STUDIES ON MAJOR SMALL PELAGIC FISHES ALONG THE KERALA COAST WITH RESPECT TO THE POTENTIAL FISHERY ZONE (PFZ) ADVISORIES

Thesis submitted to the MANGALORE UNIVERSITY

In partial fulfilment of the degree of

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Under the Faculty of Science and Technology

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Declaration

The candidate, Preetha G Nair, do hereby declare that this thesis 'Studies on major small pelagic fishes along the Kerala coast with respect to the Potential Fishery Zone (PFZ) advisories' is a genuine record of the research work carried out by me under the guidance of Dr. Shoji Joseph (Principal Scientist, Central Marine Fisheries Research Institute, Kochi, India) in partial fulfillment for the award of Ph.D. degree under the faculty of Bioscience, Mangalore University and no part of the work has previously formed the basis for the award of any degree, diploma, associateship, or any other title or recognition from any University / Institution

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Acronyms

ANCOVA - Analysis of Covariance
ANOVA - Analysis of Variance
AVHRR - Advanced Very High Resolution Radiometry
°C - Degree Centigrade
Chl. *a* - Chlorophyll *a*
CIESM - Mediterranean Science Commission
CMFRI - Central Marine Fisheries Research Institute
CPUE - Catch per Unit Effort
CZCS - Coastal Zone Colour Scanner
DOC - Dissolved Organic Carbon
EDB - Electronic Display Board
ELEFAN - Electronic Length Frequency Analysis
HNF - Heterotrophic Nanoflagellates
HP - Horse Power
HTB - Heterotrophic Bacteria
ICAR - Indian Council of Agricultural Research
ICMAM- Integrated Coastal and Marine Area Management
INCOIS - Indian National Centre for Ocean Information Services
IRS - Indian Remote Sensing Satellite
LWR - Length Weight Relationship
m - Meter
µm – Micrometer
µM - Micromole
MODIS - Moderate Resolution Imaging Spectroradiometer
MSP - Mesozooplankton
MZP - Microzooplankton
NIO - National Institute of Oceanography
NOAA - National Oceanic and Atmospheric Administration
OAL - Overall Length
OCM - Ocean Colour Monitor
OCR - Ocean Colour Radiometry
PFZ - Potential Fishery Zone
PRIMER - Plymouth Routines In Multivariate Ecological Research
SST - Sea Surface Temperature
SSH- Sea Surface Height

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ABSTRACT

Indian National Centre for Ocean Information Services (INCOIS), Hyderabad, India provides fishery forecast services all along the Indian coast free of cost, referred to as 'Potential Fishery Zone (PFZ) Advisories'. These services include geo-referenced maps showing marked regions where probability of finding sizeable schools of fishes is high. These advisories are provided to help the fisher folks to improve their income from fishing by saving engine fuel for searching and locating fish stocks.

Based on 124 controlled fishing experiments carried out in the PFZ and Non-PFZ zones along the Kerala coast during 2008-2012 periods, the present study evidenced that commercially important fishes were abundant in the PFZ, forming richer fisheries compared to the non-PFZ areas. The profit from controlled experiments showed consistently higher values in the PFZ than that in the non-PFZ. The highest profit during the entire controlled fishing experiments was obtained when the catch was dominated by relatively high-priced fishes such as tunas, carangids, seer fishes and mackerel. Indian oil sardine was the major single species obtained during the Northeast Monsoon (November-February), whereas, Indian mackerel dominated during the Southwest Monsoon (June-October) and Spring Intermonsoon (March - May) periods. Anchovies were found to dominate only in two fishing experiments in the entire study period.

The analyses of catch data of the small pelagic fishes of interest (Indian oil sardine, Indian mackerel and Commerson's anchovy) showed that the PFZ advisories better predicted the catches of Indian oil sardine during the Northeast Monsoon (November-February) and Indian mackerel during the rest of the period. Conversely, the catch data of controlled experiments showed that PFZ advisory has less efficiency to support the exploitation of anchovies.

Attempts have been made to outline the recurrent PFZ along the Kerala coast based on the advisories generated for the study period (2008-2012). Altogether 432 PFZ advisories were digitised and month-wise repeat PFZs have been demarcated. In general, most of the very prominent recurrent PFZs were found within the 50m depth contour. The highest number of recurrent PFZs was in December, January and February. On the other hand, the lowest number of recurrent PFZs was found in April, May and June.

Plankton components in the diet of Indian oil sardine, Indian mackerel and Commerson's anchovy based on fortnightly fish samples analysed during a year period are presented. *Coscinodiscus*, *Nitzschia*, *Pleurosigma* and *Thalassiosira* were found in the gut of Indian oil sardine almost throughout the year, whereas microzooplankton was mostly dominant only during the October - December period. *Coscinodiscus* and Tintinids were predominant in the gut of Indian mackerel throughout the year. Furthermore, *Thalassiosira*, *Ceratium*, *Dinophysis*, *Protoperidinium*, *Pyrophacus* and copepods were also found in the gut of Indian mackerel almost throughout the year. The dominant value index showed the dominance of phytoplankton, microzooplankton and copepods in the diet of Indian mackerel throughout the year, indicating their almost equal preference for both phytoplankton and zooplankton. The food items in the gut content of Commerson's anchovy showed characteristic difference from both Indian

oil sardine and Indian mackerel and found to be a zooplankton feeder predominantly feeding on copepods, fish eggs, ostracods, lucifers and tintinids.

The environmental observations based on monthly field sampling carried out in two locations (10m and 20m depth contours) situated off Kochi are presented. During seven out of nine observations, PFZ bands were observed around 10m location. High values of chlorophyll (> 3mg m-3) were found in August, September and October, which could be attributed to the combined effect of Cochin backwater influx and upwelling. The seasonal evolution of hydrographical parameters showed significantly higher concentration of nutrients and chlorophyll during the Southwest Monsoon period compared to the rest of the sampling. The chlorophyll concentration was found to be significantly higher in 10m location (PFZ) compared to the 20m location (non-PFZ).

The status of the Length-Weight Relationship (LWR) and condition factor of Indian oil sardine, Indian mackerel and Commerson's anchovy along the Kerala coast is presented. The LWR of Commerson's anchovy is the very first detailed report from this region. LWR and condition factor of Indian mackerel and Oil sardine were not significantly different from the values reported in the historical studies, indicating that these parameters are not affected significantly by the expected long-term environmental changes.

The results of the growth and maturity studies of the small pelagic fishes of interest have been discussed. The analyses were based on a fortnightly sampling carried out in two major landing centres during 2010 - 2011 periods. The maximum life span of Indian oil sardine was estimated to be 2.63 years. Two peaks of recruitment of juveniles to the fishery were observed; a large peak during July - August and a small peak in February - March. The length at first maturity was calculated as 15.7 cm while the length at first capture was 15 cm, suggesting that the peak exploitation of the species occurs before they attain sexual maturity. Comparison of the length at first maturity of oil sardine reported in historical studies with the present study shows that only minor variation exists between the two. The life span of Indian mackerel is estimated to be 2 years. The recruitment pattern showed the presence of mature mackerel all year round. However, two recruitment peaks of Indian mackerel were evident; June to August and February to March with the highest recruitment in July (28%). Probability of capture of mackerel showed higher values (22.43 cm) than the length at first maturity (17.7 cm) indicating that their peak exploitation occurs after attaining sexual maturity.

Long-term changes in length at first maturity of Indian mackerel indicated a prominent decrease in length in the recent decade, probably indicating a response to the long-term environmental changes. The present study on the growth and maturity parameters of Commerson's anchovy forms the first such study from Indian waters and the life span of the species was found to be 3.06 years. Two recruitment peaks of Commerson's anchovy were observed; first during February - March and a second during June - July. The probability of capture of Commerson's anchovy showed that they get exposed to maximum exploitation after they attain maturity. Lack of past data on length at first maturity of Commerson's anchovy from the Indian coast hindered a possible comparison with the present data.

CHAPTER 1

GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1. Marine Pelagic Fishes

Marine pelagic fishes live near the surface or in the water column and they consist of smaller (eg. sardine) as well as larger species (eg. tuna). The major part of the Indian marine fish production (55%) is contributed by pelagic fishes occurring along the west coast of India. The long term trend in Indian marine pelagic fish production shows significant increase over the last seven decades and the average production increased from 362548 tonne in 1950 -1959 to 1358578 tonne in 2000 – 2008 period (ICAR, 2011).

Even though more than 250 species of pelagic fishes are recorded from the Indian waters, only 60 of them including Indian oil sardine, lesser sardines, anchovies, Bombay duck, ribbonfishes, carangids and Indian mackerel constitute the major marine fisheries in India (Pillai and Katiha, 2004; James, 2010). Fluctuations in certain biological and environmental characteristics can disturb the production of small pelagic fishes and any such negative impact in production of Indian oil sardine, Indian mackerel and Bombay-duck can significantly decline the overall marine fish production in India (Krishnakumar et al., 2008; James, 2010). Such a decline in marine fish production often causes socio-economic upsets along the west coast of India, where these fishes are predominant and the fisherman community utilise these resources for their livelihood.

Small marine pelagic fishes belong to several distinct families, but they have certain general biological characteristics. Most of these species form massive schools and perform migrations along the coasts as well as from inshore to offshore and vice versa (Balan, 1961; James, 2010). Small pelagic fishes grow very fast, but have relatively short life span (Balan, 1961, 1964; James, 2010). Their breeding process is quite prolonged, often throughout the year, shedding the gametes in batches at short intervals (Balan, 1965; James, 2010). They have high fecundity; their eggs and larvae are small, transparent, pelagic and mostly feed on plankton (Hornell and Nayudu, 1924; Krishnakumar et al., 2008; James, 2010).

Small marine pelagic fishes are closely linked to the plankton food web, which in turn, is governed by the prevailing environmental conditions. Planktivorous fishes occupy niches that sustain their nutritional requirements and therefore, understanding the trophic cycles at sea is an efficient tool to understand the fluctuations in abundance of these pelagic fishes.

Competition for food, predation at various levels and pollution of coastal waters can also negatively impact the abundance of small pelagic fishes (James, 2010).

1.2. Fishes of Interest and their Fishery along the Kerala Coast

Kerala contributes ~10% of India's total coastline. About 70% of the marine fishes exploited along the Kerala coast are pelagic and the rest demersal (ICAR, 2011). An assessment of the contribution of different maritime states to the total pelagic fish production in India conducted in 2008 showed that Kerala ranks first (about 39%) followed by Tamilnadu (ICAR, 2011). The following account presents some relevant baseline information on three important small pelagic fishes (Indian oil sardine, Indian mackerel and Anchovies), which are commercially exploited along the Kerala coast and their exploitation based on satellite techniques form the main topic of research in the present study.

1.2.1. Indian Oil Sardine (*Sardinella longiceps*) (Valenciennes, 1847)

Indian oil sardine (hereafter referred as oil sardine) is a small pelagic fish, which contributes about 40% of the marine fish catch in Kerala (Figure 1.1). Oil sardine belongs to the family Clupeidae of the order Clupeiformes. Globally, they are distributed in the Indo-pacific region and forms large schools/shoals in the coastal waters with evident migratory behaviour. Oil sardine grow rapidly, mature early and a few continue to survive in the subsequent year (Longhurst and Wooster, 1990). They attain sexual maturity when they are ~ 15 cm length, at around a year old (Hornell and Nayudu., 1924; Balan, 1963; Raja, 1969, Whitehead., 1985; Krishnakumar et al., 2008). The life span of oil sardine is ~ 2.5 years and they attain a maximum total length of about 23 cm (Balan, 1963). They play a crucial role in the pelagic ecosystem as a dominant plankton feeder (predator) as well as a major food source (prey) for large predators. Studies show that oil sardine feeds mainly on phytoplankton and copepods (Whitehead, 1985).

Oil sardine spawns during the period between June and September and they do spawn only once in a spawning season (Nair, 1959; Krishnakumar et al., 2008). The spawning pattern of oil sardine is primarily determined by their age and size. They attain the first maturity stage at around one year when they attain about 15 cm of length (Hornell and Nayudu, 1924; Chidambaram and Venkataraman, 1946). Early in the spawning season, the oldest and most mature individuals between 17 -19 cm spawns, while the juveniles in the same population start spawning at a later stage in the spawning season (Nair, 1959). Ring seines and purse seines are the two major gears used for exploiting the oil sardine resources available along the Kerala coast though several other gears such as trawls and gill nets are also used to exploit oil sardine stock along the southwest coast of India (Jayaprakash and Pillai, 2000).

The oil sardine fishery is mostly restricted to the narrow coastal belt/continental shelf of about 20 km from the shore, and this region is exclusively exploited by indigenous crafts and gears. It is considered that the oil sardine fishery begins with the entry of adult fishes in the inshore areas in June – July months (Chidambaram, 1950; Raja, 1969). The exact spawning ground of oil sardine along the Indian coastline is still unclear; however, it is generally believed that the spawning of oil sardine occurs during the Summer (Southwest) Monsoon period when temperature, salinity and suitable food availability are conducive for larval survival (Murty, 1976; Jayaprakash and Pillai, 2000; Krishnakumar et al., 2008). This belief is heavily depending on studies that recorded high abundance of post larvae and juveniles of oil sardine during July-September period in the near shore waters of the Malabar Coast (Hornel and Nayudu., 1924; Devanesan, 1943; Nair, 1959; Raja, 1969; UNDP/FAO, 1976; Binu, 2004; Krishnakumar et al., 2008).

Figure 1.1 – Indian Oil Sardine (*Sardinella longiceps*)

The fishery of oil sardine continues beyond March and the peak landings are from October to January (Murty, 1976; Jayaprakash and Pillai, 2000). The fishery of oil sardine is characterized by remarkable seasonal and annual fluctuations, which have been mainly attributed to the fluctuations in the environmental factors (Murty, 1976; Longhurst and Wooster, 1990; Jayaprakash and Pillai, 2000; Krishnakumar et al., 2008). The Summer Monsoon and the resultant changes in the oceanographic and meteorological conditions seem to be the major factors responsible for the fluctuations in the fish catch (Murty, 1976; Longhurst and Wooster, 1990; Jayaprakash and Pillai, 2000; Krishnakumar et al., 2008). It is generally believed that the weakening of the Summer Monsoon seems to negatively impact the fish catches along the southwest coast of India (Murty, 1976; UNDP/FAO, 1976; Jayaprakash and Pillai, 2000; Krishnakumar et al., 2008).

1.2.2. Indian Mackerel (*Rastrelliger kanagurta*) (Cuvier, 1817)

The Indian mackerel, a small pelagic fish, widely distributed in the Indo-pacific region, belongs to the family Scombridae of the order Perciformes (Figure 1.2). Indian mackerel is an important fishery resource in the Exclusive Economic Zone of India especially along the southwest coast of India. They also function as important forage (prey) for the seer fishes and tunas that occupy the higher trophic levels in the food web (Vivekanandan et al., 2009). Mackerel forms a common table fish in Kerala and the fishery is commercially important along the west coast of India after oil sardine (Qasim, 1972). The body of the Indian mackerel is moderately deep; the head is longer than the body depth. Their average length frequency distribution along the west coast of India is constituted mainly by 11—15 cm size group (Yohannan and Sivadas, 1998). Indian mackerel attains a maximum of about 25cm length and about **4.5 kg** weight and their life span is believed to be 2 years and they grow very fast especially in the juvenile stage (Yohannan and Sivadas, 1998). Their spawning and recruitment peak in Indian waters coincide with the summer (south west) and winter (north east) monsoon seasons (Qasim, 1973). Dense shoals of mackerel usually occur up to 50 m depth along the west coast of India.

Mackerel feeds on both phytoplankton and zooplankton and they move in large shoals shoreward when inshore waters are rich in plankton following the monsoon seasons (Sivadas and Bhaskaran., 2009; ICAR., 2011; Ganga, 2010). Mackerel shoals are easily identifiable even from a faraway distance and such shoals mostly consist of large number of individuals of the same age group and size. Their feeding rate increases with maturity but, it is generally low both in juveniles as well as spawners. Spawning occurs in succession starting in April and lasts up to September. It is thought that the spawning grounds of mackerel are located in the near shore waters along the west coast of India (Krishnakumar et al., 2008).

The mackerel fishery assumes great importance in the west coast between Ratnagiri and Kollam and the maximum fishing occurs between Mangalore and Ponnani where landings are very high. The gears useful to exploit mackerel resources include shore seines, boat seines, ring seines, purse seines, drift nets, gill nets cast nets etc. However, along the Malabar upwelling zones from where bulk of the mackerel catch is obtained, the exploitation is chiefly by employing large seines; ring seines dominate in Kerala while purse seines are common in Karnataka and these gears together contribute 62% of the total mackerel catch in India (ICAR 2011).

Figure 1.2 – Indian Mackerel (*Rastrelliger kanagurta*)

The contribution of Indian mackerel to the total marine fish production in India varies between 1.8 and 3.5 % (Abdusamad et al., 2006). Indian marine fish catch records over the past 50 years clearly indicate that the annual production of Indian mackerel is characterized by wide fluctuations (Krishnakumar et al., 2008; ICAR, 2011). Therefore, as a fluctuating resource like oil sardine, it plays a significant role in determining the total catch of marine fishes in India. In early 80's, the average annual catch of mackerel in Kerala was of the order of 13,000 tonne, which was nearly 4% of the total annual marine fish landed in the state. During the 90's there was a dramatic increase in the catches of Indian mackerel along the Kerala coast, which is believed to be the result of the introduction of efficient ring seines. However, during the next few years after the increase, mackerel catches again declined and remained low until the mid-half of the last decade (Pillai et al., 2007; Krishnakumar et al., 2008).

1.2.3. Anchovies

Anchovies are a group of small marine (coastal) schooling fishes distributed between 60°N and 50°S (Nair, 1998). They are characterised by a small pig like snout projecting beyond the tip of the lower jaw and comprise fishes belonging to the genera *Stolephorus*, *Coilia*, *Setipinna*, *Thryssa* and *Thryssina*. The dominant component of anchovies present in Indian waters is commonly called as whitebaits, which consist of fishes belonging to the genera *Encrasicholina* and *Stolephorus*. An earlier estimate indicate that anchovies contribute

~ 4% of the Indian marine fish production (Luther et al., 1992), whereas, a more recent estimate using long term data (1990 to 2008) indicate that their contribution is ~ 2% of the total marine fish production (ICAR, 2011).

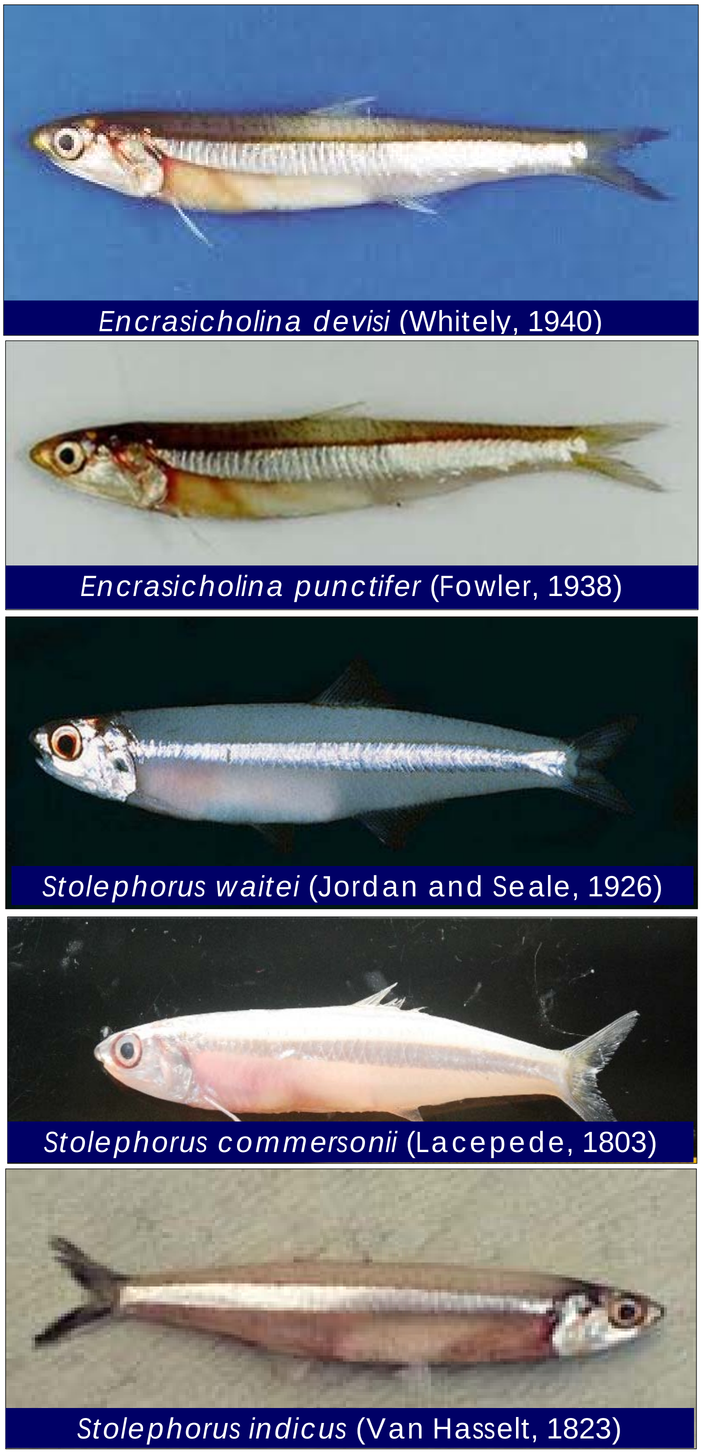


Figure 1.3 – Whitebait Anchovies (Source: Open Source, Fish base)

Even though 10 species of whitebaits are present in Indian waters, only five species namely *Encrasicholina devisi*, *E. punctifer*, *Stolephorus waitei*, *S. commersonii* and *S. indicus* are contributing on a commercial scale (Figure 1.3 ; ICAR, 2011) and these clupeoid fishes belong to the Family Engraulidae. Due to their close similarity in morphological characters, taxonomic misidentifications of anchovies are noticed from the Indo-Pacific regions (Nair, 1998). Anchovies can be lured by artificial light kept over the surface in the inshore waters on dark nights and this habit of anchovies gathering around light is taken advantage of in some areas (Luther, 1979). Anchovies are prone to quick spoilage and are labile to get crushed while handling due to their soft and fragile body.

Anchovies are a preferred food item of several carnivorous fishes and therefore the movement of anchovy shoals into the inshore regions usually coincides with the stock of larger sized carnivorous and piscivorous fishes such as carangids, ribbon fishes, tunas, seer fishes, barracudas, sciaenids, sharks, wolf herrings etc. (Luther, 1979). Considering the high catches and short life span of anchovies, their spawning ground is believed to be not far away from the inshore waters of the southwest coast of India (Luther, 1979). Anchovies have large air bladder relative to their body size which makes them efficient in making extensive vertical migrations (Luther, 1979).

The whitebait anchovies constitute more than 90% of the anchovy catch along the Kerala coast and therefore the present study addresses only these dominant species. An earlier estimate of anchovy stock along the southwest coast of India under UNDP pelagic fishery project evidenced large stock of anchovy resource between Ratnagiri and Tuiticorin (Menon and George, 1975). The whitebait fishes are short lived and their mean life span of is 0.5 year. They are multiple spawners with an extended spawning season that span over November to July and spawn about three successive batches of egg in a spawning season (Luther, 1979; ICAR. 2011). The distribution of their schools generally coincides with areas of high density of zooplankton which is their major food item.

The gears commonly used for exploiting whitebaits include boat seines, shore seines, bag nets and gill nets. Purse seines, ring seines, and trawl nets are also efficient in exploiting whitebaits. Purse seines are common along the Karnataka and Kerala coasts since 1970s. Similarly, ring seines are common along the southern Karnataka and northern Kerala coasts since mid-1980s (CMFRI, 1982). Along the Kerala coast, a special gill net known as Netholivala (mesh 15mm) is widely used for harvesting whitebaits during main fishing seasons. The fishing season of whitebaits differs in different Indian states and it is from July to December in Kerala.

1.3. Legislation to conserve the fishery along the Kerala coast

In late 1970s, there was an overall decline in the fish landing along the Kerala coast, which triggered unhealthy conflicts between mechanised and traditional (artisanal) sectors of fishermen and they competed for fishing time, space as well as resources (Ghosh, 2004). Traditional sector fishermen pointed out the destructive fishing practices of mechanised sector fishermen such as trawling, purse seining and ring seining as the major causative factor for the decline in fish production. These allegations led to clashes between traditional and mechanised sector fisherman along the Kerala coast. The artisanal fishermen protested against mechanised means of fishing and argued for a total ban on destructive fishing methods adopted by the mechanised sector fishermen and this situation later led to law and order issues along the Kerala coast (Ghosh, 2004).

As a remedial measure to the growing conflicts between different fishing sectors, after series of discussion and consensus through various Committees, the Govt. of Kerala banned the trawling during the summer (south west) monsoon months. The ban was implemented as an accepted measure for marine fishery resource management along the Kerala coast. The regulation is intended to preserve different varieties of commercially important fishes, whose breeding period is June to August. Later studies indicated that the regulation has a positive impact preserving and improving marine fishery production along the Kerala coast (Ghosh, 2004).

1.4. Important oceanographic features of the Kerala coast

The south eastern Arabia Sea, bordering the Kerala coast has unique oceanographic features. These oceanographic features of the Kerala coast are believed to be the main causative factors making the region conducive for several commercially important pelagic fishes. The area is influenced by two seasonal climatic forcing associated with the Southwest (Summer) Monsoon (June – September) and the Northeast (Winter) Monsoon (November –

February). The warming period between monsoons are referred to as Pre- Monsoon/Spring Intermonsoon period (March- May).

In addition to the above climatic aspects, Kerala is blessed with a network of numerous rivers (41 rivers), which originate from the Western Ghats and drain their influx into the south eastern Arabian Sea (Table 1.1, Figure 1.4). These rivers and their estuaries certainly supply large amount of nutrient and plankton rich waters into the coastal waters making the near shore waters of the Kerala coast highly productive. Even though this is our general understanding of the role of river influx and coastal input in increasing the productivity and fishery resources, detailed quantification and assessment of river inputs and various ways by which such inputs influencing the fish production along the Kerala coast is yet to be carried out.

