Penaeus monodon* postlarvae in Karnataka, India. *Diseases of Aquatic Organisms* **54,** 97-104. doi: 10.3354/dao054097

Corsin F, Turnbull JF, Hao NV, Mohan CV, Phi TT, Phuoc LH, Tinh NT, Morgan KL (2001) Risk factors associated with white spot syndrome virus infection in a Vietnamese rice-shrimp farming system. *Diseases of Aquatic Organisms* **47,** 1-12. doi: 10.3354/dao047001

Cousin M, Cuzon G, Blanchet E, Ruelle F, AQUACOP (1993) Protein requirements following an optimum dietary energy to protein ratio for *Penaeus vannmei* juveniles. In ‘Proceedings of the aquaculture feed processing and nutrition workshop: Fish nutrition in practice’. (Eds S Kaushik, P Luquet) pp. 599-606. (INRA - Institut National de la Recherche Agronomique: France)

Cowx IG (1994) ‘Rehabilitation of freshwater fisheries.’ (Fishing News Books, Blackwell Science: Oxford, UK)

Csavas I (1988) Shrimp farming in Asia. IPFC WPA/WP11, FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

Curtis KS, Pitt WC, Conover MR (1996) ‘Overview of techniques for reducing bird predation at aquaculture facilities.’ (Jack H. Berryman Institute, Department of Fisheries and Wildlife, College of Natural Resources, Utah State University: Logan, Utah, United States of America)

Cuzon G, Rosas C, Gaxiola G, Taboada G, Van Wormhoudt A (2000) Utilization of carbohydrates by shrimp. In ‘Avances en Nutrición Acuícola V. Memorias del V. Simposium internacional de nutrición acuícola'. 19-22 Noviembre 2000, Mérida, Yucatán, México (Eds LE Cruz-Suárez, D Ricque-Marie, M Tapia-Salazar, MA Olvera-Novoa, R Civera-Cerecedo) pp. 328-339.

Cyril ARL, Immanuel S, Ananthan PS, Thongam B, Viswanatha BS (2013) Association of socio-economic attributes with adoption of better management practices in shrimp farming in Karnataka, India. *Fishery Technology* **50**, 265-271.

D'Abramo LR (1989) Lipid requirements of shrimp. In 'Advances in tropical aquaculture: AOUACOP IFREMER actes de colloque 9' 20 February–4 March, 1989, Tahiti, pp. 277–285, (AOUACOP IFREMER: France). Available at https://archimer.ifremer.fr/doc/1989/acte-1470.pdf [Verified 12 May 2021].

Dalai SK, Das SK (1992) Economic analysis of fish production under extensive aquaculture practice in Ganjam district of Orissa. *Sea Food Export Journal* **XXIV** (8), 21-23.

Dall W, Hill BJ, Rothlisberg PC, Staples DJ (1990) Biology of the Penaeidae. In 'Advances in Marine Biology.' Vol. 27. (Eds JHS Blaxter, AJ Southward) pp. 1- 489. (Academic Press: London, UK)

Das A, Kumar NR, Krishnan M, Yadav VK, Immanuel S (2014) Adoption of improved aquaculture technologies in Tripura, India. *Fishery Technology* **51**, 58-63.

Das P, Bhaumik U, Pandit PK, Roy B, Banerjee BK, Mondal SK (1988) Some variables contributing to the adoption of composite fish culture innovations. In 'Proceedings of the first Indian Fisheries Forum' (Ed. MM Joseph). pp. 467-470. (Asian Fisheries Society: Mangalore, India).

Datta SK, Kundu R (2007) Socio-economic appraisal of culture-based fishermen: Case study in West Bengal. *Journal of Social Sciences* **15** (3), 255-262. doi: https://doi.org/10.1080/09718923.2007.11892590

Davis DA and Gatlin DM (1996) Dietary mineral requirements of fish and marine crustaceans. *Reviews in Fisheries Science* **4** (1), 75-99. doi: 10.1080/10641269609388579

Day F (1878) 'The Fishes of India.' (Bernard Quaritch: London, UK)

Dayal JS, Ali SA, Ambasankar K, Singh P (2003) Effect of dietary protein level on its in vitro and in vivo digestibility in the tiger shrimp *Penaeus monodon* (Crustacea: Penaeidae). *Indian Journal of Marine Sciences* **32** (2),151-155.

De Ionno PN, Wines GL, Jones PL, Collins RO (2006) A bioeconomic evaluation of a commercial scale recirculating finfish grow out system – An Australian perspective. *Aquaculture* **259**, 315-327.

De La Pena Jr DT, Prospero OQ (1984) Floating nursery cage culture for higher sugpo survival. *Asian Aquaculture* **41** (3), 4-7.

De Long Jr DC (1996) Defining biodiversity. *Wildlife Society bulletin* **24** (4), 738-749. Available at http://www.jstor.org/stable/3783168 [Verified 11 November 2021].

De Walt BR, Ramírez-Zavala JR, Noriega L, González RE (2002) Shrimp aquaculture, the people and the environment in coastal Mexico. Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment. (World Bank, NACA, WWF and FAO consortium) Available at http://www.enaca.org/ shrimp [Verified 11 November 2021]

Deb AK (1998) Fake blue revolution: Environmental and socio-economic impacts of shrimp culture in the coastal areas of Bangladesh. *Ocean & Coastal Management* **41,** 63-68. doi: 10.1016/S0964-5691(98)00074-X

Debnath PP, Karim M, Kudrat-E-Kabir QAZM (2013) Comparative study on growth performance of Bagda (*Penaeus monodon,* Fabricius, 1798) in traditional and semi-intensive culture systems. *Science and Technology* **3** (1), 1-16.

Deepa KM (2014) Seasonal variation in avifauna with respect to habitat changes in Pokkali field of Ernakulam District Kerala. PhD thesis (Mahatma Gandhi University: Kottayam, Kerala)

Dekker W, Leeuw JJ de (2003) Bird–fisheries interactions: the complexity of managing a system of predators and preys. In ‘Interactions between fish and birds: Implications for management.’ (Ed. IG Cowx) pp. 3-14 (Fishing News Books: UK)

Delmendo MN (1989) Some advances attained in shrimp farming research and management practices: insights to future prospects for expansion of production. ASEAN/SF/89/Tech. 10, ASEAN/UNDP/FAO Regional Small-Scale Coastal Fisheries Development Project, Manila, Philippines. Available at: https://www.fao.org/3/ag164e/ag164e00.htm [Verified 16 November 2021]

Deo AD, Anand PSS, Biswas G (2013b) Site selection, design and construction of shrimp farm for optimization of production. In 'NFDB sponsored training manual on BMP in shrimp farming with special reference to West Bengal' CIBA special publication no. 67. (Eds AD Deo, PSS Anand, P Ravichandran) pp. 21-28. (Kakdwip Research Centre of Central Institute of Brackishwater Aquaculture (CIBA): Kakdwip, West Bengal, India)

Deo AD, Jayanti M, Anand PSS, Balasubramaniam (2013c) Harvest and post-harvest management of farmed shrimp. In 'NFDB sponsored training manual on BMP in shrimp farming with special reference to West Bengal' CIBA special publication no. 67. (Eds AD Deo, PSS Anand, P Ravichandran) pp. 67-69. (Kakdwip Research Centre of Central Institute of Brackishwater Aquaculture (CIBA): Kakdwip, West Bengal, India)

Deo AD, Ravichandran P, Anand PSS, Gopal C (2013a) Present issues and future strategies of shrimp farming in West Bengal. In 'NFDB sponsored training manual on BMP in shrimp farming with special reference to West Bengal' CIBA special publication no. 67. (Eds AD Deo, PSS Anand, P Ravichandran) pp. 1-5. (Kakdwip Research Centre of Central Institute of Brackishwater Aquaculture (CIBA): Kakdwip, West Bengal, India)

Deshimaru O, Yone Y (1978) Effect of dietary carbohydrate source on growth and feed efficiency of prawn. *Nippon Suisan Gakkaishi* **44,** 1161-1163.

Devadasan K, Lakshmanan PT, Girija S, Pillai PCK, Mathew S, Namboothiri DD (2008) Report of the task force on processing and marketing of fish. Department of Fisheries, Government of Kerala, Thiruvananthapuram, Kerala, India.

Devaraj M (2008) Report of the expert committee on development of marine fisheries in Kerala. Department of Fisheries, Government of Kerala, Thiruvananthapuram, Kerala, India.

Devi SK, Jayalakshmi KV, Venugopal P (1991) Communities and co-existence of benthos in northern limb for Cochin backwaters. *Indian Journal of Geo-Marine Sciences* **20**, 249-254.

Dey MM, Paraguas FJ, Bimbao G, Regaspi PB (2000) Technical efficiency of tilapia grow out pond operations in Philippines. *Aquaculture Economics and Management* **4** (1&2), 33-47. doi: https://doi.org/10.1080/136573 00009380259

Dhamijia SK, Jain Y (1994) Variation in the physico-chemical characteristics of a lentic water body of Jabalpur MP *Journal of Environment and Pollution* **1,** 125-128.

Dhondyal SP, Singh GN (1968) Benefit cost ratios in fish culture. *Indian Journal of Agricultural Research* **23** (4), 235-239.

Dinesh K (2016) Shrimp farming in India-history, status and thoughts for the future. In 'Progress of shrimp and prawn aquaculture in the world.' (Eds I C Liao, N Chao, EM Leaño) pp. 221-231. (National Taiwan Ocean University: Taiwan, Asian Fisheries Society: Malaysia, World Aquaculture Society: USA)

Dixon RB (1982) Counting women in agricultural labour force. *Population and Development Review* **8**(3), 539-566.

DoF (1994) 'Fisheries development and management policy.' (Department of Fisheries, Government of Kerala: Trivandrum, India)

DoF (2002) 'Data on the water resources for the development of inland fisheries in Kerala. Master Panfish Book- 1.' (Department of Fisheries, Kerala, Thiruvananthapuram, India)

DoF (2019) 'Kerala fisheries statistics at a glance.' (Directorate of Fisheries, Government of Kerala, Thiruvananthapuram, Kerala, India). Available at https://fisheries.kerala.gov.in/sites/default/files/inline-files/D002% 20%281%29.pdf [Verified 11 July 2021]

DoF (2020) 'Fisheries handbook.' (Department of Fisheries, Government of Kerala, Thiruvananthapuram, Kerala, India). Available at https://fisheries.kerala.gov.in/publications [Verified 11 July 2021]

Dona P, Immanuel S, Ohja S, Ananthan P (2016) Occupational needs of shrimp farmers in Kerala. *Indian Research Journal Extension Education* **16** (3), 20-24. Available at http://krishi.icar.gov.in/jspui/handle/123456789/ 48936 [Verified 11 July 2021]

Doubrovsky A, Paynter JL, Sambhi SK, Atherton JG, Lester RJG (1988) Observations on the ultra-structure of baculovious in Australian *Penaeus monodon* and *Penaeus merguensis*. *Australian Journal of Marine and Freshwater Research* **39**, 743-749.

Dow K (1992) Exploring differences in our common future(s): the meaning of vulnerability to global environmental change. *Geoforum* **23**, 417-436.

Dresdner J, Estay M (2016) Biosecurity versus profits: A multi objective model for the aquaculture industry. *Journal of the World Aquaculture Society* **47** (1), 61-73. doi: 10.1111/jwas.12256

Duenas J, Harmsen A, Emberson C (1983) Penaeid shrimp culture in Ecuador. In 'Proceedings of the first international conference on warmwater aquaculture- Crustacea'. (Eds GL Rogers, R Day, A Lim) pp. 99-108. (Brigham Young University: Laie, Hawaii, USA)

Durai V, Alagappan M, Venkatesan M (2020) Techno-economic analysis of shrimp farming in coastal districts of Tamilnadu. *Journal of Entomology and Zoology Studies* **8** (4), 2193-2196.

Dutta OK (1998) Socio economic status of fish culture in Assam. In 'Current and emerging trends in aquaculture: Proceedings of the national seminar on current and emerging trends in aquaculture and its impact on rural development'. 14-16 February 1995 (Ed. PC Thomas) pp. 304-318. (Daya Publishing House: Delhi)

Dwyer D and Bruce J (1988) A home divided: Women and income in the third world. (Stanford University Press: Palo Alto, USA)

Edwards P (1993) Environmental issues in integrated agriculture-aquaculture and wastewater-fed fish culture systems. In 'Environment and aquaculture in developing countries. ICLARM conference proceedings no. 31' (Eds RSV Pullin, H Rosenthal, JL Maclean) pp. 139-170 (International Center for Living Aquatic Resources Management (ICLARM): Manila, Philippines)

Eldani A, Primavera JH (1981) Effect of different stocking combinations on growth, production and survival of milkfish (*Chanos chanos* Forskal) and prawn (*Penaeus monodon* Fab.) in polyculture in brackishwater ponds. *Aquaculture* **23**,59-72.

Elson D, McGee R (1995) Gender equality, bilateral program assistance and structural adjustment: Policy and procedures. *World Development* **23** (11), 1987-1994.

Emberson CR, Samocha TM, Wood GF (1999) Use of ground saline water for commercial production of *Litopenaeus vannamei* in the Sonora Desert, Arizona, USA In 'Book of abstracts. World Aquaculture 1999'. p. 668. (World Aquaculture Society: Baton Rouge, Louisiana, USA)

Emmerson WD, Andrews B (1981) The effect of stocking density on growth, development and survival of *Penaeus indicus* Milne Edwards larvae. *Aquaculture* **23,** 45-57. https://doi.org/10.1016/0044-8486(81)90006-5

Engle CR (2010) Aquaculture economics and financing: management and analysis. 1st edn. (Wiley-Blackwell, Ames, Iowa, USA)

Engle CR, McNevin A, Racine P, Boyd CE, Paungkaew D, Viriyatum R, Tinh HQ, Minh HN (2017) Economics of sustainable intensification of aquaculture: evidence from shrimp farms in Vietnam and Thailand. *Journal of the World Aquaculture Society* **48** (2). doi: https://doi.org /10.1111/ jwas.12423

Engstrom H (2001) Long term effects of cormorant predation on fish communities and fishery in a freshwater lake. *Ecography* 24, 127-138. doi: https://www.jstor.org/stable/3683688

Estrada-Pérez M, Ruiz-Velazco JMJ, Hernandez-Llamas A, Zavala-Leal I (2015) A bio-economic approach to analyze the role of alternative seeding-harvesting schedules, water quality, stocking density and duration of cultivation in semi-intensive prodction of shrimp in Mexico. *Latin American Journal of Aquatic Research* **43**, 466-472. doi. 10.3856/vol43-issue3-fulltext-8

Evans DO, Henderson BA, Bax NJ, Marshall TR, Oglesby RT, Christie WJ (1987) Concepts and methods of community ecology applied to freshwater fisheries management. *Canadian Journal of Fisheries and Aquatic Sciences* **44** (2), 448–470.

Faizbakhs R (2003) The economics of shrimp culture in Iran and future strategies. Final project (United Nations University Fisheries Training Programme: Reykjavik, Iceland)

FAO (1984) 'FAO Species identification sheets for fishery purposes Western Indian Ocean Fishing Area 51.' (Food and Agriculture Organization: Rome, Italy)

FAO (1995) 'The state of world fisheries and aquaculture.' (FAO Fisheries Department, Food and Agriculture Organisation of the United Nations: Rome, Italy). Available at http://www.fao.org/3/v5550e/v5550e00.pdf [Verified 11 July 2021]

FAO (2005) 'Fish pond construction and management (A field guide and extension manual)', Technological information materials from NSPFS rural aquaculture training workshops in Nigeria. 17 March- 8 April 2003 (National Special Programme for Food Security (NSPFS), FAO: Abuja, Nigeria). Available at http://www.fao.org/3/ak506e/ak506e.pdf [Verified 12 August 2021]

FAO (2010) 'Aquaculture development. 4. Ecosystem approach to aquaculture.' FAO technical guidelines for responsible fisheries. no. 5 (Food and Agriculture Organisation of the United Nations: Rome, Italy)

FAO (2016) 'The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all.' (Food and Agriculture Organisation, Rome, Italy). Available at http://www.fao.org/3/i5555e/i5555e.pdf [Verified 11 July 2021]

FAO (2018) 'The state of world fisheries and aquaculture 2018. Meeting the sustainable development goals.' (Food and Agriculture Organisation, Rome, Italy). Available at http://www.fao.org/3/i9540en/i9540en.pdf [Verified 11 July 2021]

FAO (2020) ‘The state of world fisheries and aquaculture 2020. Sustainability in action.’) Food and Agriculture Organisation: Rome, Italy). Available at http://www.fao.org/3/ca9229en/ca9229en.pdf [Verified 11 December 2021]

FAO (2021) ‘Cultured aquatic species information programme *Penaeus monodon* (Fabricius, 1798).’ Available at https://www.fao. org/fishery/ culturedspecies/Penaeus_monodon/en [Verified 14 November 2021].

FAO/NACA (1995) Regional study and workshop on the environmental assessment and management of aquaculture development. TCP/RAS/2253), NACA environment and aquaculture development series no. 1. (Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand). Available at https://www.fao.org/3/ac279e/AC279E00.htm [Verified 11 January 2022]

Farber DA, Hemmersbaugh PA (1993) The shadow of the future: Discount rates, later generations and the environment. *Vanderbilt Law Review* **46,** 267-304. Available at http://www.ciesin.org/docs/010-291/010-291.html [Verified 11 January 2022]

Fast AW (1992a) Penaeid grow-out systems: An overview. In 'Marine shrimp culture: Principles and practices.' (Eds AW Fast, LJ Lester) pp. 345-353. (Elsevier Science Publishers BV: Amsterdam)

Fast AW (1992b) Penaeid extensive grow out systems. In 'Marine shrimp culture: Principles and practices.' (Eds AW Fast, LJ Lester) pp. 355-368. (Elsevier Science Publishers BV: Amsterdam)

Fast AW (1992c) Penaeid semi-intensive grow out systems. In 'Marine shrimp culture: Principles and practices.' (Eds AW Fast, LJ Lester) pp. 369-380. (Elsevier Science Publishers BV: Amsterdam)

Fast AW, Boyd CE (1992) Water circulation, aeration and other management practices. In 'Marine shrimp culture: Principles and practices.' (Eds AW Fast, LJ Lester) pp. 415-429. (Elsevier Science Publishers BV: Amsterdam)

Felix S, Sukumaran N (1988) Performance of *Penaeus indicus* and *Penaeus monodon* under mono and mixed culture systems. In 'Proceedings of the first Indian Fisheries Forum' (Ed. MM Joseph) pp. 129- 130. (The Asian Fisheries Society, Indian Branch: Mangalore, India)

Ferdouse F (1996) Shrimp market situation in Asia. *INFOFISH International* **2**, 14-22. Available at https://agris.fao.org/agris-search/search.do?record ID=XF2016055448 [Verified 11 July 2021]

Fernandez PM (1979) Effect of stocking densities on the survival and growth of wild and hatchery produced sugpo (*Penaeus monodon* Fabricius) fry in nursery ponds with artificial shelters. MS thesis (University of the Philippines: Diliman Quezon City 1101, Philippines)

Fernando CH, Holcik J (1991) Fish in reservoirs. *International Review of Hydrobiology* **76** (2), 149-167. doi: 10.1002/IROH.19910760202

FFP (1999) ‘Fourth fisheries project, project proforma.’ (Department of Fisheries: Dhakka, Bangladesh)

Fischer W, Hureau JC (Eds) (1985) 'FAO species identification sheets for fishery purposes. Southern Ocean (Fishing area 48, 58 and 88).' (Food and Agriculture Organization (FAO): Rome, Italy) Available at https://www.fao.org/3/ah841e/ah841e00.htm [Verified 12 May 2021]

Fitzgerald WJ (1988) Comparative economics of four aquaculture species under monoculture and polyculture production in Guam. *Journal of World Aquaculture Society* **19** (3), 132-142. doi: 10.1111/j.1749-7345.1988.tb00941.x

Flaherty M, Vandergeest P, Miller P (1999) Rice paddy or shrimp pond: Tough decisions in rural Thailand. *World Development* **27** (12), 2045-2060.

Focken U, Groth A, Coloso RM, Becker K (1998) Contribution of natural food and supplemental feed to the gut content of *Penaeus monodon* Fabricius in semi–intensive pond system in the Philippines. *Aquaculture* **164,** 105–116.

Forster JRM, Beard TW (1974) Experiments to assess the suitability of nine species of prawns for intensive cultivation. *Aquaculture* **3**, 355-368.

Francis G, Focken U, Becker K (2000) 'Improving profitability of small-scale farming by integrating fish culture into traditional rice farming in Kerala State, India.' (Department of Animal Nutrition and Aquaculture, Institute for Animal Production in the Tropics and Subtropics, University of Hohenheim (480): D 70593 Stuttgart, Germany). Available at ftp://ftp.gwdg.de/pub/tropentag/proceedings/2000/Full%20Papers/Section%20IV/WG%20e%20Poster/Francis%20G.pdf [Verified 20 December 2021)

Franco AR, Ferreira JG, Nobre AM (2006) Development of a growth model for penaeid shrimp. *Aquaculture* **259** (1), 268-277. doi: 10.1016/j.aquaculture.2006.05.051

Funge-Smith SJ, Aeron-Thomas M (1995) 'The economic factors and risks influencing the sustainability of Thai intensive shrimp farms.' (Institute of Aquaculture, University of Stirling: UK)

Funge-Smith SJ, Briggs MRP (1998) Nutrient budgets in intensive shrimp ponds: implications for sustainability. *Aquaculture* **164**, 117-133. doi: https://doi.org/10.1016/S0044-8486(98)00181-1

Gabasa Jr PG (1982) Recent developments in design and management of small-scale hatchery for *Penaeus monodon* in the Philippines. In 'Working party on small-scale shrimp/prawn hatcheries in Southeast Asia, 16-21 November 1981, Semarang, Central Java, Indonesia. Vol. II. Technical report' pp. 77-86. Report no. SCS/GEN/82/40, South China Sea Fisheries Development and Coordinating Programme, Manila, Philippines.

Gacutan RQ (1979) Diseases of prawns (pests and diseases of sugpo). In 'Proceedings of the technical consultation on available aquaculture technology in the Philippines'. 8-11 February 1979, Tigbauan, Iloilo. pp. 170-179. (Aquaculture Department, Southeast Asian Fisheries Development Center (SEAFDEC): Iloilo City, Philippines)

Galgotia JS (1968) Role of co-operatives in fisheries development in Maharashtra state. *Indian Journal of Agricultural Research* **23** (4), 259-263.

Galib SM, Mohsin ABM, Chaki N, Fahad MFH, Haque SMM (2013) An overview of the traditional rice -prawn-fish farming in Kalia of Narail district, Bangladesh. *Journal of Fisheries* **1** (1), 1-6.

Gammanpila M (2015) Economic viability of small-scale shrimp (*Penaeus monodon*) farming in the northwestern province of Sri Lanka. (United Nations University Fisheries Training Programme: Iceland) [final project]. Available at: http://www.unuftp.is/static/fellows/document/menake14prf.pdf [Verified 19 December 2021)

Ganesan S, Chinnaswami KN, Chandrasekharan B, Budhar MN, Jayaseelan, MJP (1991) Duck-cum-fish culture in rice farming system in Cauvery delta region of Tamil Nadu: The Aduthurai experiment. *Indian Journal of Agricultural Economics* **46** (2), 313-318.

Gao W, Tian L, Hu W, Luo M, Liu J, Xu Q, Tian J. (2016) Optimal dietary protein level for the white shrimp (*Litopenaeus vannamei*) in low salinity water. *The Israeli Journal of Aquaculture - Bamidgeh* **68,** 1320-1328. doi: 10.46989/001c.20798

Gastwirth JL (1971) A general definition of the Lorenz Curve. *Econometrica* **39**,1037-1038.

Gautam P, Ananthan PS, Krishnan M (2017) Fish farmers development agencies and farmers empowerment: An impact assessment study in Uttar Pradesh. *Agricultural Economics Research Review.* **30** (1) 113-124. doi: 10.5958/0974-0279.2017.00010.6

Gautier D, Bastidas M, Aragon L, Urango W, Ramos C, Garcia S, Pastrana JA, Newmark F (2001) The relative importance of natural food and pelleted feed in the gut content of *Litopenaeus vannamei* raised in semi-intensive ponds – role of benthic diatoms. In 'Book of abstracts, Aquaculture 2001- The annual international conference and exhibition of the World Aquaculture Society' 21-25 January 2001, Orlando. pp. 247. (World Aquaculture Society: USA)

Gawde MM (2004) Adoption of improved aquaculture practices by shrimp farmers in South Konkan region of Maharashtra, India. MFSc thesis (Dr Balasaheb Sawant Konkan Krishi Vidyapeeth: Dapoli, Ratnagiri, Maharashtra, India)

Gawde MM, Chandge MS, Shirdhankar MM (2006) Adoption of improved aquaculture practices by shrimp farmers in South Konkan region of Maharashtra, India. *Journal of Agriculture and Social Research* **6** (2),1-8. doi: 10.4314/jasr. v6i2.47010

Gawde MM, Chandge MS, Shirdhankar MM (2009) Improved techniques in shrimp farming: constraints and adoption. *Fishing Chimes* **29** (5), 40-42.

Gazi AK (2019) The problem and prospect of shrimp cultivators in the coastal area of Bangladesh: An analysis. *United International Journal for Research & Technology* **1** (2), 48-57.

George KV (1974) Some aspects of prawn culture in the seasonal and perennial fields of Vypeen Island. *Indian Journal of Fisheries* **21** (1), 1-19.

George KV (1980) Economics of traditional prawn culture practices in Kerala with a note on the advantages of intensive prawn culture. In 'Proceedings the first national symposium on shimp farming'. 16-18 August 1978, Bombay. pp. 131- 137. (Marine Products Export Development Authority: Cochin, India)

George MJ (1962) On the breeding of penaeids and the recruitment of their postlarvae into the backwaters of Cochin. *Indian Journal of Fisheries* **9** (1), 110-116.

George MJ (1975) Observations on the growth of certain Penaeid prawns studied in prawn culture experiments in paddy fields. *Bulleti of the Department of Marine Sciences, University of Cochin* **7** (1), 41-75.