SL.NO.	Name of the River	SL.NO.	Name of the River
1	Achenkovil (128)	22	Kuttyadi (73)
2	Anjarakkandi (52)	23	Maahi (54)
3	Baikal (10)	24	Manimala (91)
4	Bharathapuzha (209)	25	Manjeshwaram (16)
5	Chalakkudy (144)	26	Maugral (33)
6	Chaliyar (168)	27	Meenachil (67)
7	Chandragiri (104)	28	Muvattupuzha (120)
8	Chittar (25)	29	Neeleshwaram (46)
9	Itthikkara (56)	30	Neiyyar (56)
10	Kaariyankode (64)	31	Pampa (176)
11	Kadalundi (130)	32	Periyar (244)
12	Kallada (120)	33	Perumpa (40)
13	Kallai (22)	34	Purapparamba (8)
14	Kalnadu (8)	35	Ramapurampuzha (19)
15	Karamana (67)	36	Shiriya (65)
16	Karuvannoor (48)	37	Thalasseri (28)
17	Kavvai (22)	38	Tiroor (48)
18	Keecheri (43)	39	Uppala (50)
19	Korappuzha (40)	40	Valapattanam (112)
20	Kumbala (10)	41	Vamanapuram (80)
21	Kuppam (80)		

Table 1.1 – Westward flowing Rivers of Kerala (Length in km in parenthesis).

During the Southwest Monsoon, strong south-westerly winds (>8 m s^{-1}) are predominant in the Arabian Sea. This season is characterised by strong coastal upwelling along the Kerala coast, which plays a crucial role by significantly enhancing the phytoplankton production (Figure 1.5; Madhupratap and Parulekar, 1993; Madhupratap et al., 2001). This high organic production available in the coastal waters during the Southwest Monsoon period favours large number of fish and crustaceans in the area (Madhupratap et al., 2001).

The upwelling along the coast starts by May/ June and usually lasts till September causing nutrient rich subsurface waters available in the surface triggering phytoplankton blooms (Madhupratap and Parulekar, 1993, Banse et al., 1996; Sarangi and Mohammed., 2011).

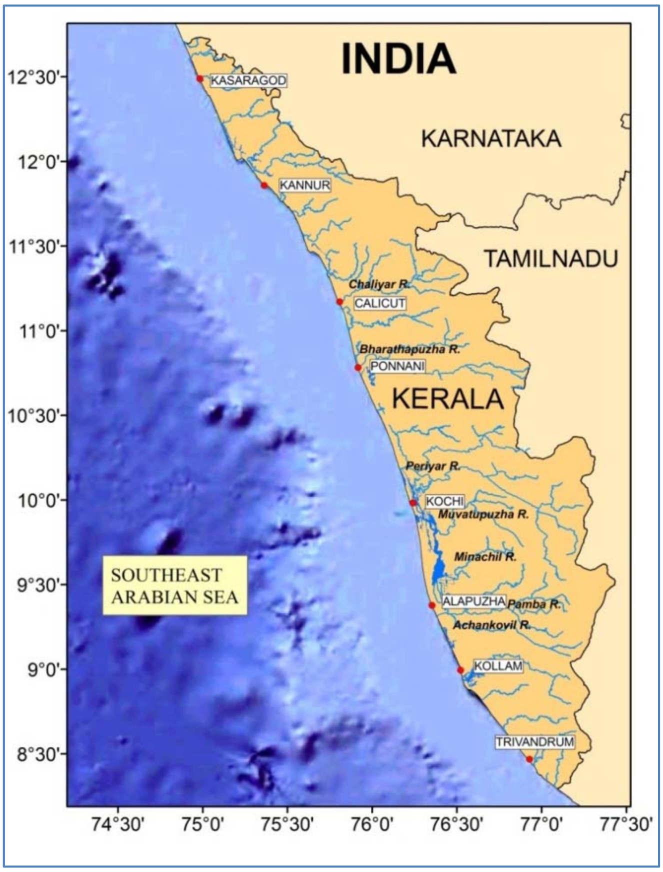


Figure 1.4 – Map showing spatial distribution of numerous rivers of Kerala that drain into the south-eastern Arabian Sea. Major rivers (based on distance) and their flushing points can be seen along the coastline. The Cochin/Kochi backwaters, which receives influx from seven rivers is the largest estuarine body along the west coast of India is located in Kerala between 9°30' N and 10° 15'N. The large fresh water influx from the Kochi backwaters and coastal upwelling process are the two significant processes controlling the biological production in the near shore waters of the region during the southwest monsoon period.

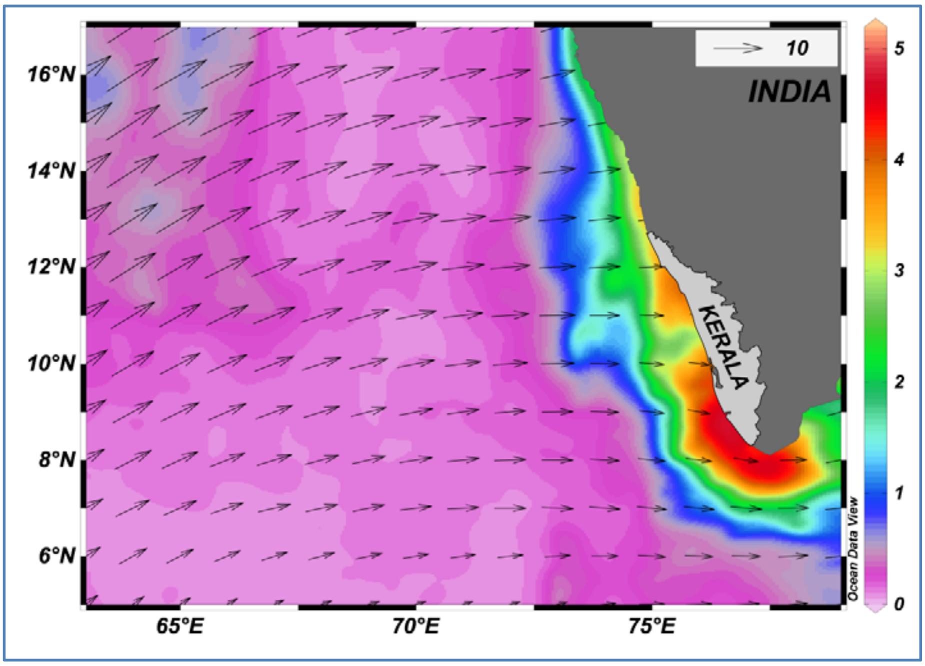


Figure 1.5- Enhancement of chlorophyll *a* along the Kerala coast during the Southwest Monsoon period as evidenced in satellite imagery. Strong south-westerly winds during the period are overlaid on chlorophyll image. Source: chlorophyll data from MODIS and wind data from NOAA

Historical studies present the view that the south-westerly winds cause upwelling along the Kerala coast (Shetye et al., 1985, Banse, 1996), but recent studies suggest remote forcing (Kelvin waves) as the major responsible factor behind the upwelling process along the Kerala coast (McCrery et al., 1993; Smitha et al., 2008). Studies also evidence that upwelling is not a continuous process along the entire southwest coast of India and intense upwelling occurs in regions such as off Kochi and Kollam (MacCreary et al., 1993; Smitha et al., 2008). Though the physical mechanisms causing upwelling weakens by September, the high phytoplankton and zooplankton biomass persist along the Kerala coast till the end of October (Jyothibabu et al., 2010).

In addition to the coastal upwelling, large amount of nutrient rich freshwater influx form 42 rivers originating from the Western Ghats also make the near shore waters of Kerala nutrient rich and biologically productive during the Summer Monsoon period (Madhupratap and Parulekar 1993; Jyothibabu et al., 2010). This oceanographic feature was strongly supported by the recent field studies, which evidenced exceptionally high chlorophyll concentration (av. 3.4 mg m^{-3} in the surface waters and av. 70 mg m^{-2} in the euphotic column) and primary production (av. 140 mgC m^{-3} in the surface waters and av.1795 mgC

m^{-2} in the euphotic column) in the near shore waters of the Kerala during the Summer Monsoon period (NIO Report, 2008).

During the Northeast/Winter Monsoon (November – February), the predominant north – easterly winds facilitate a cool climate with moderate rainfall along the southwest coast of India. Normally, the freshwater influx is low along the west coast of India during the Northeast Monsoon period (Rao and Rao, 1995). However there are instances when high rainfall was noticed along the southwest coast of India during the Winter Monsoon period (Madhupratap et al., 1993).

Generally, around 30% of the annual rainfall along the Kerala coast occurs during the northeast monsoon period (Qasim, 2003). Similar to the case during the south west monsoon period, the estuarine waters containing rich and diverse plankton community are periodically being flushed into the coastal waters of the Kerala and this will sustain moderate level of plankton production (Figure 1.6; Achuthankutty et al., 1997; see review by Qasim, 2003, Jyothibabu, et al., 2006, Madhu et al., 2007).

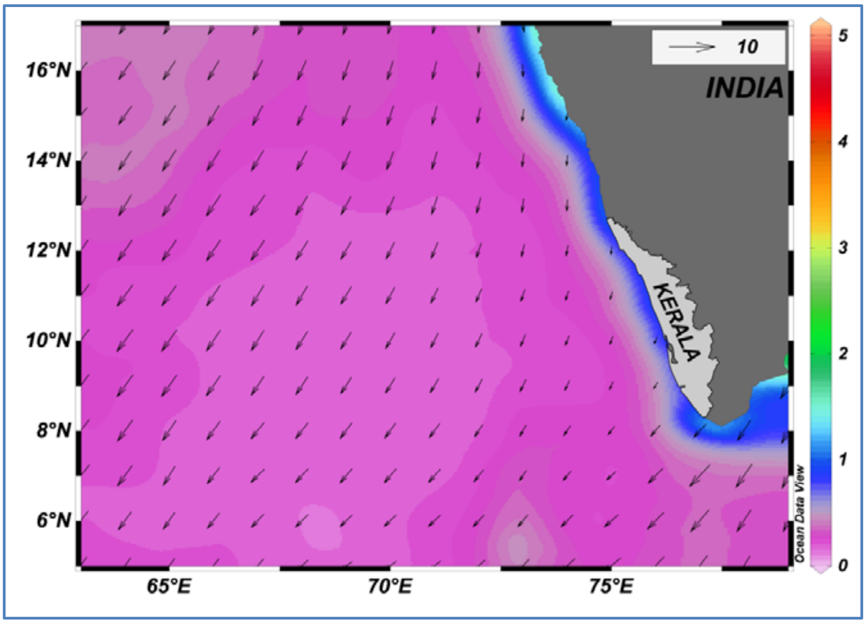


Figure 1.6 – Moderate level of chlorophyll along the Kerala coast during the northeast monsoon period as evidenced in satellite imagery. Moderate north-easterly winds during the period are overlaid on chlorophyll images. Source: chlorophyll data from MODIS and wind data from NOAA

The Pre-Monsoon/Spring Intermonsoon (March – May) is a transition period between Southwest and Northeast Monsoons. As a result of the weak winds and high solar radiation in the eastern Arabian Sea, the mixed layer remains thin and more or less uniform (Prasannakumar and Prasad, 1996). In addition to this, the thin layer of low saline, oligotrophic Bay of Bengal water present at the surface layers of the south-eastern Arabian Sea as a part of the seasonal circulation would further intensify the stratification during the spring-intermonsoon period (Sanilkumar et al., 2003). This strong stratification results in depleted nutrients in the upper water column, which makes the region oligotrophic, characterised by the lowest annual phytoplankton standing stock and production (Figure 1.7; Bhattathiri et al., 1996). This strong stratification and nitrogen limitation favours blooms of atmospheric nitrogen fixers, *Trichodemium* in the eastern Arabian Sea (Bhattathiri et al., 1996; Jyothibabu et al., 2010).

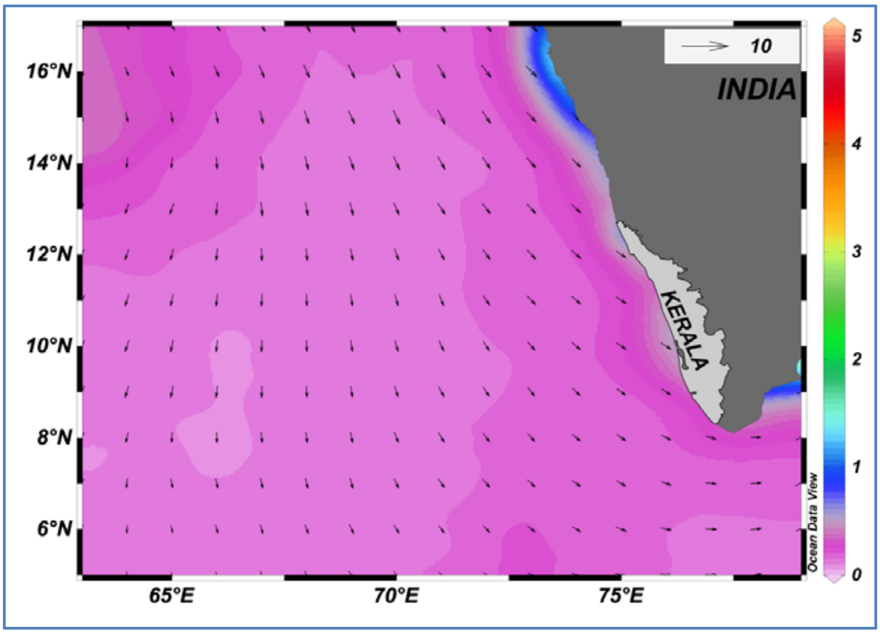


Figure 1.7 – The seasonal lowest chlorophyll concentration along the Kerala coast during the spring-intermonsoon period as evidenced in satellite imagery. Weak northerly winds during the period are overlaid on chlorophyll images. Source: chlorophyll data from MODIS and wind data from NOAA

This low productive nature of the southwest coast of India during the Spring Inter-monsoon (pre- monsoon) evident in earlier literature was strongly supported by the recent field studies as well, which showed significantly low chlorophyll concentration (av. 0.46 mg m-3 in the surface and av. 22.1 mg m-2 in the euphotic column) and primary production (av. 5 mgC m-3 in the surface and av. 223 mgC m-2 in the euphotic column) along the near shore waters of the Kerala coast during the Summer Monsoon (NIO Report, 2008).

1.5. Satellite oceanography and mapping of fishery resources

Satellite oceanography has revolutionised the traditional oceanography and has a far reaching role in all areas of ocean and climate research. Essentially, there is a very strong link between satellite oceanography and operational oceanography. The development of operational oceanography has been mainly driven by the development of satellite oceanography capabilities. The ability to observe the global ocean in near real time at high space and time resolution is indeed a prerequisite to the development of global operational oceanography and its applications. The first ocean parameter globally monitored from space was the sea surface temperature (SST) on board meteorological satellites in the late 1970s. It is, however, the advent of satellite altimetry in the late 1980s led to the development of ocean data assimilation and global operational oceanography. Operational oceanography critically depends on the near real time availability of high quality in-situ and remote sensing data with a sufficiently dense space and time sampling.

IOCCG Report, (2008 and 2009) summarised the societal applications of the satellite remote sensing in the context of marine ecosystem functioning. The microscopic, single celled plants present in the marine ecosystem (phytoplankton) absorb solar energy for carrying out primary production. Only the visible part of the electromagnetic radiation can be captured by the phytoplankton for photosynthesis. The pigment molecules (principally chlorophyll *a*) contained in phytoplankton cells captures the solar energy. As phytoplankton absorb and scatter light from the sun, they exert a profound influence on the submarine light field including the flux upwards across the water surface. The intensity and wavelength of this flux is measured by radiometers carried on space craft, and thus providing the basis for visible spectral radiometry, also known as ocean-colour radiometry (OCR) or simply ocean colour (IOCCG Report, 2008 and 2009).

The conventional ways of mapping and assessing fishery resources for utilization require extensive ship time and sampling time. In this context the applications of satellite remote-sensing is very relevant as it provides synoptic views of the ocean and also the signatures of mesoscale features of high biological production through thermal infrared and visible sensors (Lasker et al., 1981; Laurs et al., 1984; Fiedler et al., 1984). Therefore, it is logical to consider the remote-sensing techniques assisted with conventional fishery data collection methods as a powerful and realistic tool for designing the harvesting strategies for marine fishery resources (Solanki et al., 2005). Assessment and mapping of potential areas of high fishery resources availability using remote sensing techniques is based on the understanding that fishes tend to concentrate in regions of high biological productivity (Solanki et al., 2005). These regions of high biological productivity are generally considered as regions of high probability of finding fish schools.

The review of literature on mapping of fishery resources using satellite data evidence that the fishery resource advisories in earlier times were exclusively based on SST gradients developed by oceanographic features such as fronts, eddies and upwelling (Laskar et al., 1981; Laurs et al., 1984; Maul et al., 1984; Xingwei et al., 1988; Beenakumari and Nayak, 2000). Later, it was found that advisories exclusively based on SST have several technical uncertainties arising from the fact that (a) remotely sensed SST represent surface layer only up to 10 micrometres and therefore the heating of sea surface in tropics gives rise to strong stratification of surface waters that prevents coming up of cool and nutrient rich waters from the deeper layers to the surface and (b) the prevailing surface winds or current even of moderate magnitude can disturb the surface signatures of the frontal structures (Dwivedi, 2009). These disturbances cause lack of enough signatures as SST gradients in the satellite image and therefore, SST images are always not a dependable method for identification of regions with high fishery resources. However, the ocean colour (chlorophyll) sensor has advantage over SST sensor, since it can detect signals from below surface due to penetration of visible radiation. This characteristic feature of ocean colour sensor is utilised to locate and predict the occurrence of oceanic features like diverging fronts and eddies (Dwivedi, 2009).

Arnone (1987) showed that the water masses classified by satellite-derived sea surface temperature (SST) and ocean colour images are based on different physical and biological processes. While adopting the same approach, Solanki et al., (1998) characterised the relationship between the physical and biological variables along Indian coastal waters and found that the chlorophyll concentration and SST were inversely correlated. Later, detailed analyses showed that chlorophyll and SST features coincide in regions and cases where there was a close coupling between biological and physical parameters (Solanki et al., 2001b). These observation paved the way to an integrated approach using ocean colour monitor

(OCM) derived chlorophyll and AVHRR derived SST for forecasting potential areas of high fishery resources availability in the Indian waters (Figure 1.8; Solanki et al., 2000, 2001b).

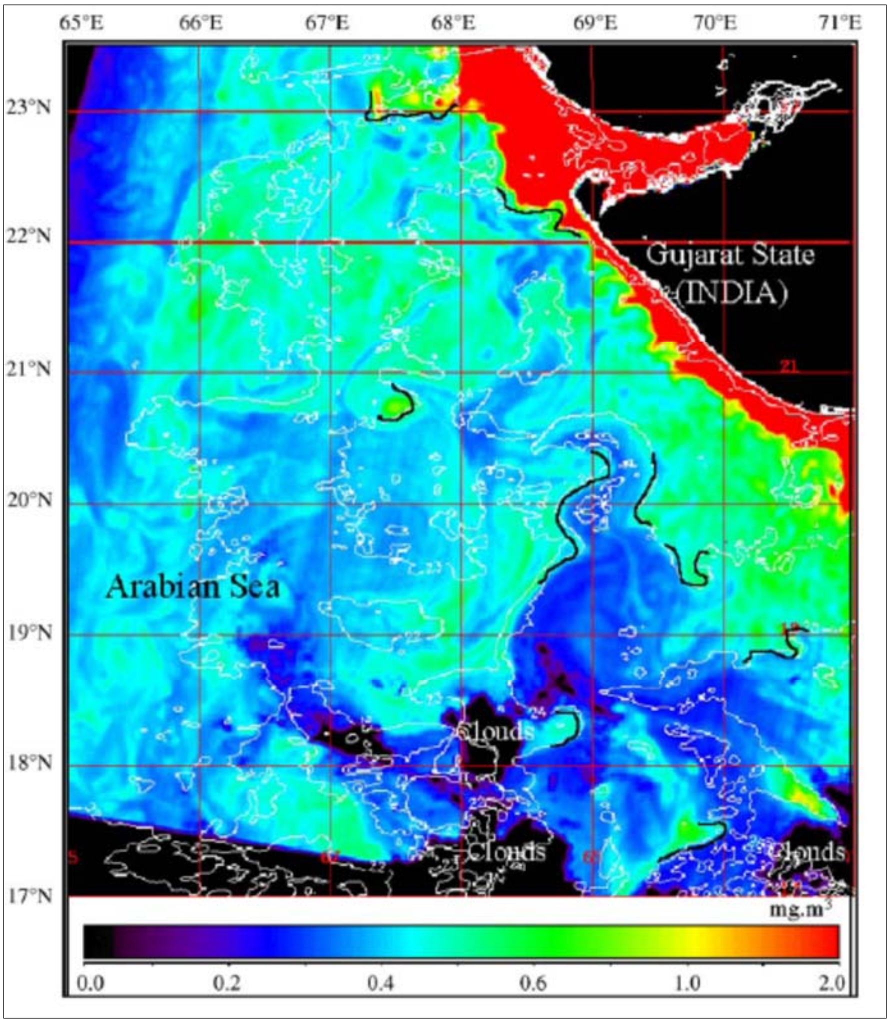


Figure 1.8 – Typical composite image generated from satellite derived chlorophyll *a* concentration and sea surface temperature (SST in °C) contours. Near real time satellite data of 8th March 2000 are presented. The image shows matching features of chlorophyll *a* and SST. Black lines indicate the suggested PFZ (adapted from Solanki et al., 2005).

There are two basic approaches in practice to map and forecast regions of high concentration of fishery resources along the Indian coasts. Overlaying of SST contours on chlorophyll images is the first method, by which it is possible to locate frontal structures with high biological productivity and such regions are considered to have high fishery resources. In the second method, ocean colour images alone are used to map and forecast regions with high availability of fish stocks. In many instances, ocean colour (chlorophyll a) images provide information on several other biologically productive regions, which are not evident in SST images. It is logical to consider the fact that for the efficient forecast of the fishery resources availability, the time taken in information extraction from satellite data should be kept minimal. In this direction, near real time retrieval of SST and chlorophyll data has been practiced now and the fishery forecasts were generated using the integrated approach within 24 hour of satellite over pass.

1.6. Topics presented in chapters

Chapter 1: Introduction and review of literature (Section above)

A detailed introduction and review of literature of small pelagics covered in this study. It also contains information on various aspects covered in this study.

Chapter 2: PFZ advisory and its usefulness

This chapter introduces various kinds of PFZ advisories and the scientific basis behind each kind. Detailed information on the usefulness of PFZ advisories along the Kerala coast for exploiting small pelagic fishes is also presented based on intensive validation fishing experiments conducted during the last five year periods (2007 – 2012).

Chapter 3: Recurrence of PFZ along the Kerala coast

PFZ advisories are available thrice in a week in clear sky conditions except during the Summer Monsoon period when ban on fishing activity is strictly implemented along the Kerala coast. Since PFZ represents regions of high biological productivity caused by physical processes such as eddies and frontal structures, attempts were made to understand the recurrence of such events (repetition) along the Kerala during different months. This approach is intended to generate new insights about the regions of repeat PFZ and to suggest the probable coastal processes.

Chapter 4: Food and feeding habits

This chapter mainly presents the result of a year round study on the food and feeding habits of small pelagic fishes of interest based on samples collected from the landing centre in Kalamukku, Kochi, India. A critical review of literature on the food and feeding habits of small pelagic fishes of interest has also been carried out. Such an approach is expected to be useful in the context of long term changes in marine environments due to coastal pollution and climate change.

Chapter 5: Fisheries Environment in the PFZ off Kochi

Observations and measurements in the field are inevitable to truly understand the environmental conditions that exist in the PFZ. This would help to understand the environmental features conducive for large schools of fishes. This chapter present the hydrographical and biological features in the PFZ off Kochi based on data collected from monthly field sampling carried out over a year (2010 - 2011).

Chapter 6: Length -Weight relationship and condition factor

The chapter consist of a newer data set of Length -Weight relationship and condition factor of the Indian oil sardine, Indian mackerel and Commerson's anchovy from the Kerala coast. Assessment of variations from the general LWR is useful to understand the condition (quality) of a particular fish, which is usually represented by means of 'condition factor'.

Chapter 7: Growth and maturity

The chapter presents the growth and maturity of the small pelagic fishes of interest. The studies on age and size at which fish attain sexual maturity, the time and place of spawning and the duration of the reproductive cycle beginning from the development of the ovary to the final release of eggs are essential for the realistic understanding of the stocks and also for implementing useful management practices for their sustainable utilization.

Chapter 7 is followed by the bibliography of references

CHAPTER 2

POTENTIAL FISHING ZONE (PFZ) ADVISORY & ITS USEFULLNESS

2.1. Introduction

The optimum utilization of fishery resources using remote sensing techniques is not a very recent concept. The application of satellite oceanographic data to support commercial fishing operation began in the mid-1970s along the Pacific coast (Breaker, 1981) and during this beginning phase, fishery forecasts were exclusively based on Sea Surface Temperature (SST) data (Vinuchandran, et al., 2004). The introduction of new approaches to map fishery resources by combining ocean colour from Coastal Zone Colour Scanner (CZCS) and SST from NOAA- AVHRR come into place in the early 1980s (Muller and Violate., 1980; Laurs and Brucks., 1985). Now, fishery resource mapping based on satellite remote sensing data are operational in several countries including India (Mansor et al., 2001; Nayak et al., 2003; Nurdin et al., 2012).

Seas around India have rich biodiversity, which is contributed also by around 1570 species of finfishes and 1000 species of shellfishes (ICAR, 2011). The adaptations of fishes are primarily developed under the influence of physical, chemical and biological factors prevailing in the environment. Therefore, understanding the abundance of fishes in a particular region is possible with certain level of accuracy by understanding the physical, chemical and biological processes prevailing in that environment. Common physical processes in the ocean having direct impact on biological/fishery productivity include upwelling, eddies, gyres, frontal structures and ocean currents (Banse., 1986; Madhupratap et al., 1994; Solanki et al., 2001, 2003, 2005; Jyothibabu et al., 2010).

It is a prerequisite for ecosystem based fishery resource management to assimilate generalised information on relevant fishery aspects from the review of vast literature available (Solanki et al., 2005). Consolidated and generalised information on the food and feeding habits of fishes, their physiological status including growth, breeding and migration (as presented in Bal and Rao, 1990; Froese and Pauly, 2000) are very important for the effective management of fishery resources (Solanki et al., 2005). Locating fishing (feeding) grounds of commercially important fishes is the challenge before the fisherman to exploit the resource in a cost effective manner. The feeding grounds of fishes can be mapped with certain level of accuracy by the interpretation of the synoptic features in oceanographic parameters collected using satellite remote sensing techniques. Proper knowledge on the food web relationships is also important to understand the availability of fish in a particular area, which would help to arrive at meaningful conclusions on their management using remote sensing techniques (Polovina et al, 2001).