George MJ, Mohamed KH, Pillai NN (1968) Observations on the paddy field prawn filtration of Kerala, India. *FAO Fisheries Report* **57** (2), 427-442.

George MJ, Suseelan C (1982) Distribution of species of prawns in the backwaters and estuaries of India with reference to coastal aquaculture. In 'Proceedings of the symposium on coastal aquaculture Part 1'. 12-18 January 1980, Cochin. (Eds EG Silas, PV Rao, PVR Nair, K Alagarswami, T Jacob, KC George, K Rengarajan, PP Pillai, KJ Mathew, VK PiIIai, AG Ponniah) pp. 273-284. (Marine Biological Association of India: Cochin, India)

Ghosh A (1979) Scope for paddy-cum-fish culture in India. In 'Book of abstracts, Ecology and development: Fifth international symposium of tropical ecology' 16-21 April 1979, Kuala Lumpur, Malaysia. pp. 55. (Ed. JI Furtado). pp. 55. (International Society of Tropical Ecology: Kuala Lumpur)

Ghosh A (1990) Rice-cum-fish culture and its economic feasibility. In 'Technologies for inland fisheries development.' (Eds VV Sugunan, U Bhaumik) pp. 69-84. (Central Inland Capture Fisheries Research Institute: Barrackpore, West Bengal, India)

Ghosh A, Chakrabarti PK (1990) Rice-fish production system: A viable technology for coastal wetland management in West Bengal. In 'Rice in wetland ecosystem' (Eds RR Nair, KPV Nair, CA Joseph) pp. 261-264. (Kerala Agricultural University: Thrissur, Kerala, India)

Ghosh A, Saha SK, Banerjee RK, Mukherjee AB, Naskar KR (1985) 'Package of practices for increased production in rice-cum-fish farming system. Aquaculture' Extension manual 4 (Central Inland Fisheries Research Institute: Barrackpore, West Bengal, India)

Ghosh DS (1991) Ulnadan malsya thozhilalikalum malsya bandhana rithikalum in 'Keralithile ulnadan malsya mekhala' (in Malayalam). (Eds JJ Kaleekal) pp. 46-66. (MJM Centre: Mavelikara, Kerala, India)

Ghosh DS (1996) 'Sasthreeya chemmeen krishi' (in Malayalam). (Kerala Bhasha Institute: Thiruvananthapuram, Kerala, India)

Glahn JF, Harrel JB, Vyles C (1998) The diet of wintering double-crested cormorants feeding at lakes in the southeastern United States. *Colonial Waterbirds* **21**, 446-452.

Glencross BD, Smith DM, Thomas MR, Williams, KC (2002) Optimising the essential fatty acids in the diet for weight gain of the prawn, *Penaeus monodon. Aquaculture* **204** (1-2), 85-99. doi: 10.1016/S0044-8486(01)00644-5

Goddard S (1996) 'Feed management in intensive aquaculture.' (Chapman and Hall: New York, USA)

GoI (2011) 'Census of India' (Registrar General and Census Commissioner, Government of India) Available at: https://censusindia.gov.in/2011-Common/Latest_Releases.html [Verified 11 January 2022]

GoI (2014) 'Handbook on fisheries statistics 2014.' (Department of Animal husbandry, Dairying and Fisheries, Government of India: New Delhi, India).

GoI (2019) 'Handbook on fisheries statistics 2018.' (Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India, New Delhi, India). Available at https://dof.gov.in/sites/default /files/2020-08/HandbookonFS2018.pdf [Verified 11 July 2021]

GoI (2020a) Year-end review 2020: Department of Fisheries. Ministry of Fisheries, Animal Husbandry & Dairying, Government of India, New Delhi, India. Available at https://pib.gov.in/PressReleasePage.aspx? PRID=1682945 [Verified 11 July 2021]

GoI (2020b) National fisheries policy, 2020. Sixth draft for consideration. Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India, New Delhi, India. Available at http://dof.gov.in/sites/default/files/2020-12/Policy_0.pdf [Verified 11 July 2021]

GoI (2020c) 'Handbook on fisheries statistics 2020.' (Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India, New Delhi, India) Available at https://dof.gov.in/sites/ default/files/2021-02/Final_Book.pdf [Verified 11 January 2022]

GoI (2020d) Annual report 2019-20. Department of Fisheries, Ministry of Fisheries, Animal husbandry and Dairying, Government of India, New Delhi, India.

GoK (2021) 'Economic review 2020.' (State Planning Board, Thiruvananthapuram, Kerala, India) Available at https://spb.kerala. gov.in/sites/default/files/2021-01/English-Vol-1_0.pdf [Verified 12 July 2021]

Gopal C (1986) Nutritional studies on juvenile *Penaeus indicus* with reference to protein and vitamin requirements. PhD thesis (University of Cochin: Cochin, India).

Gopal C, Raj RP (1990) Protein requirement of juvenile *Penaeus indicus*. 1. Food consumption and growth. *Proceedings of the Indian Academy of Sciences (Animal Sciences)* **99**(5), 401-409.

Gopalakrishnan TC, Devi CBL, Aravindakshan PN, Nair KKC, Balasubramanian T, Kutty MK (1988) Phytoplankton and zooplankton of some paddy-cum-prawn culture fields in and around Cochin. *Mahasagar* **21** (2), 85-94. Available at: http://ijs.nio.org/index.php/msagar/ article/view/ 1936 (Verified 27 July 2021)

Gopalan C (1995) Towards food and nutrition security. *Economic and Political Weekly* **30** (52), 134-141.

Gopalan UK (1987) The fishery resources of Kerala and their exploitation. In 'Proceedings of the state level seminar on fisheries crisis and policy approach, Kerala'. 27-28 August 1987, Thiruvananthapuram (Programme for Community Organisation (PCO) Centre: Thiruvananthapuram, India)

Gopalan UK, Purushan KS (1981) Present status of back water shrimp culture in India. *Sea Food Export Journal* **8 (**1&3), 9-14.

Gopalan UK, Purushan KS, Rao TSS (1980) Case studies on the economics of an improved method of paddy field shrimp culture in Vypeen Island, Kerala. In 'Proceedings the first national symposium on shimp farming'. 16-18 August 1978, Bombay. pp. 175- 186. (Marine Products Export Development Authority: Cochin, India)

Gopalan UK, Purushan KS, Santhakumari V, Kunjamma PPM (1982) Experimental studies of high density, short-term rearlng of shrimp *Penaeus indicus* in a pokkali field in Vypeen Island, Kerala. In 'Proceedings of the symposium on coastal aquaculture Part 1'. 12-18 January 1980, Cochin. (Eds EG Silas, PV Rao, PVR. Nair, K Alagarswami, T Jacob, KC George, K Rengarajan, PP Pillai, KJ Mathew, VK PiIIai, AG Ponniah) pp. 151-159. (Marine Biological Association of India: Cochin, India).

Gopalan UK, Vengayil DT, Verma PU, Kutty MK (1983) The Shrinking Backwaters of Kerala. *Journal of Marine BioIogical Association of India* **25** (1&2), 131-141.

Gopinath K (1956) Prawn culture in the rice fields of Travancore Cochin, India. *Proceedings of Indo-Pacific Fisheries Council* **18,** 419-425.

Gopinathan CP, Nair PVR, Pillai VK, Pillai PP, Vijayakumaran M, Balachandran VK (1982) Environmental characteristics of the seasonal and perennial prawn culture fields in the estuarine system of Cochin. In 'Proceedings of the symposium on coastal aquaculture Part 1'. 12-18 January 1980, Cochin. (Eds EG Silas, PV Rao, PVR. Nair, K Alagarswami, T Jacob, KC George, K Rengarajan, PP Pillai, KJ Mathew, VK PiIIai, AG Ponniah) pp. 369-382. (Marine Biological Association of India: Cochin, India).

Gordon DV, Bjorndal T (2009) A comparative study of production factors and productivity for shrimp farms in three Asian countries: Bangladesh, India and Indonesia. *Aquaculture Economics & Management* **13** (2), 176-190. doi: 10.1080/13657300902885519

Gosselin F (2001) Lorenz partial order: The best known logical framework to define evenness indices. *Community Ecology,* **2** (2), 197-207. doi: 10.1556/ComEc.2.2001.2.7

Goswami B (2012) Factors affecting the attitude of fish farmers towards scientific fish culture in West Bengal. *Indian Research Journal of Extension Education* **12** (1).

Goswami M, Biradar RS, Sathiadhas R (2009) Techno-economic viability of rice-fish culture in Assam. *Aquaculture Economics and Management* **8** (5&6), 309-317.

Goswami M, Sathiadhas R (2000) Fish farming through community participation in Assam. *Naga* **23** (3), 29-32.

Goswami M, Sathiadhas R, Goswami UC, Ojha SN (2002) Socio-economic dimension of fish farming in Assam. *Journal of Indian Fisheries Association* **29,** 103-110.

Grace BL (2015) Correlation study of physico-chemical parameters and biodiversity of Poonthura Backwater (Kerala, India). *Applied Ecology and Environmental Sciences* **3** (2), 42-50. doi: 10.12691/aees-3-2-3

Grafton RQ (2004) 'The economics of the environment and natural resources.' (Blackwell Publications: Malden, USA)

Griffin WL (1995) Economic aspects of shrimp culture. In 'Proceedings of the seventh biennial conference of the International Institute of Fisheries Economics and Trade'. (Ed. D Liao) pp. 168-188. (National Taiwan Ocean University: Taiwan ROC)

Griffith DRW, Wigglesworth JM (1993) Growth rhythms in the shrimp *Penaeus vannamei* and *P. schmitti. Marine Biology,* **115**, 295-299.

Grman E, Lau JA, Schoolmaster Jr DR, Gross KL (2010) Mechanisms contributing to stability in ecosystem function depend on the environmental context. *Ecology Letters* **13**, 1400–1410. doi: 10.1111/j.1461-0248.2010.01533.x

Guary J, Kayama M, Murakami Y, Ceccaldi H (1976) The effects of a fat–free diet and compounded diets supplemented with various oils on moult, growth and fatty acid composition of prawn, *Penaeus japonicus* Bate. *Aquaculture* **7,** 245-254.

Guest WC, Durocher PP (1979) Palaemonid shrimp, *Macrobrachium amazonicum*: effects of salinity and temperature on survival. *The Progressive Fish-Culturist* **41**, 14-19. doi: https://doi.org/10.1577/1548-8659

Guillaume J, Kaushik S, Bergot P, Metailler R (2001) 'Nutrition and feeding of fish and crustaceans.' (Springer: London, UK)

Gundermann N, Popper D (1975) Experiment in growing *Penaeus merguiensis* (de Man 1888) in a fish pond in Fiji. *Aquaculture* **6**, 197-198. doI:10.1016/0044-8486(75)90072-1

Gupta BP, Krishnani KK, Joseph KO, Muralidhar M, Ali SA, Gopal C (2001) Soil and water characteristics and the growth of shrimp *Penaeus* *monodon* fed with formulated feed in experimental tanks. *Indian Journal of Fisheries* **48** (4), 345-351.

Gupta MV, Rab MA (1994) Adoption and economics of silver barb (*Puntius gonionotus*) culture in seasonal waters in Bangladesh, ICLARM technical report 41, International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines. Available at http://pubs. iclarm.net/libinfo/Pdf/Pub%20TR4%2041.pdf [Verified 12 May 2021]

Gupta MV, Sollows JD, Mazid MA, Rahman A, Hussain MG, Dey MM (1998) Integrating aquaculture with rice farming in Bangladesh: feasibility and economic viability, its adoption and impact. ICLARM technical report. International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines.

Gupta S (2018) 'Fundamentals of Statistics.' (Himalaya Publishing House: New Delhi)

Gupta T, Dey M (2014) Socioeconomic and cultural profile of fish farmers: a study in and around Lumding town, Nagaon district of Assam. *International Journal of Life Sciences Biotechnology and Pharma Research* **3** (4), 83-93

Guzman C, Gaxiola G, Roasa C, Torre-Blanco A (2001) The effect of dietary protein and total energy content on digestive enzyme activities, growth and survival of *Litopenaeus setiferus* (Linnaeus 1767) postlarvae. *Aquaculture Nutrition* **7,**113-122.

Hajra A, Ghosh A, Mandal SK (1988) Biochemical studies on the determination of optimum dietary protein to energy ratio for tiger prawn, *Penaeus monodon* (Fab.) juveniles. *Aquaculture* **71,** 71–9.

Hamid MA, Alauddin M (1996) Shrimp production and employment generation in Bangladesh: Changing role of women. In ‘Proceedings of Bangladesh: Economy, People and the Environmental Conference’.10 June 1996, Brisbane. (Eds M Alauddin and S Hasan) pp.301-321. (Department of Economics, University of Queensland: Brisbane, Australia)

Haneesh P (2005) Comparative study on the marketing and export of wild caught and farmed giant freshwater prawn *Macrobrachium rosenbergii* from Kochi, Kerala. Paper presented at Sustain Fish 2005- International symposium on improved sustainability of fish production systems and appropriate technologies for utilization. 16-18 March 2005, Cochin. Cochin University of Science and Technology, Cochin, India and University Grants Commission, New Delhi, India.

Hanson JA, Goodwin HL (Eds) (1977) 'Shrimp and prawn farming in the Western Hemisphere'. (Dowden Hutchingson and Ross Inc.: Pennsylvania, USA)

Haque ABMM, Dey MM (2016) Impact of the community-based fish culture system on expenditure and inequality: Evidence from Bangladesh. *Journal of World Aquaculture Society*, **47** (5), 646-657. doi: https://doi.org/ 10.1111/jwas.12317

Haque S (2011) Efficiency and institutional issues of shrimp farming in Bangladesh. In 'Farming & rural systems economics' (Eds W Doppler, S Bauer). Vol. 124. (Margraf Publishers: GmbH, Germany)

Harikrishnan M, Kurup BM (2006) On the sustainability issues of the fishery of the giant freshwater prawn *Macrobrachium rosenbergii* (de Man) in the Vembanad Lake, South India. In 'Proceedings of Sustain Fish 2005 - International symposium on improved sustainability of fish production systems and appropriate technologies for utilization' (Eds BM Kurup, K Ravindran) pp. 502-510. (School of Industrial Fisheries, Cochin University of Science and Technology: Cochin, India)

Harikrishnan M, Vipin PM, Kurup BM (2011) Status of exploited fishery resources of Azhikode Estuary, Kerala, India. *Fishery Technology* **48** (1), 19-24.

Harkell L (2017) Chinese shrimp farmgate prices stabilizing in key production regions. Undercurrent news. Seafood business news from beneath the surface. Available at https://www.undercurrentnews.com/2017/08/07/chinese-shrimp-farmgate-prices-stabilizing-in-key-production-regions/ [Verified 13 November 2021]

Hartoyo KL, Fariyanti A, Suharno S (2018) Risk and improvement strategy of vannamei shrimp production in the Blanakan sub-district Subang Regency. *Jurnal of Sosial Ekonomi Kelautan Dan Perikanan* **13** (1), 99-110. doi: http://dx.doi.org/10.15578/jsekp.v13i1.6764

Harvey B, Soto D, Carolsfeld J, Beveridge M, Bartley DM (Eds) (2017) Planning for aquaculture diversification: the importance of climate change and other drivers. FAO technical workshop, 23–25 June 2016, FAO fisheries and aquaculture proceedings no. 47 (Food and Agriculture Organisation of the United Nations, Rome, Italy)

Hegde A (1997) Epidemiology of white spot disease of cultured shrimp in Karnataka. MFSc thesis (University of Agricultural Sciences: Bangalore, India)

Hepher B (1962) Ten years of research in fish ponds fertilization in Israel. 1. The effect of fertilization on fish yields. *Bamidgeh* **14** (2), 29-38.

Hertrampf J (2006) Quick method for crude fibre estimation. *Feed Technology* **10** (2), 29-31.

Hirasawa Y (1985) Economics of shrimp culture in Asia. In 'Proceedings of the first international conference on the culture of penaeid prawns/ shrimps' (Eds Y Taki, JH Primavara, JA Llobrera) pp. 131-150. (Aquaculture Department, Southeast Asian Fisheries Development Center (SEAFDEC): Iloilo City, Philippines)

Hirono Y (1983) Preliminary report on shrimp culture activities in Ecuador. *Journal of World Mariculture Society* **14**, 451-457. doi: https://doi.org/10.1111/j.1749-7345. 1983.tb00097.x

HLPE (2014) Sustainable fisheries and aquaculture for food security and nutrition. A report by the high-level panel of experts on food security and nutrition, Committee on World Food Security, Rome, Italy.

Available at https://www.fao.org/3/i3844e/i3844e.pdf [Verified 12 January 2022]

Holland A (1998) A study of conflict and inequity in shrimp aquaculture in Vietnam, Bangladesh and Mozambique. ARP/DFID, University of Sussex, UK.

Hollin D, Griffin WL (1985) Preliminary economics of shrimp mariculture in Texas. Paper presented at the Texas shrimp farming workshop. 19-20 November 1985, Texas. Texas Agriculture Extension Service, Corpus Christi, Texas, USA.

Holthuis LB (1980) 'FAO species catalogue.Vol.1. Shrimps and prawns of the world. An annotated catalogue of species of interest to fisheries, FAO Fisheries Synopsis (125).' (Food and Agriculture Organization of the United Nations: Rome. Italy)

Hooper DU, Dukes JS (2004) Overyielding among plant functional groups in a long-term experiment. *Ecology Letters* **7,** 95– 105.

Hoq ME, Halder GC, Begum M (1994) Experimental pond culture of tiger shrimp, *Penaeus monodon* (Fab.) with various stocking rates and supplemental feeding. *Progressive Agriculture* **5** (2), 55-61.

Hora SL (1943) Paddy cultivation cum fish culture. *Current Science* **12** (6), 169–172.

Horstkotte-Wesseler G (1999) Socioeconomics of rice-aquaculture and IPM in the Philippines: Synergies, potential and problems. ICLARM technical report 57, International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines.

Hossain M (1990) 'Green revolution in Bangladesh: Impact on growth and distribution of incomes.' (International Food Policy Research Institute: Washington DC, USA and Bangladesh Institute of Development Studies: Dhaka, Bangladesh)

Hossain MAR, Hasan MR (2017) An assessment of impacts from shrimp aquaculture in Bangladesh and prospects for improvement, FAO fisheries and aquaculture technical paper No. 618, Food and Agriculture Organization (FAO), Rome. Available at https://www.fao.org/3/i8064en/i8064en.pdf [Verified 12 January 2022]

Hossain MI, Siwar C, Mokhtar MB, Dey MM, Jaafar AH (2009) Socio-economic condition of fishermen in seasonal floodplain beels in Rajshahi district, Bangladesh. *Research Journal of Social Sciences* **4,** 74-81.

Hossain MS, Dewan S, Islam MS, Hossain SMA (1992) Survey of pond fishery resources in a village of Mymensingh district. Bangladesh. *Bangladesh Journal of Aquaculture* **14** (16), 33-37.

Hu Y, Tan B, Mai K, Ai Q, Zheng S, Cheng K (2008) Growth and body composition of juvenile white shrimp, *Litopenaeus vannamei*, fed different ratios of dietary protein to energy. *Aquacuture Nutrition* **14,** 499–506. doi: https://doi.org/10.1111/j.1365-2095.2007.00555.x

Huang HJ (1993) Factors affecting the successful culture of *Penaeus stylirostris* and *Penaeus vannamei* at an estuarine power plant site. Temperature, salinity, inherent growth variability, damselfly nymph predation, population density and distribution. PhD thesis (Texas A&M University: College Station, TX, USA)

Huang HJ, Griffin WL, Aldrich DV (1984) A preliminary economic feasibility analysis of a proposed commercial penaeid shrimp culture operation. *Journal of World Mariculture Society* **15,** 95-105.

Huang J-h, Ma Z-m, Zhou F-l, Ye L, Jiang S-g, Li S-d (2006) The growth characteristics of *Penaeus monodon* in pond-culture. *Marine Fisheries Research* **27** (1), 14-20.

Hughes B, Kirby J, Rowcliffe JM (1999) Waterbird conflicts in Britain and Ireland: Ruddy ducks *Oxyura jamaicensis*, Canada geese *Branta canadensis*, and cormorants *Phalacrocorax carbo*. *Wildfowl Journal* **50**, 77-99.

Hung LT, Quy OM (2013) On farm feeding and feed management in whiteleg shrimp (*Litopenaeus vannamei*) farming in Viet Nam. In 'On-farm feeding and feed management in aquaculture'. (Eds MR Hasan, MB New) pp. 337–357. FAO Fisheries and aquaculture technical paper no. 583, Food and Agriculture Organization (FAO), Rome.

Hunter B (1996) Nutritional complementation of natural and applied feeds in intensive and semi-intensive shrimp ponds. In 'Proceedings of the 3rd Roche Aquaculture Centre conference on nutrition and disease'. 12 December 1996, Bangkok, Thailand (Ed. B Hunter), pp. 82–96. (Roche Aquaculture Centre: Thailand)

Hunter B, Pruder G, Wyban J (1987) Biochemical composition of pond biota, shrimp ingesta, and relative growth of *Penaeus vannamei* in earthen ponds. *Journal of the World Aquaculture Society* **18** (3), 162-174.

Hurlbert SH (1971) The nonconcept of species diversity: A critique and alternative parameters. *Ecology***, 52,** 577-586.

Hussan A, Choudhury TG, Vinay TN, Gupta SK (2016) Common problems in aquaculture and their preventive measures. *Aquaculture times* 2(5), 6-9.

Ibrahim KH (1957) Bionomics of forage fishes: observations on the fecundity of three common species of minor barbels. *Journal of Bombay Natural History Society* **54** (4), 826-834.

ICAR (2013) 'Handbook of fisheries and aquaculture. (Indian Council of Agriculture Research (ICAR): New Delhi, India).

Ignatius CA (1995) Ecological and productivity studies of prawn farms in Central Kerala. PhD thesis (Cochin University of Science and Technology: Kochi, India)

INFOFISH (2011) 'Handbook on organic aquaculture.' CFC/FAO/INFOFISH project on organic aquaculture in Myanmar, Thailand and Malaysia. (INFOFISH: Malaysia). Available at https://docplayer.net/36794349-Handbook-on-organic-aquaculture-cfc-fao-infofish-project-on-organic-aquaculture-in-myanmar-thailand-and-malaysia [Verified 12 July 2021]

Irz X, Stevenson JR, Tanoy A, Villarante P, Morissens P (2007) The equity and poverty impacts of aquaculture: Insights from the Philippines. *Development Policy Review* **25** (4), 495-516.

Islam MS (1999) Social and institutional aspects of shrimp-rice farming in Bangladesh. In 'Proceedings of the workshop on economic, social and environmental implications of shrimp-rice integrated farming system in Bangladesh'. 26 December 1999, BIDS, Dhaka (Bangladesh Institute of Development Studies: Dhaka)

Islam MS, Islam MS, Wahab MA, Miah AA, Kamal AHMM (2003) Impacts of shrimp farming on the socioeconomic and environmental conditions in the coastal regions of Bangladesh. *Pakistan Journal of Biological Sciences* **6**, 2058-2067.

Islam MS, Wahab MA (2000) A PRA report of socioeconomic and environmental impact of shrimp farming in Bangladesh. NORAD Project, Bangladesh Agricultural University, Mymensingh, Bangladesh.

IUCN (2018) The IUCN red list of threatened species version 2018-2. Available at https://www.iucnredlist.org/ [Verified 12 July 2021]

Iyer MS (1989) Studies on macro, meso and micromorphology and clay mineralogy of the acid sulphate soils of Kerala. PhD thesis (Kerala Agricultural University: Thrissur, Kerala, India)

Iyer R, Gulati L, Nair R, Hartmann WD (1993) Socio-economic baseline survey of five reservoir fishing communities. Indo-German Reservoir Fisheries Development Project Malampuzha, Palakkad District, Kerala, India.

Jackson CJ, Burford MA (2003) The effects of temperature and salinity on growth and survival of larval shrimp *Penaeus semisulcatus* (Decapoda: Penaeoidea). *Journal of Crustacean Biology* **23** (4), 819-826. doi: https://doi.org/10.1651/C-2379

Jackson CJ, Wang Y-G (1998) Modelling growth rate of *Penaeus monodon* Fabricius in intensively managed ponds: effects of temperature, pond age and stocking density. *Aquaculture Research* **29** (1), 27-36.

Jagadeesh T (2015) An economic analysis of shrimp farming practices in Prakasam district, Andhra Pradesh. MFSc thesis (Tamil Nadu Fisheries University: Nagapattinam, Tamil Nadu, India).

James PSBR (1999) Shrimp farming development in India – an overview of environmental, socio-economic, legal and other implications. *Aquaculture Magazine* (online), December 1999. http://www.ioa.com/~aquamag/html/featart.html.

Jana P, Sahu NP, Sardar P, Shamna N, Varghese T, Deo AD, Harikrishna V, Paul M, Panmei H, Gupta G, Nanda C, Krishna G (2021) Dietary protein requirement of white shrimp, *Penaeus vannamei* (Boone, 1931) juveniles, reared in inland groundwater of medium salinity *Aquaculture Research* **52**(6), 2501-2517. doi: https://doi.org/10.1111/are.15100

Janakiram P, Loka J, Rokkam M (2011) Survival, growth and production of *Penaeus monodon* in modified- extensive and semi-intensive culture systems of Andhra Pradesh, India. *Asian Journal of Experimental Sciences* **25** (2), 53-61.

Jayachandran KV (1987) Palaemonid prawn resources in the estuaries of Kerala with description of a new species of *Macrobrachium*. In 'Proceedings of the national seminar on estuarine management' Trivandrum. (Ed. NB Nair) pp. 367-372. (State Committee on Science, Technology and Environment, Government of Kerala: Trivandrum, India)

Jayachandran PR, Nandan SB, Sreedevi OK (2012) Water quality variation and nutrient characteristics of Kodungallur-Azhikode Estuary, Kerala, India. *Indian Journal of Geo- Marine Sciences,* **41** (2), 180-187.

Jayagopal P, Sathiadhas R (1993) Productivity and profitability of prawn farming practices. In 'Mariculture research under the postgraduate programme in mariculture' Part 4 CMFRI special publication no. 55. (Eds K Rengarajan, A Noble, P Rohit, V Kripa, N Sridhar, M Zakhriah) pp. 16-25. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Jayan PR, Sathyanathan N (2010) Overview of farming practices in the water-logged areas of Kerala, India. *International Journal of Agricultural and Biological Engineering* **3 (**4), 1-16.

Jayanthi M, Thirumurthy S, Muralidhar M, Ravichandran P (2018) Impact of shrimp aquaculture development on important ecosystems in India. *Global Environmental Change* **52,** 10-21.

Jayaprakas V, Sambhu C (1988) Growth characteristics of white prawn *Penaeus indicus* (Decapoda-Crustacea) under dietary administration of protein hormones. *Indian Journal of Geo-Marine Sciences* **27** (3), 389-395.

Jayaram KC (1999) 'The freshwater fishes of the Indian region.' (Narendra Publishing House: Delhi, India)

Jayaraman R (1997) Carp culture in Thanjavur district, Tamil Nadu, India: An economic analysis. *Asian Fisheries Science* **9**, 275-288.

Jayaraman RK, Marx K, Sunderraj V (1994) Economics of improved extensive shrimp farming in Vedarnyam. In 'Proceedings of national seminar on aquaculture for 2000 AD'. (Madurai Kamaraj University: Madurai, India)

Jayasankar P (2018) Present status of freshwater aquaculture in India - A review. *Indian Journal of Fisheries* **65** (4), 157-165. doi:10.21077/ijf.2018.65.4.81300-20

Jayasinghe JMPK, Gamage DGND, Jayasinghe JMHA (2019) Combating climate change impacts for shrimp aquaculture through adaptations: Sri Lankan perspective. In 'Sustainable solutions for food security.' (Eds A Sarkar, SR Sensarma, GW VanLoon) pp. 287- 309. (Springer Nature: Switzerland AG)

Jena JK, George G (2020) Climate Change impacts on fisheries and aquatic systems in Indian Ocean region. In 'Book of abstracts, Climfishcon 2020: International conference on impact of climate change on hydrological cycle, ecosystem, fisheries and food security'. 11-14

February 2020, Cochin. (Eds BM Kurup, MR Boopendranath, M Harikrishnan, AV Shibu, VPAncy, NM Sekharan, S Sabu, M Sileesh, R Radhika, HS Harisankar, OK Sreedevi, S Sreelakshmi, S Reshma, P Anju, Sariga) pp. 12-17. (Cochin University of Science and Technology: Cochin, India)

Jha BC (1997) Salient ecological features of mans and chaurs of North Bihar and their fisheries. In ‘Fisheries enhancement in small reservoirs and lakes. Bulletin no. 75. (Eds. V Sugunan, M Sinha) pp. 167-174. (Central Inland Capture Fisheries Research Institute: Barrackpore, India)

Jha UM (2009) ‘Economics of fish farming in flood-prone areas of Bihar with special reference to Koshi River System.’ Chankya Education Trust: Bhagalpur, India). Available at https://niti.gov.in/planningcommission.gov.in/docs/reports/sereport/ser/ser_fish1703.pdf [Verified 11 May 2021]

Jhingran AG, Ghosh A (1987) Aquafarming in coastal India. *Journal of Indian Society for Coastal Agriculture Research* **5** (1), 1-8.

Jhingran VG (1991) 'Fish and Fisheries of India.' (Hindustan Publishing Company, New Delhi, India)

Johnson KH, Vogt KA, Clark HJ, Schmitz OJ, Vogt DJ (1996) Biodiversity and the productivity and stability of ecosystems. *Trends in Ecology & Evolution* **11**(9), 372-7. doi: 10.1016/0169-5347(96) 10040-9

Johnson SK (1995) ‘Handbook of shrimp diseases. (Department of Wildlife and Fisheries Sciences, Texas A&M University: Austin, Texas, USA). Available at https://nsgl.gso.uri.edu/tamu/tamuh95001.pdf [Verified 1 May 2021]

Johny PK (1993) Marketing channels and price spread for aquaculture products. MSc dissertation (Cochin University of Science and Technology: Kochi, India)

Jory DE (2016) The proper management of commercial shrimp feeds, Part 2. Responsible Seafood Advocate, Global Seafood Alliance, 19 December 2016. Available at https://www.globalseafood.org/advocate/the-proper-management-of-commercial-shrimp-feeds-part-2 [Verified 23 October 2021]

Jory DE (2018) Current production, challenges and the future of shrimp farming. Responsible Seafood Advocate, Global Seafood Alliance, 18 June 2018. Available at https://www.globalseafood.org/advocate/current-production-challenges-and-the-future-of-shrimp-farming [Verified 23 October 2021]

Jose MM, Mathew PM, Jose S (1987) Feasibility and economic viability of selective culture of *Penaeus indicus* in pokkali fields. In 'Proceedings of national seminar on estuarine management'. Trivandrum. (Ed. NB Nair) pp.379-381. (State Committee on Science, Technology and Environment, Government of Kerala: Thiruvananthapuram, India)

Jose RV, Thomas PM (1998) Socio-economic profile of inland fishermen and problems and prospects of inland fishing in Kuttanad region. Kerala

Research Programme on Local Level Development (KRPLLD), Thiruvananthapuram, India

Jose S, Nair KGR, Mathew PT, Stephen J, Madhavan P (2002) Modified extensive culture of *Penaeus monodon* using indigenous feed. *Fishery Technology* **39** (1), 62-66.

Joseph EA (2016) Rice cultivation in saline tracts of Kerala: An overview. *International Journal of Fisheries and Aquatic Studies* **4** (4),355-358.

Joseph J (2004) Economic analysis of externalities in coastal mariculture. PhD thesis (Central Institute of Fisheries Education (CIFE): Mumbai, India)

Joseph J, Sathiadhas R (2006) Economics of selected coastal aquaculture practices in Kerala, India. In 'Proceedings of Sustain Fish 2005-International symposium on improved sustainability of fish production systems and appropriate technologies for utilization' (Eds BM Kurup, K Ravindran) pp. 802-811. (School of Industrial Fisheries, Cochin University of Science and Technology: Cochin, India)

Joseph KS (1978) Notes on *Macrobrachium rosenbergii* (de Man), the giant freshwater prawn - its larval rearing and culture with Indian and exotic carps. Paper presented in the first national symposium on shrimp farming. 16-18 August 1978, Bombay. Marine Products Export Development Authority, Cochin, India.

Joseph KS, Sadanandan R (1976) Notes on larval rearing experiments of *Macrobrachium rosenbergii* (De Man) in captivity using prepared feed. *Bulletin of the Department of Fisheries*, Kerala **1** (1), 37-39.

Joseph MM, Kumar CSR, Renjith KR, Kumar TRG, Chandramohanakumar N (2011) Phosphorus fractions in the surface sediments of three mangrove systems of south west coast of India. *Environmental Earth Sciences* **62,** 1209-1218. doi: 10.1007/s12665-010-0609-0

Jost L (2006) Entropy and diversity. *Oikos*,**113**, 363–375. doi: https://doi.org/ 10.1111/j.2006.0030-1299.14714.x

Joy A (2013) Development impact on pokkali fields: A case of international container transhipment terminal, Vallarpadam, Kochi. *IOSR Journal of Humanities and Social Science* **10** (5), 1-5.

Kabir MH, Eva IJ (2014) Ecological consequences of shrimp farming in Southwestern Satkhira district of Bangladesh. *Austin Journal of Earth Science* **1,** 1-7.

Kanazawa A, Teshima S, Tokiwa S (1977) Nutritional requirements of prawn – VII. Effect of dietary lipids on growth. *Bulletin of the Japanese Society of Scientific Fisheries* **43**, 894-856.

Kanittha P (1987) 'An economic analysis of giant freshwater prawn pond culture in Thailand.' (University Pertanian: Malaysia)

Kannappan T (2015) Studies on the physico- chemical and biological parameters of Manakudy estuary, Kanyakumari District, South West Coast of India, Tamil Nadu. PhD thesis (Madurai Kamaraj University: Madurai, India)

Karim MR (2003) Present status and strategy for future development of shrimp farming in Bangladesh. In 'Environmental and socioeconomic impacts of shrimp farming in Bangladesh' Technical proceedings of the BAU-NORAD Workshop. (Ed. MA Wahab) pp. 1-8. (BAU-NORAD: Dhaka, Bangladesh)

Kartha KNR, Nair PK (1979) 'Chemmeen kettu' (in Malayalam) (Krishi Vigyan Kendra, Central Marine Fisheries Research Institute (CMFRI): Cochin)

Karunasagar I, Otta SK, Karunasagar I (1998) Disease problems affecting cultured penaeid shrimp in India. *Fish Pathology* **33** (4), 413-419.

Karuppasamy A, Mathivanan V, Selvisabhanayakam (2013). Comparative growth analysis of *Litopenaeus vannamei* in different stocking density at different farms of the Kottakudi Estuary, South East Coast of India. *International Journal of Fisheries and Aquatic Studies* **1** (2), 40-44.

Kasperson RE, Kasperson JX, Dow K (2001) Vulnerability, equity, and global environmental change. In 'Global Environmental Risk' (Eds JX Kasperson, RE Kasperson) pp. 247-272. (Earthscan: London, UK)

Katiha PK (2000) 'Freshwater aquaculture in India: Status, potential and constraints. In 'Proceedings of the aquaculture development in India: Problems and prospects workshop' (Ed. M Krishnan, PS Birthal), pp. 98–108. (National Centre for Agricultural Economics and Policy Research: New Delhi, India)

Katiha PK (2002) Socio-economic aspects of culture-based fisheries. In 'Culture based fisheries for inland fisheries development.' Book no. 113. (Eds. VV Sugunan, BC Jha, MK Das) pp. 155-164. (Central Inland Capture Fisheries Research Institute (CICFRI): Barrackpore, India)

Katiha PK, Jena JK, Pillai NGK, Chakraborty C, Dey MM (2005) Inland aquaculture in India: Past trend, present status and future prospects. *Aquaculture Economics & Management* **9** (1), 237-264.

Keller T (1995) Food of cormorants *Phalacrocora carbo sinensis* wintering In Bavaria, Southern Germany. *Ardea* **83**(1), 185-192.

Kesteven GL, Job TL (1957) Shrimp culture in Asia and the Far East: a preliminary review. *Proceedings of the Gulf and Caribbean Fisheries Institute* **10,** 49-68.

Kevan SD, Weseloh DV (1992) A survey on bird predation at Ontario trout farms. *Ontario Aquaculture Association Newsletter* **1** (7), 1-3.

Khan YSA, Hossain MS (1996) Impact of shrimp culture on the coastal environment of Bangladesh. *International Journal of Ecology and Environmental Sciences* **22,** 145–158.

Khannapa A (1977) The effect of various protein levels on growth and survival rates of *Penaeus monodon* Fabricius. *SEAFDEC Aquaculture Department Quarterly Research Report* **1** (1), 24-28.

Khannapa A (1979) The effects of various protein levels on the growth and survival rates of *Penaeus monodon*. *Thai Fisheries Gazette* **31**, 51-60.

Khatun S, Adhikary RK, Rahman M, Sikder MNA, Hossain MB (2013) Socioeconomic status of pond fish farmers of Charbata, Noakhali, Bangladesh. *International Journal of Life Sciences Biotechnology and Pharma Research* **2** (1), 356-365.

Khuman ON, Singh YJ (2019) Fish farmers' perceived constraints and suggestions towards the adoption of scientific fish farming of pengba (*Osteobrama belangeri*) in the valleys of Manipur. *International Journal of Current Microbiology and Applied Sciences* **8** (3), 2489-2494.

Knight JDM (2010) On a record of *Puntius gelius* (Hamilton, 1822) (Teleostei: Cypriniformes: Cyprinidae) from Tamil Nadu. *Journal of Threatened Taxa* **2** (3), 786-787. doi :https://doi.org/10.11609/JoTT.o2298.786-7.

Knight JDM, Ramadevi KR (2010) Species persistence: a re-look at the freshwater fish fauna of Chennai, India. *Journal of Threatened Taxa,* **2** 12), 1334-1337. doi: https://doi.org/10.11609/JoTT.o2519.1334-7

Kongkeo H (1990) Pond management and operation. In 'Technical and economic aspects of shrimp farming. Proceedings of the Aquatec '90 Conference, Kuala Lumpur, Malaysia'. (Eds MB New, H de Saram, T Singh) pp. 56-65. (INFOFISH International: Malaysia)

Kongkeo H (1995) How Thailand made it to the top. *INFOFISH International* **1,** 25-31.

Kontara EK (1988) Shrimp culture management techniques. In 'Report of the training course on shrimp culture.' Jepara, Indonesia 2–19 December 1987. ASEAN/SF/88/GEN/3 August 1988 (ASEAN/UNDP/FAO Regional Small-Scale Coastal Fisheries Development Project: Manila, Philippines). Available at http://www.fao.org/3/AC418E/AC418E03.htm#ch2.4 [Verified 12 September 2021]

Koshy PM (2013) Environmental stress studies with reference to the pollution in the Vattakayal Backwaters near the industrial area of Chavara, Kollam District, Kerala. PhD thesis (Mahatma Gandhi University: Kottayam, India)

Koteswari N, Immanual S, Cyril ARL, Viswanatha BS (2014) Impact of aqua societies on shrimp farming in Andhra Pradesh, India. *Fishery Technology* **51**(2), 130-135.

Kotler PT (1994) 'Marketing management: analysis, planning, implementation and control'. (Trentice Hall: Delhi, India)

Kovari J (1984) Considerations in the selection of sites for aquaculture. In 'Inland Aquaculture Engineering.' (Ed. TVR Pillay) pp. 3-8. (Food and Agriculture Organization of the United Nations: Rome, Italy)

Krishnaiah NV (1989) A study on effectiveness of short duration training programme conducted by FFDA in Andhra Pradesh. MSc (Ag) thesis (Acharya NG Ranga Agricultural University: Hyderabad, India)

Krishnakumar K, Ali A, Pereira B, Raghavan R (2011) Unregulated aquaculture and invasive alien species: a case study of the African catfish *Clarias gariepinus* in Vembanad Lake (Ramsar Wetland), Kerala, India. *Journal* *of Threatened Taxa*, **3** (5), pp. 1737-1744. doi: https://doi.org/10.11609/JoTT.o2378.1737-44

Krishnakumar K, Raghavan R, Prasad G, Bijukumar A, Sekharan NM, Pereira B, Ali A (2009) When pets become pests–exotic aquarium fishes and biological invasions in Kerala, India. *Current Science* **97**, 474-476.

Krishnakumar K, Rajan PD (2012) Fish and fisheries in Vembanad Lake. Consolidated report of Vembanad fish count 2008- 2011, Community Environment Resource Centre (CERC), Ashoka Trust for Research in Ecology and the Environment (ATREE), Alapuzha.

Krishnamoorthy R, Mohamed EHS., Rao TS, Venugopalanj VP, Hameed PS (2008) Temperature effect on behaviour, oxygen consumption, ammonia excretion and tolerance limit of the post larvae of shrimp *Penaeus indicus*. *Journal of Environmental Science and Engineering* **50** (1), 29-32.

Krishnan M, Birthal PS, Ponnusamy K, Kumaran M, Singh H (2001). An economic evaluation of brackishwater aquacultural systems in India. (Central Institute of Brackishwater Aquaculture (CIBA): Chennai, India and National Center for Agricultural Economics and Policy Research, New Delhi, India.

Krishnan M, Ravisankar T, Gupta PSP, Vimala, DD, Gopinathan K (1995) The economics of production of brackishwater in Krishna District of Andhra Pradesh. *Seafood Export Journal* **26** (8), 19-26.

Krishnan Y, Josy JM, Paul N, Biju S, Jacob JP (2020) A Survey on the species diversity and water quality parameters of selected site in Vembanad Lake. *Journal of Fisheries Sciences.com* **14** (6), 1-5.

Krishnani KK, Gupta BP, Muralidhar M, Saraswathy R, Pillai SM, Ponnusamy K, Nagavel A (2011) Soil and water characteristics of traditional paddy and shrimp fields of Kerala. *Indian Journal of Fisheries* **58** (4), 71-77.

Krishnani KK, Joseph KO, Muralidhar M, Gupta BP, Nagavel A (2001) Water quality management in brackishwater aquaculture. In 'Water quality management in brackishwater aquaculture.' CIBA special publication no. 13. pp. 18-29. (Central Institute of Brackishwater Aquaculture (CIBA): Chennai, India)

Krishnani KK, Kathiravan V, Natarajan M, Kailasam M, Pillai SM (2010) Diversity of sulphur- oxidizing bacteria in green water system of coastal aquaculture. *Applied Biochemistry and Biotechnology* **162,** 1225-1237.

Krishnani KK, Rajendran KV, Joseph KO, Gupta BP (1997) Soil and water characteristics of shrimp ponds affected with viral disease. *Journal of Inland Fisheries Society of India* **29** (1), 37-42.

Kula E (2004) Estimation of a social rate of interest for India. *Journal of Agricultural Economics* **55** (1), 90-95.

Kumar D (1999) 'Trickle Down System (TDS) of aquaculture extension for rural development' RAP Publication 1999/23. (Regional Office for Asia and the Pacific, Food and Agriculture Organization of the United

Nations: Bangkok, Thailand). Available at https://www.fao.org/3/x6946e/x6946e.pdf [Verified 23 October 2021].

Kumar D and Ananthan PS (2009) Extension strategies for sustainable development of fisheries and aquaculture in India. Paper presented at national workshop on extension education in fisheries and animal husbandry. 4-5 September 2009. Bidar University, Karnataka.

Kumar G, Engle C, Tucker C (2016) Costs and risk of catfish split-pond systems. *Journal of the World Aquaculture Society*, **47** (3), 327-340.

Kumar K (1997) Employment generation through development of reservoir fisheries in Himachal Pradesh. *Fishing Chimes* **17** (3), 17-18.

Kumar MK (1996) Communication behaviour of fish farmers in Tamil Nadu. PhD thesis (Central Institute of Fisheries Education (CIFE): Mumbai, India)

Kumar P, Dey MM, Paraguas FJ (2016) Fish supply projections by production environments and species types in India. *Agricultural Economics Research Review* **19**, 327-351.

Kumar P, Khar S, Sharma R, Choudhary P, Himabindu KV, Sharma S, Sharma SK, Jagmohan S (2015) Identifying socio-economic features of fish farmers. *Agro Economist* **2**(1), 29-34

Kumar PR, Raman NN, Pranav P, Pamanna D, Amin A, Sumanjali SS (2017) The physicochemical characteristics of Vembanad backwaters at Eramalloor region, Alappuzha district, Kerala, India. *International Journal of Fisheries and Aquatic Studies*. **5** (5), 258-262.

Kumar RS (1995) Macro benthos in the mangrove ecosystem of Cochin backwaters, Kerala (Southwest coast of India). *Indian Journal of Marine Sciences*, **24,** 56-61.

Kumar RS, Antony A (1994) Preliminary studies on the polychaete fauna of the mangrove areas of Cochin. In 'Proceedings of the 6th Kerala Science Congress' pp. 74-77. (State Committee on Science, Technology and Environment: Thiruvananthapuram, India)

Kumar V (1984) Economic analysis of fish farming financed by commercial banks in Sultanpur District (UP). MSc dissertation (Gobind Ballab Pant University of Agriculture and Technology: Pantnagar, Uttarakhand, India)

Kumaraguru VKP, Ramesh S, Balasubramanian T (2006) Dietary value of different vegetable oil in black tiger shrimp Penaeus monodon in the presence and absence of soy lecithin supplementation: effect on growth, nutrient digestibility and body composition. *Aquaculture* **250** (1), 317–327.

Kumaran M (2006) Farm opinion leaders and transfer of aquaculture technology. *Indian Journal of Extension Education* **37** (1&2), 31-35.

Kumaran M, Kalaimani N (2005) 'Information utilisation and extension needs assessment in shrimp farming in Tamil Nadu.' (Central Institute of Brackishwater Aquaculture (CIBA): Chennai, India)

Kumaran M, Ponnusamy K, Kalaimani N (2001) Diffusion and adoption of shrimp farming technology. Paper presented in the international symposium on fish for nutritional security in the 21st century. 4-6th December 2001, CIFE, Mumbai. Central Institute of Fisheries Education (CIFE), Mumbai, India.

Kumaran M, Ponnusamy K, Kalaimani N (2003a) Diffusion and adoption of shrimp farming technologies. *Aquaculture Asia* **8** (2), 20-23.

Kumaran M, Ponnusamy K, Krishnan M (2004) Utilizationof information sources by shrimp farmers. *Indian Journal of Extension Education* **40** (1-2), 63-66.

Kumaran M, Ravichandran P, Gupta BP, Nagavel A (2003b) Shrimp farming practices and its socio-economic consequences in East Godavari district, Andhra Pradesh, India- A case study. *Aquaculture Asia* **8** (3), 48-52.

Kumaran M, Ravisankar T, Anand PR, Vimala DD, Balasubramanian CP (2017) Knowledge level of shrimp farmers on better management practices (BMPs) of *Litopenaeus vannamei* farming: A comparative assessment of East and West coast of India. *Indian Journal of Fisheries* **64** (3), 93-99.

Kumlu M, Jones DA (1995) Salinity tolerance of hatchery-reared postlarvae of Penaeus indicus H. Milne Edwards originating from India. *Aquaculture* **130** (2-3), 287-296. https://doi.org/10.1016/0044-8486(94)00319-J

Kumlu M, Turkmen S, Kumlu M (2010) Thermal tolerance of *Litopenaeus vannamei* (Crustacea: Penaeidae) acclimated to four temperatures. *Journal of Thermal Biology*, **35**(6), 305-308.

Kungvankij P, Tiro JrLB, Pudadera JrBJ, Potestas IO, Chua TE (1986) 'An improved traditional shrimp culture technique for increasing pond yield.'

NACA technology Series, NACA/WP/85/17 (NACA Regional Lead Centre:Philippines)

Kureshy N, Davis DA (2002) Protein requirement for maintenance and maximum weight gain for the Pacific white shrimp, *Litopenaeus vannamei*. *Aquaculture* **204,** 125–43.

Kurien CV, Sebastian VO (1982) 'Prawns and prawn fisheries of India.' 2nd edn. (Hindustan Publishing Corporation (India), Delhi, India).

Kurien CV, Sebastian VO, Gopakumar G, Pillai VN (2002) ‘Prawns and prawn fisheries of India.’ 5th edn. (Hindustan Publishing Corporation (India), New Delhi, India).

Kurup BM (1982) Studies on the systematics and biology of fishes of the Vembanad Lake. PhD thesis (University of Cochin: Cochin, India)

Kurup BM, Harikrishnan M, Shibu AV, Sileesh M (2020) Global warming: Impact on fisheries and aquaculture- a threat to food security. In ‘Souvenir. Climfishcon 2020: International conference on impact of climate change on hydrological cycle, ecosystem, fisheries and food security’. 11-14 February 2020, Cochin. (Eds BM Kurup, MR Boopendranath, M Harikrishnan, AV Shibu, VP Ancy, NM Sekharan, S

Sabu, M Sileesh, R Radhika, HS Harisankar, OK Sreedevi, S Sreelakshmi, S Reshma, P Anju, Sariga) pp. 23-33. (Cochin University of Science and Technology: Cochin, India)

Kurup BM, Nair KKC, Unnithan KA, Vijayan KK, Shylaraj KS, Padmakumar KG, Rajendran G, Gopalan UK, Sahadevan P, Ajayan S, Sairabanu, KA, Saju MS (2013) Report of the expert committee for studying sustainable aquaculture policies in pokkali and kole lands in Kerala. Department of Fisheries, Government of Kerala, Thiruvananthapuram, Kerala, India.

Kurup BM, Ranjeet K (2002) Integration of freshwater prawn culture with rice farming in Kuttanad, India. *Naga, World Fish Center Quarterly* **25** (3 & 4), 16-19.

Kurup BM, Ranjeet K (2005) Multiple stocking for enhancing survival production and marketable yield structure of *Macrobrachium rosenbergii* (de Man). *Indian Journal of Fisheries* **52**(1), 37-46.

Kurup BM, Samuel CT (1983) Systematics and distribution of the fishes of the family Leignathidae (Pisces) of the Vembanad Lake, Kerala, S. India. *Records of the Zoological Survey of India* **80,** 387-411.

Kurup BM, Samuel CT (1985) Fish and fishery resources of Vembanad Lake. In 'Harvest and post-harvest technology of fish'. (Eds K Ravindran, NU Nair, PA Perigreen, PA Madhavan, GG Pillai, P Panicker, AM Thomas) pp. 77-82. (Society of Fisheries Technologists: Cochin, India)

Kurup BM, Samuel CT (1987) Ecology and fish distribution of a tropical estuary. In 'Proceedings of national seminar on estuarine management'. Trivandrum. (Ed. NB Nair) pp. 339-349. (State Committee on Science, Technology and Environment, Government of Kerala: Trivandrum)

Kurup BM, Sankaran TM, Rabindranath P, Sebastian MJ (1993a) Seasonal and spatial variations in fishing intensity and gear-wise landings of the Vembanad Lake. *Fishery Technology* **30,** 15-20.

Kurup BM, Sebastian MJ, Sankaran TM, Rabindranath P (1989) Exploited fishery resources of the Vembanad Lake, Final report presented to Kuttanad Water Balance Study Project.

Kurup BM, Sebastian MJ, Sankaran TM, Rabindranath P (1992) Exploited fishery resources of the Vembanad Lake: fishery based on pokkali fields and polders. *Fishery Technology* **29**, 21-26.

Kurup BM, Sebastian MJ, Sankaran TM, Rabindranath P (1993b) Exploited fishery resources of the Vembanad Lake. *Indian Journal of Fisheries* **40** (4), 199-206.

Kurup PG (1971) Silting in Cochin harbour. *Sea Food Export Journal* **3** (1): 111-113.

Kutty MN (1999) Aquaculture development in India from a global perspective. *Current Science* (Special Section – Fisheries & Technology), **76** (3), 333-341.

Kutty MN, Nair CM, Appukkuttan KK, Bhat V, Sobhanakumar K, Ramesan KK, Sobhana VS (2008) Report of task force on inland fisheries and aquaculture. Department of Fisheries, Government of Kerala, Thiruvananthapuram, Kerala, India.