Several pelagic fishes tend to concentrate in regions where there is a sharp horizontal gradient in temperature and/or phytoplankton biomass (Benaka, 1999; Martens, 2001; Jeffrey et al., 2001). Ship based measurements of ocean parameters are laborious and highly expensive. Moreover, such *in-situ* measurements are unable to generate a real time distribution of environmental parameters with large spatial coverage. In this context, indirect method of monitoring oceanographic parameters such as Sea Surface Temperature (SST) and phytoplankton biomass (chlorophyll *a*) from satellites is found to be a useful tool to map and forecast regions of high biological productivity. The advantage of this approach is that the required data of ocean parameters can be generated with high recurrence and large spatial coverage. These data can be processed and forecast maps can be made available to the end users in near real time.

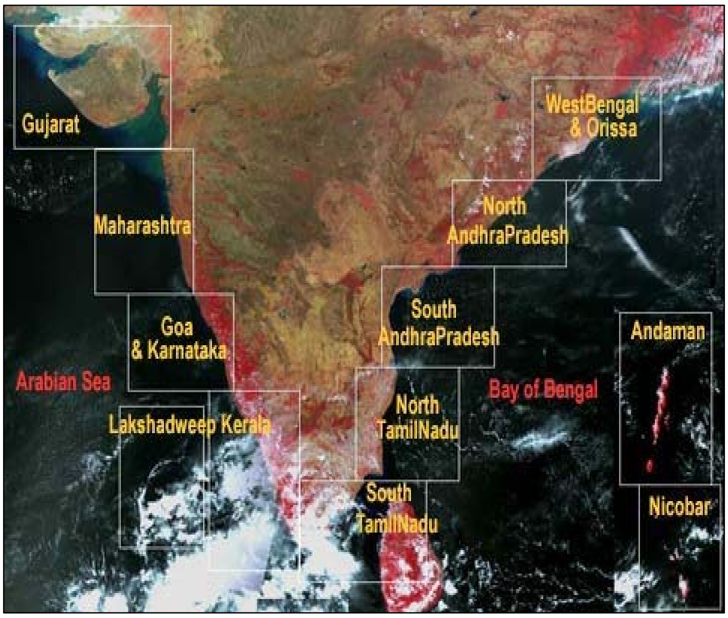


Figure 2.1 – Various fishing sectors selected along the Indian coastline for which INCOIS multi-lingual sector wise PFZ advisories are available (Source - WWW.incois.gov.in)

Adopting the above mentioned scientific insights into an operational mode, Indian National Centre for Ocean Information Services (INCOIS), Hyderabad, India has been providing fishery advisory services to fisherman community all along the Indian Coast free of cost (Figures 2.1 and 2.2). These advisories are referred to as **'Potential Fishing Zone (PFZ) Advisories'**, which essentially provide geo-referenced map showing marked regions where there is a high probability to find sizeable schools of fishes (WWW.incois.gov.in). The advisories are provided primarily to help the fisher folks to improve their income from fishing activity by saving costly engine fuel for searching and locating fishable concentrations of fish stocks. Thus, PFZ advisories are intended to increase the Catch Per Unit Effort (CPUE) of the fishing activity and thereby propose an economically beneficial fishing practice along the Indian coast.

A Typical Potential Fishing Zone (PFZ) Advisory Map
(Map based on SST/Chlorophyll Composite Image of November 12 & 13, 2007)

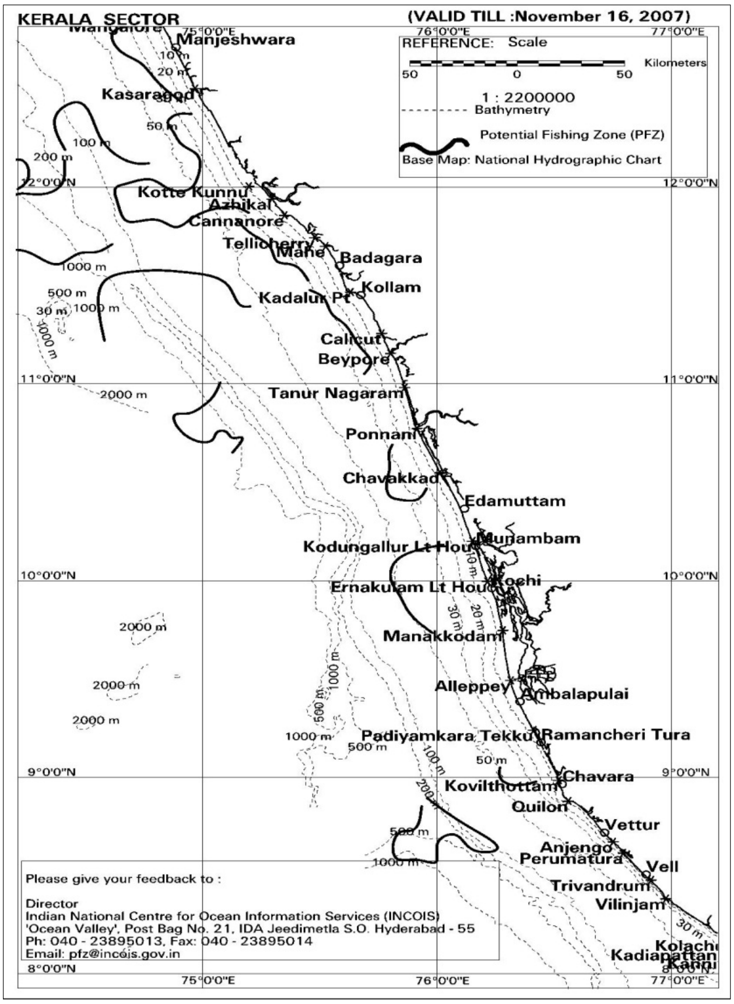


Figure 2.2 – Potential Fishing Zone (PFZ) advisory map disseminated to the fisherman community along the Kerala coast. The black bands indicate the PFZs valid for 13 – 16 November 2007.

INCOIS generates and disseminates multi-lingual PFZ advisories on every Monday, Wednesday and Friday (thrice a week) to about 500 fish landing centres / fishing villages located along the Indian coast line under 12 fishing sectors viz., Gujarat, Maharashtra, Karnataka & Goa, Kerala, South Tamilnadu, North Tamilnadu, South Andhra Pradesh, North Andhra Pradesh, Orissa & West Bengal, Lakshadweep Islands, Andaman Islands and Nicobar Islands (Figure 2.1. Source: WWW.incois.gov.in). However, it is pertinent to note that there are no advisory available on cloudy days and also during the trawling ban period. PFZ advisories are disseminated to fisherman community over several communication media including telephone, fax, e-mail, website, doordarshan, radio, news media, etc. Adopting the state-of-the-art technology available, INCOIS installed Electronic Display Boards (EDB) in major fishing harbours and now proceed towards installing New Generation EDBs in collaboration with the Industry.

2.1.1. Principle behind PFZ advisory

The ocean processes capable of enhancing the biological production leave their imprints on the surface ocean parameters that can be traced and mapped by satellite remote sensing techniques (Sarangi and Mohammed, 2011). Studies along the Indian coastal waters evidenced that in many cases the regions characterised with noticeable gradients in SST also represent regions with large gradients in phytoplankton stock (Solanki et al., 2005). It is fundamental that marine fishes tend to aggregate in regions where their food resources are available in optimum concentrations (Solanki et al., 2005). Sea Surface Temperature (SST) from NOAA-AVHRR and chlorophyll *a* (index of phytoplankton biomass) from IRS-P4 OCM / MODIS Aqua are primarily used for identifying/mapping Potential Fishing Zones (WWW.incois.gov.in).

2.1.2. Various kinds of PFZ advisory

There are four major kinds of PFZ advisories practiced from time to time to help the fisherman community to improve their income from fishing activities. These advisories include (a) SST based PFZ advisory, (b) chlorophyll based advisory, (c) SST and chlorophyll composite advisory and (d) SST and chlorophyll composite advisory corrected with wind data for the shifting features. The sequential order of these advisories also marks the technological advancement and improved understanding on methods to detect and mark regions of high fishery potential with more accuracy. Details of these advisories and their scientific basis are presented in detail below.

2.1.2.1. SST based PFZ advisory

As evident in literature, the first satellite oceanographic parameter that has been monitored on a regular basis since 1970s is the Sea Surface Temperature (SST). Therefore, naturally, the initial attempts to provide fishery resource advisories were exclusively based on gradients evident in SST satellite maps (Figure 2.3), which were considered as imprints of oceanographic processes such as fronts, eddies and upwelling (Laurs and Brucks., 1985; Beenakumari and Nayak, 2000). However, on an operational basis, the application of SST gradients as a tracer for mapping the fishery resources has inherent practical issues.

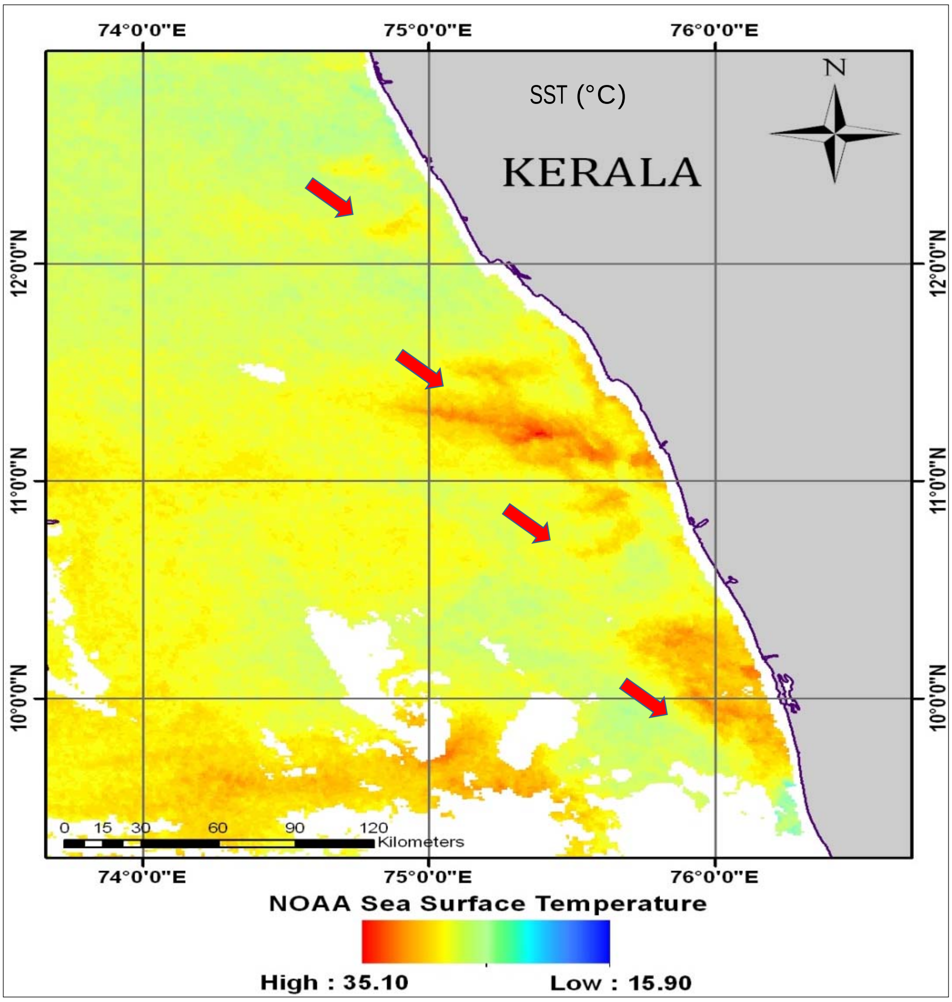


Figure 2.3 – SST image based on data retrieved from thermal infrared channels of NOAA-AVHRR. Regions with noticeable gradients in SST are indicated with red arrows. White patches indicate absence of data.

The satellite SST data represent only the skin SST (only up to 10 micrometres), and therefore, this data could not reflect oceanographic signatures present even just few inches below the surface. This practical problem creates certain level of uncertainties in the tropical seas where the water column exhibit strong surface stratification. It is also found that surface winds or currents, even of moderate magnitude, can disturb the signatures of SST gradients in frontal structures (Dwivedi, 2009). These disturbances can some time cause lack of traceable signatures in SST images to demarcate the oceanographic processes. Therefore, SST images alone are not enough to prepare PFZ advisories in some instances. In recent times, effective use of SST data along with satellite chlorophyll has been practiced, which seems to be useful in forecasting fishery resources along the Indian coast line. Consider section 2.1.2.3 to know more about this application.

2.1.2.2. Chlorophyll *a* based PFZ advisory

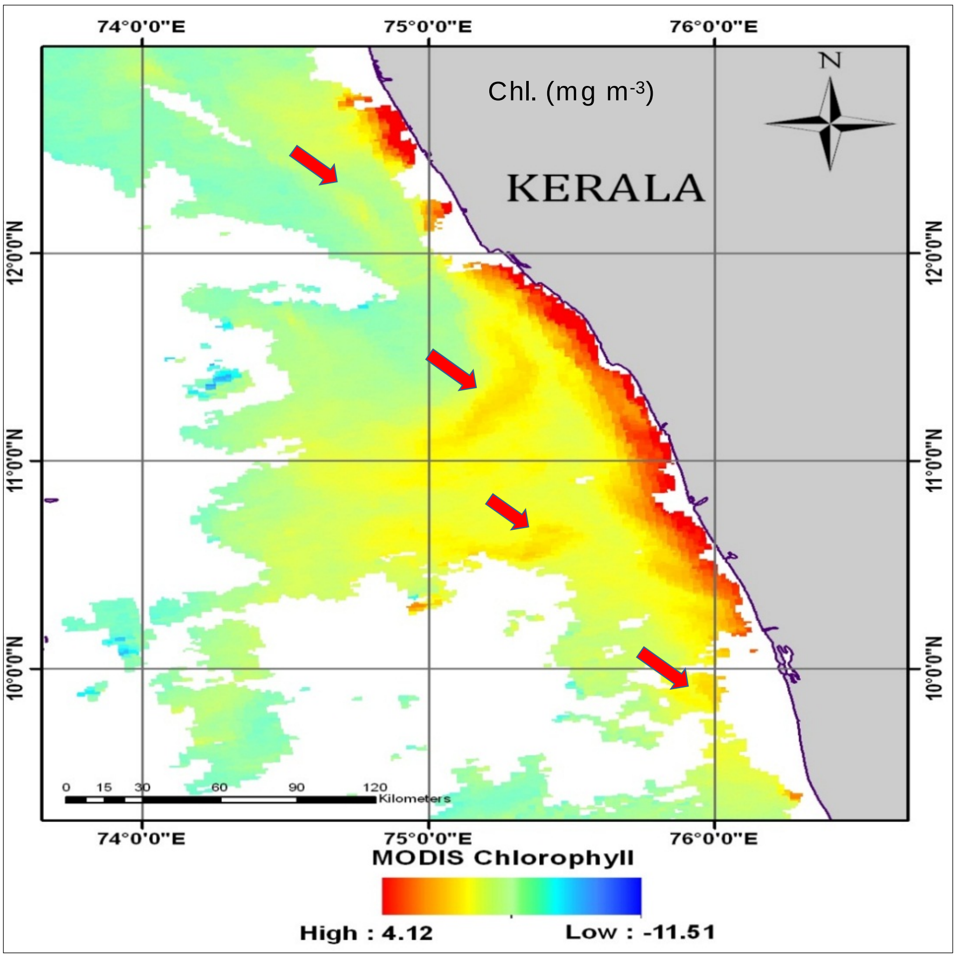


Figure 2.4 – Chlorophyll image based on data retrieved from MODIS Aqua. Regions with noticeable gradients in chlorophyll are indicated with red arrows. White patches indicate absence of data.

Advancement in technology by the introduction of visible optical bands on satellites paved the way for the detection of chlorophyll, an index of phytoplankton biomass, using remote sensing techniques (Figure 2.4). This has revolutionised the application of satellite oceanography to understand ocean physical processes and their biological responses in terms of phytoplankton biomass (Banse, 1986; Jyothibabu et al., 2010). Moreover, the optical sensor of the ocean colour (chlorophyll) has advantage over SST sensor, since it can also detect signals from below surface waters due to the better penetration of the visible radiation in the water column. The visible radiation penetration in the sea water depends primarily on the clarity of the water column and in clear sea conditions; it can penetrate a few tens of meters (Platt and Sathyendranath, 2008). This advantage of ocean colour sensor is utilised to locate and predict the occurrence of oceanographic features such as diverging fronts and eddies, which are biologically productive zones and therefore the regions with possibly higher concentrations of fishes (Dwivedi, 2009).

2.1.2.3. SST and Chlorophyll *a* based PFZ advisory

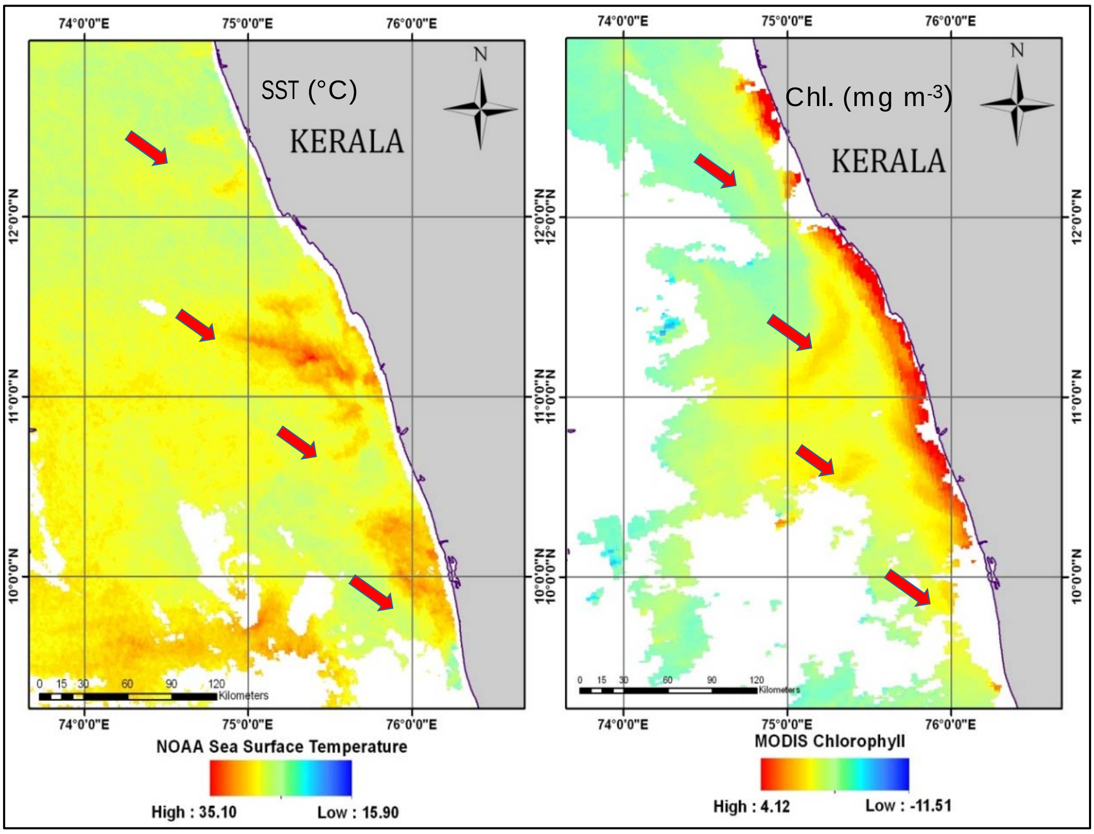


Figure 2.5 – SST image based on data retrieved from the thermal infrared channels of NOAA-AVHRR (on the left) and chlorophyll images from MODIS- Aqua (on the right). The coinciding gradients in SST and chlorophyll images considered for generating the PFZ advisory are indicated by red arrows White patches indicate absence of data.

Considering the close coupling between the physical and biological processes, it is possible to successfully classify different water masses by satellite-derived SST and ocean colour images (Arnone, 1987). Research in similar line in Indian waters showed that there is generally an inverse correlation between the chlorophyll concentration and SST (Solanki et al., 1998). Detailed analyses confirmed that chlorophyll and SST features coincide in regions and cases where there is a coupling between the physical processes and their biological responses (Solanki et al., 2001a, b; 2003). Regions of high phytoplankton concentration are generally associated with upwelling, eddies, fronts, meanders, coastal jets (Solanki et al., 2001b; Figure 2.5). These understanding formed the scientific basis for initiating an integrated approach for forecasting PFZ using Ocean Colour Monitor (OCM) derived chlorophyll and AVHRR derived SST (Solanki et al., 2000, 2001; Figure 2.6).

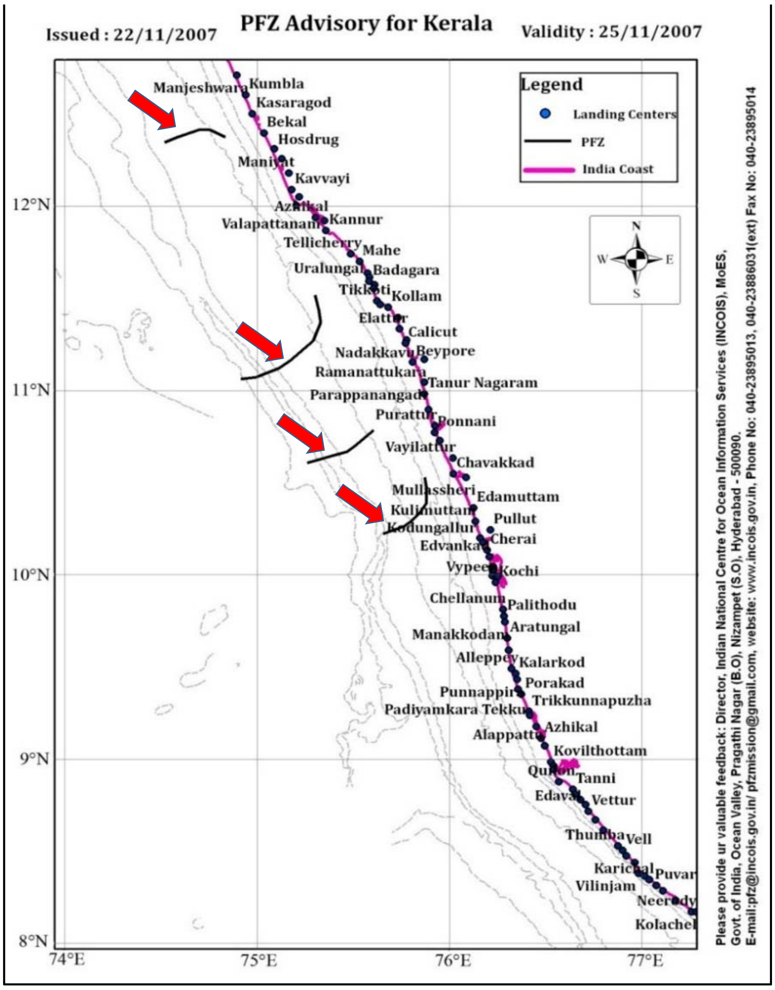


Figure 2.6 – INCOIS PFZ advisory disseminated to the fisherman community along the Kerala coast based on SST and chlorophyll images presented in figure 2.4. The thick black bands of PFZ are indicated by red arrows.

Majority of the PFZ advisories considered for the present study (April 2007 – April 2012) are generated based on composite imageries of SST and chlorophyll (Figure 2.6). As mentioned earlier, PFZ advisories based on composite images of SST and chlorophyll have advantages over earlier advisories, which were based either on SST or chlorophyll. Recent research indicated that there are further scope for improving the accuracy of the PFZ advisory by incorporating necessary corrections for the possible spatial shift in the observed features in satellite data over short period of time (days). This understanding lead to the development of wind based PFZ advisory. Consider section 2.1.2.3 for further details about this aspect.

2.1.2.4. Wind based PFZ advisory

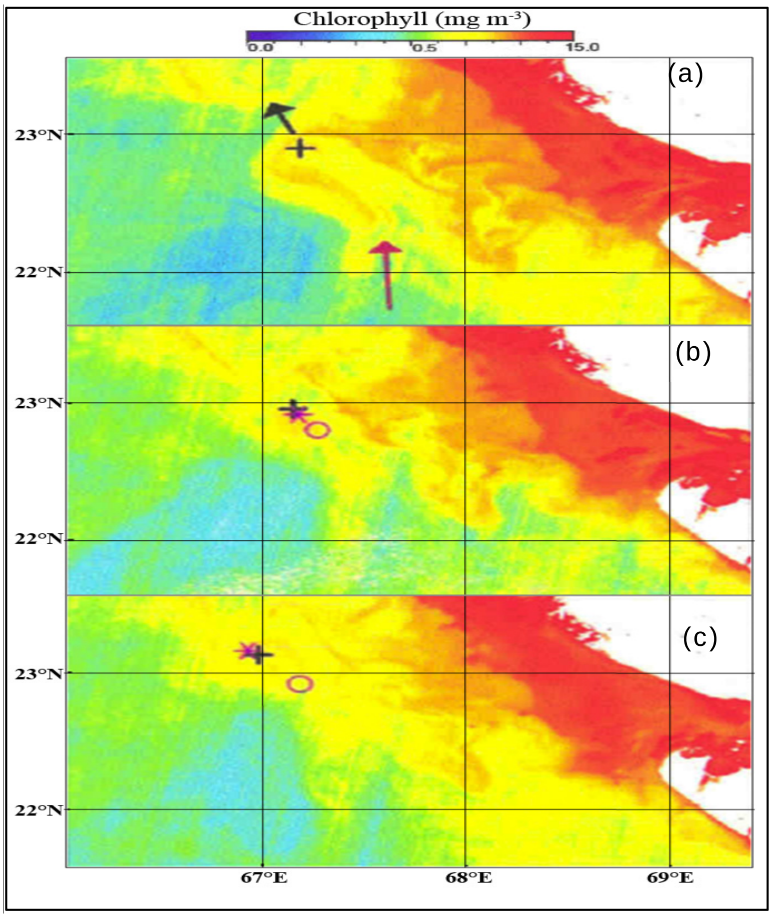


Figure 2.7 – The concept of wind based PFZ advisory. Time series chlorophyll images of November 2001 showing the actual and calculated position of a shifting feature during a week time. Red and black arrows in panel (a) indicate the direction of advection of surface features. Symbol + shows the observed position, O the original position and * the calculated position (adapted from Vinuchandran et al., 2004).