Kutty MN, Nair CM, Appukuttan KK, Ghosh DS, Saseendran VV, Bava AK, Jayaseelan AP, Dinakaran V, Ummer O, Lawrence P, Salin KR, Rajendran G, Sahadevan P, Lathy KM, Kumar SS (2011) Report of expert committee on formulation of fisheries leasing policy. Department of Fisheries, Government of Kerala, Thiruvananthapuram, Kerala, India.

Kuttyamma VJ (1974) Observations on the food and feeding habits of some penaeid prawns of Cochin area. *Journal of Marine Biological Association of India* **15** (1), 189-194.

Lai-Fa Z, Boyd CE (1988) Nightly aeration to increase the efficiency of channel catfish production. *The Progressive Fish-Culturist* **50,** 237–242. doi: 10.1577/1548-8640(1988)050<0237: NATITE>2.3.CO;2

Lakshmi S (1978) On the hydrology of the prawn culture fields at Narakkal. CMFRI bulletin No. 28. (Central Marine Fisheries Research Institute (CMFRI): Cochin)

Laluraj CM, Padma P, Sujatha CH, Nair SM, Kumar NC, Chacko J (2002) Base line studies on the chemical constitutes of Kayamkulam Estuary near to the newly commissioned NTPC power station. *Indian Journal of Environmental Protection* **22** (7), 721- 731.

Lasdon LS, Waren AD, Jain A, Ratner R (1978) Design and testing of a generalized reduced gradient code for nonlinear programming. *ACM Transactions on Mathematical Software* **4** (1), 34-50.

Laureatte S, Sureshbabu PP, Venugopal G, Biradar RS, Narashimacharyulu V, Das PM (2012) Comparative evaluation of two farming practices of *Penaeus monodon* (Fabricius, 1798) in low saline waters of Andhra Pradesh, India. *Journal of the Marine Biological Association of India* **54,** 20-25. doi: 10.6024/jmbai.2012.54.1.01683-03

Lavilla-Pitogo CR, Lio-Po GD, Cruz-Lacierda ER, Alapide-Tendencia EV, De la Peña LD (2000). 'Diseases of penaeid shrimps in the Philippines'. 2^{nd} edn. (Aquaculture Department, Southeast Asian Fisheries Development Center (SEAFDEC): Iloilo City, Philippines)

Lawrence AL (1985) Marine shrimp culture in the Western Hemisphere. In 'Proceedings of the second Australian national prawn seminar'. 22- 26 October 1984, Kooralbyn, Queensland, Australia (Eds PC Rothlisberg, BJ Hill, DJ Staples) pp. 327-336. (Cleveland: Queensland, Australia)

Lawrence AL, Huner JV (1987). Penaeid shrimp culture in the United States: A brief overview stressing species, seed production and grow out. In 'Reproduction, maturation and seed production of culture species.' NOAA technical report, National Marine Fisheries Service, 47 (Ed. CJ Sindermann) pp. 31-41. (United States Department of Commerce: USA)

Lawrence AL, Lee PG (1997) Research in the Americas. In 'Crustacean nutrition.' Vol. 6. (Eds LR D'Abramo, DE Conklin, DM Akiyama) pp. 566–587. (World Aquaculture Society: Baton Rouge, USA)

Lawrence AL, McVey JP, Huner JV (1985) Penaeid shrimp culture. In 'Crustacean and Mollusk Aquaculture in the United States.' (Eds JV Huner, EE Brown) pp. 127-157. (AVI Pubishing Company Inc.: Westoprt, Connecticut, USA)

Lazarus S, Muthu MS, Nandakumaran K, Ali SA (1988) Experimental field culture of white prawn, *Penaeus indicus*, in the polyethylene film - lined ponds using pelletised feed. *Indian Journal of Fisheries* **35** (3), 171 - 177.

Lee C, Lee KJ (2018) Dietary protein requirement of Pacific white shrimp *Litopenaeus vannamei* in three different growth stages. *Fisheries and Aquatic Science*, **21** (1), 30-36. doi: https://doi.org/10.1186/s41240-018-0105-0

Lee DL (1971) Studies on the protein utilisation related to growth in *Penaeus monodon*. *Aquaculture* **1,** 1-13.

Leinster T, Cobbold CA (2012) Measuring diversity: the importance of species similarity. *Ecology* **93,** 477–489. doi: 10.1890/10-2402.1

Leiros MC, Trasar-Cepeda C, Seoane S, Gil-Sotres F (1999) Dependence of mineralization of soil organic matter on temperature and moisture. *Soil Biology and Biochemistry* **31,** 327-335.

Lemos D, Phan VN, Alvarez G (2001) Growth, oxygen consumption, ammonia-N excretion, biochemical composition and energy content of *Farfantepenaeus paulensis* Pérez-Farfante (Crustacea, Decapoda, Penaeidae) early postlarvae in different salinities. *Journal of Experimental Marine Biology and Ecology* **261,** 55-74. doi: 10.1016/s0022-0981(01)00260-x

Lester LJ, Pante MJR (1992) Penaeid temperature and salinity responses. In 'Marine shrimp culture: Principles and practices.' (Eds AW Fast, LJ Lester) pp 515-534 (Elsevier Science Publishers BV: Amsterdam)

Leung PS, Engle CR (Eds.) (2006) ‘Shrimp culture: economics, market and trade.’ (Blackwell Publishing: Ames, USA).

Leung PS, Sharma KR (Eds) (2000) ‘Economics and management of shrimp and carp farming in Asia: A collection of papers based on the ABD/NACA Farm performance survey.’ (Network of Aquaculture Centers in Asia-Pacific (NACA): Bangkok, Thailand)

Leung PS, Tran LT, Fast AW (2000) A logistic regression of risk factors for disease occurrence on Asian shrimp farms. *Diseases of Aquatic Organisms* **41,** 65-76. doi: 10.3354/dao041065

Li XQ, Chai XQ, Liu DY, Chowdhury MAK, Leng XJ (2015) Effects of temperature and feed processing on protease activity and dietary protease on growths of white shrimp, *Litopenaeus vannamei*, and tilapia, *Oreochromis niloticus* x *O. aureus*. *Aquaculture Nutrition* **22**(6). doi: https://doi.org/10.1111/anu.12330

Liao IC (1977) A culture study on grass prawn *Penaeus monodon* in Taiwan – the patterns, the problems and prospects. *Journal of Fisheries Society of Taiwan* **5**, 11-29.

Liao IC (1981) Status and problems of grass prawn culture in Taiwan. Paper presented in the ROC- Japan symposium on mariculture. 13-24 December 1981, Taipei, ROC.

Liao IC (1992) Penaeid larviculture: Taiwanese method. In 'Marine shrimp culture: Principles and practices.' (Eds AW Fast, LJ Lester) pp. 193-215. (Elsevier Science Publishers BV: Amsterdam)

Liao IC, Huang TL (1972) Experiments on the propagation and culture of prawns in Taiwan. In 'Coastal aquaculture in the Indo- Pacific region.' (Ed. TVR Pillay) pp. 328-354. (Fishing News (Books) Ltd: London)

Liao IC, Kou GH, Chen SN, Lai IY (1985) Preliminary investigation on the diseases of cultured prawns in the Pingtang area. COA fisheries series no. 4, Fish Disease Research (VII) (Council of Agriculture: Taipei, Taiwan, ROC)

Lightner DV (2005) Biosecurity in shrimp farming: Pathogen exclusion through use of SPF stock and routine surveillance. *Journal of the World Aquaculture Society* **36,** 229-248.

Lightner DV (2011) Virus diseases of farmed shrimp in the Western Hemisphere (the Americas): A review. *Journal of Invertebrate Pathology* **106** (1), 110–130.

Lightner DV, Bell TA, Redman RM, Mohney LL, Natividad JM, Rukyani A, Poernomo A (1992) A review of some major diseases of economic significance in penaeid prawns/ shrimp of the Americas and Indopacific. In 'Proceedings of the first symposium on diseases in Asian aquaculture' (Eds M Shariff, R Subasinghe, JR Arthur) pp. 57-80. (Fish Health Section, Asian Fisheries Society: Manila, Philippunes).

Lightner DV, Hedrick RP, Fryer JL, Chen SN, Liao IC, Kou GH (1987) A survey of cultured penaeid shrimp in Taiwan for viral and other important diseases. *Fish Pathology* **22,** 127-140.

Lin CK (1989) Prawn culture in Taiwan: what went wrong? *World Aquaculture* **20,** 19-20.

Lin CS, Chang BG, Su MS, Shitauda K (1981) Requirement of white fish meal protein in diet of grass shrimp *Penaeus monodon*. *China Fisheries Monthly* **337**, 13-15.

Lio-Po GD, Leaño EM (2016) Important diseases of Penaeid shrimps. In 'Progress of shrimp and prawn aquaculture in the world.' (Eds GD Lio-Po, EM Leaño) pp. 269-315. (National Taiwan Ocean University: Keelung, Taiwan)

Littauer G (1990) Avian predators: Frightening techniques for reducing bird damage at aquaculture facilities. SRAC publication no. 401 (Southern Regional Aquaculture Center (SRAC), Mississippi State University, Stoneville, USA)

Liu MS, Mancebo VJ (1983) Pond culture of *Penaeus monodon* in the Philippines: survival, growth and yield using commercialyy formulated feed. *Journal of World Mariculture Society* **14,** 75-85.

Looman J, Campbell JB (1960) Adaptation of Sorensen's K (1948) for estimating unit affinities in prairie vegetation. *Ecology*, **41** (3), 409-416. doi: https://doi.org/10.2307/1933315

Losordo TM, Westerman PM (1994) An analysis of biological, economic and engineering factors affecting the cost of fish production in recirculating aquaculture systems. *Journal of the World Aquaculture Society* **25**, 193-203.

Lutterschmidt WI, Hutchison VH (1997) The critical thermal maximum: History and critique. *Canadian Journal of Zoology* **75(**10), 1561-1574.

MacArthur RH (1965) Patterns of species diversity. *Biological Reviews* **40,** 510–533. doi: https://doi.org/10.1111/j.1469-185X.1965.tb00815.x

Madernjian CP (1990) Patterns of oxygen production and consumption in intensively managed shrimp ponds. *Aquaculture and Fisheries Management* **21,** 407-417.

Madhukumar A (1996) Hydrochemical and sorption studies in tropical backwater systems vis a vis retting practices. PhD thesis (University of Kerala: Thiruvananthapuram, India)

Magurran AE (1991) 'Ecological diversity and its measurement.' (Chapman & Hall: London, England)

Magurran AE (2004) 'Measuring biological diversity.' 2nd edn. (Blackwell Science Ltd.: Oxford, UK)

Mahapatra S (2002) 'Women participation in labour force.' (Rajat publications: New Delhi, India).

Mammen T (1984) Kerala fisheries - backwater fisheries. *Fishing Chimes* **4** (9), 13-20.

Mandal B, Dubey SK (2015) Present status and prospects of black tiger shrimp farming: A case study in maritime state of West Bengal, India. In 'Perspectives in animal ecology and reproduction.' Vol. 10. (Eds VK Gupta, AK Verma, GD Singh) pp. 83-102. (Daya Publishing House: New Delhi)

Manik R, Kahar R, Tiensogrusmee B (1978) The culture of shrimp, *Penaeus monodon*, in a low saline pond. *Bulletin of the Brackishwater Aquaculture Development Center* **4** (1-2), 288-292.

Manjare SA,Vhanalakar SA, Muley DV (2010) Analysis of water quality using physicochemical parameters Tamdalge tank in Kolhapur district, Maharashtra. *International Journal of Advanced Biotechnology and Research* **1 (**2), 115-119.

Marcon E (2015) Mésures de la Biodiversité. PhD thesis (Agro ParisTech: Paris, France)

Margalef R (1958) Information theory in ecology. *International Journal of General Systems* **3**, 36-71.

Marichamy R (1995) Killer virus strikes shrimp farms. *Fishing Chimes* **15(**8): 57-58.

Marothia DK (1995) Village ponds and aquaculture development: Is conflict inevitable? Paper presented in the national workshop on poultry, fisheries and food processing organised for the honourable members of parliament. 4-7 July 1995. National Academy of Agricultural Research Management, Hyderabad, India.

Marshall TR, Ryan PA (1987) Abundance patterns and community attributes of fishes relative to environmental gradients. *Canadian Journal of Fisheries and Aquatic Sciences* **44** (2), 198–215.

Martinez-Cordova LR, Torres AC, Porchas-Cornejo MA (2003) Dietary protein level and natural food management in the culture of blue (*Litopenaeus stylirostris*) and white shrimp (*Litopenaeus vannamei*) in microcosms. *Aquaculture Nutrition* **9,** 155-160.

Mathew G, Rahamathulla VK (1993) Biodiversity in the Western Ghats – a study with reference to Moths (Lepidoptera: Heterocera) in the Silent Valley National Park, India. *Entomon* **20** (2), 25-33.

Mathew PM (1988) Paddy- cum- fish culture in pokkali fields. In ‘Proceedings of seminar on problems and prospects of freshwater aquaculture in Kerala'. pp. 13-17. (Kerala Agriculture University Union and Students' Union, College of Fisheries: Cochin, India)

Mathew PM (1991) Recent developments in paddy-cum- fish culture in Kerala. *Journal of Inland Fisheries Society of India* **23** (2), 113-119.

Mathew PM (1993) Selective culture of prawn in pokkali fields. In 'Proceedings of the national seminar on aquaculture development in India- Problems and prospects.' (Eds P Natarajan, V Jayaprakas) pp. 59-66. (University of Kerala: Thiruvananthapuram, India)

Mathew PM, George KM (1987) Preliminary observations on paddy- cum- fish culture in pokkali fields. In 'Proceedings of national seminar on estuarine management'. Trivandrum. (Ed. NB Nair) pp.382-388. (State Committee on Science, Technology and Environment, Government of Kerala: Trivandrum)

Mathew PM, Sebastian MJ, Thampy DM, Nair CM (1993) Observations on the culture of giant freshwater prawn, *Macrobrachium rosenbergii* in pokkali fields. In 'Proceedings of the second Indian Fisheries Forum' (Eds TJ Varghese, P Keshavanath, KV Radhakrishnan, RR Lokeshwar) pp. 43-46. (The Asian Fisheries Society, Indian Branch: Mangalore, India)

May RM (1975) Patterns of species abundance and diversity. In ‘Ecology and evolution of communities.’ (Eds ML Cody, JM Diamond) pp. 81-120. (Harvard University Press: Cambridge, MA 02138, USA)

Mazid MA, Hussain MG (1996) Rice-fish farming technology–a popular practice in Bangladesh. *Fisheries Newsletter, Bangladesh Fisheries Research Institute*, Mymensingh **4** (4), 2-6.

Mazumdar S, Guruswamy M (2006) Female work force participation in Kerala: problems and prospects. Paper presented at 2006 annual meeting programme of Population Association of America, Westin Bonaventure, Los Angeles, California, 30 March- 1 April 2006. Population Association of America, Westin Bonaventure, Los Angeles, California, USA. Available at https://paa2006.princeton.edu/papers/60878. [Verified 12 May 2021]

McCune B, Grace JB (2002) 'Analysis of ecological communities.' (Mjm Software Design: Gleneden Beach, Oregon, USA)

McElhinny C, Gibbons P, Brack C, Bauhus J (2005) Forest and woodland stand structural complexity: its definition and measurement. *Forest Ecology and Management,* **218** (1-3), 1-24. doi: https://doi.org/10.1016/j.foreco.2005.08.034

McGee MV, Boyd CE (1983) Evaluation of the influence of water exchange in channel catfish ponds. *Transactions of the American Fisheries Society* **112** (4), 557-560. doi: 10.1577/1548-8659(1983)112<557: EOTIOW> 2.0.CO;2

McIntosh RP, Drennan DP, Bowen BM (1999) Belize aquaculture: Development of an intensive, sustainable, environmentally friendly shrimp farm in Belize. In 'Proceedings of the Vth Central American symposium on aquaculture'. (Eds BW Green, HC Clifford, M MacNamara, GM Moctezuma) pp. 85-99. (Latin American Chapter of the World Aquaculture Society: San Pedro Sula, Honduras)

McKenney Jr CL, Neff JM (1979) Individual effects and interactions of salinity, temperature and Zinc on larval development duration through metamorphosis. *Marine Biology* **52**, 177-188. doi: https://doi.org/10.1007/BF00390426

McVey JP (1993) 'CRC Handbook of mariculture Vol. I. Crustacean aquaculture'. 2nd edn. (CRC Press: Boca Raton, FL, USA)

Meade JW (1989) 'Aquaculture management.' (Van Nostrand Reinhold Company: New York, USA)

Meena SB, Kirway TN, Lema NM, Nalitolela AJ (2002) 'Farming system approach to technology development and dissemination. A teaching manual and tutors' guide for training at certificate and diploma levels.' (Color Print Limited, Ministry of Agriculture and Food Security: Dar es Salaam, Tanzania)

Meera S, Nandan SB (2010) Water quality status and primary productivity of Valanthakad Backwater in Kerala. *Indian Journal of Marine Sciences* **39** (1), 105-113.

Meeran NK, Sebastian MJ (1972) On rearing the larvae of freshwater prawn, *Macrobrachium rosenbergii* (de Man). In 'Proceedings of seminar on mariculture and mechanised fishing'. 28-29 November 1972, Madras (India). pp. 94-95 (Department of Fisheries, Government of Tamil Nadu: Madras, India).

Meeran NK, Sebastian MJ (1976) On rearing the larvae of *Macrobrachium rosenbergii* (de Man). *Bulletin of the Department of Fisheries, Kerala* **1** (1), 33-36.

Meeran NM, Prince MJJ (1999) Sociopersonal, socioeconomic and socio psychological profile of shrimp farmers. *Journal of Extension Education* **10** (2), 45-48.

Megahed, ME, Ghoneim S, Dsouky G, EL-Dakar A (2013) Major constraints facing development of marine shrimp farming in Egypt. *Journal of the Arabian Aquaculture Society* **8** (2), 321-329.

Menon MK (1954) On the paddy field prawn fishery of Travancore-Cochin and an experiment in prawn culture. *Proceedings of Indo-Pacific Fisheries Council* **25,** 1-5.

Menon MK, Raman K (1961) observations on the prawn fishery of the Cochin backwaters with special reference to the stake net catches. *Indian journal of Fisheries* **8** (1), 1-23.

Menon N, Balchand AN, Menon NR (2000) Hydrobiology of the Cochin backwater system – a review. *Hydrobiologia* **430** (1), 149-183.

Menon V (2000) A way of life bowing out: A rice granary's culture of kaipad cultivation in transition, In 'Proceedings of the international workshop on rice fish farming'. pp. 147-157. (Can Tho University: Can Tho city, Viet Nam)

Miao S, Tu S (1996) Modelling the effect of thermic amplitude on growing Chinese shrimp, *Penaeus chinensis* (Osbeck). *Ecological Modelling* **88**, 93-100.

Millamena OM, Primavera JH, Pudadera RA, Caballero RV (1986) The effect of diet on the reproductive performance of pond reared *Penaeus monodon* Fabricius broodstock. In ‘Proceedings of the first Asian Fisheries Forum’. (Eds JL Maclean, LB Dizon, LV Hosillos) pp. 593-596. (Asian Fisheries Society: Manila, Philippines)

Mishra AK, Verdegem M, van Dam A (2002) A dynamic simulation model for growth of penaeid shrimps. In ‘Avances en Nutrición Acuícola VI. Memorias del VI. Simposium internacional de nutrición acuícola. 3 al 6 de Septiembre del 2002, Cancún, Quintana Roo, México (Eds Cruz-Suárez LE, Ricque-Marie D, Tapia-Salazar M, Gaxiola-Cortés MG, Simoes N). pp. 448-470.

Misra SR (1987) ‘Fisheries in India.’ (Ashish Publishing House: New Delhi)

Misra SR (2006) ‘Inland Fisheries in India: Issues and Concerns.’ (Concept Publishing Company: New Delhi, India)

Mochizuki H (1979) 'The present prawn culture in the Philippines.' (Aquaculture Department, Southeast Asian Fisheries Development Center (SEAFDEC): Iloilo City, Philippines) (mimeo)

Mogalekar HS, Ansar CP, Golandaj A, Dinesh K (2015a) Biodiversity of decapod crustacean in the Vembanad Lake at Panangad- Kumbalam region of Kochi, Kerala. *Environment and Ecology*. **33** (4B), 1920-1923.

Mogalekar HS, Ansar CP, Raman NN, Jayachandran KV, Dinesh K, Kolhe S (2015b) Fish diversity of Vembanad Lake in the Panangad-Kumbalam region of Kochi, Kerala, India. *Pollution Research,* **34** (2), 345-349.

Mogalekar HS, Golandaj A, Ansar CP, Raman NN, Ajinkya D (2015c) Temporal variation in the hydrobiology of Vembanad Lake at Panangad-Kumbalam mangrove patches of Kochi, Kerala. *Research Journal of Animal, Veterinary and Fishery Sciences* **3** (3), 1-7. Available at: www.isca.in [Verified 12 May 2021]

Mohan CV, Philipps MJ, Bhat BV, Umesh NR, Padiyar PA (2008) Farm level plans/husbandry measures, changing trends in managing aquatic animal disease emergencies: Tools for preparedness and response. *OIE Scientific and Technical Review* **27** (1), 161-173.

Mohite YT (2007) Efficacy and constraints in adoption of improved aquaculture practices by shrimp farmers in Raigad district of Maharashtra. MFSc thesis (Dr Balasaheb Sawant Konkan Krishi Vidyapeeth: Dapoli, Maharashtra, India)

Molina C (2009) Feed programs: maximizing feed and feeding efficiency in shrimp farming. In 'The rising tide - Proceedings of the special session on sustainable shrimp farming'. (Eds CL Browdy, DE Jory) pp. 218–229 (World Aquaculture Society: Baton Rouge, Louisiana, USA)

Molnar JJ, Hanson TR, Lovshin LL (1996) Social, economic, and institutional impacts of aquaculture research on Tilapia. The PD/A CRSP in Rwanda, Honduras, the Philippines, and Thailand. Research and development series no. 40, International Center for Aquaculture and Aquatic Environments, Alabama Agricultural Experiment Station, Auburn University, USA.

Mondal KM (1981) The role of marketing and co-operatives in rural aquaculture. In 'Proceedings of seminar on fishery (inland) as an economic programme for integrated rural development' 28-30 September 1981, Barrackpore, India. (Central Inland Fisheries Research Institute: Barrackpore, India)

Moriarty DJW (1997) The role of microorganisms in aquaculture ponds. *Aquaculture* **151**, 333-349. doi: https://doi.org/10.1016/S0044-8486(96) 01487-1

Moya M, Lawrence AL, Collins CA, Samocha TM (1999) Acclimation of *Litopenaeus vannamei* postlarvae to 2 ppt ground saline water in Sonora Desert, Arizona. In 'Book of abstracts, World Aquaculture Society Annual Conference'. p. 424. (World Aquaculture Society: Sydney, Australia)

MPEDA (2021) Marine products exports. Marine Products Export Development Authority, Kochi, India. Available at https://mpeda.gov.in/?page_id=438 [Verified 12 July 2021]

MPEDA/NACA (2003) 'Shrimp health management extension manual'. Prepared by the NACA and MPEDA, India, in cooperation with the AAH Research Institute, Bangkok, Thailand, Siam Natural Resources Ltd, Bangkok, Thailand and Australia Veterinary Animal Health Services, Australia. (Marine Products Export Development Authority: Cochin, India) Available at http://library.enaca.org/Shrimp/manual/ShrimpHealthManual.pdf [Verified 12 May 2021]

Mruthyunjaya (2004) Strategies and options for increasing and sustaining fisheries and aquaculture production to benefit poor households in India. National Centre for Agricultural Economics and Policy Research, New Delhi, India and World Fish Centre, Penang, Malaysia.

Mumthaz KM, George MJ (2017) Significance of pokkali fields at Kadamakkudy, Kerala. *Journal of Global Biosciences* **6 (**10), 5308-5312.

Munro ISR (2000) ‘The marine and fresh water fishes of Ceylon.’ (Biotech Books: Delhi, India).

Muralidhar M, Kumaran M, Jayanthi M, Muniyandi B, Ponniah AG, Nagothu US, White P, Eknath A (2012) ‘Case study on the impacts of climate change on shrimp farming and developing adaptation measures for small-scale shrimp farmers in Krishna District, Andhra Pradesh, India.’ (Network of Aquaculture Centers in Asia-Pacific: Bangkok, Thailand)

Musig Y, Boonnom S (1998) Low salinity culture of *Penaeus monodon* Fabricius and its effect on the environment. In 'Advances in shrimp biotechnology' (Ed. TW Flegel) p. 123 (National Center for Genetic Engineering and Biotechnology: Bangkok, Thailand)

Musig Y, Ruttanagosrigit W (1982) Effects of salinity on survival rate of *Penaeus monodon* larvae. Report no. 5, Brackishwater Fisheries Division, Thai Department of Fisheries, Bangkok, Thailand.

Muthu MS (1978) A general review of penaeid prawn culture. In 'Summer institute in breeding and rearing of marine prawns’. CMFRI special publication no.3. pp. 25- 33. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Muthu MS (1980) Site selection and type of farms for coastal aquaculture of prawns. In 'Proceedings of the Symposium on shrimp farming'. 16-18 August 1978, Bombay. pp.97-106. (Marine Products Export Development Authority: Cochin, India)

Muthu MS, Alagaraswami K, Kathirvel M (1992) 'Prawn farming- candidate species.' CIBA bulletin no. 2. (Central Institute of Brackishwater Aquaculture (CIBA): Madras, India)

Muthu MS, Pillai NN, George KV, Lakshmi S (1981) Growth of the Indian white prawn *Penaeus indicus* in relation to stocking density. *Journal of the Marine Biological Association of India*, **23** (1&2), 205-208.

Muthuraman AL (2005) Tecnology package development for sustainable scampi farming. Paper presented at Sustain Fish 2005- International symposium on improved sustainability of fish production systems and appropriate technologies for utilization. 16-18 March 2005, Cochin. Cochin University of Science and Technology, Cochin, India and University Grants Commission, New Delhi, India.