The PFZ advisories are provided in near real time and the time required for processing the satellite data and preparation of PFZ advisories are done within minimum possible time.

However, studies shows that the ocean colour features like chlorophyll fronts are dynamic and therefore, they tend to drift with respect to surface current advection induced by winds. Considering the time lag (though it is small) between the satellite data acquisition and dissemination of PFZ advisories, there could be a shift in the observed ocean colour features. The extent of this shift primarily depends on the strength of the winds/ currents in a particular region (Figure 2.7).

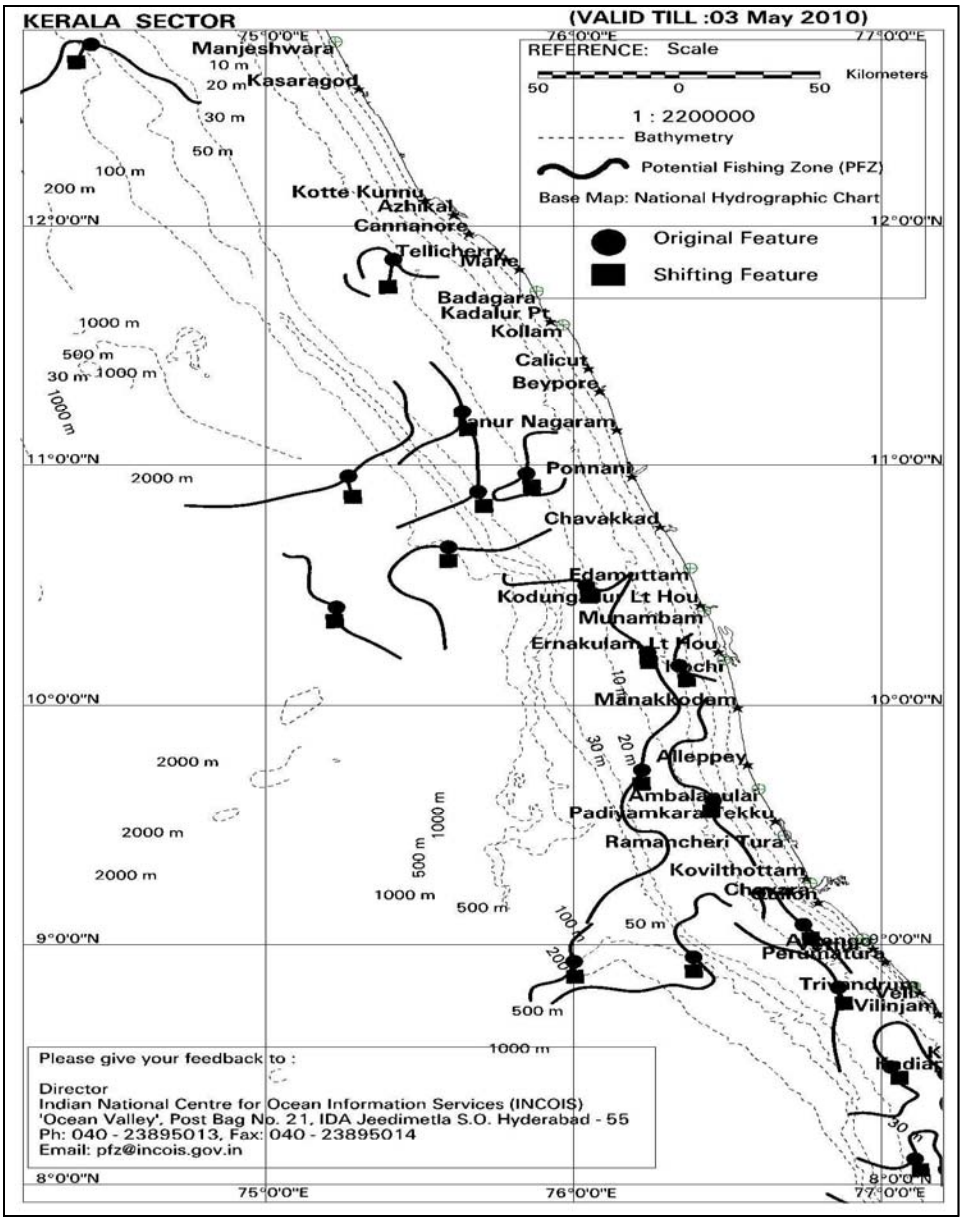


Figure 2.8 – Typical wind based PFZ advisory disseminated by INCOIS for April 29 – May 03, 2010. The original locations of the feature and their geographical shift in locations over short period of time (days) are clearly indicated with suitable symbols

Recent research indicate that even this shift in the ocean colour products can be corrected with empirical relationships, which can be efficiently used to correct the PFZ advisory for the shifted features (Vinuchandran et al., 2004). This approach includes processing of atmospherically corrected chlorophyll satellite images and wind data by deriving a mathematical relationship between the wind data and the sifted feature (Figure 2.8). After validating the relationship with a second set of time series images, the data can be used for updating the location of the PFZ features even up to 96 hour within an error of 12% (Vinuchandran et al., 2004).

2.2. Objectives

This chapter basically presents the detailed results of 124 PFZ validation (controlled fishing) experiments carried out along the Kerala coast between Kollam and Kannur during March 2007 – March 2012 (5 years). The data presented are expected to improve our understanding on the PFZ advisory and the associated pelagic fishery along the Kerala coast. In addition to the detailed information regarding various kinds of PFZ advisories, this chapter addresses the following major objectives (a) the usefulness of the PFZ advisories to improve the fish catch and the profit earned from 124 controlled fishing experiments (b) the effectiveness of PFZ advisories for locating various kinds of pelagic fishes with emphasis on economically important small pelagics such as Indian oil sardine, Indian mackerel and anchovies and (c) seasonal difference in the usefulness of the PFZ advisory for locating these small pelagic fishes along the Kerala coast.

2.3. Study area

The area of interest of the present study is the continental shelf waters of the Kerala coast between Kollam and Kannur. In the present study, 20 base stations distributed along the Kerala coast were selected to carry out fishing experiments in the shelf waters (Table 2.1). These base stations along the coastline were selected considering that (a) they should be capable of providing good spatial representation of the study region between Kollam and Kannur for enabling the controlled fishing experiments and (b) they should be capable to provide necessary logistics support for conducting the controlled fishing experiments, employing the desired craft and gear. The base locations are listed in Table 2.1 and their geographical distribution along the coastline is shown in Figure 2.9.

SL.NO.	Stations	SL.NO.	Stations
1	Neendakara	11	Kodungalloor
2	Kovilthottam	12	Edamuttom
3	Ramancheri Tura	13	Chavakkad
4	Padiyamkara Tekku	14	Ponnani
5	Ambalapuzha	15	Tanur
6	Manakkodam	16	Baypore
7	Vypin	17	Kozhikodu
8	Kalamukku	18	Puthiappa
9	Murikkumpadam	19	Vadakara
10	Munambam	20	Kannur

Table 2.1 – Base stations selected along the Kerala coast between Kollam and Kannur for carrying out the controlled fishing experiments

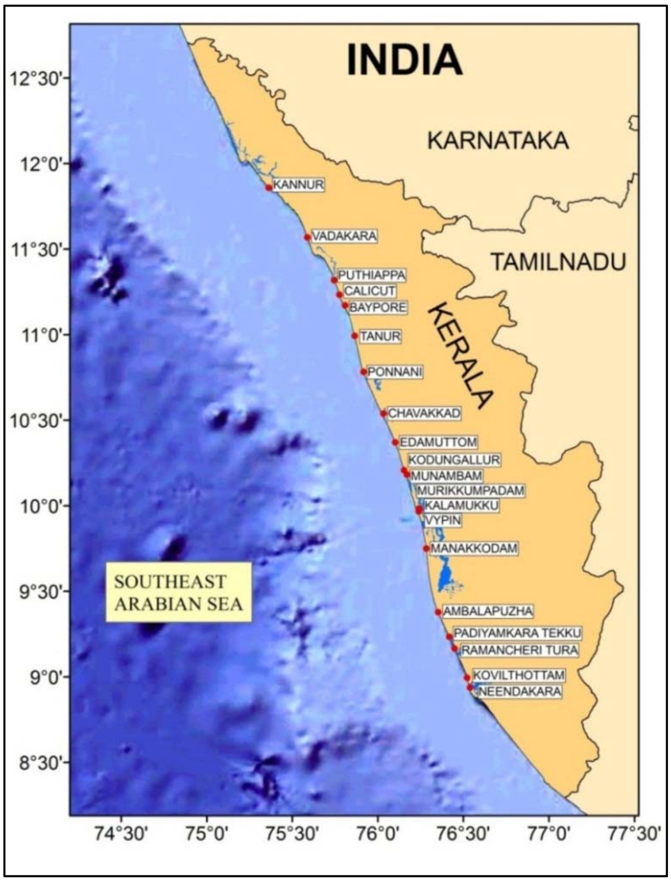


Figure 2.9 – Base stations selected along the Kerala coastline between Kollam and Kannur (red circles) for carrying out controlled fishing experiments to validate the PFZ advisories.

The base stations selected for operating the controlled fishing experiments are essentially represent the centres of major fishing activity along the Kerala coast including the major fish landing centres such as Neendakara, Kochi and Kozhikodu (Figure 2.9). Moreover, in all these base locations, PFZ advisories of INCOIS are available through any/all the media such as telephone, fax and digital display boards. These operational conveniences made the base stations technically suitable for carrying out controlled fishing experiments to validate the accuracy/usefulness of the advisories. The controlled fishing experiments carried out in the shelf waters of Kerala based on various base locations selected are represented in Figure 2.6.

2.4. Methods

2.4.1. Controlled Fishing Experiments

Fish landing data refers to the part of the fish catch that is put ashore. The landings mostly provide the only record of total catch on a longer time scales. Accurate landing statistics are among the most important data for the assessment and management of sustainable fisheries. For many fishes, however, landing data may not be entirely accurate or complete for several reasons. The fishing operators may report their catches in masses other than from where the fishes were actually caught.

In order to scientifically analyse the usefulness of the PFZ advisories, it is necessary to conduct long term controlled fishing experiments in the region of interest. Such long term experimental approach is useful to assess the usefulness of PFZ advisories on a quantitative and relative basis. **Controlled Fishing Experiments** refers to the dedicated experimental fishing carried out in the PFZ and non-PFZ regions in the shelf waters along the Kerala coast during 2008 -2012 period (Figure 2.10). The fishing experiments are planned in such a way that similar fishing boats equipped with identical fishing gears can simultaneously conduct the fishing operations in the PFZ and non-PFZ regions.

Taking into consideration the availability of fishing vessels and also other logistic aspects associated with the PFZ advisories, necessary networks were established with the fisherman/boat owners in various base locations selected along the Kerala coast. These networks/links with the fisherman/boat owners were helpful to successfully carryout the controlled fishing experiments. Ring seine was extensively used for the controlled fishing experiments as this gear forms the common/efficient one for catching small pelagic fishes along the Kerala coast.

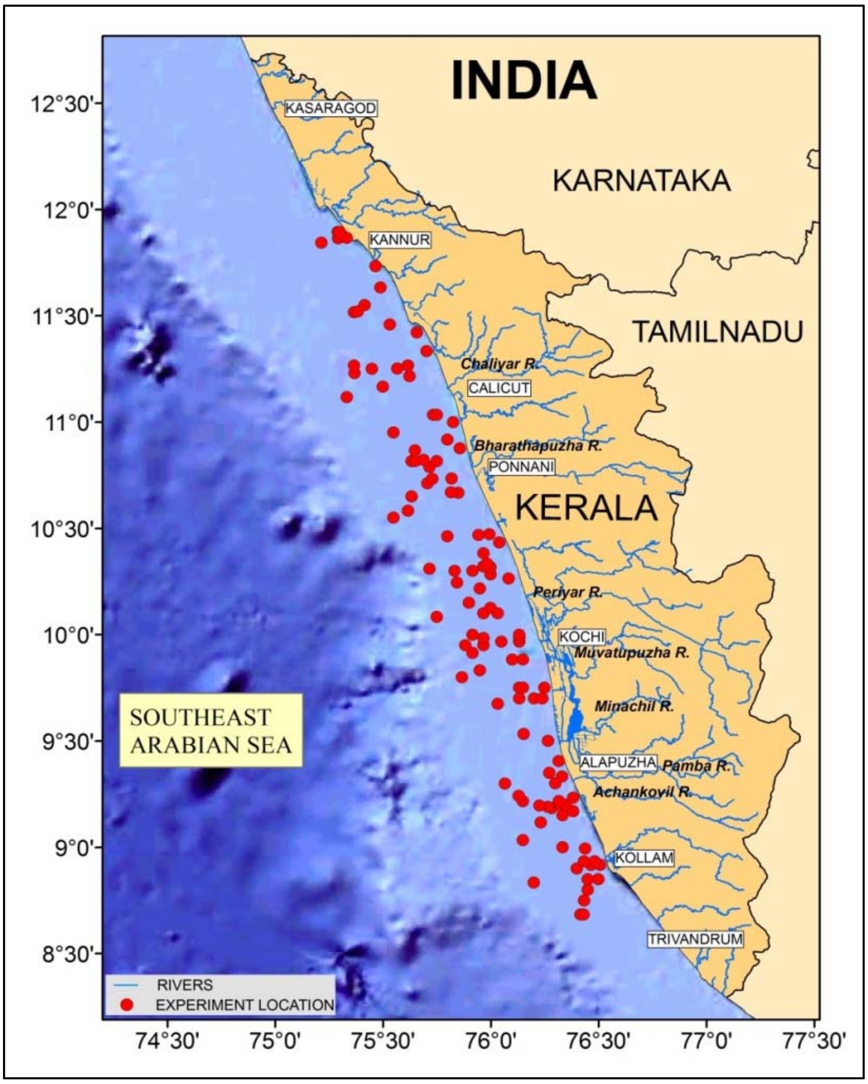


Figure 2.10 – The distribution of controlled fishing experiments carried out in the PFZ along the Kerala coast between Kollam and Kannur during the study period (2008-2012).

Mechanised, single day fishing crafts (20m OAL and 100HP engine) with ring seining facility were employed for the Controlled Fishing Experiments (Figures 2.11 and 12). The controlled fishing experiments normally start in the early morning and the fish catch lands in the base locations in the afternoon/evening. For technical reasons, the fishing boats employed in the experiments were assigned code numbers and their identity was maintained undisclosed and the actual/realistic catch data they provided were used exclusively for the validation of the PFZ advisories. This consensus with the boat owners was essential to obtain accurate fish catch data from the crafts engaged in controlled fishing experiments.

Figure 2.11 – Ring seining in the PFZ off Kochi during controlled fishing experiments in December 2009

In order to assuring good quality catch data from controlled fishing experiments, three approaches were generally adopted (a) the owners of the boat engaged in fishing experiments were reasonably paid so that they would keep up the fishing location as per the PFZ advisory (b) employed a technical staff on board the vessel to assure the accuracy of fishing activity in the PFZ and Non- PFZ regions and (c) confirmed the catch data by physically verifying the fish catch in landing centres.

Figure 2.12 – Fish catch from a ring seining in the PFZ off Kochi during controlled fishing experiments in December 2009. High sardine catch obtained from the PFZ region is evident in the image

2.4.2. Catch Per Unit Effort (CPUE)

CPUE is an indirect measure of the abundance of fishes. Changes in the CPUE are inferred to signify changes in the abundance of fishes. Although CPUE is a relative measure of abundance, it can be used to estimate absolute abundances. The main difficulty when using measures of CPUE is to define the unit of effort. The general formula for estimating CPUE can be considered as:

Total fish catch divided by the estimated effort

CPUE = TOTAL CATCH ÷ EFFORT

However, in the present case, the experimental fishing had only one day duration and therefore the effort is considered as 1

2.4.3. Economics of fishing (Profit)

The accurate calculation of profit is an important aspect to assess the financial success of a fishing activity. The financial term 'profit' can be defined many ways based on different modes of fishing. In the present context, the term 'profit' is used to represent the income gained in Indian Rupees after deducting all expenditures incurred associated with the fishing activity such as fuel oil, labourers and other such expenditures.

PROFIT (RS.) = TOTAL INCOME - TOTAL EXPENDITURE

2.4.4. Statistics: Mann-Whitney U test

The Mann-Whitney U test (also known as Mann-Whitney-Wilcoxon, Wilcoxon rank-sum test or Wilcoxon-Mann-Whitney test) is a non-parametric statistical hypothesis test for assessing whether one of the two samples of independent observations tends to have larger values than the other. It is one of the most well-known non-parametric significance tests (Frank Wilcoxon in 1945). The non-parametric statistical methods are advantageous as it makes fewer assumptions; and therefore their applicability is much wider as compared to the parametric methods. In particular, they may be applied in situations where less is known about the application in question.

The Mann–Whitney U test for the present study was carried out using the statistical software XL Stat pro version 1 of Microsoft Corporation, USA. The steps involved in U statistics include the following calculations:

$$U_1 = R_1 - \frac{n_1(n_1+1)}{2}$$

Where n_1 is the sample size for sample 1, and R_1 is the sum of the ranks in sample 1.

$$U_2 = R_2 - \frac{n_2(n_2+1)}{2}.$$

The smaller value of U_1 and U_2 is the one used when consulting significance tables. The sum of the two values is given by

$$U_1 + U_2 = R_1 - \frac{n_1(n_1+1)}{2} + R_2 - \frac{n_2(n_2+1)}{2}.$$

2.5. Results and discussion

2.5.1. Composition of dominant fishes in fishing experiments

The 126 controlled fishing experiments conducted during the study period evidenced the dominance of 15 fishes in the PFZ regions (Table 2.2). These fishes include relatively small, low priced pelagic fishes such as oil sardine, mackerel and anchovies as well as large, high priced pelagic fishes such as tunas and seer fishes. The diversity of fish stock in the PFZ was mostly contributed by several taxonomic groups consisting of Clupeids (1 species), Scombrids (6 species), Carangids (5 species), Barracuda (1 species) and Penaeid shrimp (1 species).

Most of these species are pelagic and exhibit schooling behaviour and feed actively on plankton living in the euphotic layer of the seas. An exception to this general feature was the penaeid shrimp *Metapenaeus dobsoni*, which is predominantly benthic, but obtained in large quantities in ring seine operation during controlled experiments conducted off Kochi in September 2009.

S. No	Binomial/group name	Common name	Major group	Family
1	*Sardinella longiceps*	Indian oil sardine	Clupeids	Clupeidae
2	*Rastrelliger kanagurta*	Indian mackerel	Scombrids	Scombridae
3	*Trachurus trachurus*	Horse mackerel	Carangids	Carangidae
4	Anchovies	Whitebait	Anchovy	Engraulidae
5	*Euthynnus affinis*	Coastal tuna	Scombrids	Scombridae
6	*Alepes djeddaba*	Shrimp scad	Carangids	Carangidae
7	*Decapterus russelli*	Mackerel scad	Carangids	Carangidae
8	*Formio niger*	Black pomfret	Carangids	Carangidae
9	*Megalaspis cordyla*	Torpedo scad	Carangids	Carangidae
10	*Sphyraene sp.*	Kolas	Barracuda	Sphyraenidae
11	*Scomberomorus commerson*	Seer fish	Scombrids	Scombridae
12	*Thunnus albacares*	Yellow fin tuna	Scombrids	Scombridae
13	*Auxis rochei*	Bullet tuna	Scombrids	Scombridae
14	*Katsuwonus pelamis*	Skipjack tuna	Scombrids	Scombridae
15	*Metapenaeus dobsoni*	Poovalan/Kadal shrimp	Penaeids	Penaeidae

Table 2.2 – Dominant fishes recorded during controlled fishing experiments in the PFZ

Detailed information on the compositional variations of the dominant fishes obtained in controlled experiments is presented in Figures 2.13 – 2.16. When the entire data of the controlled experiments were pooled and treated together, it was found that carangids consisting of five species (*Alepes djeddaba*, *Decapterus russelli*, *Trachurus trachurus*, *Formio niger* and *Caranx ignobilis*) were dominant in 42% of the total observations. However, Indian mackerel was found to be the most dominant single species (25%) in the controlled experiments followed by Indian oil sardine (21%). The percentage dominance of tunas and other fishes (others) was relatively less with 5% and 7% of the total controlled experiments, respectively.

Among Carangids, *Decapterus russelli* was found to be the most dominant species in the pooled data of controlled experiments with a percentage contribution as high as 42% followed by *Alepes djeddaba* (23%), *Trachurus trachurus* (17%), *Formio niger* (14%) and *Caranx ignobilis* (2%). In tuna group, *Euthinnus affinis* was the most dominant (34%) followed by

Thunnus albacares (11%), *Katsuwonus pelamis* (22%) and *Auxis rochei* (11%). Among other fishes (others), anchovies and *Sphyraene* sp. contributed the highest (33% each) followed by *Scomberomorus commerson* (17%) and *Metapenaeus dobsoni* (17%).

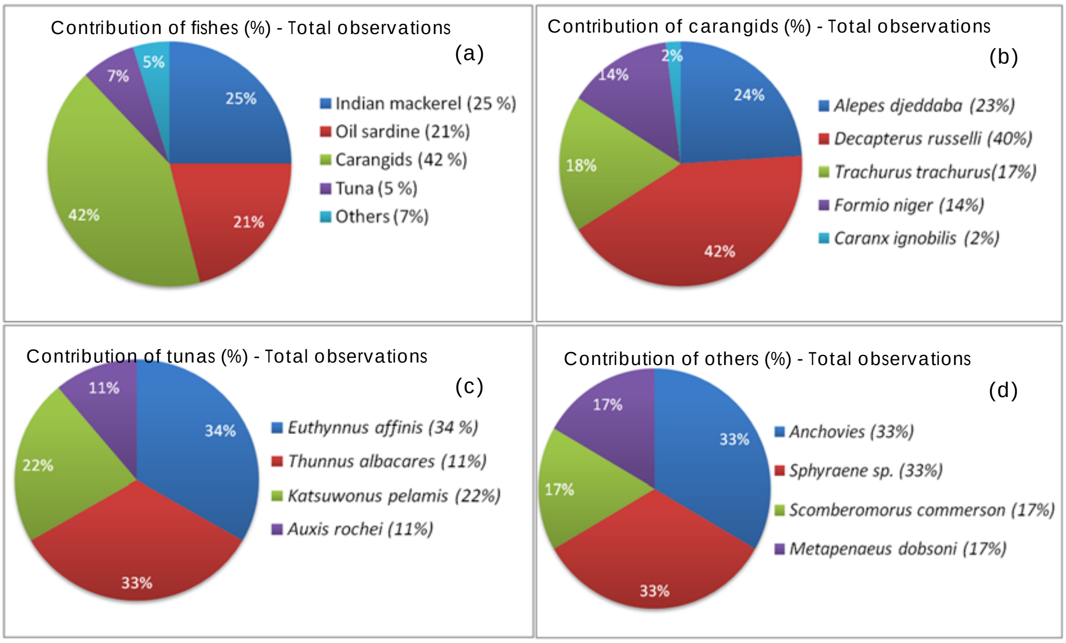


Figure 2.13 – Percentage contribution of fishes in the pooled data of controlled fishing experiments

Compared to the overall feature evident in pooled data of the controlled experiments, there were some noticeable differences in species composition when the data was treated on a seasonal basis. The percentage contribution of various fishes obtained in controlled experiments conducted during the Spring Intermonsoon (March –May), Southwest Monsoon (June – September) and Northeast Monsoon (October – February) are presented in Figures 3.14, 3.15 and 3.16, respectively.

The percentage dominance of fishes during the spring intermonsoon presented in Figure 2.11 shows the dominance of carangids (48%), followed by Indian mackerel, oil sardine (17% each), tuna (9%) and others (5%). The dominance of carangid group was mostly contributed by *Decapterus russelli* (35%) followed by *Alepes djedeba* (24%), *Trachurus trachurus* (23%) and *Formio niger* (18%). The tuna group was consist of two species and the major contribution was from *Katsuwonus pelamis* (67%) followed by *Euthinnus affinis* (33%). The other fishes (others) consist of anchovies (34%), Sphyraena *sp.* and *Auxis rochei* (33%) dominated in some controlled experiments during the Spring intermonsoon period.

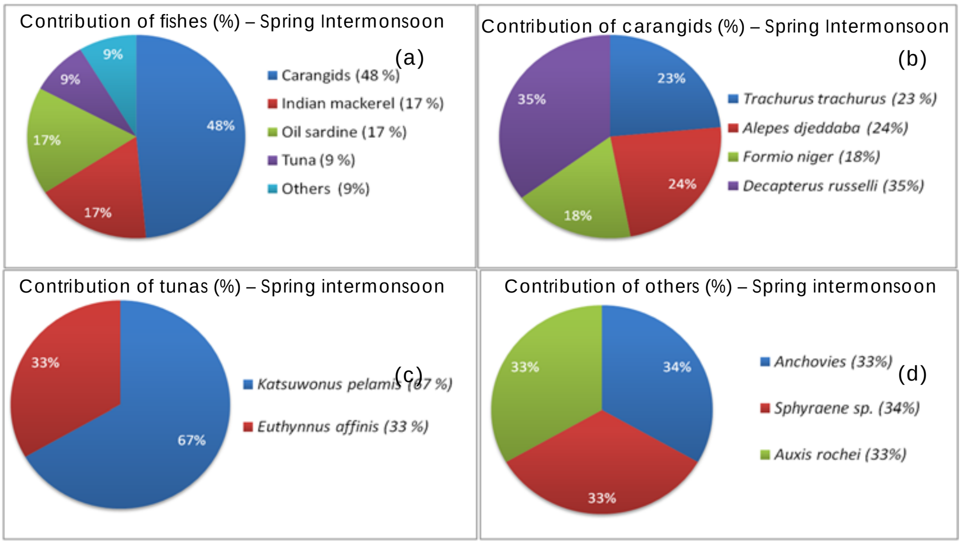


Figure 2.14 – Percentage contribution of dominant fishes in controlled experiments conducted during the Spring Intermonsoon period of 2007 – 2012 periods

In controlled experiments during the Southwest Monsoon, the percentage contribution of dominant fishes showed some characteristic features (Figure 2.15). The important feature in the catch data was the noticeable increase in the percentage contribution of Indian mackerel (55%) and the decrease of carangids (29%) and oil sardine (7%). Among carangid group, *Decapterus russelli* was dominant in most cases (56%) followed by *Trachurus trachurus* (22%) and *Alepes djeddaba*(22%). *Euthinnus affinis* was the only one species dominated in tuna group. Similarly, during the Southwest monsoon, *Metapenaeus dobsoni* was the single species found dominant among other groups (others).

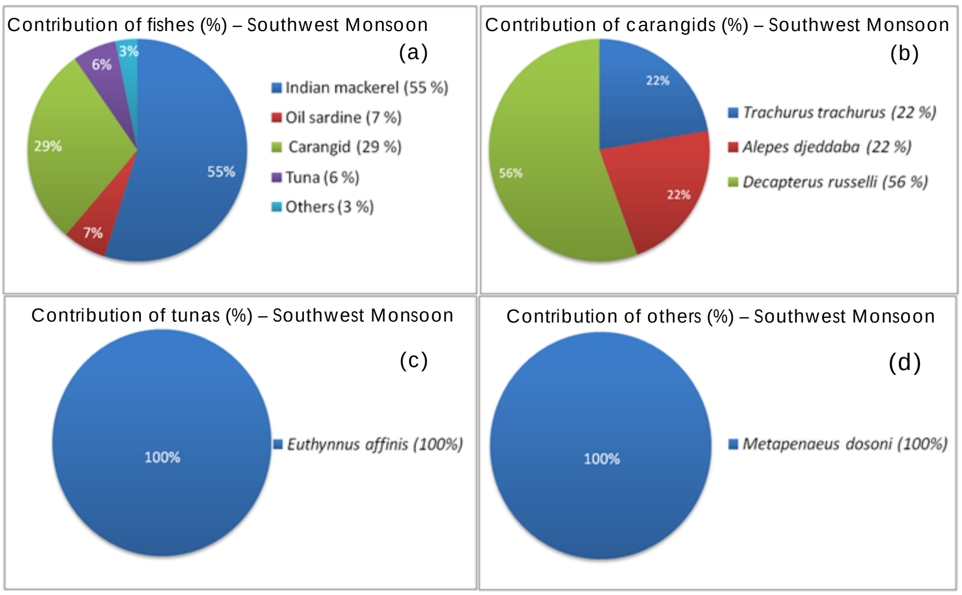


Figure 2.15 – Percentage contribution of dominant fishes in controlled experiments conducted during the Southwest Monsoon period of 2007 – 2012

During the Northeast Monsoon, the pattern of percentage dominance of different fishes is presented in Figure 2.16, which shows differences in the percentage contribution of some dominant fishes as compared to the Southwest Monsoon. Similar to the spring intermonsoon, carangid group dominated the catches during the Northeast monsoon (42%).

The oil sardine was the second dominant one (29%) followed by Indian mackerel (16%). The most striking feature is the increase in percentage dominance of Indian oil sardine and the decrease in the percentage of Indian mackerel (Figure 2.16a).

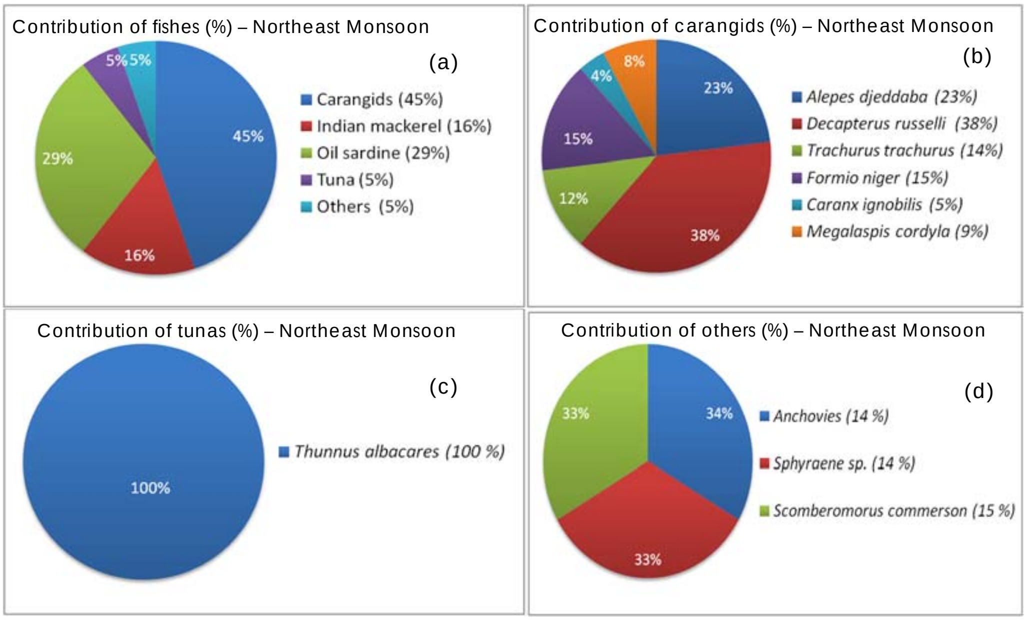


Figure 2.16 – Percentage contribution of dominant fishes in controlled experiments conducted during the Northeast Monsoon of 2007 -2012 periods

The carangid group showed more species diversity during the Northeast monsoon period (Figure 2.16b). As also evident in the pooled data, *Decapterus russelli* was the most dominant carangids during the northeast monsoon (38%) followed by *Alepes djeddaba* (23%), *Formio niger* (15%) and *Trachurus trachurus* (14%).

In a few controlled experiments, *Megalaspis cordyla* and *Caranx ignobilis* dominated the catch, which were 9 and 5 percentage of the total incidence of carangid dominance. During the northeast monsoon, the tuna group was dominated by a single species *Thunnus albacares* (Figure 2.16c) whereas, the other fishes was consist of anchovy, *Sphyrnae* sp. and *Somberomorus commerson* (Figure 2.16d).

2.5.2. Usefulness of the PFZ advisory

The fish catch data of 121 controlled experiments conducted in the PFZ and non-PFZ regions along the Kerala coast is presented in Figure 2.17. The figure essentially shows the difference in fish catch obtained in the PFZ and non-PFZ zones. It is evident that the fish catch obtained from the entire experiments was noticeably higher in the PFZ than that in the non-PFZ zones.

The dominant fishes in controlled experiments are presented in Figure 2.18. The highest catches (>500 kg) in the entire fishing experiments was found for oil sardine, carangids and tunas (Figure 2.15). It is also noticed that the catch of the Indian mackerel never exceeded 500 kg during the entire fishing experiments.

The profit earned from the controlled experiments is presented in Figure 2.19. It is evident that the profit from the fishing activities in the PFZ was consistently higher than that in the non-PFZ. The highest profit during the entire controlled fishing experiments was obtained when the catch was dominated by relatively high priced fishes such as tunas, carangids, seer fishes and mackerel.

The seasonal occurrence of the dominant fishes during the controlled experiments is shown in Figure 2.20, and it was evident that there is a seasonal difference the catch composition of dominant fish species. Even though the carangid group generally dominated during all the three seasons, the detailed analyses shows a noticeable seasonal difference in the percentage contribution of different species present in the catch. Oil sardine was the major single species during the Northeast Monsoon whereas, Indian mackerel dominated during the Southwest Monsoon and Spring Intermonsoon periods.

The profit earned from the fishing experiments conducted during different seasons is presented in Figure 2.21. Fluctuations in profit earned were more prominent during the southwest and northeast monsoons as compared to the Spring Intermonsoon. The highest mean profit was obtained during the Southwest monsoon period followed by the northeast monsoon period (Figure 2.21).

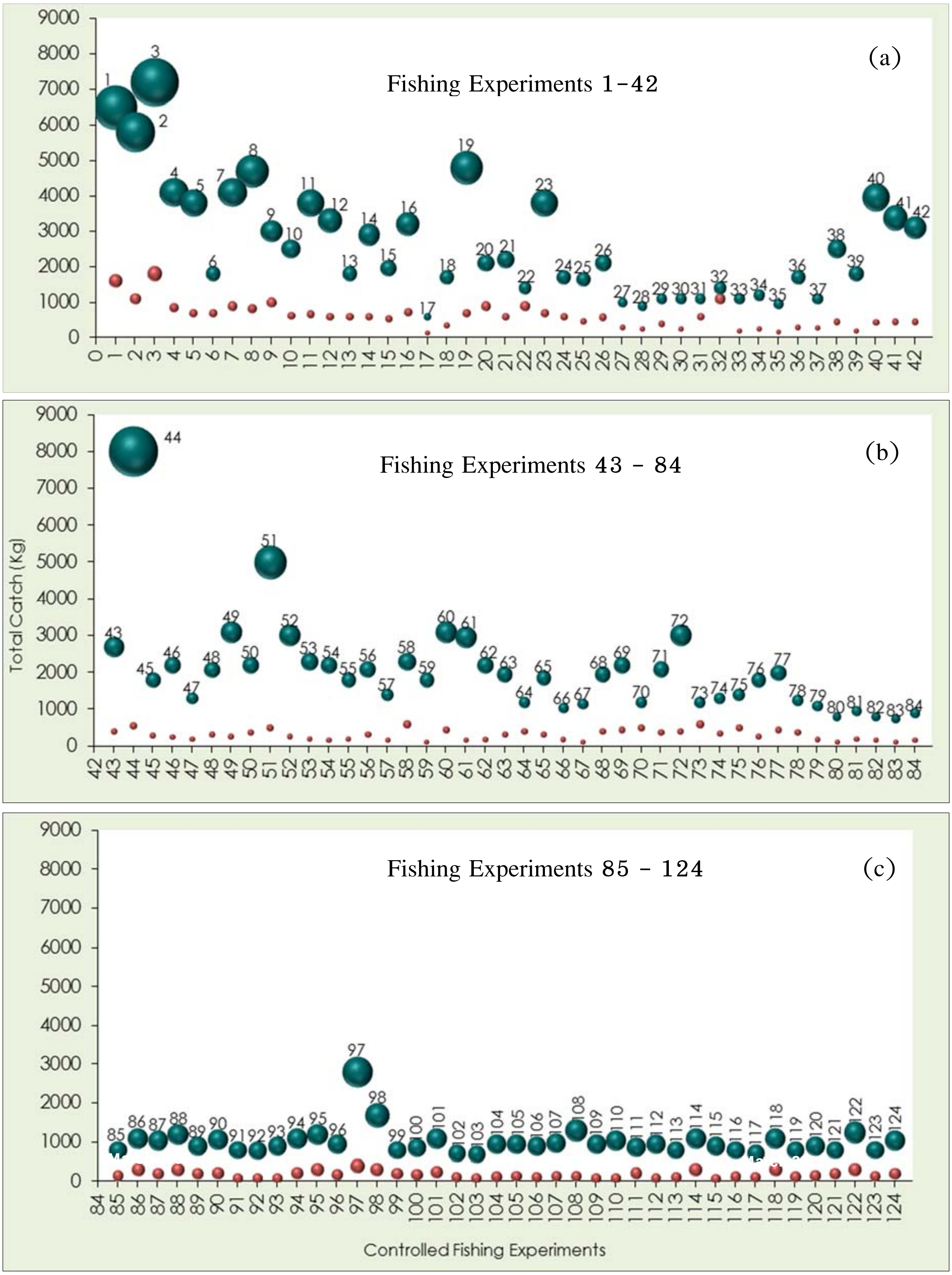


Figure 2.17 – Bubble plot showing the fish catch in 124 controlled fishing experiments conducted along the Kerala coast during 2007 – 2012 periods. The total fish catch with in the PFZ and outside the PFZ are represented in green and red bubbles, respectively. The size of the bubble shows the proportionate size of the fish catch. Controlled experiments from 1-42, 43-84 and 85 – 124 are represented in panel I, II and III, respectively.

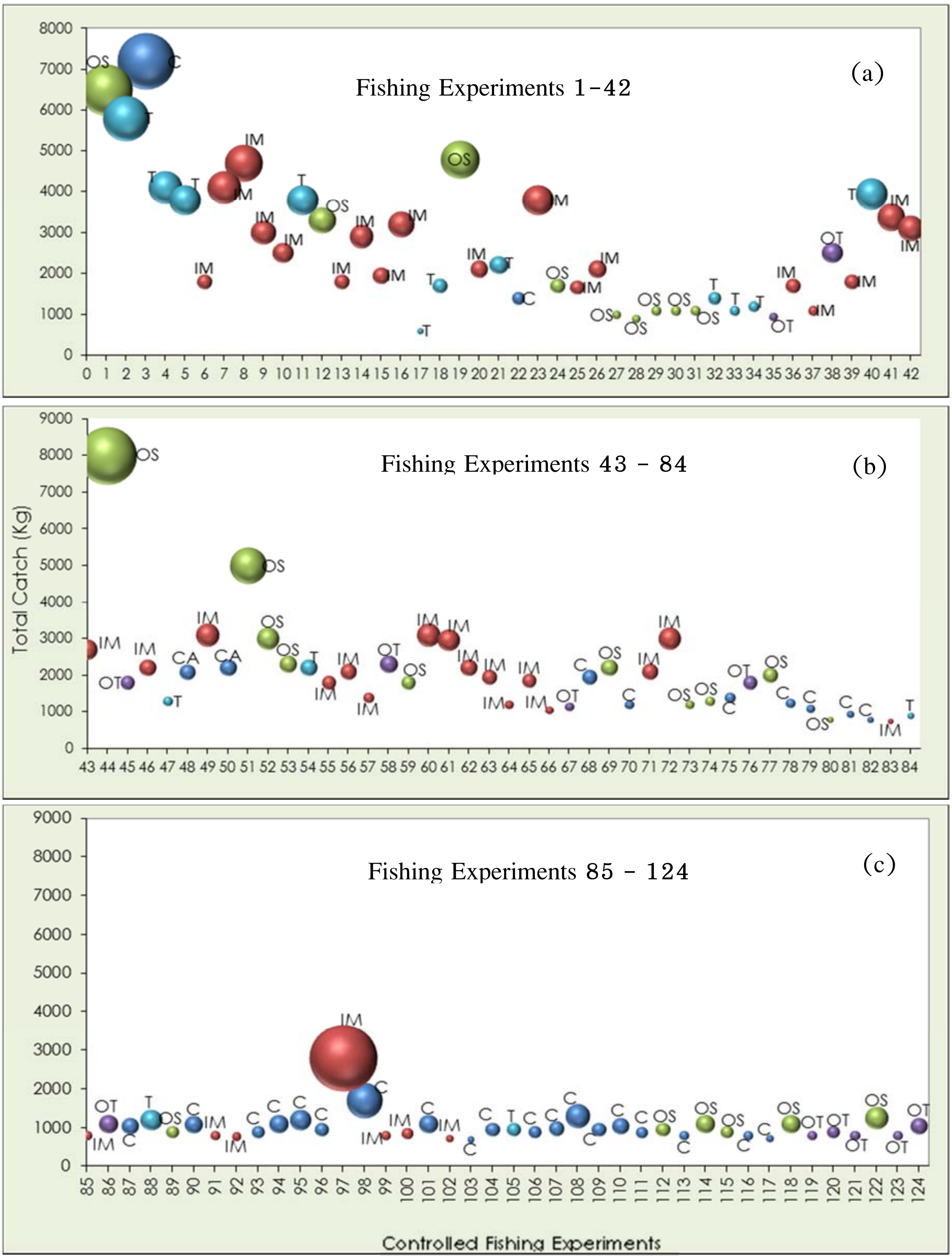


Figure 2.18 – Bubble plot showing the fish composition in 124 controlled fishing experiments conducted along the Kerala coast during 2007 – 2012 periods. Controlled experiments from 1-42, 43-84 and 85 – 124 are represented in panel (a), (b) and (c), respectively. The size of the bubble shows the proportionate size of the fish catch. Abbreviations: (C) Carangids, (IM) Indian mackerel, (T) Tuna, (OS) Oil sardine, (A) anchovies and (OT) others.

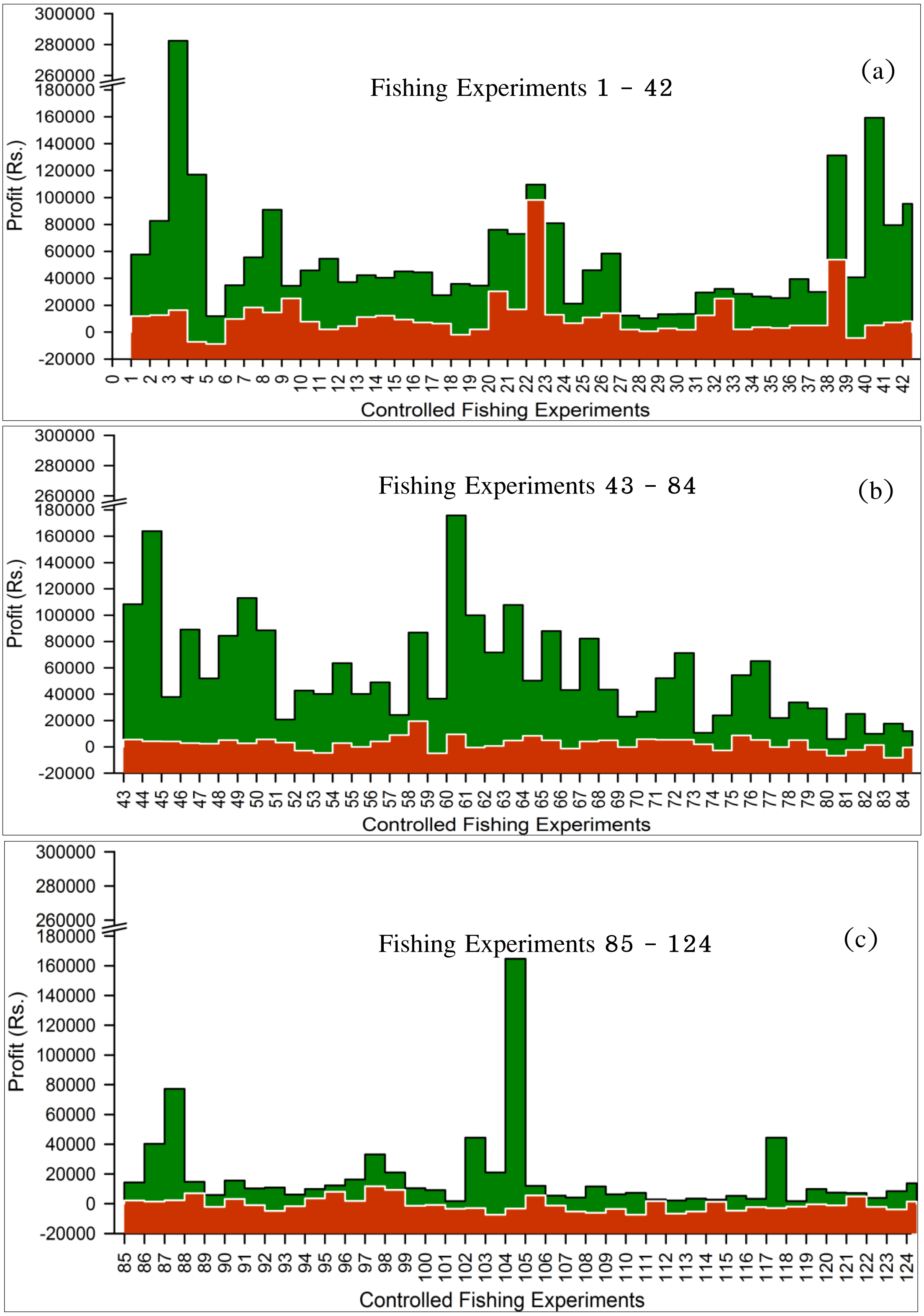


Figure 2.19 – Profit from 124 controlled fishing experiments conducted during 2007 – 2012 periods. Green and red bars indicate the profit from PFZ and non-PFZ regions, respectively. Fishing experiments from 1-42, 43-84 and 85 – 124 are represented in panels (a), (b) and (c), respectively. Significantly high profit from the fishing operations in the PFZ region is evident in all the three panels.

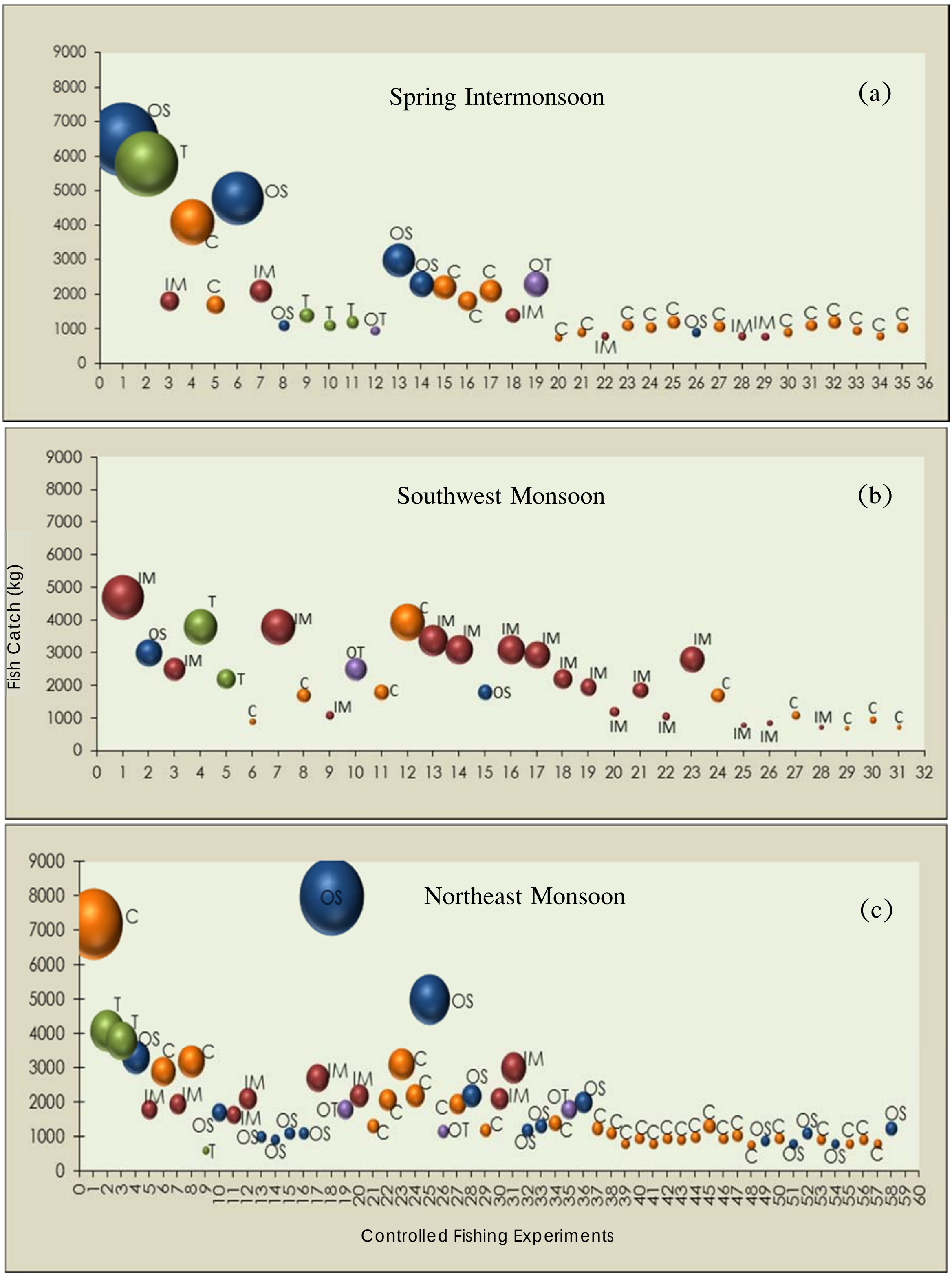


Figure 2.20 – Bubble plot showing the fish composition in controlled fishing experiments. The panels represent (a) Spring Intermonsoon, (b) Southwest Monsoon and (c), Northeast Monsoon. Abbreviations: (C) Carangids, (IM) Indian Mackerel, (T) Tuna, (OS) Oil Sardine, (A) Anchovies and (OT) Others. Ccarangids, as a group, dominated the catch. On the other hand, Oil Sardine and Indian mackerel were the two species found predominant in the catch.

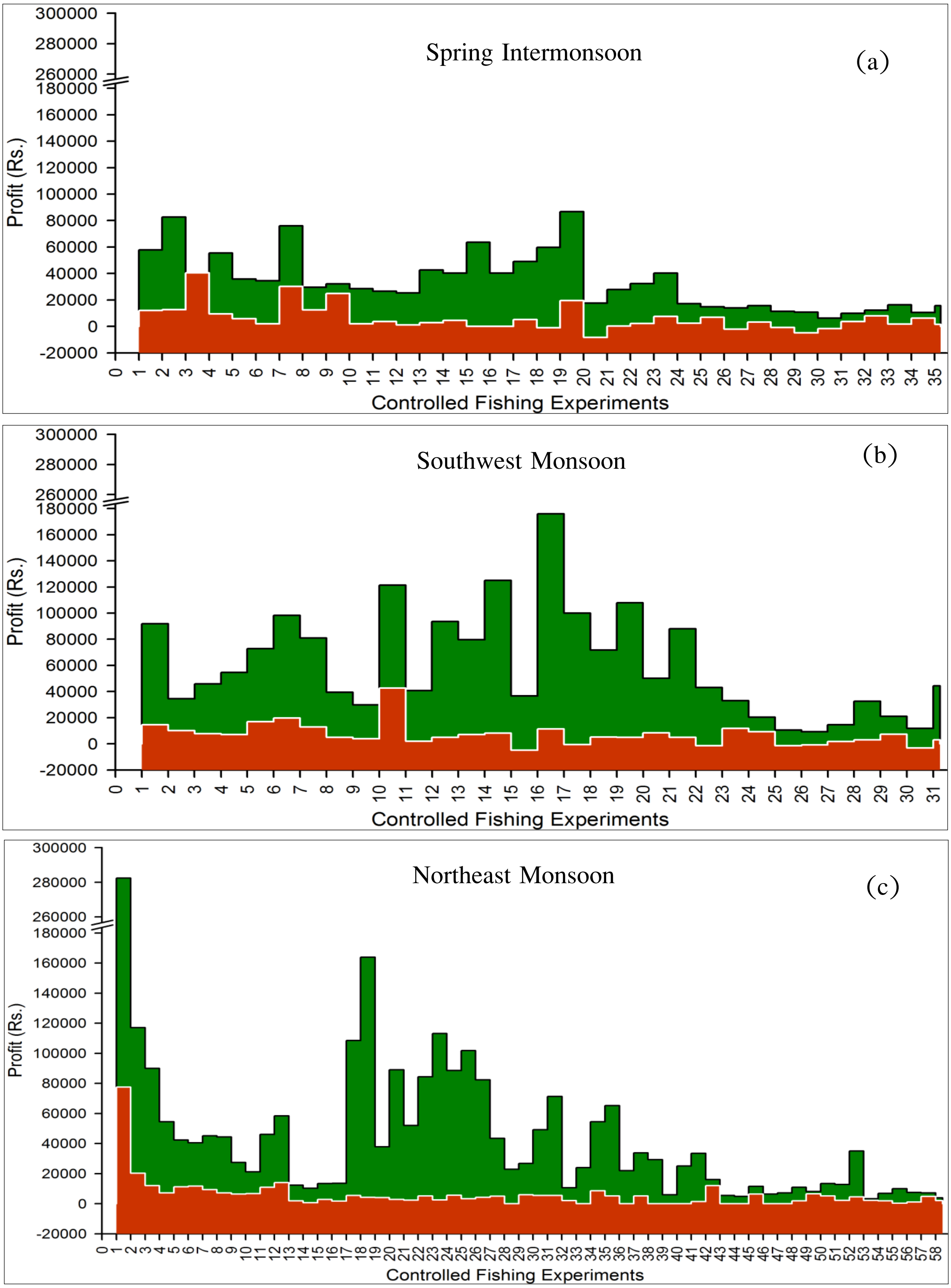


Figure 2.21 – Profit earned from controlled fishing experiments conducted during different seasons. Green and red bars indicate the profit from PFZ and non PFZ regions, respectively. (a), (b) and (c) represent the Spring Intermonsoon, Southwest Monsoon and Northeast Monsoon periods, respectively. The profit was found to be higher during the Southwest Monsoon period.