Nag SK, Ghosh BD, Aftabuddin M, Sarkar UK, Das BK (2020) Carbon sequestration potential in different wetlands of West Bengal in the context of changing Climatic cenerio. In ‘Book of abstracts, Climfishcon

2020: International conference on impact of climate change on hydrological cycle, ecosystem, fisheries and food security’. 11-14 February 2020, Cochin. (Eds BM Kurup, MR Boopendranath, M Harikrishnan, AV Shibu, VPAncy, NM Sekharan, S Sabu, M Sileesh, R Radhika, HS Harisankar, OK Sreedevi, S Sreelakshmi, S Reshma, P Anju, Sariga) pp. 76. (Cochin University of Science and Technology: Cochin, India)

Nagamani K, Vimala DD (2015) Socioeconomic frame work of fish farmers in Tamil Nadu. *Journal of Advanced Research in Geo Sciences and Remote Sensing* **2** (3-4), 115-121.

Nagesh TS, Abraham TJ, Ghosh AR (2009) Threats associated with non-infectious diseases in modified extensive shrimp farming systems of West Bengal, India. *Asian Fisheries Science* **22,** 1015-1029. doi: https://doi.org/10.33997/j.afs.2009.22.3.012

Naik BV, Patil SV, Shirdhankar MM, Yadav BM, Tibile RM, Chaudhari KJ, Wasave SM, Yewale VG (2020) Socio-economic profile of shrimp farmers of South Konkan region, Maharashtra, India. *International Journal of Current Microbiology and Applied Sciences* **9** (9), 1371-1380.

Nair CM, Salin KR, Joseph J, Aneesh B, Geethalakshmi V, New MB (2014) Organic rice–prawn farming yields 20% higher revenues. *Agronomy for sustainable development* **34** (3), 569-581. doi. 10.1007/s13593-013-0188-zff. ffhal01234809f

Nair CM, Thampy DM (1998) Freshwater prawn culture and seed production. In Proceedings of seminar on problems and prospects of freshwater aquaculture in Kerala'. pp. 93-111. (Kerala Agriculture University Union and Students' Union, College of Fisheries: Cochin, India)

Nair CM, Thampy DM, Sebastian MJ, Syamlal P (1989) Mass production of seed of the giant freshwater prawn *Macrobrachiunm rosenbergii* (De Man). Paper Presented at the national seminar on forty years of freshwater aquaculture in India. 7-9 November 1989, Kausalyaganga, Bhubaneswar. Association of Aquaculturists and Central Institute of Freshwater Aquaculture, Bhubaneswar, India.

Nair KKC, Sankaranarayanan VN, Gopalakrishnan TC, Balasubramanian T, Devi CBL, Aravindakshan PN, Kutty MK (1998) Environmental conditions of some paddy cum prawn culture fields of cochin backwaters, Southwest coast of India. *Indian Journal of Marine Sciences* **17**, 24-30.

Nair KN, Menon V, Mahesh VR (2002) The lure of prawn culture and the waning culture of rice fish farming: A case study from North Kerala Wetlands. Kerala Research Programme on Local Level Development (KRPLLD), Centre for Developmental studies, Thiruvananthapurram, India.

Nair MNM (1995) Studies on Beypore estuary: trace metals distribution and physico-chemical characteristics. PhD thesis (Cochin University of Science and Technology: Cochin, India)

Nair NB (1989) Report of the expert committee on marine fishery resources management in Kerala. Submitted to Government of Kerala, Thiruvananthapuram, Kerala, India.

Nair PG, Money NS (1972) Studies on some chemical and mechanical properties of salt affected rice soils of Kerala. *Agricultural Research Journal of Kerala* **10**(1), 51-53.

Nair PVR, Gopinathan CP, Pillai VK, Vijayakumaran M, Balachandran VK (1978) Productivity of the prawn fields adjoining Cochin backwaters and its nutrient regeneration. CMFRI bulletin no. 28. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Nair SRS, Kutty MK (1975) Note on the varying effects of salinity on the growth of the juveniles of *Penaeus indicus* from the Cochin backwater. *Bulletin of the Department of Marine Sciences, University of Cochin* **8** (1), 181-184.

Nambiar GR, Raveendran K (2009) Exploration of untapped potentiality of coastal paddy fields of Kerala (India)-A case study. *Middle-East Journal of Scientific Research*, **4 (**1), 44-47.

Nandan SB, Jayachandran PR, Sreedevi OK (2012) Temporal pattern of fish production in a microtidal tropical estuary in the south-west coast of India. *Indian Journal of Fisheries* **59**, 17-26.

Narayanan SP, Thapanjith T, Thomas AP (2005) A study on the Ichthyofauna of Aymanam panchayath, in Vembanad wetland, Kerala. *Zoos' Print Journal* **20** (9), 1980-1982.

Nasser AKV, Noble A (1992) Economics of prawn culture in Vypeen, Kerala, with emphasis on some little-known facts. *Aquaculture Economics* **7,** 55-64.

Nataraj S (1948) The prawns of Travancore. Report of the Department of Research, University of Travancore, Trivandrum, India.

Natarajan AV (1985) Potential and prospects of inland fisheries in India. In 'Harvest and post-harvest technology of fish'. (Eds K Ravindran, NU Nair, PA Perigreen, P Madhavan, AGG Pillai, PA Panicker, M Thomas) pp. 14-18. (Society of Fisheries Technologists: Cochin, India)

Navas K A and Sebastian M J (1989) Effect of low salinities on the survival and growth of *Penaeus monodon* (Fabricius). *Indian Journal of Fisheries*, **36** (3), 257-261.

Navghan M, Kumar NR, Prakash S, Gadkar D, Yunus S (2015) Economics of shrimp aquaculture and factors associated with shrimp aquaculture in Navsari District of Gujarat, India. *Ecology, Environment and Conservation* **21** (4), 247-253.

Nayak AA, Behera BK, Mishra CK, Mukhi SK, Kohli MPS (2001) Constraints in adoption of shrimp farming in Orissa. *Applied Fisheries and Aquaculture* **1**(1), 111-112.

Nayak N, Nandakumar D, Amruth M, Unnikrishna P, Padmanabhan TP (2000) Wetland resources of northern Kerala: A case study of Pazhayangadi and Kunhimangalam in Kannur District. Discussion paper No. 15, Kerala Research Programme on Local Level Development (KRPLLD), Centre for Development Studies, Thiruvananthapuram, India.

Neiland AE, Shaw SA, Bailly D (1991) Social and economic impact of aquaculture: a European review. In 'Aquaculture and the environment.' European Aquaculture Society special publication no. 16. (Eds N D Pauw, J Joyce) pp. 469-482. (European Aquaculture Society: Gent, Belgium)

Neiland AE, Soley N, Varley JB, Whitmarsh DJ (2001) Shrimp aquaculture economic perspectives for policy development. *Marine Policy* **25,** 265-279.

New MB (1976) A review of dietary studies with shrimps and prawns. *Aquaculture* **9,** 101-144.

New MB, Rabanal HR (1985) A review of the status of penaeid aquaculture in South East Asia. In 'Proceedings of the second Australian national prawn seminar'. 22- 26 October 1984, Kooralbyn, Queensland, Australia (Eds PC Rothlisberg, BJ Hill, DJ Staples) pp. 307-326. (Cleveland: Queensland, Australia)

Nezaki G (1986) Nutritional requirements of prawn (*Penaeus monodon* Fabricius) II. Effect of dietary protein and carbohydrate. Terminal report, Aquaculture Department, Southeast Asian Fisheries Development Center (SEAFDEC), Iloilo City, Philippines.

NFDB (2020) National fisheries policy, 2020. National Fisheries Development Board, Hyderabad. Available at https://nfdb.gov.in/PDF/National_Fisheries_Policy_2020.pdf [Verified 12 July 2021]

Nguyen HTK, Thu TTN, Lebailly P, Azadi H (2019) Economic challenges of the export-oriented aquaculture sector in Vietnam. *Journal of Applied Aquaculture* **31** (3):1-17 doi: 10.1080/10454438.2019.1576568

Nguyen KAT, Nguyen TAT, Jolly C, Nguelifack BM (2020) Economic efficiency of extensive and intensive. *Sustainability* **12,** 2140. doi: https://doi.org/10.3390/su12052140

Nguyen TAT, Jolly CM (2017) Macro-economic and product challenges facing Vietnamese the pangasius industry. *Reviews in Fisheries Science & Aquaculture* **26** (36),1-12. doi: https://doi.org/10.1080/23308249.2017.1379948

Nguyen THA (2012) Profitability and technical efficiency of black tiger shrimp (*Penaeus monodon*) culture and white leg shrimp (*Penaeus vannamei*) culture in Song Cau District, Phu Yen Province, Vietnam. Master thesis (University of Tromso: Norway and Nha Trang University: Vietnam)

Nikol'sky GV (1963) 'The ecology of fishes.' (Academic press: London, UK)

Ninawe AS, Raj RP (1993) Studies on certain nitrogen cycle bacteria. In 'Mariculture research under the postgraduate programme in mariculture' Part 5 CMFRI special publication no. 56. (Eds K Rengarajan, A Noble, P Rohit, V Kripa, N Sridhar, M Zakhriah) pp. 57-65. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Nisar U, Zhang H, Navghan M,Zhu Y, Mu Y (2021) Comparative analysis of profitability and resource use efficiency between *Penaeus monodon* and *Litopenaeus vannamei* in India. *PLoS ONE*, **16** (5). e0250727. doi: https://doi.org/10.1371/journal. pone.0250727

Nongmaithem BD, Ngangbam AK (2014) Socioeconomic conditions and cultural profile of the fishers in India- a review. *IOSR Journal of Agriculture and Veterinary Science* **7** (9), 42-48. doi: 10.9790/2380-07914248

Norfolk JRW, Javellana DS, Paco JN, Subosa PF (1981) The use of ammonium sulfate as a pesticide during pond preparation. *Asian Aquaculture* **4** (3), 4-7.

Nunes AJP (2009) Overview on the contribution of natural food items to shrimp growth in aquaculture ponds. In 'Book of abstracts, XI Congresso Ecuatoriano deAcuiculture & AquaExpo AQUA 2009'. pp. 48–50. (Cámara Nacional deAcuacultura: Guayaquil, Ecuador)

Nunes AJP, Parsons GJ (2000) Effects of the southern brown shrimp, *Penaeus subtilis*, predation and artificial feeding on the population dynamics of benthic polychaetes in tropical pond enclosures. *Aquaculture* **183**, 125-147. doi: 10.1016/S0044-8486(99)00278-1

Offem BO, Ikpi GU, Ada F (2010) Fish culture technologies in South-eastern Nigeria. *African Journal of Agricultural Research 5* (18) 2521-2528.

Ofuoku AU, Emah GN, Itedjere BE (2008) Information utilization among rural fish farmers in central agricultural zone of Delta State, Nigeria. *World Journal of Agricultural Science* **4** (5), 558-564.

Ogunmefun SO, Achike AI (2017) Socioeconomic characteristics and constraints of pond fish farmers in Lagos State, Nigeria. *Agricultural Science Research Journal* **7** (10), 304-317.

Orchard SE, Stringer LC, Quinn CH (2015) Impacts of aquaculture on social networks in the mangrove systems of northern Vietnam. *Ocean and Coastal Management* **114,** 1-10.

Ovenden AE (1961) 'Costs and earnings investigations of primary fishing enterprises: a study of concepts and definitions.' (Food and Agriculture Organisation of the United Nations: Rome, Italy)

Overstreet RM (1973) Parasites of some penaeid shrimps with emphasis on reared hosts. *Aquaculture* **2** (2), 105-140. doi: 10.1016/0044-8486(73)90140-3

Padmakumar KG (1988) Paddy–cum fish culture in punja fields. In Proceedings of seminar on problems and prospects of freshwater aquaculture in Kerala'. pp. 61-73. (Kerala Agricultural University Union and Students' Union, College of Fisheries: Cochin, India)

Padmakumar KG (2003) Prawns on a comeback trial in Kuttanad! Souvenir of internatioanl symposium on freshwater prawns 2003 (Eds KS Purushan, BM Kumar, K Dinesh) pp. 47-50 (College of Fisheries, Kerala Agricultural University: Cochin, India)

Padmakumar KG, Bindu L, Joseph N, Sreekumar B, Sunil G, Unnikrishnan N, Kurien JS (2006) River fish inventory under participatory approaches: 'Meenachil fish count 2004. *Environmental Ecology* **24** (3), 584-590. https://eurekamag.com/research/023/541/023541821.php

Padmakumar KG, Krishnan A, Manu PS, Shiny CK, Radhika R (2002) Thaneermukkom barrage and fishery decline in Vembanad wetlands, Kerala. In 'Proceedings of the fifth Kerala Science Congress' 28-30 January 1993, Kottayam. pp. 27-36. (Kerala State Council for Science, Technology and Environment: Thiruvananthapuram, India)

Padmakumar KG, Krishnan A, Nair RR (1990) Rice-fish farming system for wetlands: A case study with special reference to Kuttanad, Kerala. In: 'Rice in wetland ecosystem' (Eds RR Nair, KPV Nair, CA Joseph) pp. 268-275. (Kerala Agricultural University: Thrissur, India)

Panayotou T (1981) Cost structure and profitability of small-scale fishing operations: methodological framework. Paper presented at the IDRC small-scale fisheries workshop, May 1981, Singapore. International Development Research Centre Ottawa, Canada.

Pandey AC, Mishra JP (2001) Economic feasibility of fish culture in the district Faizabad (U.P), India: A case study. In 'Encyclopaedia of agricultural marketing.' Vol. 7- Livestock, poultry, dairy, fish etc. (Eds J. Prasad) pp. 263- 270. (Mittal Publications: New Delhi, India)

Pandey DK, De HK, Hijam B (2014) Fish farmers' perceived constraints in transfer of aquaculture technology in Bishnupur District of Manipur, India. *International Journal of Fisheries and Aquatic Studies* **2** (1), 1-4.

Pandey DK, Upadhayay A (2012) Socio-economic profile of fish farmers of an adopted model aquaculture village: Kulubari, West Tripura. *Indian Research Journal of Extension Education*, Special Issue (**II**), 55-58.

Pandey SK, Dewan R (2006) Constraints in fish farming practices in Uttar Pradesh, India- an analysis. *Journal of Indian Fisheries Association* **33**, 183-189.

Pandey SK, Dewan R (2008) Institutional support for freshwater aquaculture development- a study of Mirzapur district of Uttar Pradesh. *Journal of Indian Fisheries Association* **35**, 51- 73.

Panigrahi A (2012) Biosecurity and the essential principles of shrimp health management in *Litopenaeus vannamei* hatcheries and farms. In 'NFDB sponsored training programme on management of emerging diseases of shrimp with special reference to pacific white shrimp, *Litopenaeus vannamei*.' CIBA special publication no. 64 (Ed. KP Jithendran) pp.32-37. (Central Institute of Brackishwater Aquaculture (CIBA): Chennai, India).

Panikkar KKP (1990) Socio - economic analysis of prawn farming in Orissa state. *Marine Fisheries Information Service Technical and Extension Series* 106**.** 3-10.

Panikkar NK (1937) The prawn industry of the Malabar Coast. *Journal of the Bombay Natural History Society* **39** (2), 343-352.

Panikkar NK (1952) Possibilities of further expansion of fish and prawn culture practices in India. *Current Science* **21,** 29-33.

Panikkar NK, Menon MK (1956) Prawn fisheries of India. *Proceedings of Indo-Pacific Fisheries Council* **5** (2), 31-35.

Pante MJR (1990) Influence of environmental stress on the heritability of molting frequency and growth rate of the penaeid shrimp, *Penaeus vannamei*. MSc thesis (University of Houston-Clear lake,Houston, TX, USA)

Parashar V, Bara SK, Damde D, Kumar A, Vyas V (2016) Assessment of the socioeconomic status of fishermen communities: a case study from a selected reach of River Narmada, India. *International Journal of Research in Fisheries and Aquaculture* **5** (2), 47-59.

Parker JC, Conte FS, Macgrath WS, Miller BW (1974) An intensive culture system for penaeid shrimp. *Proceedings of the annual meeting of World Mariculture Society* **5**: 65-79. doi: https://doi.org/10.1111/j.1749-7345.1974.tb00179.x

Parker NC, Suttle MA (1987) Design of airlift pumps for water circulation and aeration in aquaculture. *Aquacultural Engineering* **6**, 97-110.

Parvathi D, Padmavathi P (2018) Stocking density, survival rate and growth performance of *Litopenaeus vannamei* (Boone, 1931) in different cultured shrimp ponds from Vetapalem, Prakasam District, Andhra Pradesh, India. *International Journal of Zoology Studies* **3** (2), 179-183.

Pascual FP (1989) Status of shrimp nutrition and feed development in Southeast Asia. In 'Fish nutrition research in Asia- Proceedings of the third Asian fish nutrition network meeting.' (Ed. SS De Silva) pp.80-89. (Asian Fisheries Society: Manila, Philippines and International Development Research Centre: Canada)

Pascual FP, Coloso RM, Tamse CT (1983) Survival and some histological changes in *Penaeus monodon* Fabricius juveniles fed various carbohydrates. *Aquaculture* **31**,169-180.

Patil GP, Taillie C (1982) Diversity as a concept and its measurement. *Journal of the American Statistical Association* **77,** 548-567. doi: 10.1080/01621459.982.10477845

Patil SV, Sharma A (2018) Assessing and prioritizing training needs of shrimp farmers of Palghar district, Maharashtra. *Indian Journal of Ecology* **45** (2), 406-410.

Patil SV, Sharma A (2019a) Need of women specific interventions for sustainable and equitable brackish water aquaculture development. Paper Presented in the world conference on brackishwater aquaculture (Braqcon-2019), 23-26 January 2019, ICAR-CIBA Chennai. Central Institute of Brackishwater Aquaculture (CIBA), Chennai, India.

Patil SV, Sharma A (2019b) Shrimp industry gender gap in India: Case of Maharashtra state. *Journal of Entomology and Zoology Studies*. **7** (6), 380-383.

Patil SV, Sharma A (2020) Empirical analysis of constraints faced by shrimp farmers of Maharashtra. *Journal of Experimental Zoology* **23** (2), 1867-1875.

Patil SV, Sharma A, Ojha SN, Shirdhankar MM, Dhaker HS (2019a) Improving professional competencies and employment opportunities through capacity building of shrimp aquaculture extension personnel. Paper presented in the Asian Pacific Aquaculture. 19-21 June 2019, Chennai. World Aquaculture Society, Bangkok.

Patil SV, Sharma A, Ojha SN, Shirdhankar MM, Dhaker HS (2019b) Emergence of shrimp farming and profile of shrimp farmers in Palghar district, Maharashtra. *Contemporary Research in India* **9** (1), 37-41.

Patil SV, Sharma A, Shirdhankar MM, Ojha SN, Singh H (2018) Using discrepancy scores of importance and competency for designing training programmes for shrimp farmers of Maharashtra. In 'Book of abstracts, The national conference on empowerment of rural communities through aquaculture' 9-10 February 2018, Ratnagiri, Maharashtra, (Eds BR Chavan, HS Dhaker, SD Naik, SY Metar, A Rather, RA Pawar). pp. 112. (College of Fisheries, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth: Ratnagiri, India)

Paul P, Chakraborty S (2016) Impact of inland fisheries on the socio – economic development: A focus on perspectives on development, Nadia District West Bengal, India. *International Journal of Fisheries and Aquaculture Sciences* **6** (1), 59-76.

Peet RK (1974) The measurement of species diversity. *Annual Review of Ecology and Systematics* **5**, 285-307.

Peet RK (1975) Relative diversity indices. *Ecology* **56,** 496-498.

Peter M, Susan S (2014) Determinants of adoption of pond fish farming innovations in Salamaua of Morobe Province in Papua New Guinea. *South Pacific Studies* **35** (1), 21-36.

Pielou EC (1966) The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* **13**, 131–144.

Pielou EC (1975) 'Ecological diversity.' (Wiley Interscience: New York)

Pillai NGK (1977) Distribution and seasonal abundance of macrobenthos of the Cochin backwaters. *Indian Journal of Marine Sciences* **6**, 1-5.

Pillai NGK, Katiha PK (2004) 'Evolution of fisheries and aquaculture in India.' (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Pillai SM (1999) Traditional and improved traditional shrimp farming in the

pokkali fields of Kerala. *Journal of Indian Society of Coastal Agricultural Research* **17** (1,2), 171-181.

Pillai SM (2003) Fishery and production of shrimps from perennial and seasonal fields of Kerala. *Indian Journal of Fisheries* **50** (2), 173-180.

Pillai SM, Krishnan L (1998) On some aspects of the biology and fishery of *Penaeus indicus* from traditional fields. Paper presented in the symposium on advances and priorities in fisheries technology. 11-13 February 1998, Cochin. Central Institute of Fisheries Technology (CIFT), Cochin, India.

Pillai SM, Krishnan L, Venugopal N, Sasidharan CS (1997) ‘Traditional system of brackishwater aquaculture of Kerala.’ CIBA bulletin. (Central Institute of Brackishwater Aquaculture (CIBA): Chennai, India)

Pillai SM, Krishnan L, Venugopal N, Sasidharan CS (2002) ‘Traditional system of brackishwater aquaculture of Kerala.’ CIBA bulletin No. 14. (Central Institute of Brackishwater Aquaculture (CIBA): Chennai, India)

Pillai VK, George KV (1974) Prawn fishery resources of Cochin backwaters. *Seafood Export Journal* **6** (5), 33-39.

Pillay TVR, Kutty MN (2005) ‘Aquaculture: Principles and practices. 2nd edn. (Blackwell Publishing Ltd: Oxford)

Pinello D, Gee J, Dimech M (2017) ‘Handbook for fisheries socio-economic sample survey: Principles and practice.’ FAO fisheries and aquaculture technical paper eng no. 613. (Food and Agriculture Organisation of the United Nations (FAO): Rome, Italy). Available at https://agris.fao.org/agris-search/search.do?recordID=XF2017003178 [Verified 12 January 2022)

Poernomo A (1990) Site selection for coastal shrimp ponds. In 'Technical and economic aspects of shrimp farming- Proceedings of the Aquatec '90 Conference, Kuala Lumpur, Malaysia'. (Eds MB New, H de Saram, T Singh) pp. 3-19. (INFOFISH International: Malaysia)

Ponnusamy K, Gopinathan K, Krishnan M (1999) A study on cultural and economic aspects of aquafarming practices and extension needs of farmers in Prakasam district of Andhra Pradesh. Paper presented in national seminar on development and transfer of fisheries technology. 3-5 February 1999, Thoothukudi. Fisheries College and Research Institute, Thoothukudi, Tamil Nadu, India.

Porter M (2012) Why the coast matters for women: a feminist approach to research on fishing communities. *Asian Fisheries Science* **255**, 59-73.

Posadas BC (1988) Economic analysis of various prawn farming systems. In ‘Technical considerations for the management and operation of intensive prawn farms’. (Eds YN Chiu, LM Santos, RO Juliano). pp. 12-24. (University of the Phiippines Aquaculture Society: Iloilo City, Philippines)

Pradhan V, Mohsin M, Gaikwad B (2012) Assessement of physico-chemical parameters of Chilika Lake water. *International Journal of Research in Environmental Science and Technology* **2** (4), 101-103.

Prakash KP (2004) Better management practices in shrimp farming- soil and water quality management. *Aqua International* **20,** 25-26.

Prasad D (1968) Economic aspects of fisheries development in Bihar. *Indian Journal of Agricultural Research* **23** (4), 239-242. doi: 10.22004/ag.econ. 270800

Prasad G (1999) Growth and production of *Penaeus indicus* in a low saline semi-intensive culture system of Kerala. *Indian Journal of Fisheries,* **46** (1), 25-31.

Prasad G (2006) An economic analysis of small scale semi- intensive shrimp farming of *Penaeus monodon* in Kerala. In 'Proceedings of Sustain Fish 2005- International symposium on improved sustainability of fish production systems and appropriate technologies for utilization' (Eds BM Kurup, K Ravindran). pp 793-801. (School of Industrial Fisheries, Cochin University of Science and Technology: Cochin, India)

Praveena M, Santhosh S (2018) Monsoonal influence on water chemistry and primary productivity of Kappil backwaters, Kerala, India. *Eco-chronicle* **13** (3), 151-158.

Pravin P (2003) Studies on shrimp harvesting techniques in aquaculture. PhD thesis (Central Institute of Fisheries Education (CIFE): Versova, Mumbai, India)

Prein M (2002) Integration of aquaculture into crop-animal systems in Asia. *Agricultural Systems* **71**(1-2), 127-146.

Prema P, Palavesam A, Venkadesh B (2004) Primary productivity in a minor estuary along the south west coast of India. *Indian Journal of Fisheries* **51** (3), 359-364.

Pretto RM (1983) Penaeus shrimp pond grow-out in Panama. In 'CRC handbook of mariculture. Vol. 1. Crustacean aquaculture.' (Ed JP McVey) pp. 169-178. (CRC Press: Boca Raton, FL, USA)

Primavera JH (1991) Intensive prawn farming in the Philippines: Ecological, social, and economic implications. *AMBIO: A Journal of the Human Environment*, **20** (1), 28-33. http://hdl.handle.net/10862/1342

Primavera JH (1993) Environmental and socio-economic effects of shrimp farming: the Philippine experience. *INFOFISH International* 1 (94), 44-49.

Primavera JH (1997) Socio-economic impacts of shrimp culture. *Aquaculture Research* **28**, 815-827.

Primavera JH, Apud F, Usigan S (1976) Effects of different stocking densities on survival and growth of sugpo (*Penaeus monodon* Fabricius) in a milkfish rearing pond. *The Philippine journal of science* **105** (3), 193-203.

Pudadera BJ (1980) Evaluation of milkfish (*Chanos chanos* Forskal) and prawn (*Penaeus monodon* Fabricius) in polyculture systems. MS thesis (University of the Philippines: Iloilo, Philippines)

Pudjiatno, Baliao DD (1987) 'Production of prawn (*Penaeus monodon* Fabricius) using the modular pond system.' NACA/WP/87/59 (Network of Aquaculture Centres in Asia: Bangkok, Thailand). Available at https://www.fao.org/3/AC203E/AC203E00.htm [Verified 1 May 2021]

Pullin RSV, Williams MJ, Preston N (1998) Domestication of crustaceans. *Asian Fisheries Science* **11**, 59-69.