The noticeable features evident the catch data of small pelagics of interest obtained from the controlled fishing experiments are presented in Figures 2.22 and 2.23. As the dominance of anchovies was noticed only in two instances during the entire fishing experiments, their data is not included in this seasonal analysis. The discontinuous/transient availability of the anchovies along the Kerala coast could be a reason for their low representation in controlled experiments (Nair, 1998). Large fluctuation in catch was evident in the case of oil sardine, particularly during the southwest monsoon (Figure 2.22a). The dominance of oil sardine showed higher incidence of dominance during the northeast monsoon period as compared to the rest of the seasons (Figure 2.23). On the other hand, the dominance of oil sardine was the lowest during the southwest monsoon period (Figure 2.23b), which could be partly due to the lack of fishing experiments during the trawl ban period (July-August).

The seasonal pattern of Indian mackerel obtained from the fishing experiments is presented in Figure 2.22b. The fluctuation in catch data of Indian mackerel was relatively low as compared to the oil sardine. Indian mackerel dominance was noticeably higher during the southwest monsoon period as compared to the rest of the seasons (Figures 2.22b and 2.23). The dominance of Indian mackerel was low during the spring intermonsoon period (Figure 2.22b), which was even lower than during the southwest monsoon, when trawl ban was practiced in the study area (July-August).The results of Mann-Whitney U statistics is presented in Tables 2.3-2.16. The statistical significance of the data used in the present study was decided as $p < 0.05$. The overall results obtained from the pooled data showed statistically highly significant difference ($p<0.0001$) in the fish catch and profit earned in controlled experiments carried out in the PFZ and non-PFZ (Tables 2.3 and 2.4). Similar was the results obtained when the seasonal data of fish catch (Tables 2.5 to 2.7) and profit (Tables 2.8 to 2.10) was treated separately. All these results essentially indicated the significant increase in the fish catch as well as the profit in the PFZ as compared to the non-PFZ.

The Mann-Whitney U statistics treatments on seasonal data of Oil Sardine and Indian Mackerel are presented in Tables 2.11 to 2.13 and 2.14 to 2.16, respectively. It was evident that the highest statistical significance (lowest p values) for the oil sardine catch data was obtained for the northeast monsoon period (Table 2.13). This indicated that the fishing activity for catching oil sardine was more efficient during the northeast monsoon period as compared to the rest of the seasons. Similarly the highest statistical significance (lowest p values) for the Indian mackerel was obtained for the Southwest Monsoon period (Table 2.15) indicating that the fishing activity for catching Indian mackerel was more efficient during the northeast monsoon period as compared to the rest of the seasons.

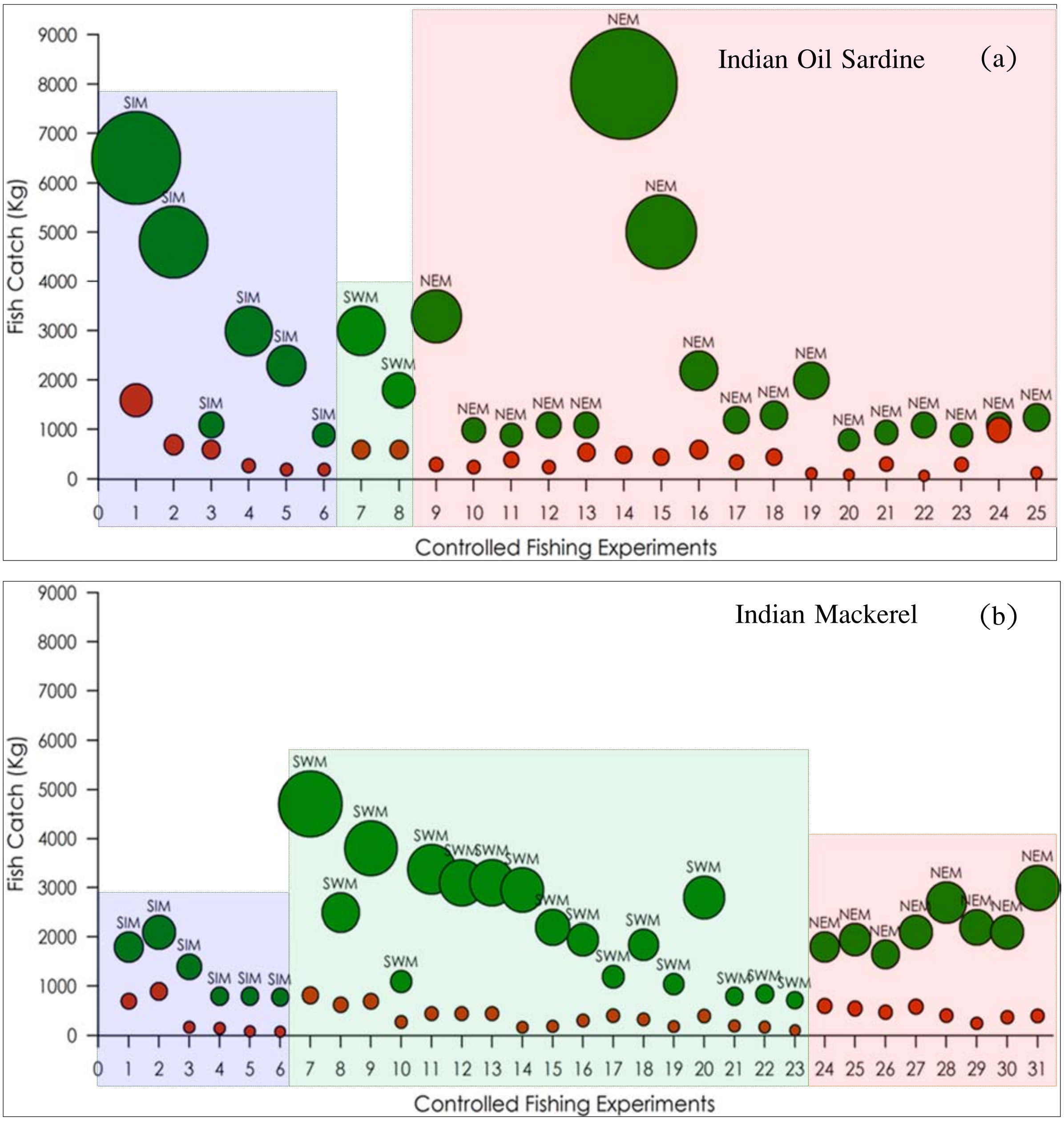


Figure 2.22 – Bubble plot showing the seasonal dominance of small pelagic fishes of interest in controlled fishing experiments conducted along the Kerala coast. Abbreviations: (IM) Indian Mackerel and (OS) Oil Sardine. The anchovies are not considered in this treatment, as they were found dominant only in two experiments during the entire study period. The panel (a) shows the dominance of oil sardine during the northeast monsoon period followed by the southwest monsoon. Similarly, dominance of Indian Mackerel during the Southwest monsoon followed by the northeast monsoon is evident in panel (b). In a few controlled experiments, exceptionally high catches of Oil Sardine (>5000 kg) was found, whereas, such instances were absent in the cases of Indian Mackerel.

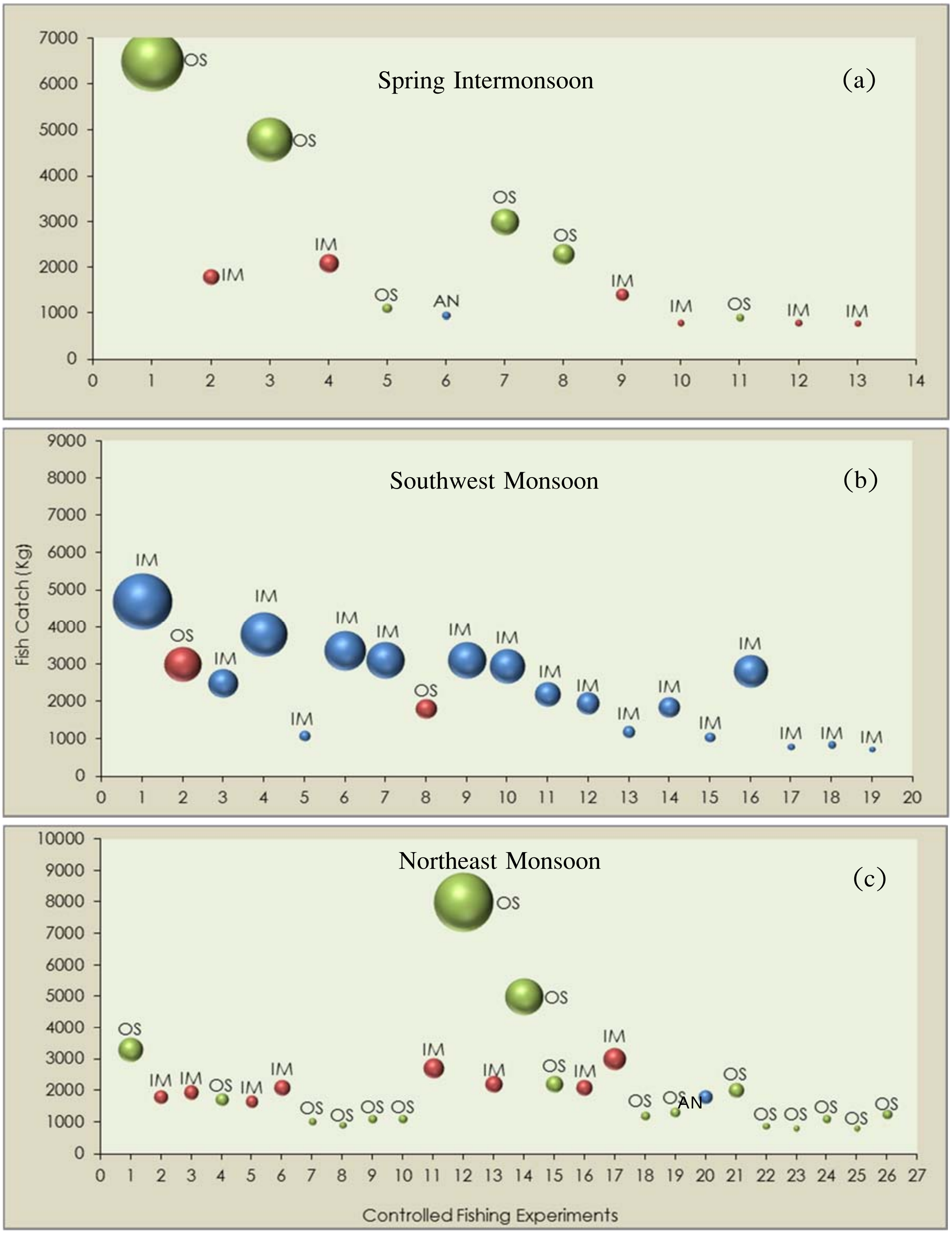


Figure 2.23 – Bubble plot showing the dominance of (IM) Indian Mackerel, (OS) Oil Sardine, (AN) Anchovies in controlled fishing experiments conducted along the Kerala during different seasons (I) Spring Intermonsoon (II) Southwest Monsoon and (III) Northeast monsoon, respectively. The dominance of Indian Mackerel during the Southwest Monsoon and Oil Sardine the Northeast Monsoon are clearly represented. Anchovies were found dominant only during two instances.

U	15001.000
Expected value	7688.000
Variance (U)	318848.555
p-value	**< 0.0001**
Alpha	0.05

Table 2.3 – Mann-Whitney U test of pooled fish catch data

U	14163.000
Expected value	7812.500
Variance (U)	326820.909
p-value	**< 0.0001**
Alpha	0.05

Table 2.4 – Mann-Whitney U test of pooled profit data

U	1160.000
Expected value	612.500
Variance (U)	7233.207
p-value	**< 0.0001**
Alpha	0.05

Table 2.5 – Mann-Whitney U test of fish catch data during the Spring Intermonsoon

U	949.500
Expected value	480.500
Variance (U)	5042.328
p-value	**< 0.0001**
Alpha	0.05

Table 2.6 – Mann-Whitney U test of fish catch data during the Southwest Monsoon

U	3315.000
Expected value	1682.000
Variance (U)	32777.565
p-value	**< 0.0001**
Alpha	0.05

Table 2.7 – Mann-Whitney U test of fish catch data during the Northeast Monsoon

U	1130.500
Expected value	612.000
Variance (U)	7247.917
p-value	< **0.0001**
Alpha	0.05

Table 2.8 – Mann-Whitney U test of profit during the Spring Intermonsoon

U	928.000
Expected value	480.500
Variance (U)	5045.123
p-value	< **0.0001**
Alpha	0.05

Table 2.9 – Mann-Whitney U test of profit during the Southwest Monsoon

U	3089.500
Expected value	1682.000
Variance (U)	32777.817
p-value	< **0.0001**
Alpha	0.05

Table 2.10 – Mann-Whitney U test of profit during the Northeast Monsoon

U	34.000
Expected value	18.000
Variance (U)	38.864
p-value	0.013
Alpha	0.05

Table 2.11 – Mann-Whitney test of Oil Sardine catch during the Spring Intermonsoon

U	4.000
Expected value	2.000
Variance (U)	1.667
p-value	0.033,< 0.05
Alpha	0.05

Table 2.12 – Mann Whitney test of Oil Sardine catch during the Southwest Monsoon

U	289.000
Expected value	144.500
Variance (U)	840.598
p-value	< 0.0001
Alpha	0.05

Table 2.13 – Mann Whitney test of Oil Sardine catch during the Northeast Monsoon

U	33.000
Expected value	18.000
Variance (U)	38.864
p-value	0.020
alpha	0.05

Table 2.14 – Mann Whitney test of Indian Mackerel catch during the Spring Intermonsoon

U	287.000
Expected value	144.500
Variance (U)	842.273
p-value	< 0.0001
alpha	0.05

Table 2.15 – Mann Whitney test of Indian Mackerel catch during the Southwest Monsoon

U	64.000
Expected value	32.000
Variance (U)	90.533
p-value (Two-tailed)	0.001
alpha	0.05

Table 2.16 – Mann Whitney test of Indian Mackerel catch during the Northeast Monsoon

There are a few earlier studies available on the usefulness of the PFZ advisory to exploit fishery resources in Indian waters (Solanki et al., 2001; Nayak et al., 2003). These studies mostly showed that the PFZ advisories are useful to improve the profit gained from the overall fishing activity by reducing the searching time and saving valuable engine fuel. The relevance of the present study is that it presents for the first time the detailed results of controlled fishing experiments conducted along the Kerala coast to understand the usefulness of PFZ advisories to exploit small pelagics such as Indian oil sardine, Indian mackerel and anchovies based on a large data set. The study also presents the seasonal differences in usefulness of the PFZ advisory to exploit the small pelagic fishes and this aspect is not clearly addressed in earlier studies.

2.6. Conclusion

The results of the controlled fishing operations within and outside PFZ showed that the average income received by vessels operated in the PFZ were considerably higher (2 to 3 times) than those operated in the non PFZ. It was also observed that commercially importance species of fishes were abundant in the PFZ causing richer fisheries compared to the non-PFZ areas. The profit earned from controlled experiments shows consistently higher values in the PFZ than that in the non-PFZ. The highest profit during the entire controlled fishing experiments was obtained when the catch was dominated by relatively high priced fishes such as tunas, carangids, seer fishes and mackerel. The results of Mann-Whitney U statistics confirmed the significant increase in catch and profit in the PFZ as compared to the non-PFZ.

The overall results showed the dominance of carangid group in the catch data obtained from the PFZ area. However, the detailed analyses showed a noticeable seasonal difference in the percentage contribution of different species in the catch data of controlled experiments. Oil Sardine was the major single species obtained during the Northeast monsoon (October-January), whereas, Indian Mackerel dominated during the Southwest Monsoon (June-September) and Spring Intermonsoon (March – May) periods. Anchovies were found dominant only in two fishing experiments in the entire study period. Large fluctuation in catch data was found in the case of Oil Sardine, particularly during the Southwest Monsoon, whereas, such fluctuation was less in the case of Indian Mackerel. The analyses of catch data of the small pelagic fishes of interest showed that the PFZ advisories are more useful to catch Oil Sardine during the Northeast Monsoon and Indian Mackerel during the rest of the period. Conversely, the catch data obtained from controlled experiments showed that PFZ advisory has less efficiency to support the exploitation of anchovies along the Kerala coast.

CHAPTER 3

RECURRENCE OF PFZ

3.1. Introduction

Our limitation in understanding the mesoscale (10-100 km) and sub-mesoscale (1-10 km) oceanographic features influencing biological production is largely due to the difficulty in making *in-situ* observations at these spatial scales (CIESM, 2005). The fastest research ships still take days to map a region as small as 100km across, and eddy/ fronts can move and distort significantly even in such short time as indicated recently (Vinuchandran et al., 2004; CIESM, 2005). Satellite remote-sensing provides synoptic views of the ocean and is capable of detecting mesoscale oceanographic features through thermal infrared and visible sensors (Solanki et al., 2001, 2003, 2005; Vinuchandran et al., 2004). Ocean regions demarcated by satellite-derived SST and ocean colour have been associated with instances of physical-biological coupling and hence, they are useful for locating PFZ (Arnone, 1987; CIESM, 2005).

Coastal waters are complex and dynamic; their important ecological role and significant contribution to the economic prosperity of maritime countries have been well established (www.fishbase.org). A vast variety of physical, chemical and biological, processes interact in the coastal waters over different time and space scales. Coastal productivity supports multiple trophic levels and thereby provides a great support to the commercial fisheries. In addition to the large scale oceanographic processes that control biological productivity such as upwelling and stratification, Rivers serve as a major conduit for the delivery of significant amount of dissolved and particulate material from terrestrial environments to the coastal ocean world over (Miller, 2005). The dynamic nature of coastal waters renders most traditional field measurements and sampling protocols ineffective in capturing the range and variability of many ocean processes (Miller, 2005).

The oceanographic features characteristic of the Kerala coast hve been discussed in detail in Section 1.4. A strong seasonality in the hydrographical features is apparent in the Kerala coastal waters driven primarily by the climatic forcing associated with the seasonally reversing monsoon winds. It is also apparent that the evolution of the seasonal hydrographical features co-varies with the gradual changes in the atmospheric forcing. Kerala is bestowed with heavy rainfall of which a major part (70%) occur during the Southwest Monsoon (June – September) and the remaining during the rest of the year (Qasim, 2003). Considering the strong seasonality in the hydrography of the Kerala coastal waters, the rainfall and associated freshwater influx that it receives from the 41 Rivers originating from the Western Ghats, it is quite logical to presume recurrence of mesoscale and sub-mesoscale oceanographic features in the region over different spatial and temporal scales.

As the boundaries of the mesoscale/ sub-mesoscale oceanographic features quite often get imprinted in satellite data and having marked as PFZ bands in advisories; a detailed analysis of the numerous PFZ advisories disseminated during the study period would be useful to demarcate regions with recurrent PFZ over different spatial and temporal scales along the Kerala coast. The outcome of such analyses is expected to provide clear indications about the regions where PFZ has the highest/lowest recurrences along the Kerala coast during different months in a year. In this direction, attempts have been made in the present study to outline the recurrent PFZ along the Kerala coast based on the advisories generated/available for the study period (2008-2012) with the following objectives (a) to demarcate regions with highest recurrence of PFZ along the Kerala coast in different months in a year and (b) to analyse the overall relationship between the formation of PFZ and the seasonal rainfall pattern along the Kerala coast between Kollam and Kannur.

3.2. Methods

The hard copies of PFZ advisories disseminated during the study period (2008-2012) were collected and grouped to represent different months. These hard copies were scanned and converted as high resolution image files. These images were then used for geo-referencing using ArcGIS 9.3 software. The geo-referenced images were processed along with its position and other information to recreate the original ground geometry. After careful incorporation of the geo-referencing, the PFZ bands marked in the images were digitized as polylines.

The digitized polylines of PFZ bands were then grouped on a monthly basis. All the available digitized PFZ bands for the 2008 – 2012 periods were grouped on a monthly basis and saved as a single image to represent the recurrence of the features on a particular month. Altogether, 432 PFZ advisories were digitised in this fashion to deduce consolidated information of the recurrence of PFZ in the study area.

The details of the PFZ advisories processed for the current study is presented in Table 3.1. It is clear that the number of advisories representing different months during the study period (March 2008 - March 2012) vary significantly. This variation is primarily due to the fact that the PFZ advisory for a particular time period is positively influenced by factors such as (a) cloud free sky conditions and (b) prominent frontal features (gradients) imprinted in satellite data. Conversely, periods with heavy cloud cover (mostly during the Southwest Monsoon) and lack of noticeable gradients in satellite oceanographic data (mostly during the Spring Intermonsoon) negatively impact the number of PFZ advisories disseminated to the end users. Moreover, there is no PFZ advisory being generated/disseminated during the trawl ban period (mid-June to July) along the Kerala coast. All these have contributed to the difference in the number of the PFZ advisories available for different months considered for the present analyses (Table 3.1). Considering this limitation, the observations and conclusions drawn from the present analyses is intended basically to demarcate the regions with high fishery potential based on the available PFZ advisories during the study period.

Taking into account the variations that exist in the number of advisories available during different seasons and to understand the relative importance of PFZ during different time period, the following approach has been adopted. The frequency/number of PFZ bands in each of the advisories disseminated during the entire study period were counted individually, and the data was pooled together on a seasonal basis and analysed with suitable statistical tool to understand whether there is a significant seasonal difference in the number of PFZ bands in advisories. This pooled data for different seasons has also been used to compare with the seasonal rainfall in the coastal districts of the Kerala state to see whether there is any relationship exists between these parameters.

The detailed information on the seasonal rainfall and freshwater influx along the Kerala coast has been described in Section 1.4. The freshwater influx into the coastal waters of Kerala has strong seasonality closely linked with the seasonal rainfall pattern in the region (Qasim, 2003). Around 75% of the total annual rainfall in Kerala occurs during the Southwest Monsoon period. During the peak Southwest Monsoon period, 40-50cm of rainfall occurs in the region within a few hours (Qasim, 2003). In the present study, the five year mean rainfall over the coastal districts in Kerala has been used to analyse its possible link with the recurrence of PFZ in the coastal waters. In order to understand the general relationship between the rainfall and frequency of PFZ bands in advisories, monthly rainfall data for five years (2005 – 2010) was downloaded from the online data base of Indian Meteorological Department (IMD), Pune, India (www.imdpune.gov.in) and used for the present study.

3.2.1. Statistical analyses

Analysis of variance (ANOVA) is a collection of statistical models used to analyse the differences between group means and their associated procedures such as 'variation' among and between groups (www.wikipedia.org). In ANOVA, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes t-test to more than two groups. Doing multiple two-sample t-tests would result in an increased chance of committing a type I error. For this reason, ANOVAs are useful in testing three or more means (groups or variables) for statistical significance (www.wikipedia.org). To compare the mean number of the bands between seasons, data sets were initially analysed for their homogeneity and normal distribution. The initial analysis indicated that the data set differs from the normal distribution. Therefore, non-parametric ANOVA (Kruskal Wallis) test was performed to carry out the overall analysis of comparisons (Zar, 2010). The Dunnets post hoc test with Bonferroni corrected significance was used for the multiple pair wise comparisons (Zar, 2010).

3.3. Results and discussion

The results of the month-wise merged imageries of the digitised PFZ advisories have been presented in Figures 3.2 to 3.12. The images have been presented beginning by March and ending by February so as to sequentially represent the classification of seasons adopted in the present study. It can be noted that the number of advisories available differ from one month to the other and the lowest number of advisories were available for June (15), April (25), May (32) and February (32). Similarly, the frequency of PFZ bands in advisories also varied from one month to the other.

The consolidated information on the number of PFZ advisories used as well as the frequency of PFZ bands in advisories in each month have been presented in Table 3.1. It is clear that the frequency of PFZ bands was low during the Spring Intermonsoon, moderate during the Southwest Monsoon and high during the Northeast Monsoon (Table 3.1). Noticeable spatiotemporal variations were found in the case of recurrent PFZ along the Kerala coast.

SL.NO.	Months	No. of Advisories	Frequency of bands	Seasonal Mean and SD of bands
1	March	44	low	Av. 3 ± 1.1
2	April	25	low	
3	May	32	low	
4	June	15	Moderate	Av. 4 ± 1
5	August	38	Moderate	
6	September	39	Moderate	
7	October	47	High	Av. 5 ± 0.7
8	November	53	High	
9	December	62	High	
10	January	45	High	
11	February	32	High	

Table 3.1 – Details of the advisories analysed and the frequency of PFZ bands observed during different time period of the present study (March 2008 – March 2012). The colour shading blue, red and green represent seasons, Spring Intermonsoon, Southwest Monsoon and Northeast Monsoon, respectively. The highest number of the PFZ advisories was available for the month of December (62) followed by November (42). The lowest number of PFZ advisories was for the month of June (15) followed by April (25). There was no advisory available for the month of July due to the fishing trawl ban along the Kerala coast. Similarly, advisories were not available in cases when the sky was heavily covered with clouds as well as in occasions when there was a lack of noticeable gradients in SST and ocean colour. The general feature in the maps is that the recurrent PFZ were found mostly with in the 50 m depth contour having large spatiotemporal variation in each month as summarised below:

(a) March

The repeat PFZs were low in March. Relatively high concentration of PFZ bands were also found off Thiruvananthapuram, off Alappuzha. Similarly, repeat PFZ was also found in the inshore waters between Kochi and Ponnani as well as Ponnani and Kozhikode. Altogether four recurrent PFZs have been identified for March (Figure 3.1).

(b) April

The repeat PFZ were sparse in April. Relatively high concentration of PFZ bands were found off Kollam and Kochi (Figure 3.2). April is characterised by stratified oligotrophic surface waters along the Kerala coast and this could cause lack of noticeable gradients in satellite derived SST and ocean colour. Two recurrent PFZs, though less prominent, have been identified for March.

(c) May

Relatively higher frequency of PFZ bands were found in May. The higher concentration of PFZ bands were found off Thiruvananthapuram, off Ponnani, and inshore waters between Kozhikode and Kasargod. The concentration of PFZ bands in May was higher than that in March and April. Altogether five recurrent PFZs have been identified for May (Figure 3.3).

(d) June

As in the case of March and May, repeat PFZ were found mostly within 50 m depth contour. The concentration of PFZ bands were found generally higher south of Alappuzha. Relatively high repeat PFZ were found off Thiruvananthapuram, and the region between Thiruvananthapuram and Alappuzha. Four recurrent PFZs have been identified for June (Figure 3.4).

(e) August

Higher concentration of PFZ bands were found between Thiruvananthapuram and Kollam, south off Kochi and Ponnani, and north off Kasargod. Waters beyond 50 m contour south off Alappuzha had relatively high concentration of PFZ bands compared to the rest of the region in the same depth ranges. Six recurrent PFZs have been identified for September (Figure 3.5).

(f) September

The concentration of PFZ bands was generally higher north of Alappuzha. Relatively high concentration of PFZ bands were found between Alappuzha and Kochi, Ponnani and Kozhikode, off Mahe and Kannur. Waters beyond 50 m depth contour had low concentration of PFZ bands. Altogether eight recurrent PFZs have been identified for September (Figure 3.6).

(g) October

Relatively high concentration of PFZ bands were found in regions between Kollam and Kochi, Ponnani and Kozhikode. Similarly, higher concentration of PFZ bands was also found off Mahe and Kasargod. Higher frequency of PFZ bands were found beyond 50m depth contour especially between Kollam and Ponnani. Thirteen recurrent PFZs have been identified for the month of October (Figure 3.7).

(h) November

The repeat PFZ bands in November were found mostly within 50 m depth contour. Relatively high concentration of PFZ bands were found between Kochi and Kozhikode. Repeat PFZ was also found off Kannur and south of Kasargod, whereas, it was significantly low south of Alappuzha. Frequency of PFZ bands beyond 50 m depth contour was much lower in November as compared to October and December. Nine prominent recurrent PFZs have been identified for the month of November (Figure 3.8).

(i) December

In December, the repeat PFZ bands were found all along the Kerala coastline except the region south off Kollam and also between Kozhikode and Mahe. Very prominent repeat PFZ bands were found within the 50 m depth contour off Alappuzha, Kochi, Ponnani and Kasargod. The shelf region beyond 50 m also showed high concentration of PFZ bands with the highest off Ponnani. Ten very prominent recurrent PFZs have been identified for December (Figure 3.9).

(j) January

Similar to December, recurrent PFZ in January was distributed more or less all along the Kerala coastline except region south of Kollam. Relatively high concentration of PFZ bands were found in the inshore waters between Kollam and Alappuzha. Similarly, repeat PFZ was also found off north of Kochi, off Ponnani, off Kannur and Kasargod. Beyond 50 m depth contour, waters off Kollam, Kannur and Kasargod had higher frequency of PFZ bands. Fifteen recurrent PFZs have been demarcated for January (Figure 3.10).

(k) February

Relatively high concentration of PFZ bands were found off Kollam, Kochi, Kannur and Kasargod. Also a band of repeat PFZ was evident closer to the coastline between Kochi and Ponnani. Waters beyond 50m between Kollam and Ponnani had higher concentration of PFZ bands. Nine recurrent PFZs have been identified for February (Figure 3.11).

3.3.1. Recurrent PFZs and the small pelagic fishes in Controlled Experiments

Based on the frequency of PFZ bands in advisories, three general categories were identified; low, moderate and high. The frequency of PFZ bands was generally low during the Spring Intermonsoon, moderate during the Southwest Monsoon and high during the Northeast Monsoon periods (Table 3.1). The highest number of repeat PFZs was found all along the

Kerala coast in December, January and February. Similarly, the lowest number of repeat PFZs was found in April, May and June. The overall features evident in Figures 3.1 to 3.11 show that prominent recurrent PFZs were evident during the Northeast and Southwest Monsoon periods, whereas, such zones were less evident during the Spring Intermonsoon period. The usefulness of the repeat PFZs demarcated for different seasons have been compared with the seasonal fish catch data obtained from the Controlled Fishing Experiments conducted during the present study period. The salient observations found are detailed below.

The results of the Controlled Fishing Experiments, presented in Chapter 2 shows noticeable seasonal variations in the percentage contribution of dominant fishes. The contribution of small pelagic fishes (Oil Sardine, Indian Mackerel and anchovy) in Controlled Fishing Experiments presented in Chapter 2, provide clear indications on the effectiveness of the repeat PFZs demarcated in the present study. The catch data representing the Spring Intermonsoon shows equal percentage contribution (17% each) of Indian Mackerel and Oil Sardine in Controlled Fishing Experiments (Figure 2.14). Therefore, Indian mackerel and oil sardine probably have equal chances to be caught in Repeat PFZs demarcated for the spring intermonsoon period.

The catch data of the small pelagic fishes in Controlled Fishing Experiments during the Southwest Monsoon (Figure 2.15) shows significantly higher percentage contribution of Indian Mackerel (55%) as compared to Oil Sardine (7%). This suggests that the repeat PFZS demarcated in the present study for the Southwest Monsoon may be more efficient to harvest Indian Mackerel as compared to Oil Sardine. Conversely, during the Northeast Monsoon, the percentage dominance of fishes showed differences as compared to the Southwest Monsoon (Figure 2.16). Significantly higher percentage contribution of Oil Sardine (29%) compared with Indian Mackerel (16%) was evident during the Northeast Monsoon. This indicates that the repeat PFZs demarcated for the Northeast Monsoon periods are more useful to exploit the Oil Sardine resources compared with Indian Mackerel. Such information was impossible to draw for Anchovies as their dominance in fishing experiments were very low. On the other hand, the landing data shows that the Oil sardine landing peaks in August and December, whereas, Indian Mackerel landing Peaks in June (CMFRI, 2012). Therefore, the landing data only partially corroborates the seasonal dominance of Sardine and Mackerel in repeat PFZs presented above.

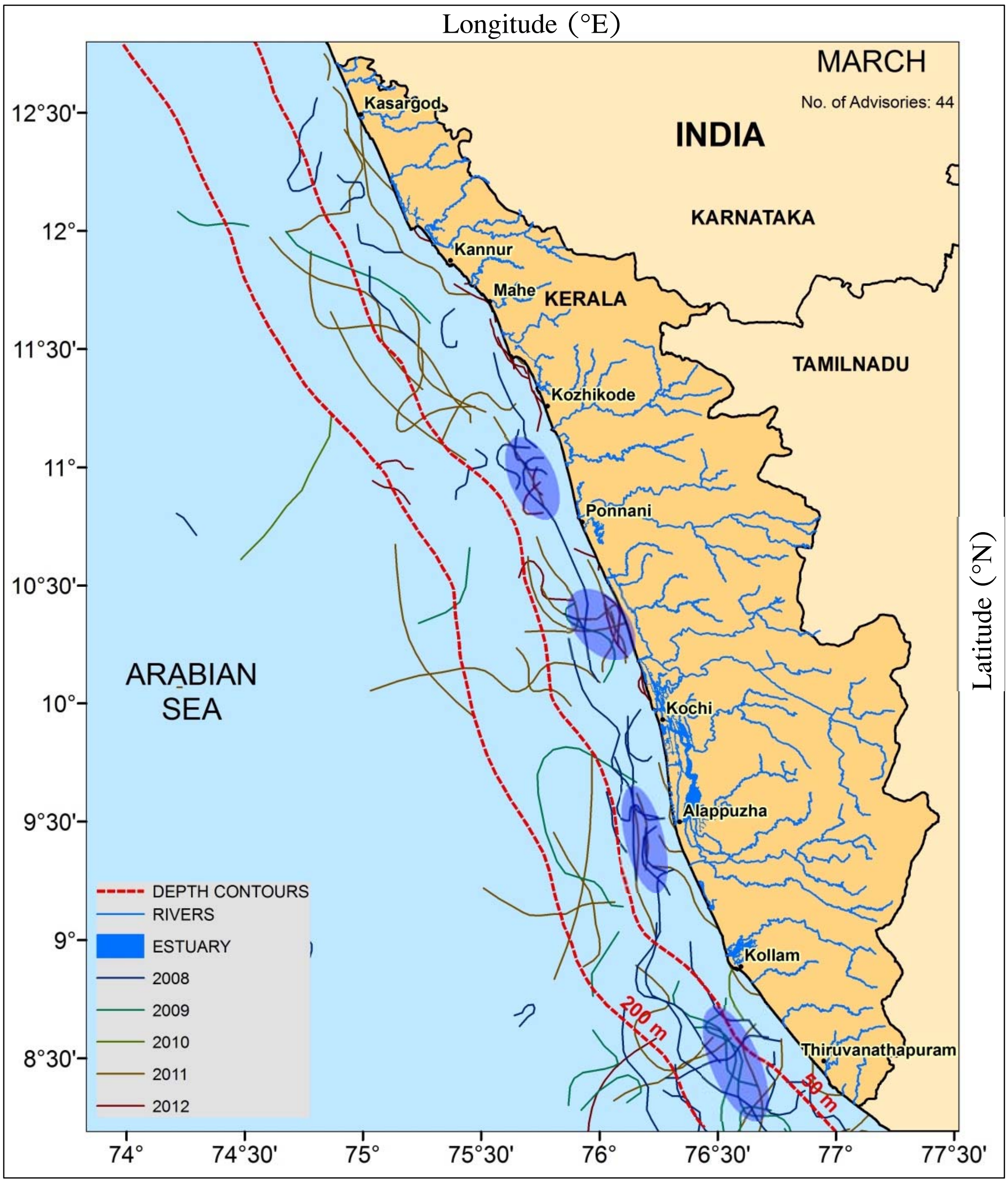


Figure 3.1 – Map showing the recurrent PFZs along the Kerala coast in March. The map is based on the PFZ advisories disseminated to the fisherman community during the five year study period (March 2008 – March 2012). The PFZ bands recorded during different years are indicated in various colours as shown in the figure legend. Rivers / estuaries draining into the study region are marked in blue colour. The depth contours (50 m and 200 m) are shown as red dotted lines. The repeat PFZs in March are highlighted in blue circular/oval shape shading and they were mostly found within the 50 m depth contour. An exception to this was the southern region (off south of Kollam) where PFZ bands were found even beyond 200 m depth contour. Repeat PFZs were found off Thiruvananthapuram and Alappuzha. Similarly, repeat PFZs were also found in isolated pockets in the inshore waters between Kochi and Ponnani as well as Ponnani and Kozhikode.

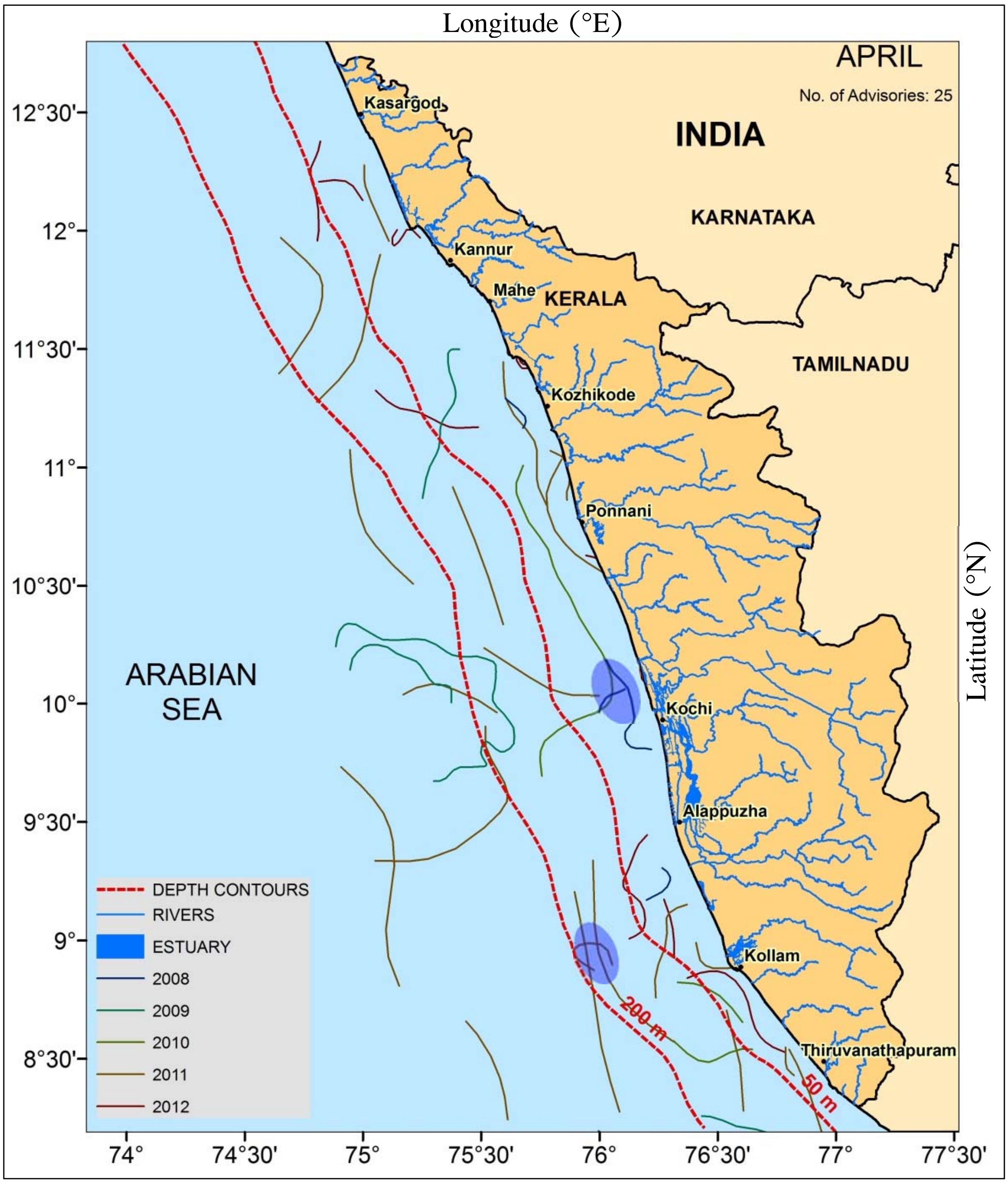


Figure 3.2 – Map showing the recurrent PFZs along the Kerala coast in April. The map is based on the PFZ advisories generated and disseminated during the five year study period (March 2008 – March 2012). The PFZ bands recorded during different years are indicated in various colours as shown in the figure legend. Rivers / estuaries draining into the study region are marked in blue colour. The depth contours (50m and 200m) are shown as red dotted lines. The repeat PFZ bands in April are highlighted in blue circular/oval shape shading. The number of PFZ advisories available was relatively low during the month of April. Similarly, repeat PFZs were also sparse in April. The Month of April is characterised by highly stratified oligotrophic waters along the Kerala coast, typical feature of the Spring Intermonsoon period and this could cause lack of noticeable gradients in satellite derived SST and ocean colour. Prominent repeat PFZs were absent in April. Relatively high concentration of PFZ bands were found off Kollam and Kochi.

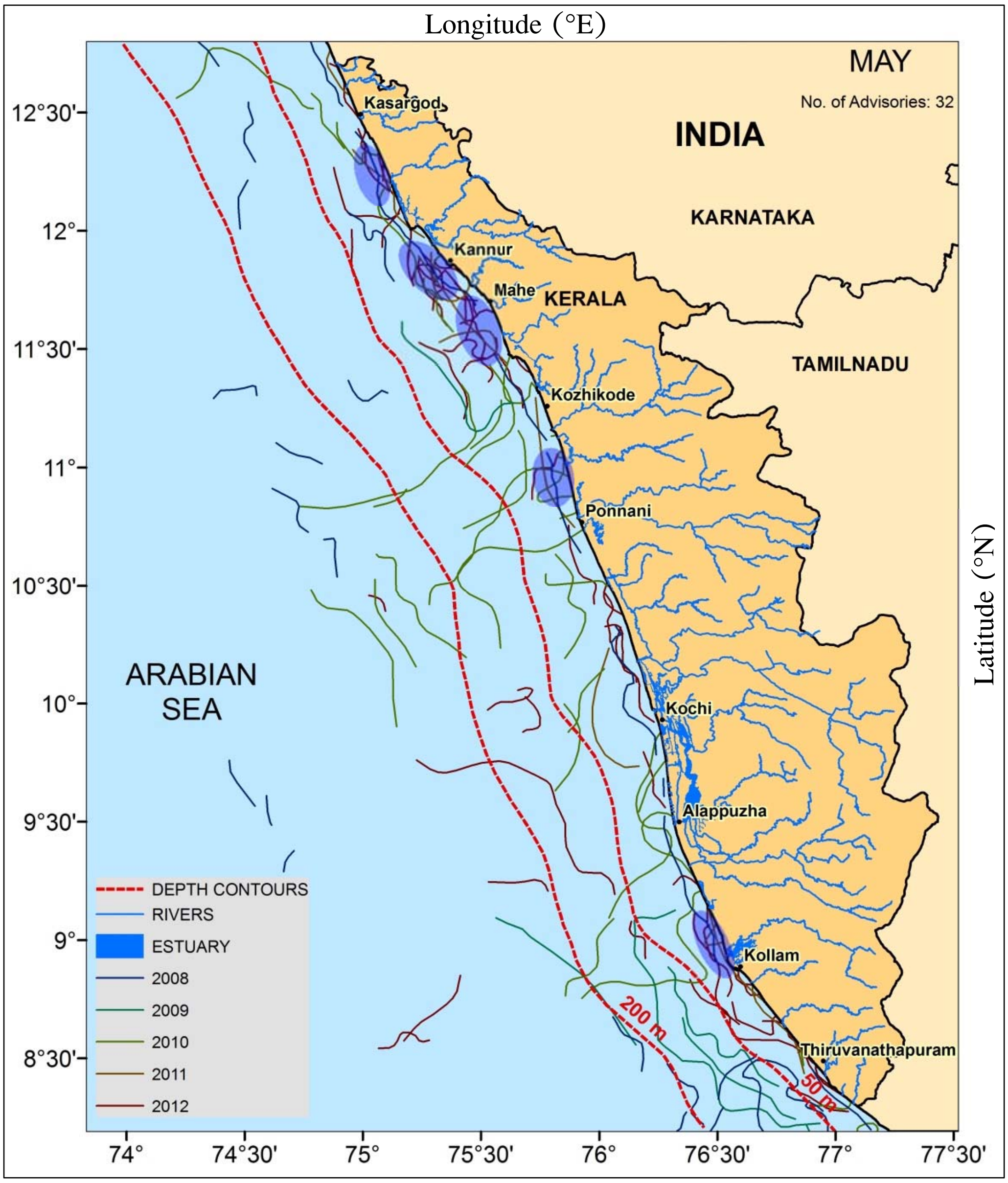


Figure 3.3 – Map showing the recurrent PFZs along the Kerala coast in May. The map is based on the PFZ advisories disseminated during the five year study period (March 2008 – March 2012). The PFZ bands recorded during different years are indicated in various colours as shown in the figure legend. Rivers / estuaries draining into the study region are marked in blue colour. The depth contours (50 m and 200 m) are shown as red dotted lines. The repeat PFZs are highlighted in blue circular/oval shape shading. As in the case of March, repeat PFZ in May was also found mostly within 50 m depth contour and an exception to this was the southern region, where PFZ bands were found even beyond 200 m depth contour. Relatively high frequency of PFZ bands was found off Thiruvananthapuram, off Ponnani, and in isolated regions in the inshore waters between Kozhikode and Kasargod. The concentration of PFZ bands in May was higher than that in March and April. Five recurrent PFZs have been identified for May.

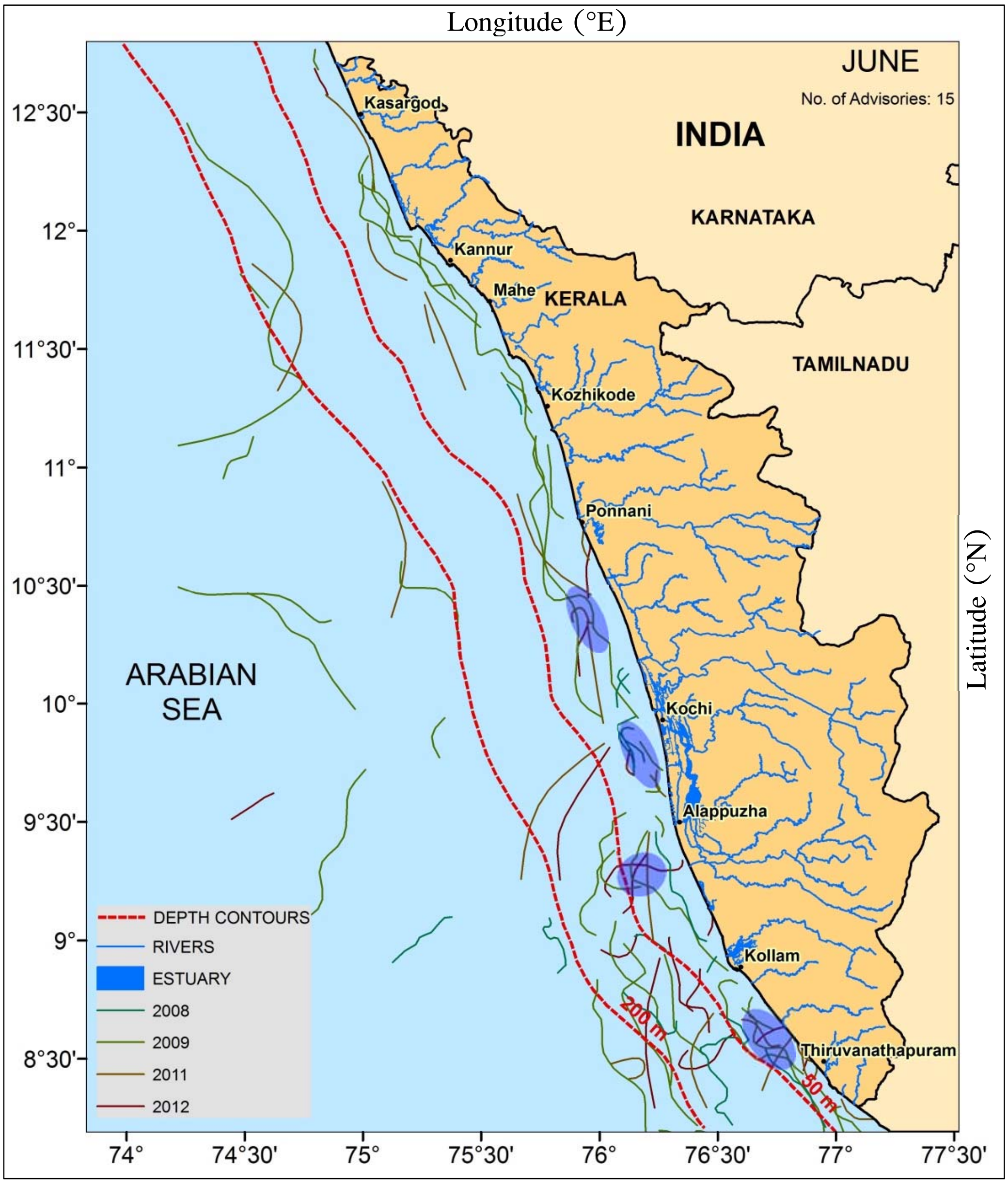


Figure 3.4 – Map showing the recurrent PFZ along the Kerala coast in June. The map is based on the PFZ advisories disseminated to the fisherman community during the five year study period (March 2008 – March 2012). The PFZ bands recorded during different years are indicated in various colours as shown in the figure legend. Rivers / estuaries draining into the study region are marked in blue colour. The depth contours (50 and 200 m) are shown as red dotted lines. The number of PFZ advisories available for the month of June was low due to heavy cloud cover and the fishery trawl ban along the Kerala coast. The repeat PFZs are highlighted in blue circular/oval shape shading. As in the case of March and May, repeat PFZ bands were found mostly within 50 m depth contour in June and an exception to this was the southern region where PFZ bands were found even beyond 200 m depth contour. Four repeat PFZs have been found off Thiruvananthapuram, and in localised regions in the inshore waters between Thiruvananthapuram and Alappuzha.