Purushan KS (1986) Economics of traditional prawn farming in Kerala. Paper presented at the seminar on brackishwater shrimp farming. 23 October 1986, Cannanore. Marine Products Export Development Authority, Cochin, India.

Purushan KS (1987a) Economics on traditional prawn farming in Kerala. *Seafood Export Journal* **19** (4), 15-19.

Purushan KS (1987b) Case studies on the prawn production potentials of traditional paddy fields at Vypeen island, Kerala. Paper presented at the seminar on fisheries research and development in Kerala. 28-29 April I987 Trivandrum. Department of Aquatic Biology and Fisheries, University of Kerala, Trivandrum, India.

Purushan KS (1988) Case studies on the prawn production potentials of traditional paddy fields at Vypeen Island, Kerala. *Aquatic Biology bulletin* **1,** 147-153.

Purushan KS (1989) Semi-intensive shrimp farming and its relevance in Kerala. *Seafood Export Journal* **21** (3), 9-15.

Purushan KS (1992) Studies on improved practices of prawn farming for higher production in Central Kerala. PhD thesis (Cochin University of Science and Technology: Cochin, India).

Purushan KS (1995) Role of women in shrimp farming. *Fishing Chimes* **14** (12), 13-14.

Purushan KS (1996a) Traditional methods of prawn farming in India-different farming systems-merits and demerits evaluation of production-economics and its scope for avocation and rural development. *Seafood Export Journal* **23** (3), 11-15.

Purushan KS (1996b) Sustainable shrimp production from traditional culture systems in Kerala: An improved farming practice. *Fishing Chimes* **16** (7), 33-35.

Purushan KS (1996c) Challenging scenario of scientific shrimp farming in India -An overview. *Seafood Export Journal* **27** (2), 17-23.

Purushan KS (2002) Wetland eco-system development and management in relation to pokkali areas. In 'Wetland conservation and management in Kerala'. (Eds K Kokkal, PN Premachandran, A Bijukumar) pp.46-55. (State Committee on Science, Technology and Environment: Thiruvananthapuram, India)

Purushan KS (2003a) Ecofriendly pokkali cultivation and prawn filtration practices in Kerala. *Fishing Chimes* **23** (3), 36-38.

Purushan KS (2003b) Pokkali cultivation in wetlands of Kerala. Paper presented at the regional workshop on wetlands of southern states. 4-6 November 2003, Kochi. Ministry of Environment and Forest, Government of India: New Delhi and Centre for Water Resources Development and Management (CWRDM): Kozhikode, India.

Purushan KS, Rajendran C.G. (1984) Prawn production in Kerala: budding or withering? *Seafood Export Journal* **16** (11), 27-31.

Radheyshyam (2001) Community based aquaculture in India- strengths, weaknesses, opportunities and threats. *Naga* **24** (1&2), 9-12. https://digitalarchive.worldfishcenter.org/bitstream/handle/20.500.12348/2371/1661.pdf?sequence1=

Raghunanda R (1999) Economic analysis of shrimp aquaculture in West Godavari district of Andhra Pradesh. *Journal of Fisheries Economics and Development* **2,** 1-23.

Rahman MA (1990) Effect of some limnological parameters of tiger shrimp *Penaeus monodon* production under semi-intensive culture. MSc thesis (Bangladesh Agricultural University: Maymensingh, Bangladesh)

Rahman ML, Ali MH (1986a) Study on the credit and marketing aspects of pond fisheries in two districts of Bangladesh. Research report no. 10, Bureau of Socio-economic Research and Training, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Rahman ML, Ali MH (1986b) Developing Pond fisheries in Bangladesh: Some findings of a study on credit and marketing aspects. *Bangladesh Journal of Agricultural Economics* **9** (2), 1-15. doi: 10.22004/ag.econ.211991

Rahman S, Barman BK, Ahmed N (2011) Diversification economies and efficiencies in a 'blue-green revolution' combination: A case study of prawn-carp-rice farming in the 'gher' system in Bangladesh. *Aquaculture International,* **19** (4), 665-682. doi: http://dx.doi.org/10.1007/s10499-010-9382-z

Rahman SA (2005) Gender analysis of labour productivity in crop production in Nassarawa state of Nigeria. In 'Agricultural rebirth for improved production in Nigeria: Proceedings of the 39th annual conference of Agricultural Society of Nigeria". 9-13 October 2005, Benin City. (Eds AM Orhamatta, SO Nwokoro, MT Ajaji, AJ Adekunle, GN Asumugha) pp. 388-390. (University of Benin: Benin City, Nigeria)

Raj PR, Raj PJS (1982) Effect of salinity on growth and survival of three species of penaeid prawns. In 'Proceedings of the symposium on coastal aquaculture Part 1'. 12-18 January 1980, Cochin. (Eds EG Silas, PV Rao, PVR Nair, K Alagarswami, T Jacob, KC George, K Rengarajan, PP Pillai, KJ Mathew, VK PiIIai, AG Ponniah) pp. 236-243. (Marine Biological Association of India: Cochin, India)

Raja RA, Jithendran KP (2013) Common shrimp diseases and their management- Provision for biosecurity in shrimp farm. In 'NFDB sponsored training manual on BMP in shrimp farming with special reference to West Bengal' CIBA special publication no. 67. (Eds AD Deo, PSS Anand, P Ravichandran) pp. 56-66. (Kakdwip Research Centre of Central Institute of Brackishwater Aquaculture (CIBA): Kakdwip, West Bengal, India)

Rajan PD, Purushothaman S, Krishnan S, Kiran MC, Deepak D, Jojo TD (2008) Strengthening communities and institutions for sustainable management of Vembanad backwaters, Kerala. In 'Proceedings of Taal 2007: The 12th World Lake Conference'. (Eds M Sengupta, R Dalwani). pp. 1158-1163 (International Lake Environment Committee: Japan)

Rajarajan P (2017) An economic analysis of *Littopenaeus vannamei* shrimp farming in Nagapattinam district, Tamil Nadu. MFSc thesis (Tamil Nadu Fisheries Univesity: Thoothukudi, India)

Rajbanshi KG, Shrestha MB (1980) A case study on the economics of integrated farming systems: agriculture, aquaculture and animal husbandry in Nepal. In 'Integrated agriculture aquaculture farming systems: ICLARM conference proceedings 4'. (Eds RSV Pullin, ZH Shehadeh) pp. 195–208. (International Center for Living Aquatic Resources Management (ICLARM): Manila, Philippines).

Rajendran CG, Abraham SF, Mrithynjayan PS, Thampy DM, Jose MM (1981) Studies on fish culture along with paddy in pokkali fields of Kerala. In 'Proceedings of the all-India symposium on freshwater biology'. 17-18 January 1981, Salem. pp. 148-159. (Salem Institute of Experimental Biology: Salem, Tamil Nadu, India)

Rajeswari KJ, Suresh G, Srikanth P, Raman NN (2018) Study of temporal variations in physico-chemical parameters of Vembanad Lake at Panangad- Kumbalam region, Kochi, Kerala, India. *International Journal of Current Microbiology and Applied Sciences* **7** (6), 2905-2917.

Raju MS (1997) Economic analysis of different aquaculture systems of Kerala: A production function approach. PhD thesis (Cochin University of Science and Technology: Kochi, India)

Raju MS (2002) Semi-intensive shrimp farming system of Kerala, India: a production function analysis. *Journal of the Indian Fisheries Association* **29**, 23-36.

Rajyalakshmi T, Chandra DM (1987) On culture of *Penaeus monodon* in saline and freshwater ponds in Andhra Pradesh, India. *Indian Journal of Animal Sciences* **57**: 348-358.

Raman K (1968) On an experiment in prawn cum tilapia culture in paddy field. *Indian journal of Fisheries* **15** (1,2), 184-197.

Raman K, Menon MK (1963) A preliminary note on an experiment in paddy field prawn farming. *Indian Journal of Fisheries* **10** (1A), 33-39.

Ramanathan N, Padmavathy P, Francis T, Athithian S, Selvaranjitham N (2005) 'Manual on polyculture of tiger shrimp and carps in freshwater' (Fisheries College and Research Institute, Tamil Nadu Veterinary and Animal Sciences University: Thothukudi, India)

Ranadhir M (1985) 'Microeconomic analysis of composite fish culture operation in India.' (Network of Aquaculture Centres in Asia, Bangkok, Thailand)

Ranadhir M (1986) Socioeconomics of aquaculture development in India. Paper presented at the workshop on socioeconomics of aquaculture development, Bangkok. Network of Aquaculture Centres in Asia-Pacific (NACA), Bangkok, Thailand. (mimeo).

Ranadhir M, Tripathi SD (1991) Production options in carp culture. In Proceedings of national symposium on freshwater aquaculture.' pp. 213-216. (Central Institute of Freshwater Aquaculture: Bhubaneswar, India)

Randive PC (2008) Adoption of shrimp health management practices in the South Konkan region of Maharashtra. MFSc thesis (Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth: Dapoli, India)

Rani BR, Daniel S, Harshitha M, Rambabu S.P. (2019) Adoption of integrated rice-fish farming system by farmers of Ramchandrapuram. International *Journal of Current Microbiology and Applied Sciences* **8** (1), 591-597. doi: org/10.20546/ijcmas.2019.801.066

Ranjith P, Karunakaran KR, Avudainayagam S, Samuel ADV (2019) Pokkali rice cultivation system of Kerala: An economic analysis. *International Multidisciplinary Research Journal* **V**, 14-19.

Ranjith P, Karunakaran KR, Sekhar C (2018) Economic and environmental aspects of pokkali rice prawn production system in central Kerala. *International Journal of Fisheries and Aquatic Studies* **6** (4), 8-13.

Rao BM (2019) Challenges and future of sustainable shrimp farming in India. In 'Souvenir, BRAQCON-World brackishwater aquaculture conference'. pp. 105-106. (Society of Coastal Aquaculture and Fisheries (SCAFi) and Central Institute of Brackishwater Aquaculture (CIBA): Chennai, India)

Rao DVS, Raju VT (1998) 'Economics of fisheries technologies.' 1st edn. (Ambica Book Agency: Jaipur, India)

Rao GRM, Ravichandran P (2001) Sustainable brackishwater aquaculture. In 'Sustainable Indian Fisheries.' (Ed. TJ Pandian). pp. 134-151. (National Academy of Agricultural Science: New Delhi, India)

Rao NS (2005) Comparative economics of small-scale aquaculture in India: Constraints and prospects. Paper presented at Sustain Fish 2005-International symposium on improved sustainability of fish production systems and appropriate technologies for utilization. 16-18 March 2005, Cochin. Cochin University of Science and Technology, Cochin, India and University Grants Commission, New Delhi, India.

Rao PS (1996) Investment pattern for aquacultural farms. *Journal of Fisheries Economics and Development* **3** (1), 31- 40.

Rao PV (1978) Recent technological advances in coastal aquaculture in India. In proceedings of the seminar on the role of small-scale fisheries and coastal aquaculture in integrated rural development, 6-9 December 1978, Madras. CMFRI special publication no. 5. pp. 93-96. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Rao PV, Soni SC (1988) Diseases and parasites of penaeid prawns of India - A short review. *Journal of the Indian Fisheries Association* **18,** 289-298.

Rashid MHA (2002) An economic study on shrimp farming in Bangladesh. PhD thesis (University of Innsbruck: Austria)

Ravaniah G, Georgeenakumari P, Murthy CVN (2010) Water quality analysis of Pennar estuary, Nellore. *Journal of Current Sciences* **15** (2), 321-334.

Ravisankar T, Sarada C, Krishnan M (2005) Diversification of fish culture and exports among major shrimp-producing countries of Asia: A spatial and temporal analysis. *Agricultural Economics Research Review* **18**, 187-195

Rawool MS (2005) Efficacy and constraints in adoption of improved aquaculture practices by shrimp farmers in Thane district of Maharashtra. MFSc thesis (Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth: Dapoli, Maharashtra, India).

Ray S, Mondal P, Paul AK, Iqbal S, Atique U, Islam MS, Mahboob S, Al-Ghanim KA, Al-Misned F, Begum S (2021) Role of shrimp farming in socio-economic elevation and professional satisfaction in coastal communities. *Aquaculture Reports* **20** 100708.

Ray WM, Chien YH (1992) Effects of stocking density and aged sediment on tiger prawn, *Penaeus monodon*, nursery system. *Aquaculture* **104** (3-4), 231-248.

Reddy GP, Reddy MN, Sontakki BS, Prakash DB (2008) Measurement of efficiency of shrimp (*Penaeus monodon*) farmers in Andhra Pradesh. *Indian Journal of Agricultural Economics* **63** (4), 653-657.

Reddy GR (2004) Economic analysis of shrimp aquaculture in West Godavari district of Andhra Pradesh, India. *Journal of Fisheries Economics and Development* **2**, 1-24.

Reddy PV (1997) A study on the entrepreneurial characteristics and farming performance of fish farmers in Nellore district of Andhra Pradesh. PhD thesis (Acharya NG Ranga Agricultural University: Hyderabad, India).

Reddy VR, Reddy PP, Kumar UH (2004) Ecological and economic aspects of shrimp farming in Andhra Pradesh. *Indian Journal of Agricultural Economics* **20** (1), 435- 447.

Reisinger EJ (1985) Harvesting cultured shrimp. In ‘Texas shrimp farming manual: an update on current technology' (Eds GW Chambelain, MG Haby, RJ Miget) pp. 49 -56. (Texas A&M University: College Station, Texas, USA)

Resmi TR (2004) Hydrogeochemical evaluation of inorganics and bioorganics in selected aquatic environments. PhD thesis (Cochin University of Science and Technology: Cochin, India)

Reymen D, Gerard M, Beer PD, Meierkord A, Paskov M, Stasio VD, Donlevy V, Atkinson I, Makulec A, Famira-Mühlberger U, Lutz H. (2015). Labour market shortages in the European Union. Report no. IP/A/EMP/ST/2013-06, Policy Department A: Economic and Scientific Policy, Directorate General for Internal Policies, European Parliament. Available at: http://www.europarl.europa.eu/studies [Verified 11 January 2022]

Rhodes RJ, Sandifer PA, Whetstone JM (1987) A preliminary financial analysis of semi-intensive shrimp farming in South Carolina. Technical report no. 64, South Carolina Marine Research Center, South Carolina, USA

Ricotta C (2005) Through the jungle of biological diversity. *Acta Biotheoretica* **53**, 29–38. doi: https://doi.org/10.1007/s10441-005-7001-6

Roberts DW (1986) Ordination on the basis of fuzzy set theory. *Vegetatio* **66** (3), 123-131. doi: https://www.jstor.org/stable/20037322

Robertson L, Samocha TM, Lawrence AL (1992) Post nursery grow out potential of *Litopenaeus vannamei* in an intensive raceway system. *Ciencias Marinas* **18,** 47-56.

Rosas C, Cuzon GY, Taboada G, Pascual C, Gaxiola G, Wormhoudt AV (2001) Effect of dietary protein and energy levels on growth, oxygen consumption, haemolymph and digestive gland carbohydrates, nitrogen excretion and osmotic pressure of *Litopenaeus vannamei* (Boone) and *L. setiferus* (Linne) juveniles (Crustacea, Decapoda). *Aquaculture Research* **32**, 531-547.

Roshnath R (2014) Fishing for living: Shrimp farmer's perception of heronry birds in Kannur District, Kerala, India. *International Journal of Research* **1** (6), 188-199.

Roshnath R, Arjun CP, Ashokkumar M, Chandramohan B (2014) Bird's threat: Perception of shrimp farmers in coastal areas of Villupuram and Cuddalore district, Tamil Nadu, India. *Research Journal of Animal, Veterinary and Fishery Sciences* **2**(9), 1-5. Available at www.isca.me [Verified 11 January 2022)

Rousseau R, Hecke PV (1999) Measuring biodiversity. *Acta Biotheoretica* **47,** 1–5.

Ruckes E (1994) Can aquaculture fill the market gap? *FAO Aquaculture Newsletter* **6,** 17-18.

Sadafule NA, Salim SS, Pandey SK (2013) Economic analysis of shrimp farming in the Coastal districts of Maharashtra. *Journal of Fisheries* **1,** 42-54.

Sahadevan P (1990) Aerators in Aquaculture. *Fishing Chimes* **10** (6), 13-15.

Sahadevan P (1991) Transportation and storage of shrimp feed. *Fishing Chimes* **11** (9), 50-51.

Sahadevan P (1992) Protein requirement of the postlarvae and juveniles of the giant freshwater prawn, *Macrobrachium rosenbergii* (de Man). MFSc thesis (Kerala Agricultural University: Thissur, India)

Sahadevan P (2012) Reasons for the low productivity of shrimp farms in Kerala. *Fishing Chimes* **31** (12), 27-30.

Sahadevan P (2013) Development of Aquaculture in Kerala: Strategies. *Fishing Chimes* **32** (10), 62-67.

Sahadevan P (2014) Aquaculture in Kerala: The ways to traverse. Paper presented in the global agro meet- 2014. 6-7 November 2014, Adlex International Convention Centre, Kochi. Department of Agriculture, Kerala, India.

Sahadevan P (2016a) Coastal aquaculture in Kerala- Status, strategies for development and perspective planning. Paper presented in the national seminar on aquaculture development in Kerala. 9 July 2016, Kollam. Department of Fisheries, Kerala, India.

Sahadevan P (2016b) Status and potential of rural aquaculture in Kerala. Paper presented in the international seminar on rural aquaculture. 4 July 2016, Kochi. Kerala University of Fisheries and Ocean Studies (KUFOS), Panangad, Kochi, India.

Sahadevan P (2016c) Diversity of fishes, crustaceans and molluscs of Puthuvypeen of Ernakulam District, Kerala, South India. *International Journal of Fisheries and Aquatic Studies* **4** (6), 101-107.

Sahadevan P (2019) Shrimp farming in India- Some policy issues. Paper presented in the 'Shrimp Class' for overseas delegates, 3-6 December 2019, Kochi. Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, India.

Sahadevan P, Sureshkumar S (2019) Status of shrimp farming in Kerala. Paper presented in the international conference on aquatic resources and blue economy (AQUABE 2019). 28-30 November 2019, Kochi. Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi, India.

Sahadevan P, Sureshkumar S (2020a) Shrimp aquaculture in India – the way forward. Paper presented in the 3rd international symposium on marine ecosystems challenges and opportunities (MECOS3), 7-10 January 2020, Kochi. Marine Biological Association of India (MBAI), Kochi, India.

Sahadevan P, Sureshkumar S (2020b) Sustainability of traditional prawn farming practice of southern India in changing climatic conditions: an economic evaluation. In 'Book of abstracts, Climfishcon 2020: International conference on the impact of climate change on the hydrological cycle, ecosystem, fisheries and food security. 11-14 February 2020, Cochin. (Eds BM Kurup, MR Boopendranath, M Harikrishnan, AV Shibu, VP Ancy, NM Sekharan, S Sabu, M Sileesh, R Radhika, HS Harisankar, OK Sreedevi, S Sreelakshmi, S Reshma, P Anju, Sariga) pp. 108-109. (Cochin University of Science and Technology: Cochin, India)

Sahu R, Swadesh P, Kumar NR, Krishnan M (2014) Adoption of better management practices (BMPs) and constraints in shrimp farming in selected districts of Odisha. *Indian Journal of Fisheries* **61** (2), 151-155.

Sahu S, Biswas PK, Dora KC, Adhikari S, Maity A, Majhi A (2013) Management strategy for shrimp (*Penaeus Monodon* Fabricius) farming at Bhagbanpur region in Purba Medinipur District of West Bengal, India. *Exploratory Animal and Medical Research* **3** (1), 65-69.

Sahu S, Jana AK, Sarkar S, Dora KC, Chowdhury S (2012) Econometric modelling of shrimp (*Penaeus monodon* Fabricius) Farming at Nandigram-II block, Purba Medinipur district (WB). *International Journal of Innovative Research in Science, Engineering and Technology* **1** (1), 121-124.

Saikia AK, Abujam SK, Das DN, Prasad BS (2015) Economics of paddy cum fish culture: A case study in Sivsagar, Assam. *International Journal of Fisheries and Aquatic Studies* **2** (5), 198-203.

Saju KA, Sukumaran N (1999) On stocking density production and economics of tiger and white shrimp extensive culture. *Fishing Chimes* **19**(9), 25-27.

Salim SS, Biradar RS (2001) 'Fisheries project formulation and management.' (Central Institute of Fisheries Education (CIFE): Mumbai, India)

Salim SS, Biradar RS, Pandey SK (2004) 'Economic analysis of fisheries projects.' (Central Institute of Fisheries Education (CIFE): Mumbai, India)

Salim SS, Biradar RS, Pandey SK (2005) 'Fisheries economics and marketing- An introduction.' (Central Institute of Fisheries Education (CIFE), Mumbai, India)

Salunkhe AB (2018). Efficacy and constraints in adoption of *Litopenaeus vannamei* (Boone, 1931) culture practices by the farmers of North Konkan region of Maharashtra. MFSc thesis (Dr Balasaheb Sawant Konkan Krishi Vidyapeeth: Dapoli, Maharashtra, India).

Salve BS, Hiware CJ (2006) Studies on water quality of Wanparkalpa reservoir, Nagapur, Near Parli Vaijinath, Dist Beed, Marathwada Region. *Journal of Aquatic Biology* **21** (2), 113-117.

Sambasivam S, Subramanian P, Krishnamurthy K (1982) Observations on growth and conversion efficiency in the prawn *Penaeus indicus* (H. Milne Edwards) fed on different protein levels. In 'Proceedings of the symposium on coastal aquaculture Part 1'. 12-18 January 1980, Cochin. (Eds EG Silas, PV Rao, PVR. Nair, K Alagarswami, T Jacob, KC George, K Rengarajan, PP Pillai, KJ Mathew, VK PiIlai, AG Ponniah) pp. 406-408. (Marine Biological Association of India (MBAI): Cochin, India)

Samikutty V (1977) Investigations on the salinity problems of pokkali and kaipad areas of Kerala State. MSc (Ag) thesis (Kerala Agricultural University: Thrissur Kerala, India)

Samocha TM, Lawrence AL, Biedenbach JM (1993) The effect of vertical netting and two-water circulation patterns on growth and survival of *Litopenaeus vannamei* postlarvae in an intensive raceway system. *Journal of the Applied Aquaculture* **2** (1), 55-64.

Samocha TM, Lawrence AL, Bray WA, Collins CA, Castille FL, Lee PG, Davies CJ (1999) Production of marketable *Litopenaeus vannamei* in greenhouse enclosed raceways in the Arizona desert using ground saline water. In 'Book of abstracts, World Aquaculture Society Annual Conference'. p. 669. (World Aquaculture Society: Sydney, Australia)

Samocha TM, Lawrence AL, Pooser D (1998) Growth and survival of juvenile *Penaeus vannamei* in low salinity water in a semi closed recirculating system. *Israeli Journal of Aquaculture- Bamidgeh* **50** (2), 55-59.

Sanchez-Zazueta E, Martinez-Cordero FJ (2009) Economic risk assessment of a semi-intensive shrimp farm in Sanola, Mexico. *Aquaculture Economics & Management* **13**, 312–327. doi: 10.1080/136573009033 51685

Sandifer PA, Hopkins JS, Stokes AD (1987) Intensive culture potential of *Penaeus vannamei. Journal of World Aquaculture Society* **18,** 94-100. doi: https://doi.org/10.1111/j.1749-7345.1987.tb00423.x

Sandifer PA, Hopkins JS, Stokes AD (1988) Intensification of shrimp culture in earthen ponds in South Carolina: Progress and prospects. *Journal of World Aquaculture Society* **19**, 218-226. doi: https://doi.org/10.1111/j.1749-7345.1988.tb00783.x

Sandifer PA, Smith TIJ (1976) Effects of population density on growth and survival of *Macrobrachium rosenbergii* reared in recirculating water management systems. In 'Proceedings of the 6th annual workshop of the World Mariculture Society' (Eds JW Avault, R Miller). pp. 43-53. (Lousiana State University Press: Baton Rouge, Lousiana, USA)

Sanhotra MK (1994) 'Shrimp feed formulation and management.' CMFRI special publication no.60. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Sankaranarayanan VN, Qasim SZ (1969) Nutrients of the Cochin Backwater in relation to environmental characteristics. *Journal of Marine Biology* **2,** 236-247.

Santhanakrishnan G (1999) Indian aquaculture in the 21st century: Prospects and the perspectives for sustainable development. *Seafood Export Journal* **26**(3), 5-13.

Santhi GR, Binitha NK, Suresh PR, Ebimol NI (2017) Assessment of physical and chemical properties of soil samples in kaipad tracts of Kannur District, India. *International Journal of Current Microbiology and Applied Sciences* **6** (11), 1464-1475.

Santhosh S, Badusha M (2017) Water quality assessment of Ashtamudi lake with special reference to environmental pollution. *Eco- Chronicle*, **12** (4),105-110.

Sapsford R, Jupp V (2006) 'Data collection and analysis.' 2nd edn. (SAGE Publications, London, UK)

Saraswathi R, Muralidhar M, Balasubramanian CP, Rajesh R, Suvarna S, Kumararaja P, Nagavel A, Vijayan KK (2020) Adaptation of *Penaeus vannamei* to climate change induced steady and drastic changes in salinity. In 'Book of abstracts, Climfishcon 2020: International conference on impact of climate change on hydrological cycle, ecosystem, fisheries and food security'. 11-14 February 2020, Cochin. (Eds BM Kurup, MR Boopendranath, M Harikrishnan, AV Shibu, VP Ancy, NM Sekharan, S Sabu, M Sileesh, R Radhika, HS Harisankar, OK Sreedevi, S Sreelakshmi, S Reshma, P Anju, Sariga) pp. 75. (Cochin University of Science and Technology: Cochin, India).

Saraswathy R, Ravisankar T, Ravichandran P, Vimala DD, Jayanthi M, Muralidhar M, Manohar C, Vijay M, Santharupan TC (2016) Assessment of soil and source water characteristics of disused shrimp ponds in selected coastal states of India and their suitability for resuming aquaculture. *Indian Journal of Fisheries* **63** (2),118-122.

Sarkar B (2010) Application of nanotechnology for improved aquaculture practices and research. *Fishing Chimes* **30** (8), 47-49.

Sarkar UK, Mishal P, Karnatak G, Das AK, Lianthumluaia L, Debnath D, Nag SK, Bakshi S, Ghosh BD, Das BK (2020) Climate resilient pen system (CRPS): An effective adaptation strategy for production enhancement and conservation in floodplain wetlands. In 'Book of abstracts, Climfishcon 2020: International conference on impact of climate change on hydrological cycle, ecosystem, fisheries and food security'. 11-14 February 2020, Cochin. (Eds BM Kurup, MR Boopendranath, M Harikrishnan, AV Shibu, VP Ancy, NM Sekharan, S Sabu, M Sileesh, R Radhika, HS Harisankar, OK Sreedevi, S Sreelakshmi, S Reshma, P Anju, Sariga) pp. 83. (Cochin University of Science and Technology: Cochin, India)

Sarker C (2004) Socioeconomic aspects of pond fish cultured women in some selected areas of Habigonj district. MS thesis (Department of Fisheries Management, Bangladesh Agricultural University: Mymensingh, Bangladesh)

Sarma BC (1988) Social issues in aquaculture. In 'Aquaculture research needs for 2000 AD.' (Ed. KK Trivedi) pp. 399-405. (Oxford& IBH publishing Company: New Delhi)

Sarmah TD (2011) Temporal variation in the hydrography and biodiversity of the Cochin backwaters of Puduveypu region. PG thesis (College of Fisheries, Kerala Agricultural University: Cochin, India)

Sasidharan NK, Abraham CT, Rajendran CG (2012) Spatial and temporal integration of rice, fish and prawn in the coastal wetlands of Central Kerala, India. *Journal of Tropical Agriculture* **50** (1-2), 15-23.

Satapathy D, Panda S (2009) 'Fish Atlas of Chilika' (Chilika Development Authority: Bhubaneswar, India)

Sathe AR (2008) Adoption of shrimp health management practices in the North Konkan region of Maharashtra. MFSc thesis (Dr Balasaheb Sawant Konkan Krishi Vidyapeeth: Dapoli, Ratnagiri, Maharashtra)

Satheesh AV, Sharma BM, Sharma VK (1985) Impact of diversification and liberal credit policy on income and employment of non-viable farmers in Pithapuram Block of East Godavari District (AP). *Indian Journal of Agricultural Economics,* **40** (3), 323-329.

Sathiadhas R (1992) Production and marketing of marine fisheries in Tamil Nadu. PhD thesis (Madurai Kamaraj University: Madurai, India)

Sathiadhas R, Joseph J (2001) Economics of diversified coastal aquaculture production systems in Kerala. In 'Proceedings of the international workshop on aquaculture and environment'. 13-14 July 2001, Kochi, Kerala, India.

Sathiadhas R, Najmudeen TM (2004). Economic evaluation of mud crab farming under different production systems in India. *Aquaculture Economics & Management* **8** (1-2), 99-110. doi: 10.1080/13657300 409380355

Sathiadhas R, Najmudeen TM, Prathap SK (2009) Break-even analysis and profitability of aquaculture practices in India. *Asian Fisheries Science* 22, 667-680.

Sathiadhas R, Narayanakumar R, Aswathy N (2012) ‘Marine fish marketing in India.’ (Central Marine Fisheries Research Institute (CMFRI): Kochi, india)

Sathiadhas R, Narayanakumar R, Najmudeen TM, Jayan KN, Joseph MA, Alagarsamy A, Rajan J (2006) Impact of environmental threats on marine fishery resources of coastal Keala: An economic assessment. In 'Proceedings of Sustain Fish 2005 -International symposium on improved sustainability of fish production systems and appropriate technologies for utilization' (Eds BM Kurup, K Ravindran) pp. 832-849. (School of Industrial Fisheries, Cochin University of Science and Technology: Cochin, India)

Sathiadhas R, Panikkar KKP, Satyavan UK, Jacob T (1989) Economic evaluation of paddy-prawn integrated farming in Kerala. *Seafood Export Journal* **21** (11), 9-21.

Sathiadhas R, Reghu R, Suresh VK (1996) Economic evaluation of composite culture practices of crab fattening and fish-shrimp farming in Kerala. *Fishing Chimes* **16,** 31 -34.

Sathiadhas R, Sehara DBS, Panikkar KKP, Narayanakumar R (2000) Economics of different production technologies in culture systems. In 'Marine fisheries research and management'. (Eds VN Pillai, NG Menon) pp. 677-687. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Sawant PB, Sawant BT (2003) Constraints in traditional shrimp farming in West Bengal. *Indian Journal of Extension Education* **30** (1&2), 12-17.

Schaeperclaus W (1933)' Textbook of pond culture: Rearing and keeping of carp, trout and allied fishes.' Fishery leaflet 311 (US Department of Interior, Fish and Wildlife Service: Washington)

Schmidt- Nielsen K (1999) ‘Fisiologia animal: adaptação e meio ambiente.’ 5th edn. (Santos: São Paulo, Brazil)

Schmidt RH, Johnson RJ (1984) Bird dispersal recordings: an overview. In ‘Vertebrate pest control and management materials: Fourth symposium’. Special technical publication no. 817. pp. 43-65. (The American Society for Testing and Materials (ASTM): Philadelphia, USA)

Schneider S, Sarukhan J, Adejuwon J, Azar C, Baethgen W, Hope C, Moss R, Leary N, Richels R, van Ypersele J-P (2001) Overview of impacts, adaptation, and vulnerability to climate change. In ‘Climate change 2001: Impacts adaptation, and vulnerability.’ Contribution of working group II to the third assessment report of the inter-governmental panel on climate change. (Eds JJ McCarthy, OF Canziani, NA Leary, DJ Dokken, KS White). pp. 75- 103. (Cambridge University Press: Cambridge, United Kingdom).

Scones I (1988) Sustainable rural livelihoods: a frame work for analysis. IDS working paper no. 72. Institute of Development Studies, Brighton, UK. Available at: https://opendocs.ids.ac.uk/opendocs/handle/20.500. 12413/ 3390 [Verified 11 January 2022)

Seaby RMH, Henderson PA (2006) 'Species diversity and richness version 4.' (Pisces Conservation Ltd: Lymington, England)

SEAFDECAQD (1989) Nursery ponds in prawn farming. *Aqua Farm News* **7**(2), 13-15.

Sebastian MJ, Thampy DM, Rajendran CG (1978) Preliminary experiments on tiger prawn culture and report on seed prospecting of penaeid prawns in Kerala backwaters. Paper presented in the first national symposium on shrimp farming. 16-18 August 1978, Bombay. Marine Products Export Development Authority, Cochin, India.

Seema V (2015) Biotic production potential in relation to environmental status of the Ashtamudi wetland ecosystem, Kerala. PhD thesis (Mahatma Gandhi University: Kottayam, India)

Segal E, Roe A (1975) Growth and behaviour of post-juvenile *Macrobrachium rosenbergii* (de Man) in closed confinement. *Proceedings of the World Mariculture Society* **6**, 67-88.

Seidman ER, Lawrence AL (1985) Growth, feed digestibility, and proximate body composition of juvenile *Penaeus vannamei* and *Penaeus monodon* grown at different dissolved oxygen levels. *Journal of the World Aquaculture Society* **16** (1-4), 333–346. doi: https://doi.org/10.1111/ j.1749-7345. 1985.tb00214. x.

Selvam S, Ramaswamy C (2001) Socio-economic and environmental impacts of shrimp farming. In 'Aquaculture development in India: Problems and prospects' (Eds M Krishnan, PS Birthal) pp.52-58. (National Centre for Agriculture Economics and Policy Research: New Delhi, India).

Sen A, Roy M (2015) Socio-economic status of fish farmers in Tripura, India. *International Journal of Current Research* **7** (6),17090-17096.

Shah WA, Phillips MJ, Kamal S, Jahan I, Sarker J (2000) The economics of bagda shrimp (*Penaeus monodon*) farming in coastal areas of Bangladesh. In 'Grassroots voice. Volume-III (Issues I & II).' (Ed. S Sen) pp. 10-15. (Bangladesh Resource Centre for Indigenous Knowledge: Dhaka, Bangladesh)

Shahid MA, Islam J (2003) Impact of denudation of mangrove forest due to shrimp farming on coastal environment in Bangladesh. In 'Environmental and socioeconomic impacts of shrimp farming in Bangladesh: Technical proceedings of the BAU-NORAD workshop'. 5 March 2002, Dhaka, Bangladesh' (Ed. MA Wahab) pp. 49–60. (Bangladesh Agricultural University: Mymensingh, Bangladesh)

Shahkar E, Yun H, Park G, Jang IK, Kim SK, Katya K, Bai SC (2014) Evaluation of optimum dietary protein level for juvenile white leg shrimp (*Litopenaeus vannamei*). *Journal of Crustacean Biology* **34,** 552-558. doi: https://doi.org/10.1163/1937240X-00002267

Shaleesha A, Stanley VA (2000) Involvement of rural women in aquaculture: An innovative approach. *Naga*, **23** (3), 13-17.

Shang Y (1992) Prospects of aquaculture development in Asia. Paper presented at the third Asian Fisheries Forum, 26-30 October 1992, Singapore. Asian Fisheries Society, Manila, Philippines

Shang YC (1981) 'Aquaculture economics: Basic concepts and method of analysis.' (Westview Press, Inc.: Colorado, USA)

Shang YC (1983a) The economics of marine shrimp farming: a survey. In 'Proceedings of the first international conference on warmwater aquaculture- Crustacea'. (Eds GL Rogers, R Day, A Lim) pp. 7-16. (Brigham Young University: Laie, Hawaii, USA)

Shang YC (1983b) Economic aspects of aqua farm construction and maintenance. Available at https://www.fao.org/3/x5744e/x5744e0p.htm [Verified 20 December 2021)

Shang YC (1990) 'Aquaculture economic analysis: An introduction.' (World Aquaculture Society: Baton Rouge, USA)

Shang YC, Fujimura T (1977) The production economics of freshwater prawn (*Macrobrachium rosenbergii*) farming in Hawai. *Aquaculture* **11,** 99-110. doi: https://doi.org/10.1016/0044-8486(77)90068-0

Shang YC, Leung P, Ling BH (1998) Comparative economics of shrimp farming in Asia. *Aquaculture* **164,** 183-200.

Shannon CE, Weaver W (1949) 'The mathematical theory of communication.' (University of Illinois Press: Urbana, USA)

Sharma BK, Kumar D, Das MK, Das SR (1979). Integrated aquaculture, crop-livestock-fish farming and its cost benefits. In 'CIFRI Souvenir'. pp. 120–124. (Central Inland Fisheries Research Institute (CIFRI): Barrackpore, India)

Shaw APM (2003) 'Economic guidelines for strategic planning of tsetse and trypanosomiasis control in West Africa', PAAT technical and scientific series 5 (Food and Agriculture Organisation: Rome)

Shawon NA, Prodhan MMH, Khan MA, Mitra S (2018) MitraFinancial profitability of small-scale shrimp farming in a coastal area of Bangladesh. *Journal of Bangladesh Agricultural University* **16**(1): 104–110. doi: 10.3329/jbau.v16i1.36490

Sheikh S, Goswami MM (2013) Socio-economic condition of fishers of Chandakhola wetland, Dhubri, Assam, India. *Bulletin of Environment, Pharmacology and Life Sciences* **3** (1), 257-261.

Shetty HPC (1963) A preliminary fishery survey of the Vembanad backwaters, Kerala. Survey reports no 2. Central Inland Fisheries Research Institute, Barrackpore, India.

Shetty HPC (1965) Observations on the fish and fisheries of the Vembanad backwaters, Kerala. *Proceedings of the National Academy of Science* **35**, 115-130

Shiau SY (1998) Nutrient requirements of penaeid shrimps. *Aquaculture* **164** (1), 77-93.

Shiau SY, Chou BS (1991) Effects of dietary protein and energy on growth performance of tiger shrimp *Penaeus monodon* reared in seawater. *Nippon Suisan Gakkaishi* **57**, 2271–2276.

Shingare PE, Shirgur GA (2000) Minimum input-oriented paddy-cum-fish culture in summer: A case study. *Fishing Chimes* **20** (5), 45-46.

Shinji J, Nohara S, Yagi N, Wilder M (2019) Bio-economic analysis of super-intensive closed shrimp farming and improvement of management plans: a case study in Japan. *Fisheries Science* **85,** 1055-1065. doi: https://doi.org/10.1007/s12562-019-01357-5

Shivaram CM, Raj RP (1997) Dietary lipid requirements of the juveniles of Indian white prawn *Penaeus indicus* H. Milne Edwards. *Journal of Aquaculture in the Tropics*, **12**(3), 165-180.

Shofiquzzoha AFM., Alam MJ, Moniruzzaman M (2009) Species diversification in coastal aquaculture: production potentials of shrimp (*Penaeus monodon*) with mono and mixed sex tilapia. *Bangladesh Journal of Fisheries Research* **13** (2),179-184.

Shyna PA, Joseph S (2000) A micro analysis of problems of displaced women agricultural labourers with special emphasis to the Pokkali fields of Vypinkara. Integrated Rural Technology Centre, Palakkad. Kerala Research Programme on Local Level Development, Centre for Development Studies, Thiruvanathapuram.

Siar SV, Johnston WL, Sim SY (2002) Study on economics and socioeconomics of small-scale marine fish hatcheries and nurseries, with special reference to grouper systems in Bali, Indonesia. Report prepared under APEC project FWG 01/2001 – Collaborative APEC grouper research and development network. Asia-Pacific marine finfish aquaculture network publication 2/2002. Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand.

Silas EG (1978) Status of prawn culture in India and strategy for its future development. Paper presented in the first national symposium on shrimp farming. 16-18 August 1978, Bombay. Marine Products Export Development Authority, Cochin, India.

Silas EG, Rao PV (1978) A master plan for the development of prawn culture in Central Kerala. CMFRI bulletin no. 28. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India)

Simpson EH (1949) Measurement of diversity. *Nature* **163,** 688.

Singh AJ, Gupta VK (1984) Fish seed production, marketing and distribution-an integrated approach. In ‘Strategy for development of inland fishery resources in India.’ (Eds UK Srivastava, S Vathsala) pp. 55-90. (Concept Publishing Company: New Delhi, India).

Singh CS, Das M (1994) Prospective of fisheries in rural development. In ‘Role of fisheries in rural development.’ (Ed. S Giraippa) pp. 159-173. (Daya Publishing House: Delhi, India)

Singh K (2007) Economics and determinants of fish production and its effects on family income inequality in West Tripura District of Tripura. *Indian Journal of Agriculture Economics* **62** (1), 113-125.

Singh K, Bhattacharjee S (1994) The Bergram Majhipara common pool fish pond- A case study. In 'Managing common pool resources- Principles and case studies.' (Ed. K Singh) pp 288-307. (Oxford University Press: Bombay, India)

Singh P, Tyagi A, Kumar BTN (2019) Vannamei culture in saline water of Mansa, Punjab, a success story. In 'Proceedings of world brackishwater aquaculture conference 2019'. (Central Institute of Brackishwater Aquaculture (CIBA): Chennai, India) (Abstract)

Singh RKP (2003) 'Economics of aquaculture'. (Daya Publishing House: Delhi, India)

Singh RKP, Sing LN, Prasad KK (1995) Economics of fish production in Hasanpur block, Samastipur District, Bihar. *Journal of Fisheries Economics and Development* **2** (2), 1-15.

Singh RKP, Singh LN, Prasad KK (2003) Economics of fish production in Hasanpur block, Samastipur district. Bihar. *Journal of Fisheries Economics and Development* **II** (2), 1-15.

Sinha M, Katiha PK (2002) Management of inland fisheries resources under different property regimes. In 'Institutionalizing common pool resources.' (Ed. DK Marothia) pp. 437-460. (Concept Publishing Company: New Delhi, India).

Sinha SP and Jha MN (1968) Development of fisheries- a study of the fisheries co-operative societies in the district of Darbhanga, Bihar. *Indian Journal of Agricultural Research*, **23** (4), 243-247.

Sinha VRP (1976) New trends in fish farm management. Report of the FAO technical conference on aquaculture, Kyoto, Japan 26 May- 2 June 1976. FAO Fisheries report no.188, Food and Agriculture Organisation, Rome, Itlay.

Sinha VRP (1983) Effects of various physico- chemical factors on pond productivity and fish growth. Lecture delivered for the short-term training course on aquaculture engineering, 3 January, -28 February 1983, Indian Institute of Technology (IIT), Kharagpur, India.

Sinha VRP (1999) Rural aquaculture in India. RAP publication 1999/21, Regional office for Asia and the Pacific, Food and Agriculture Organization of the United Nations, Bangkok, Thailand.

Sinha VRP, Srivastava HC (1983). 'Aquaculture productivity'. (Oxford and IBH Publishing Co.: New Delhi)

Slater MJ (2017) Societal and economic impacts of aquaculture. *Journal of the World Aquaculture Society* **48** (4), 539-541.

Smith LL, Lawrence AL (1988) Protein requirement of larval *Penaeus vannamei*. Paper presented at the 19th annual meeting of the World Aquaculture Society. 2-9 January 1988, Honolulu, Hawai, USA.

Smith LL, Lee PG, Lawrence AL, Strawn K (1985) Growth and digestibility by three sizes of *Penaeus vannamei* Boone: effects of dietary protein level and protein source. *Aquaculture* **46,** 85-96.

Solis NB (1988) Biology and Ecology. In 'Biology and culture of *Penaeus monodon*' pp 3-36 (Aquaculture Department, Southeast Asian Fisheries Development Center: Tigbauan, Iloilo, Philippines)

Son VN, Phuong NT, Hai TN, Yakupitiyage A (2010) Production and economic efficiencies of intensive black tiger prawn (*Penaeus monodon*) culture during different cropping seasons in the Mekong delta, Vietnam. *Aquaculture International* **19**, 555-566. doi: 10.1007/s10499-010-9371-2

Sookying D, Silva FSD, Davis DA, Hanson TR (2011) Effects of stocking density on the performance of Pacific white shrimp *Litopenaeus vannamei* cultured under pond and outdoor tank conditions using a high soybean meal diet. *Aquaculture* **319,** 231-239.

Sorensen T (1948) A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analysis of the vegetation on Danish commons. *Biologiske Skrifter* **5**: 1–34.

Soto-Rodriguez SA, Gomez-Gil B, Roque A (2009) Shrimp diseases and molecular diagnostic methods. In ‘Aquaculture microbiology and biotechnology’ Vol. 1. (Eds D Montet, RC Ray) pp. 101-131. (Science Publishers: Enfield, NH, USA)

Soundarapandian P, Gunalan, B (2008) Recent technology for the survival and production of giant tiger shrimp *Penaeus monodon* along South East Coast of India. International *Journal of Zoological Research* **4** (1), 21-27. doi: 10.3923/ijzr.2008.21.27

Spanier E (1980) The use of distress calls to repel night herons (*Nycticarax nycticarax*) from fish ponds. *Journal of. Applied Ecology* **17**, 284-287.

Sreedharan TP (2004) Biological diversity of Kerala: A survey of Kalliasseri panchayat, Kannur district. Discussion paper no. 62, Kerala Research Programme on Local Level Development, Centre for Development Studies, Thiruvananthapuram, India.

Srinath K, Sridhar M, Kartha PNR, Mohan AN (2000) Group farming for sustainable aquaculture. *Ocean and Coastal Management* **43** (7), 557-571.

Srinivas D, Venkatrayalu C (2016) Studies on present problems and prospects of shrimp farming in West Godavari district of Andhra Pradesh, India. *Advances in Applied Science Research* **7** (2), 49-54.

Srinivas D, Venkatrayulu C, Swapna B, Swathi AV, Venkateswarlu V (2019) Studies on socio-economic profile, problems and constraints of shrimp farmers in Nellore district of Andhra Pradesh, India. *Asian Journal of Science and Technology* **10** (6), 9731–9735.

Srinivasan N (1968) Economic aspects of fisheries development in Madras state. *Indian Journal of Agricultural Research* **23** (4), 248-255.

Srivastava UK (1992) Aquaculture: Marketing and economics in India. In 'Aquaculture research needs for 2000 AD.' pp. 311-325. (Oxford and IBH Publishing Co. Pvt. Ltd: New Delhi)

Srivastava UK, Dholakia BH, Rao SS, Vathsala S (1990) 'Evaluation of fish farmers' development agencies' programme for freshwater aquaculture.' (Indian Institute of Management: Ahmadabad, India)

Srivastava UK, Dholakia BH, Vathsala S (1987) 'Brackish water aquaculture development in India.' (Concept Publishing Co.: New Delhi)

Srivastava UK, Reddy MD (1983) 'Fisheries development in India - some aspects of policy management.' (Concept Publishing Co.: New Delhi)

Stanley DL (2003) The economic impact of mariculture on a small regional economy. *World Development* **31** (1), 191-210. doi: http://dx.doi.org/10.1016/s0305-750x (02)00176-6

State Planning Board (1997) Ninth five-year plan 1997-2002: Report of the taskforce on fisheries and aquaculture. State Planning Board, Government of Kerala, Thriruvanathapuram, India.

State Planning Board (2020) 'Economic Review 2019.' (Kerala State Planning Board: Thiruvananthapuram, Kerala, India). Available at https://spb.kerala.gov.in/economic-review/ER2020/ [Verified 12 January 2022)

Stephen D, David J, Anand PEV (1993) Conflicting interests in the use of Kerala's penaeid shrimp resources: A case in question. *Journal of Marine Biological Association of India*, **35** (1&2), 29-38.

Stokes AD, Sandifer PA, Hopkins JS, Smiley RA (1985) 'Comparative performance of three species of shrimp (*Penaeus setiferus*, *P. vannamei* and *P. schmitti*) in pond culture.' (Waddell Mariculture Center: Bluffton, South Carolina, USA) (Unpublished manuscript)

Sturmer LN, Lawrence AL (1988) Feeding regimes for enhanced Penaeus vannamei production in intensive nursery raceways. *Journal of World Mariculture Society* **19** (68A) (Abstract).

Sturmer LN, Samocha TM, Lawrence, AL (1992) Intensification of penaeid nursery systems. In 'Marine shrimp culture: principles and practices.' (Eds AW Fast, LJ Lester) pp. 321-344. (Elsevier Science Publishers BV: Amsterdam)

Subrahmanyam M (1973) Experimental studies on growth in *Penaeus monodon* (Fabricius). In 'Proceedings of seminar on mariculture and mechanised fishing'. 28-29 November 1972, Madras (India). pp. 70-73 (Department of Fisheries, Government of Tamil Nadu: Madras, India).

Sudhan C, Mogalekar HS, Ranjithkumar K, Sureshbhai PD (2016) Paddy cum prawn farming (pokkali fields) of Kerala. *International Journal for Innovative Research in Multidisciplinary Field*. **2** (7), 42-46.

Sui L, Ma G, Deng Y (2015) Effect of dietary protein level and salinity on growth, survival, enzymatic activities and amino-acid composition of the white shrimp *Litopenaeus vannamei* (Boone, 1931) juveniles. *Crustaceana* **88,** 82-95. doi: 10.1163/15685403-00003390.

Sujatha CH, Benny N, Raveendran R, Fanimol CL, Samantha NK (2009) Nutrient dynamics in the two lakes of Kerala, India. *Indian Journal of Marine Sciences* **38** (4), 451-456.

Sukumar D (1998) Evaluation and comparison of shrimp farm management practices prospects for sustainability. PhD thesis (Fisheries College and Research Institute: Thoothukudi, Tamil Nadu, India)

Sultan B, Jai C, Sharma S (2003) Physico-chemical characteristics of North Indian lakes. *Journal of Aquatic Biology* **11**(1), 72-78.

Sundar S, Arundhathi V, Sekharan NM (2020) Impact of deluge on the aquaculture systems in a coastal district of the South Indian State, Kerala. In 'Book of abstracts, Climfishcon 2020: International conference on impact of climate change on hydrological cycle, ecosystem, fisheries and food security'. 11-14 February 2020, Cochin. (Eds BM Kurup, MR Boopendranath, M Harikrishnan, AV Shibu, VPAncy, NM Sekharan, S Sabu, M Sileesh, R Radhika, HS Harisankar, OK Sreedevi, S Sreelakshmi, S Reshma, P Anju, Sariga) pp. 110-111. (Cochin University of Science and Technology: Cochin, India)

Sundararajan D, Bose SVC, Venkatesan V (1979) Monoculture of tiger prawn *Penaeus monodon* (Fabricius) in a brackish water pond at Madras. *Aquaculture* **16** (1), 73-75.

Surendran K (1988) Prospects and perspective of shrimp farming in Vypeen island, Cochin. DFSc dissertation (Central Institute of Fisheries Education (CIFE): Bombay, India)

Surendran V, Reddy KM, Rao VS (1991) Semi-intensive shrimp farming-TASPARC's reassuring experience at Nellore. *Fishing Chimes* **10**, 23–29.

Suresh R, Selvaraj P, Ramkumar RK (1992) Costs and returns of composite fish culture in Madurai District, Tamil Nadu. In 'Proceedings of the workshop on aquaculture economics.' 20- 22 November 1991 (Eds SD Tripathi, M Ranadhir, CS Purushothaman) pp. 33-38. (Asian Fisheries Society Indian Branch: Mangalore, India)

Sureshwaran S, Greene C, Rhodes RJ, Browdy CL, Stokes A (1994) Viability of *Penaeus setiferus* versus *Penaeus vannamei* with continuous live harvesting and one final harvest strategies in South Carolina. Technical report number 84, South Carolina State University, South Carolina, USA.

Suriya M, Shanmugasundaram S, Mayavu P (2016) Stocking density, survival rate and growth performance of *Litopenaeus vannamei* (Boone, 1931) in different cultured shrimp farms. *International Journal of Current Research in Biology and Medicine* **1** (5), 26-32. doi: http://dx.doi.org/10.22192/ijcrbm.2016.01.05.004.

Suseelan C (1978) The environmental requirements for culture of marine prawns. In 'Summer institute in breeding and rearing of marine prawns.' CMFR1 special publication no. 3. pp. 103-109. (Central Marine Fisheries Research Institute (CMFRI): Cochin, India).

Suseelan C, Kathirvel M (1982) Prawn seed calendar of Cochin backwaters. In 'Proceedings of the symposium on coastal aquaculture Part 1'. 12-18 January 1980, Cochin. (Eds EG Silas, PV Rao, PVR Nair, K Alagarswami, T Jacob, KC George, K Rengarajan, PP Pillai, KJ Mathew, VK PiIIai, AG Ponniah) pp. 173-182. (Marine Biological Association of India: Cochin, India)

Susilowati T, Hutabarat J, Anggoro S, Zainuri M (2014) The improvement of the survival, growth and production of vannamei shrimp (*Litopenaeus vannamei*) and seaweed (*Gracilaria verucosa*) based on polyculture cultivation. *International Journal of Marine and Aquatic Resource Conservation and Co-Existence* **1** (1), 6-11. doi: https://doi.org/10.14710 /ijmarcc.1.1. p

Swathilekshmi PS, Balasubramani N, Chandrakandan K (2011) Diffusion of scientific shrimp farming through various stages of the adoption period. *Tropical Agricultural Research & Extension* **14** (4), 93-98. doi: 10.4038/tare. v14i4.4850

Swathilekshmi PS, Chandrakandan K, Balasubramani N (2008) Information utilization behaviour and constraint analysis among shrimp farmers. *Indian Journal of Social Research* **45,** 265-272.

Swathilekshmi PS, Chandrakandan K, Kumaran M, Balasubramani N (2005) Socio-economic profile of shrimp farmers and its influence on the extent of adoption of shrimp culture technologies. *Fishery Technology* **42** (2), 225 -230.

Swingle HS (1967) Standardization of chemical analysis for water and pond muds. FAO fisheries report no. 4. Food and Agriculture Organization (FAO), Rome, Italy.

Swingle HS (1972) Keynote address: The present status of aquaculture. *Proceedings of the Mariculture Society* **3,** 15-26.

Tacon AGJ (1993) Feed formulation and on-farm feed management. In ‘Farm-made aquafeeds: Proceedings of the FAO/AADCP regional expert consultation on farm-made aquafeeds.”. 14–18 December 1992, Bangkok, Thailand. (Eds MB New, AGJ Tacon, I Csavas) pp. 61–74 (Food and Agricultural Organisation (FAO): Rome, Italy)

Tacon AGJ, Jory DE, Nunes A (2013) Shrimp feed management: issues and perspectives. In 'On-farm feeding and feed management in aquaculture’. (Eds MR Hasan, MB New) pp. 481–488. FAO fisheries and aquaculture technical paper no. 583, Food and Agriculture Organization (FAO), Rome, Italy.

Taege M, Peters DM, Kunhi KVM (1993) Fish stocks and fish yields of the Malampuzha reservoir, Kerala, India. Indo-German Reservoir Fisheries Development Project, Malampuzha, Palakkad District, Kerala, India.

Taillie C (1979) Species equitability: a comparative approach. In ‘Ecological diversity in theory and practice.’(Eds JF Grassle, GP Patil, W Smith, C Taillie) pp. 51-62. (International Cooperative Publishing House: Fairland, Maryland, USA)

Talukder RK (1999) Financial profitability of shrimp-based farming system in Bangladesh. In 'Proceedings of the closing workshop on economic, social and environmental implications of shrimp-rice integrated farming system in Bangladesh'. 26 December 1999, BIDS, Dhaka (Bangladesh Institute of Development Studies: Dhaka)

Talwar PK, Jhingran AG (1991) 'Inland fishes of India and adjacent countries.' (AA Balkema: Rotterdam, Netherlands)

Tammaroopa K, Suwanmaneepong S, Mankeb P (2016) Socio-economic factors influencing white shrimp production in Chachoengsao province, Thailand. *International Journal of Agricultural Technology* **12** (7.2), 1809-1820.

Tandel JT, Tandel KV, Tandel GM, Patel MR (2016) A socio-economic survey of shrimp aquaculture practices in Valsad district, Gujarat, India. *International Journal of Research in Applied, Natural and Social Sciences* **4** (9), 93-98.

Taw N, Srisombat S, Chandaeng S (2002). *Litopenaes vannamei* trials in Indonesia. Responsible Seafood Advocate, Global Seafood Alliance, 1 December 2002. Available at https://www.globalseafood.org/advocate/l-vannamei-trials-inindonesia-improve-productivity/ [Verified 22 November 2021].

Thampy DM, Jose S, Mohan MV, Koya MSSI (1998) Short-term biculture of tiger prawn *Penaeus monodon* Fabricius and milk fish *Chanos chanos* Forskal in a low saline pond. In 'Proceedings of the first Indian Fisheries Forurn' (Ed. MM Joseph) pp. 139- 141. (The Asian Fisheries Society, Indian Branch: Mangalore, India)

Thitamadee S, Prachumwat A, Srisala J, Jaroenlak P, Salachan PV, Sritunyalucksana K, Flegel TW, Itsathitphaisarn O (2016) Review of current disease threats for cultivated penaeid shrimp in Asia. *Aquaculture* **452**, 69-87. doi: https://doi.org/10.1016/j.aquaculture.2015.10.028

Thomas CD (1994) Extinction, colonisation, and metapopulations: environm-ental tracking by rare species. *Conservation Biology* **8,** 373–378. doi: 10.1046/j.1523-1739.1994.08020373.x

Thomas MM (1972) Food and feeding habits of *Penaeus monodon* Fabricius from Korapuzha estuary. *Indian Journal of Fisheries* **19** (1/2), 202-204.

Thompson EP (1991) 'Customs in common: Studies in traditional popular culture.' (Merlin Press: London, UK)

Thongrak S, Prato T, Chiayvareesajja S, Kurtz W (1997) Economic and water quality evaluation of intensive shrimp production systems in Thailand. *Agricultural Systems* **53**, 121–141. doi: https://doi.org/10.1016/S0308-521X(96)00065-0

Thorpe A, Reid C, van Anrooy RV, Brugere C, Becker D (2006) Asian development and poverty reduction strategies: Integrating fisheries into the development discourse. *Food Policy* **31** (5), 385-400. doi: https://doi.org/10.1016/j.foodpol.2005.09.007

Tidwell JH, Coyle SD, Dasgupta S (2004) Effects of stocking different fraction of size graded juvenile prawns on production and population structure during a temperature limited grow out period. *Aquaculture* **231,** 123-134.

Tietze U (1995) Socio- economic aspects and the role of credit in fish marketing development. *INFOFISH International* **3** (95), 19-21.

Tisdell CA (2001) Aquaculture economics and marketing: An overview. Working paper no. 63, The University of Queensland, Australia. Available at https://www.researchgate.net/publication/37629426 [Verified 21 December 2021]

Tobey J, Clay J, Vergne P (1998) The economic, environmental and social impacts of shrimp farming in Latin America. Coastal management report. Coastal resources management project II, USAID/G/ENV, Coastal Resources Center, University of Rhode Island, USA.

Tokunaga K, Tamaru CS, Ako H, Leung PS (2015) Economics of small-scale commercial aquaponics in Hawaii. *Journal of the World Aquaculture Society* **46**(1), 20-32.

Tonn WM, Magnuson JJ, Forbes AM (1983) Community analysis in fisheries management: an application with northern Wisconsin lakes. *Transactions of the American Fisheries Society* **112,** 368–377.

Tookwinas S (1999) Coastal planning of shrimp farming: carrying capacities, zoning and integrated planning in Thailand. In 'Proceedings of the workshop- Towards sustainable shrimp culture in Thailand and the region'. 28 October–1 November 1996, Hat Yai, Songkhla. (Ed. PT Smith). pp 108-109. (Australian Centre for International Agricultural Reseach: Canberra, Australia)

Torres PLJr (1990) Pond design and construction. In 'Technical and economic aspects of shrimp farming- Proceedings of the aquatec '90 conference.' Kuala Lumpur, Malaysia'. (Eds MB New, H Saram, T Singh) pp. 37-52. (INFOFISH International: Malaysia)

Trejos-Castillo E, Molnar JJ, Meyer ST, Meyer D (2004) Income, food security and poverty reduction: case study of small-scale aquaculture producers in Santa Barbara, Honduras. *Journal of Aquaculture in Tropics* **19** (4), 243-254.

Trimble WC (1980) Production trails for monoculture of white shrimp (*Penaeus vannamei*) or blue shrimp (*P. stylirostris*) with Florida pompano (*Trachinotus carolinus*) in Alabama 1978-1979. *Proceedings of World Mariculture Society* **11**, 44-59.

Tucker CS, Robinson EH (1990) 'Channel catfish farming handbook.'(Van Nostrand Reinhold Company: New York)

Tumanda M (1980) Effects of rotenone containing derris root extract on the mortality of some predator fishes of pond culture prawns under different water temperature– salinity combination. MS thesis (University of San Carlos: Cebu City, Philippines)

Turongruang D, Demaine H (2002) Participatory development of aquaculture extension materials and their effectiveness in transfer of technology: The case of the AIT Aqua outreach programme, Northeast, Thailand. In 'Rural Aquaculture.' (Eds P Edwards, H Demaine, DC Little) pp. 307-322. (CABI Publications: Wallingford, UK)

Udo MT, Okon AO, Lebo PE, Ikpe GB (2005) Improving aquaculture through increased fisheries extension research. In '19th Annual conference of the Fisheries Society of Nigeria'. 29 November - 03 December 2004, Ilorin, pp. 54-57. (Fisheries Society of Nigeria (FISON): Nigeria). http://hdl.handle.net/1834/21647

Umesh NR, Mohan ABC, Ravibabu G, Padiyar PA, Phillips MJ, Mohan CV, Bhat BV (2010) Shrimp farmers in India: Empowering small-scale farmers through a cluster-based approach. In 'Success stories in Asian Aquaculture.' (Eds SS De Silva, FB Davy) pp. 41-66. (Springer: Dordrecht, Netherlands)

UNEP (1999) 'Environmental impacts of trade liberalization and policies for the sustainable management of natural resources: A case study on Bangladesh's shrimp farming industry.' (United Nations Environment Programme (UNEP): New York). Available at http://unep.ch/etb/pub. [Verified 11 November 2021]

United States Department of Agriculture (USDA) (2017) Soil survey manual. (Eds C Ditzler, K Scheffe, HC Monger) USDA Handbook 18. (Soil Science Division Staff, Government Printing Office: Washington, DC).

Unnithan KA (1985) 'Guide to Prawn farming in Kerala.' CMFRI. special publication no. 21. (Central Marine Fisheries Research Institute (CMFRI): Cochin, Kerala, India)

Unnithan VK, Nandan SB, Vava CK (2001) Organic pollution in Cochin backwaters. *Indian Journal of Marine Sciences* **4** (1), 39-42.

Unnithan VK, Nandan SB, Vava CK (2005) 'Fisheries and environmental assessment in selected backwaters of the SouthWest Coast of India.' CIFRI bulletin no. 139. (Central Inland Fisheries Research Institute (CIFRI): Barrackpore, West Bengal, India)

USAID (2009) An assessment of USAID's programs and policies to improve the lives of women and girls: Report provided for the White House Council on women and girls. US Agency for International Development, Washington DC, USA.

Usharani G, Reddy TC, Ravindranath K (1993) Economics of brackish water prawn farming in Nellore district of Andhra Pradesh. *Indian Journal of Aquaculture* **8,** 220-230.

Vadher KH, Manoj K (2014) Study on socio-economic profile of shrimp farmers of Gujarat State, India. *International Journal of Fisheries and Aquatic Studies* **2** (2), 202-205.

Valderrama D, Engle CR (2001) Risk analysis of shrimp farming in Honduras. *Aquaculture Economics and Management* **5** (1/2), 49-68. doi: https://doi.org/10.1080/13657300109380277

Vanaja T (2013) Kaipad – a unique, naturally organic, saline prone rice ecosystem of Kerala, India. *American Journal of Environmental Protection* **2** (2), 42-46. doi: 10.11648/j.ajep.20130202.12

Vanhaecke P, Siddal SE, Sorgeloos P (1984) International study on artemia. XXXII. Combined effects of temperature and salinity on the survival of artemia of various geographical origin. *Journal of Experimental Marine Biology and Ecology* **80**, 259-275. doi: https://doi.org/10.1016/0022-0981(84)90154-0

Varadharajan D, Soundarapandian P (2014) Effect of physico-chemical parameters on species biodiversity with special reference to the phytoplankton from Muthupettai, South East Coast of India. *Journal of Earth Science and Climatic Change* **5** (5), 200-210.

Varghese T, Thampi PS, Money NS (1970) Some preliminary studies on the pokkali saline soils of Kerala. *Journal of the Indian Society of Soil Science* **18**, 65-69.

Varma KK, Cherian CJ, Mrithunjayan PS, Raman NN, Joseph P (2002) Characteristics of temperature and salinity fluctuations in a south Indian estuary: a study of Vembanad Lake, a monsoon influenced estuary. *Earth System Monitor* **12** (4), 9-14.

Velasco M, Lawrence AL, Castille FL, Obaldo, LG (2000) Dietary protein requirement for *Litopenaeus vannamei.* In ‘Avances en Nutrición Acuícola V. Memorias del V. Simposium internacional de nutrición acuícola’. 19-22 Noviembre 2000, Mérida, Yucatán, México (Eds LE Cruz-Suárez, D Ricque-Marie, M Tapia-Salazar, MA Olvera-Novoa, R Civera-Cerecedo) pp. 181-192.

Velayudhan TD, Sulaiman S, Sunny PL (2006) Culture of green mussel at Korapuzha estuary, Kerala, India. In 'Proceedings of Sustain Fish 2005- International symposium on improved sustainability of fish production systems and appropriate technologies for utilization' (Eds BM Kurup, K Ravindran) pp. 304-313. (School of Industrial Fisheries, Cochin University of Science and Technology: Cochin, India).

Venkataraman P (2009) ‘Applied optimization with MATLAB Programming.’ (John Wiley & Sons: New York, USA).

Verdegem MCJ (2000) Sustainable aquaculture and climate change. In ‘Souvenir. Climfishcon 2020: International conference on impact of climate change on hydrological cycle, ecosystem, fisheries and food security’. 11-14 February 2020, Cochin. (Eds BM Kurup, MR Boopendranath, M Harikrishnan, AV Shibu, VP Ancy, NM Sekharan, S Sabu, M Sileesh, R Radhika, HS Harisankar, OK Sreedevi, S Sreelakshmi, S Reshma, P Anju, Sariga) pp. 46-50. (Cochin University of Science and Technology: Cochin, India)

Verghese PU (1980) Potentials of brackishwaler prawn culture in India. In 'Proceedings the first national symposium on shimp farming'. 16-18 August 1978, Bombay. pp. 189- 203. (Marine Products Export Development Authority: Cochin, India)

Verghese PU (1995) National seminar on environmental and social impacts on coastal aquaculture, Madras–1st September 1995. *Fishing Chimes* **15** (9), 9-13.

Verghese PU, Ghosh AN, Das PB (1975) On growth, survival and production of tiger prawn, *Penaeus monodon* (Fabricius) in brackish water ponds. *Bulletin of the Department of Marine Sciences, University of Cochin* **7,** 781-789.

Verghese PU, Varghese AG, Chandran KK, Thomas A, John S (1982) Improved prawn production through selective stocking. In 'Proceedings of symposium on coastal aquaculture.' Part 1. 12-18 January 1980, Cochin. (Eds EG Silas, PV Rao, PVR Nair, K Alagarswami, T Jacob, KC George, K Rengarajan, PP Pillai, KJ Mathew, VK PiIIai, AG Ponniah) pp. 338-391. (Marine Biological Association of India: Cochin, India).

Vijayagopal P (2003) Nutritional responses in indian white shrimp *Fenneropenaeus indicus* to varying protein: energy combinations in compounded artificial feeds. PhD thesis (Cochin University of Science and Technology: Kochi, India)

Vijayan K.K (2019) Technological spinoff by ICAR-CIBA Towards the development of sustainable brackishwater aquaculture. In 'Souvenir, BRAQCON- world brackishwater aquaculture conference'. pp. 1-8. (Society of Coastal Aquaculture and Fisheries (SCAFi) and Central Institute of Brackishwater Aquaculture (CIBA): Chennai, India)

Villalon JR (1991) 'Practical manual for semi-intensive commercial production of marine shrimp'. Sea Grant College program publication TAMU-SG-91-501. (Texas A&M University: College Station, Texas)

Villaluz AC (1974) Diseases and other causes of mortalities of sugpo in the hatchery and in ponds. In 'Proceedings of the first seminar of the fishpond cooperators' program on prawn culture in Mindanao.' 25-29 November 1974, Naawan, Misamis Oriental, Philippines.

Villaluz DK, Villaluz A, Ladrera B, Sheik M, Gonzaga A (1969) Production, larval development, and cultivation of sugpo (*Penaeus monodon* Fabricius). *Philippine Journal of Science* **98** (3-4), 205–233.

Villamar DF (1999) Feeding by design, appropriate technology. *International Aquafeed*, **3** (99), 37-40.

Vimala DD (2002) Training needs of shrimp farmers in Tamil Nadu. PhD thesis. (Anna University: Chennai, India).

Vimala DD, Ramachandran S, Swathilekshmi PS, Kumaran M (2006) Shrimp seed - A critical problem faced by shrimp farmers - A cross sectional analysis. *Journal of Indian Society of Coastal Agricultural Research* **24** (2), 338-340.

Vimala DD, Ravisankar T, Gopal C, Ravichandran P (2015) Use of chemical and biological products in modern shrimp farming in Northern Tamil Nadu, India. *Indian Journal of Fisheries* **62** (2), 128-131.

Viswakumar M (1992) Technical and economical consultations for shrimp culture in Andhra Pradesh. *Fishing Chimes* **6**, 30-40

Wang JK, Fast AW (1992) Shrimp pond engineering considerations. In 'Marine shrimp culture: principles and practices.' (Eds AW Fast, LJ Lester) pp. 415-429. (Elsevier Science Publishers BV: Amsterdam, USA)

Wang YB, Xu ZR, Xia MS (2005) The effectiveness of commercial probiotics in Northern white shrimp (*Penaeus vannamei* L.) ponds. *Fisheries Science* **71,** 1034-1039.

Watanabe T (2002) Strategies for further development of aquatic feeds. *Fisheries Science* **68,** 242–252. doi: https://doi.org/10.1046/j.1444-2906.2002.00418.x

Welch PS (1952) 'Limnology.' 2nd edn. (McGraw-Hill Book Co.: New York)

Wickins JF (1976) Prawn biology and culture. *Oceanography and Marine Biology: An Annual Review***14**, 435-507.

Williams M (1996) The transition in the contribution of living aquatic resources to food security. Food agriculture and the environment discussion paper no 13, International Food Policy Research Institute, Washington.

Willis SA, Hagood RW, Eliason GT (1976) Effects of four stocking densities and three diets on growth and survival of post-larval *Macrobrachium rosenbergii* and *M. acanthurus*. *Proceedings of the World Mariculture Society* **7,** 655-665.

World Bank (2000) Shrimp farming and the environment: Can shrimp farming be undertaken sustainably? A discussion paper designed to assist in the development of sustainable shrimp aquaculture. World Bank, Washington DC, USA.

World Bank, NACA, WWF, FAO (2002) Shrimp farming and the environment. A World Bank, NACA, WWF and FAO consortium program to analyze and share experiences on the better management of shrimp aquaculture in coastal areas (World Bank, NACA, WWF and FAO consortium). Available at http://www.enaca.org/Shrimp [Verified 11 November 2021]

World Bank (2012) Hidden harvest: the global contribution of capture fisheries. The World Bank report 66469-GLB, World Bank, Washington DC, The United States of America

Wyban JA, Lee, CS, Sato VT, Sweeny JN, Richards JrWK (1987) Effect of stocking density on shrimp growth rates in marine fertilized ponds. *Aquaculture* **61,** 23-32.

Wyban J, Sweeney JN (1991) 'Intensive shrimp production technology.' (High Health Aquaculture Inc.:Hawaii, USA)

Wyban J, Walsh WA, Godin DM (1995) Temperature effects on growth, feeding rate and feed conversion of the Pacific white shrimp (*Penaeus vannamei*). *Aquaculture* **138** (1-4), 267-279. doi: https://doi.org/ 10.1016/0044-8486(95)00032-1

Wyban JA, Sweeney JN, Kanna RA (1988) Shrimp yields and economic potential of intensive round pond systems. *Journal of World Aquaculture Society* **19,** 210-217.

Xue S, Ding J, Li J, Jiang Z, Fang J, Zhao F, Mao Y (2021) Effects of live, artificial and mixed feeds on the growth and energy budget of *Penaeus vannamei*. *Aquaculture Reports* **19**, 1-6. doi: https://doi.org/10.1016/ j. aqrep.2021.100634

Yadava YS (2002) Shrimp farming in India: Lessons and challenges in sustainable Development. *Aquaculture Authority News* **1**, 1-4.

Yagi H, Uno Y (1980) Influence de la combinaison des facteurs temperature et salinite sur la croissance larvaire de *Macrobrachium rosenbergii* (de Man) (Palaemonidae, Decapodes, Crustaces). *La Mer* **18,** 171-178.

Yagi H, Uno Y (1981) Influence de la combinaison des facteurs temperature et salinite sur la croissance larvaire de *Macrobrachium nipponse* (de Haan) (Palaemonidae, Decapodes, Crustaces). *La Mer* **19,** 93-99.

Yagi H, Uno Y (1983) Influence de la combinaison des facteurs temperature et salinite sur la croissance larvaire de *Macrobrachium japonicum* (de Hann) (Palaemonidae, Decapodes, Crustaces). *La Mer* **21,** 211-217.

Yahaya J (1990) An economic analysis of brackishwater shrimp pond culture, Johore, peninsular Malaysia. In 'Proceedings of the second Asian Fisheries Forum'. (Eds R Hirano, I Hanyu) pp. 255-266. (Asian Fisheries Society: Manila, Philippines)

Ye L, Jiang S, Zhu X, Yang Q, Wen W, Wu K (2009) Effects of salinity on growth and energy budget of juvenile *Penaeus monodon. Aquaculture* **290** (1/2),140-144.

Ye Y, Bishop JM, Fetta N, Abdulqader E, Al-Mohammadi J, Alsaffar AH, Almatar S (2003) Spatial variation in growth of the green tiger prawn (*Penaeus semisulcatus*) along the coastal waters of Kuwait, eastern Saudi Arabia, Bahrain, and Qatar. *ICES Journal of Marine Science* **60**, 806–817. doi: https://doi.org/10.1016/S1054-3139(03)00072-9

Yta AGD, Rouse DB, Davis DA (2004) Influence of nursery period on the growth and survival of *Litopenaeus vannamei* under pond production conditions. *Journal of the World Aquaculture Society* **35** (3), 357-365.

ZSI (2009) 'Faunal diversity of Vembanad Lake - A Ramsar site in Kerala, India'. Wetland ecosystem series 10. (Zoological Survey of India: Kolkata, India).

Zuniga- Jara S (2009) A dynamics simulation analysis of Japanese abalone (*Haliotis discus hannai*) production in Chile. *Aquaculture international* **18,** 603-620. doi: 10.1007/s10499-009-9279-x

Zweig R, Braga MIJ (1996) 'Best practices, lessons learned, and guidelines for aquaculture development: A review of completed bank-assisted aquaculture projects.' (World Bank: Washington DC, USA)

LIST OF PUBLICATIONS

1. Published in journals

Sahadevan P and Sureshkumar S (2020) Estimation of farmed shrimp production in Kerala. *International Journal of Fisheries and Aquatic Studies* **8** (4), 392-400.

Sahadevan P and Sureshkumar S (2020) A study to understand the reasons for the low productivity of shrimp farms in Kerala. *International Journal of Fisheries and Aquatic Studies* **8** (5), 96-106.

Sahadevan P and Sureshkumar S (2021) Economic evaluation of traditional prawn filtration practice in Central Kerala, South India. *Journal of Aquatic Biology & Fisheries* **9,** 33-41.

2. Published as book chapters

Sahadevan P and Sureshkumar S (2020). Investigation on the poor performance of shrimp farms. In 'Research Trends in Fisheries and Aquatic Sciences.' Vol. 10. (Eds JK Sundaray, RA Bhat) pp. 51-75. (AkiNik Publications: New Delhi).

3. Presented in seminars

Sahadevan P and Sureshkumar S (2018) Diversity of fishes, crustaceans and molluscs in the traditional prawn filtration fields. Paper presented in the 'International Biodiversity Congress (IBC 2018)', organised by the Centre for Innovation in Science and Social Action (CISSA), Navdanya, Forest Research Institute (FRI), Indian Council of Forestry Research and Education (ICFRE), Wildlife Institute of India (WII), Uttarakhand Biodiversity Board and Uttarakhand Council for Science and Technology, held at Forest Research Institute, Dehradun, 4 - 6 October 2018.

Sahadevan P and Sureshkumar S (2019) Status of shrimp farming in Kerala. Paper presented in the 'International Conference on Aquatic Resources and Blue Economy (AQUABE, 2019)' organised by the Kerala University of Fisheries and Ocean Studies (KUFOS), held at Kochi, 28-30 November 2019.

Sahadevan P and Sureshkumar S (2020) Shrimp Aquaculture in India – the Way forward. Paper presented in the '3rd International Symposium on Marine Ecosystems Challenges and Opportunities (MECOS3)' organised by the Marine Biological Association of India (MBAI), held at Kochi, 7-10 January 2020.

Sahadevan P and Sureshkumar S (2020) Diversity of fishes, crustaceans and molluscs in the traditional prawn filtration fields. Paper presented in the '3rd International Symposium on Marine Ecosystems Challenges and Opportunities (MECOS3)' organised by the Marine Biological Association of India (MBAI), held at Kochi, 7-10 January 2020.

Sahadevan P and Sureshkumar S (2020) Economic evaluation of traditional prawn farming. Paper presented in the 'International Conference on Impact of Climate Change on Hydrological Cycle, Ecosystem, Fisheries

and Food Security (Climfishcon 2020)', organised by the School of Industrial Fisheries, Cochin University of Science and Technology, held at Kochi, 11-14 February 2020.

Sahadevan P and Sureshkumar S (2020). Diversity of fishes, crustaceans and molluscs in the traditional prawn filtration fields. Paper presented in the 'International Conference on Impact of Climate Change on Hydrological Cycle, Ecosystem, Fisheries and Food Security (Climfishcon 2020)', organised by the School of Industrial Fisheries, Cochin University of Science and Technology, held at Kochi, 11-14 February 2020.