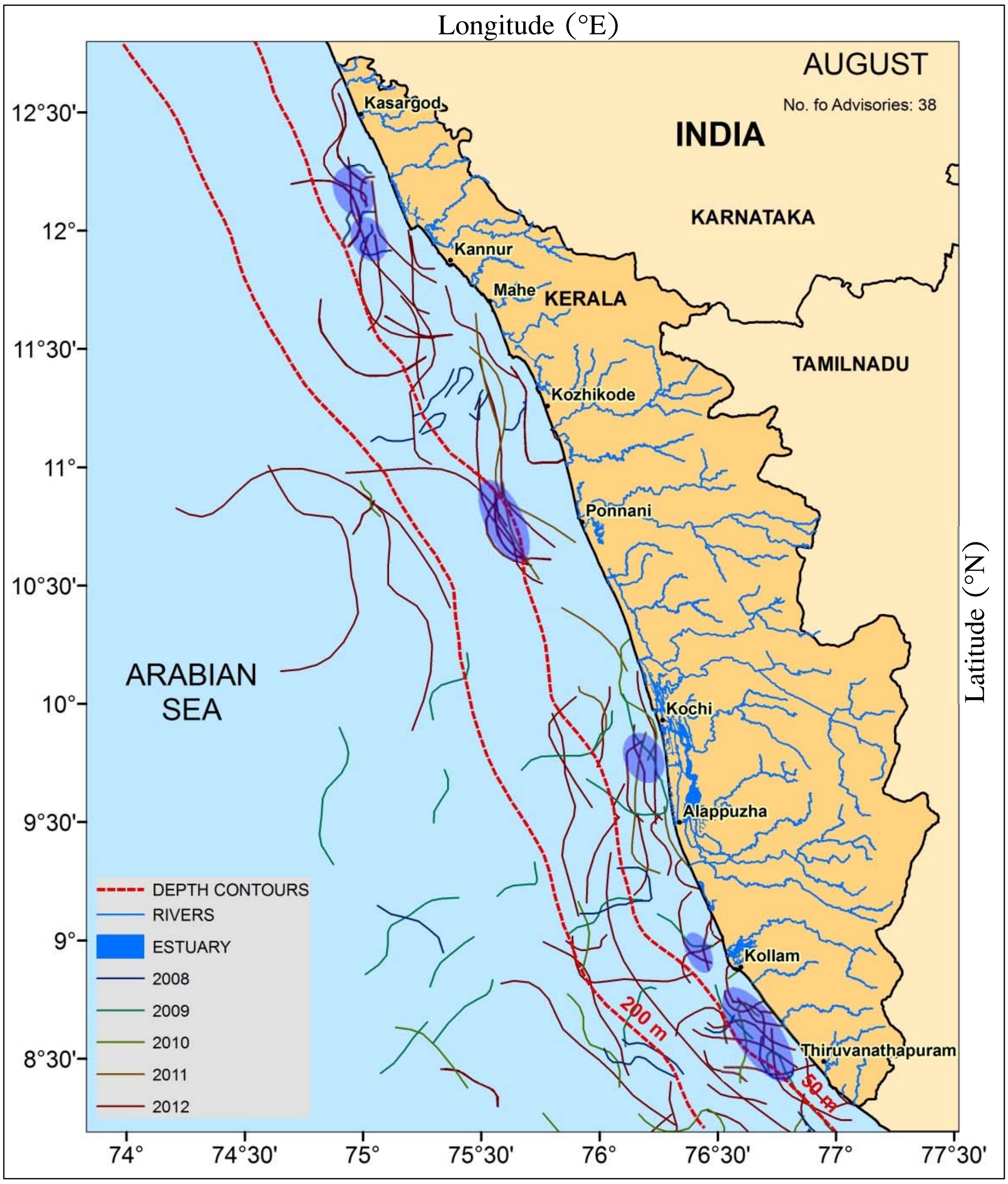


Figure 3.5 – Map showing the recurrent PFZs along the Kerala coast in August. The map is based on the PFZ advisories disseminated to the fisherman community during the five year study period (March 2008 – March 2012). The PFZ bands recorded during different years are indicated in various colours as shown in the figure legend. Rivers / estuaries draining into the study region are marked in blue colour. The depth contours (50 and 200 m) are shown as red dotted lines. The repeat PFZs are highlighted in blue circular/oval shape shading. The repeat PFZ in August were found mostly within 50 m depth contour having a scattered distribution. Relatively high concentration of PFZ bands were found in the inshore regions between Thiruvananthapuram and Kollam, off south of Kochi, Ponnani and off north off Kannur. Waters beyond 50 m contour south off Alappuzha had relatively high concentration of PFZ bands compared to the rest of the region in the same depth ranges. Six repeat PFZs have been demarcated for August.

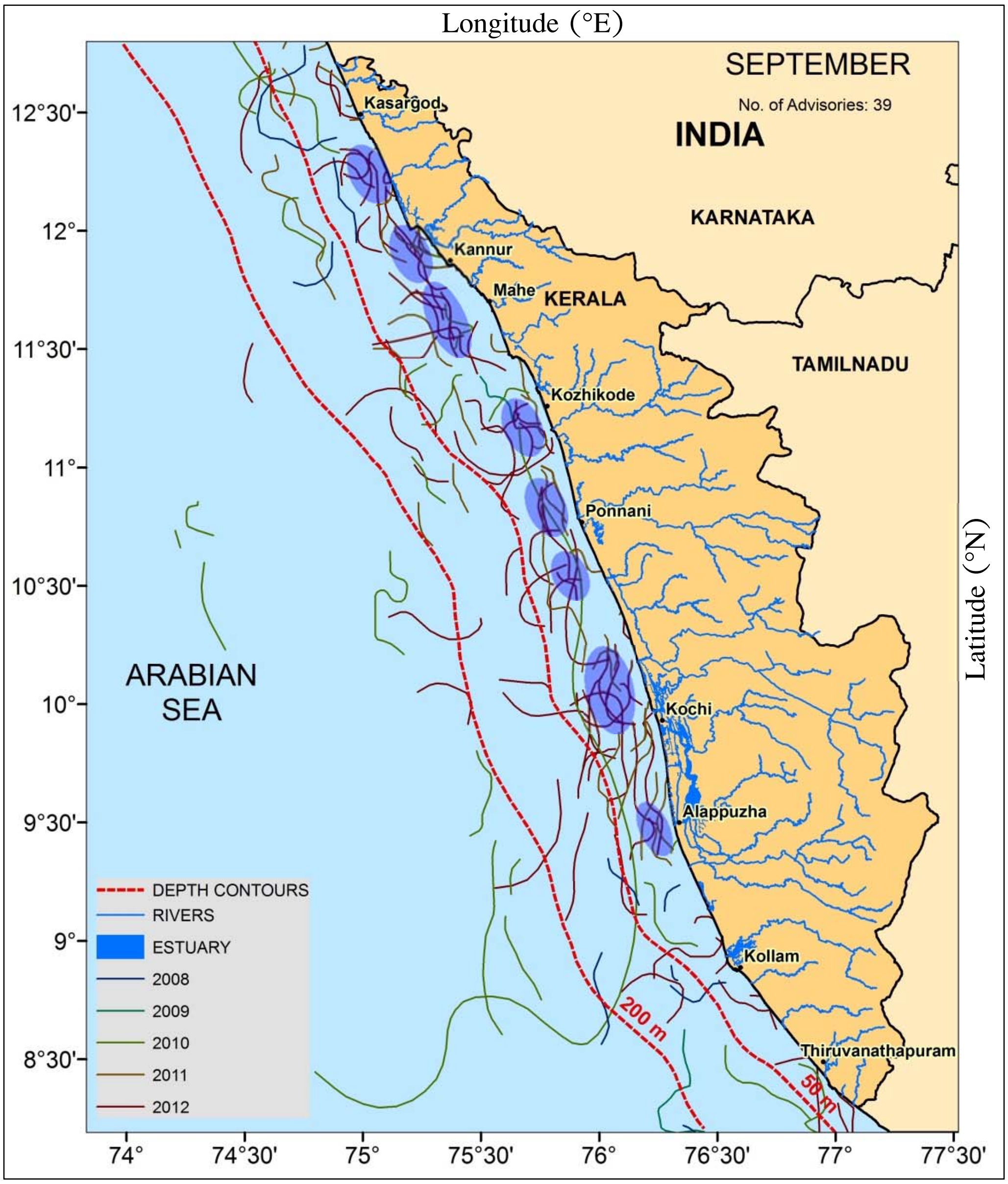


Figure 3.6 – Map showing the recurrent PFZs along the Kerala coast in September. The map is based on the PFZ advisories disseminated to the fisherman community during the five year study period (March 2008 – March 2012). The PFZ bands recorded during different years are indicated in various colours as shown in the figure legend. Rivers / estuaries draining into the study region are marked in blue colour. The depth contours (50 and 200 m) are shown as red dotted lines. The repeat PFZ bands are highlighted in blue circular/oval shape shading. The repeat PFZs in September were found mostly within 50 m depth contour and an exception to this was the region south of Alappuzha. Relatively high concentration of PFZ bands were found in the inshore waters between Alappuzha and Kochi, Ponnani and Kozhikode, off Mahe and Kannur. Waters beyond 50 m depth contour all along the Kerala coast line had low concentration of PFZ bands. Eight repeat PFZs have been evident in September.

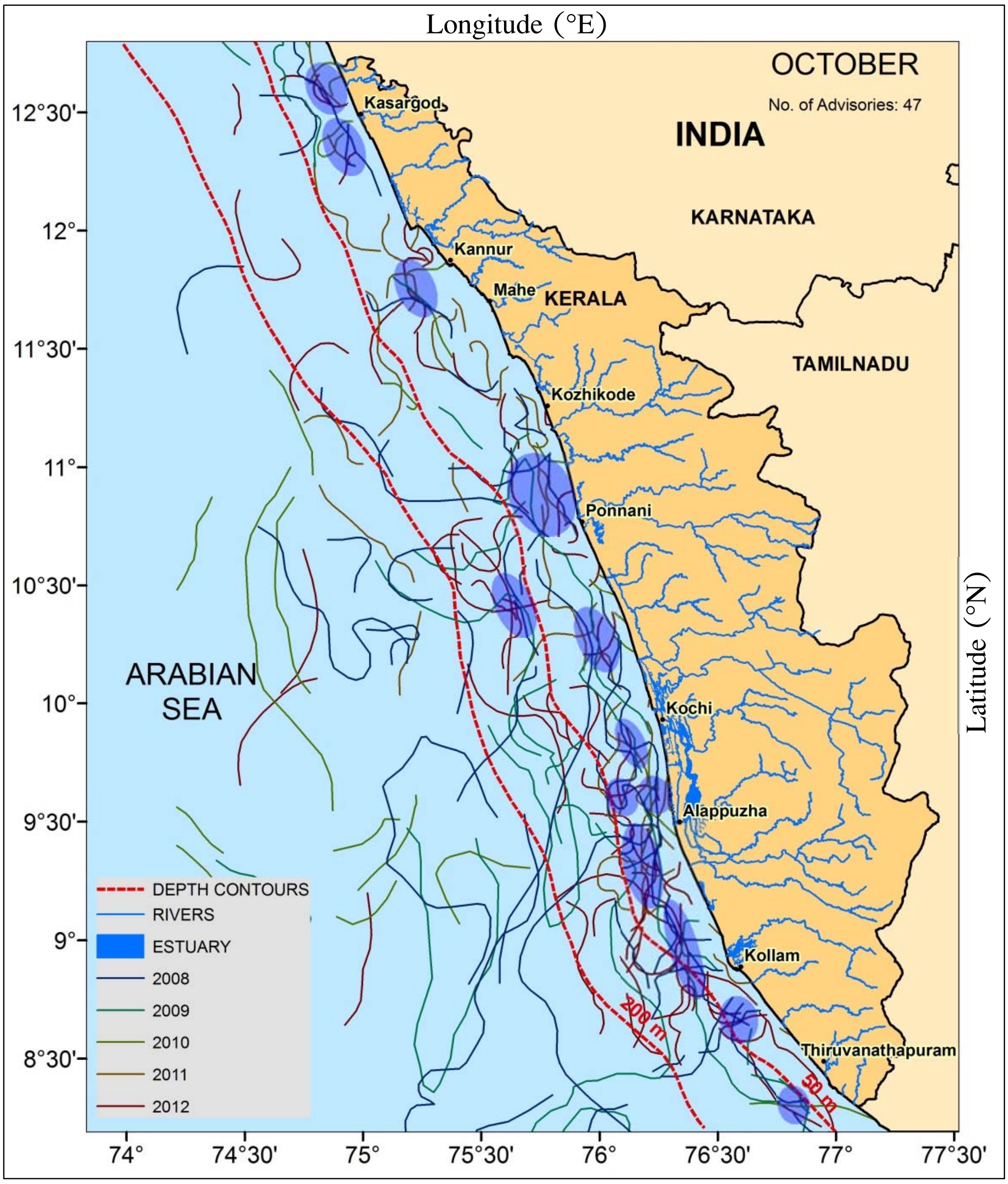


Figure 3.7 - Map showing the recurrent PFZs along the Kerala coast in October. The map is based on the PFZ advisories disseminated to the fisherman community during the five year study period (March 2008 – March 2012). The PFZ bands recorded during different years are indicated in various colours as shown in the figure legend. Rivers / estuaries draining into the study region are marked in blue colour. The depth contours (50 and 200 m) are shown as red dotted lines. The repeat PFZs are highlighted in blue circular/oval shape shading. The repeat PFZ bands in October were also found mostly within 50 m depth contour. Relatively high concentration of PFZ bands were found in isolated pockets in the inshore waters between Kollam and Kochi, Ponnani and Kozhikode. Similarly, higher frequency of PFZ bands was also found off Mahe and Kasargod. Higher abundance of PFZ bands beyond 50m depth contour was found between off Kollam and Ponnani. Thirteen repeat PFZs have been demarcated for October.

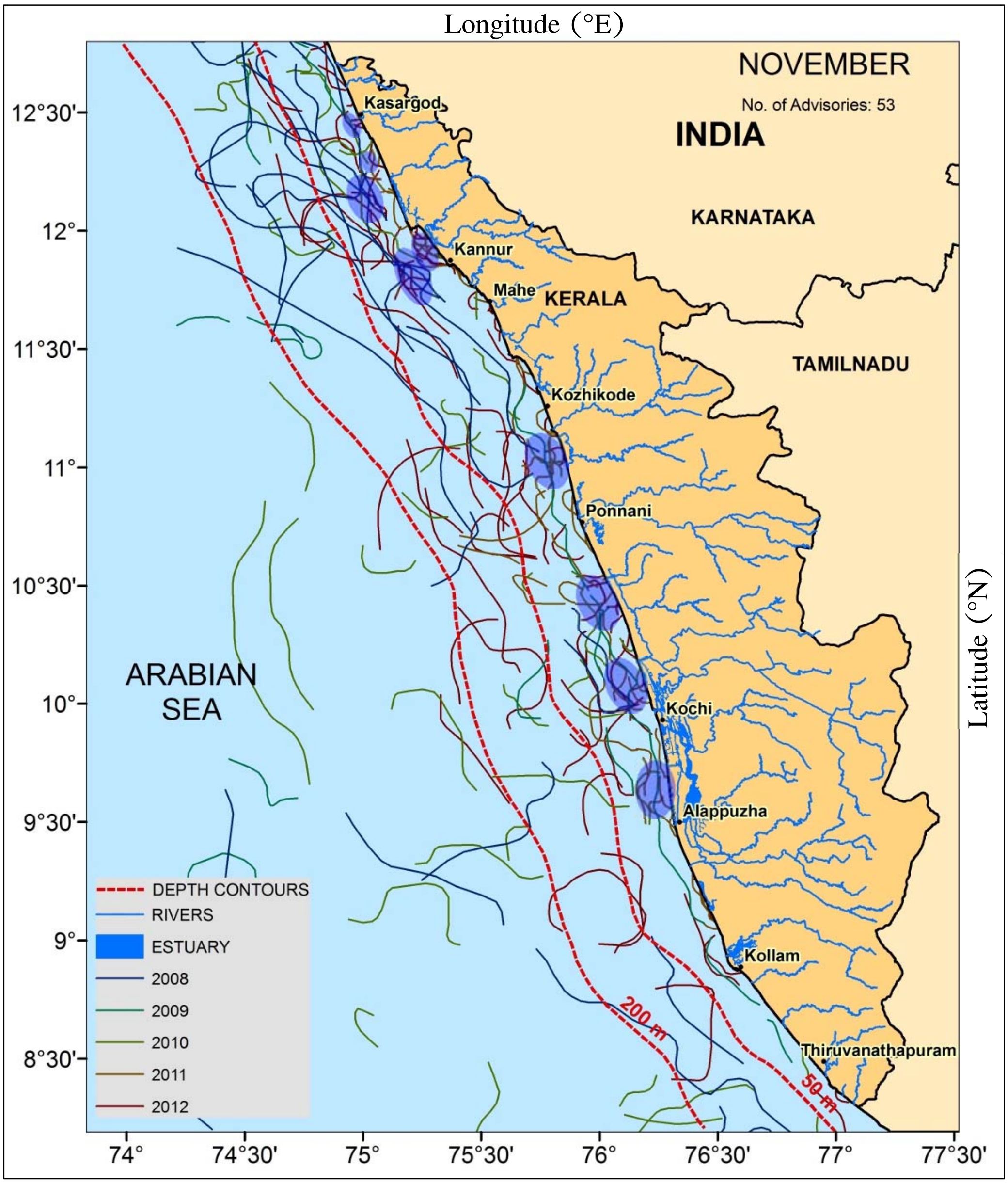


Figure 3.8 – Map showing the recurrent PFZs along the Kerala coast in November. The map is based on the PFZ advisories disseminated to the fisherman community during the five year study period (March 2008 – March 2012). The PFZ bands recorded during different years are indicated in various colours as shown in the figure legend. Rivers / estuaries draining into the study region are marked in blue colour. The depth contours (50 and 200 m) are shown as red dotted lines. The repeat PFZ bands are highlighted in blue circular/oval shape shading. The repeat PFZs in November were found mostly within 50 m depth contour. Repeat PFZs were found in the inshore waters between Kochi and Kozhikode and they were also found off Kannur and off south of Kasargod. Repeat PFZs were significantly low south of Alappuzha and they were much lower beyond 50 m depth contour in November as compared to the preceding (October) and succeeding (December) months. Nine repeat PFZs have been identified for November.

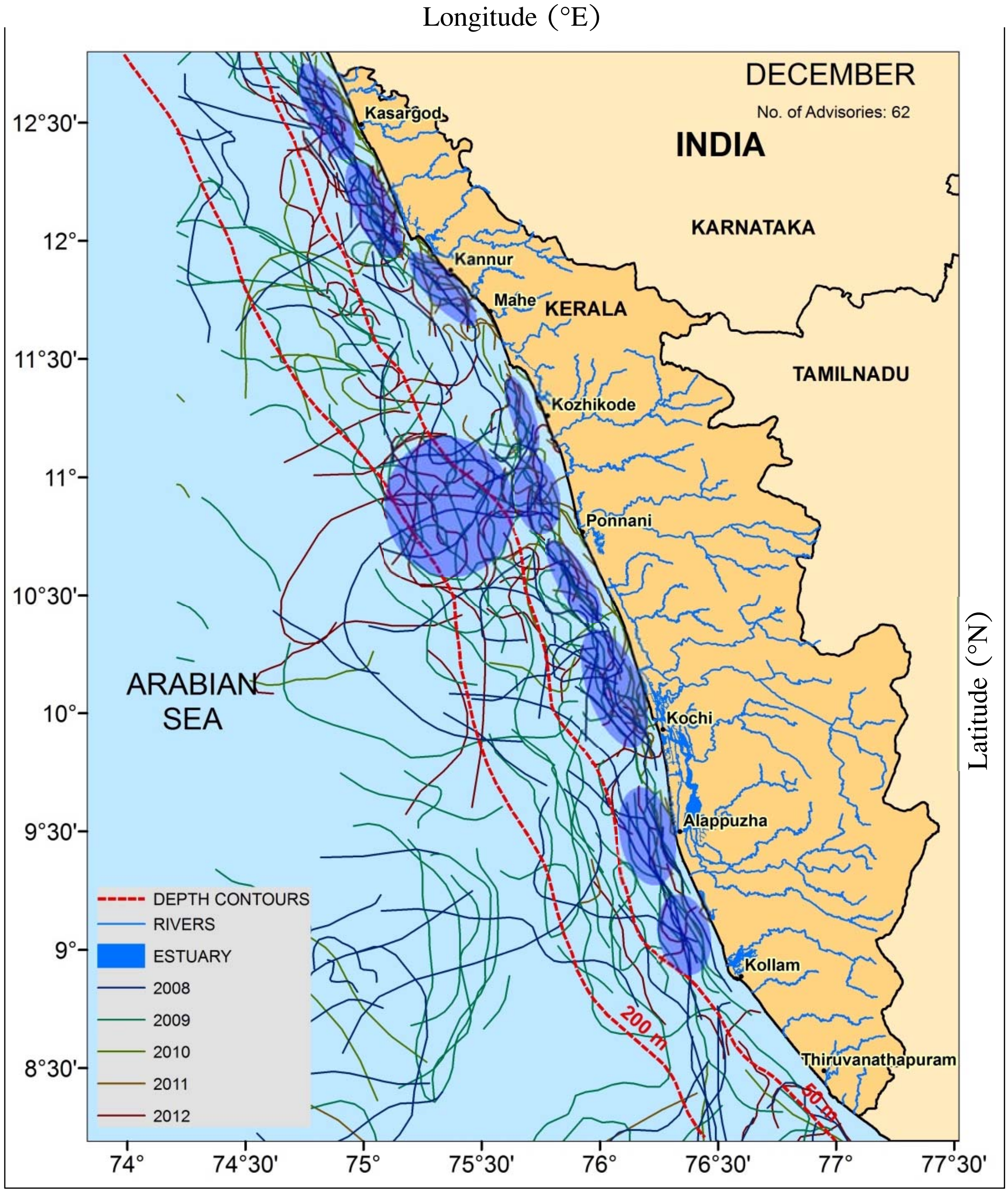


Figure 3.9 – Map showing the recurrent PFZs along the Kerala coast in December. The map is based on the PFZ advisories disseminated to the fisherman community during the five year study period (March 2008 – March 2012). The PFZ bands recorded during different years are indicated in various colours as shown in the figure legend. Rivers / estuaries draining into the study region are marked in blue colour. The depth contours (50 and 200 m) are shown as red dotted lines. The repeat PFZs are highlighted in blue circular/oval shape shading. In December, the repeat PFZ bands were found all along the Kerala coastline except the region south off Kollam and also between Kozhikode and Mahe. Very prominent repeat PFZ bands were found within the 50 m depth contour off Alappuzha, Kochi, Ponnani and Kasargod. The shelf region beyond 50 m also showed high concentration of PFZ bands. Ten repeat PFZs have been identified for December.

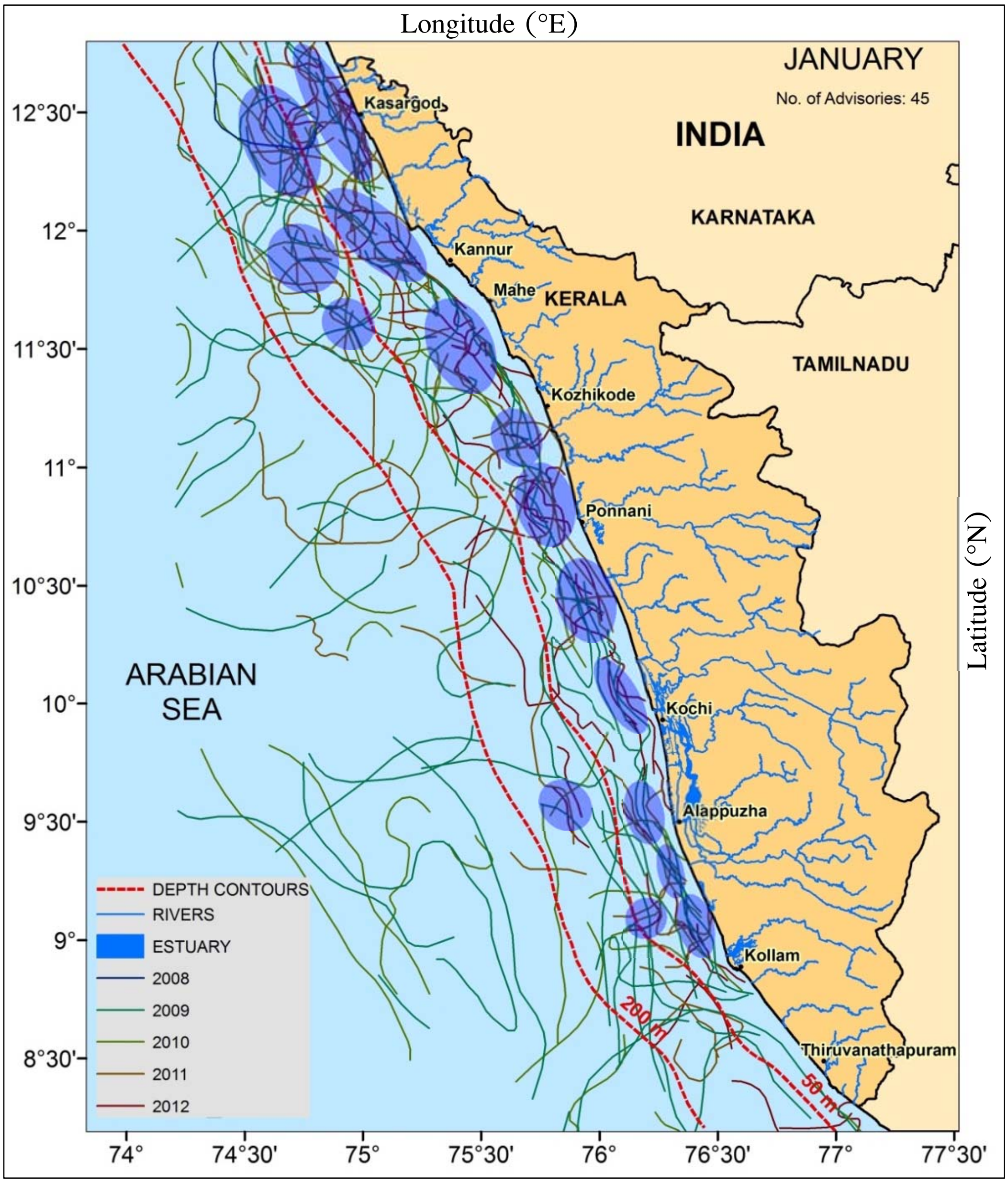


Figure 3.10 - Map showing the recurrent PFZ along the Kerala coast in January. The map is based on the PFZ advisories disseminated to the fisherman community during the five year study period (March 2008 – March 2012). The PFZ bands recorded during different years are indicated in various colours as shown in the figure legend. Rivers / estuaries draining into the study region are marked in blue colour. The depth contours (50 and 200 m) are shown as red dotted lines. The repeat PFZs are highlighted in blue circular/oval shape shading. Recurrent PFZ in January was distributed more or less all along the Kerala coastline except region south of Kollam. Repeat PFZ were found in the inshore waters between Kollam and Alappuzha and also found off north of Kochi, Ponnani, Kannur and Kasargod. Beyond 50 m depth contour, waters off Kollam, Alappuzha, Kannur and Kasargod had higher recurrent PFZ. Fifteen repeat PFZs have been identified for January.

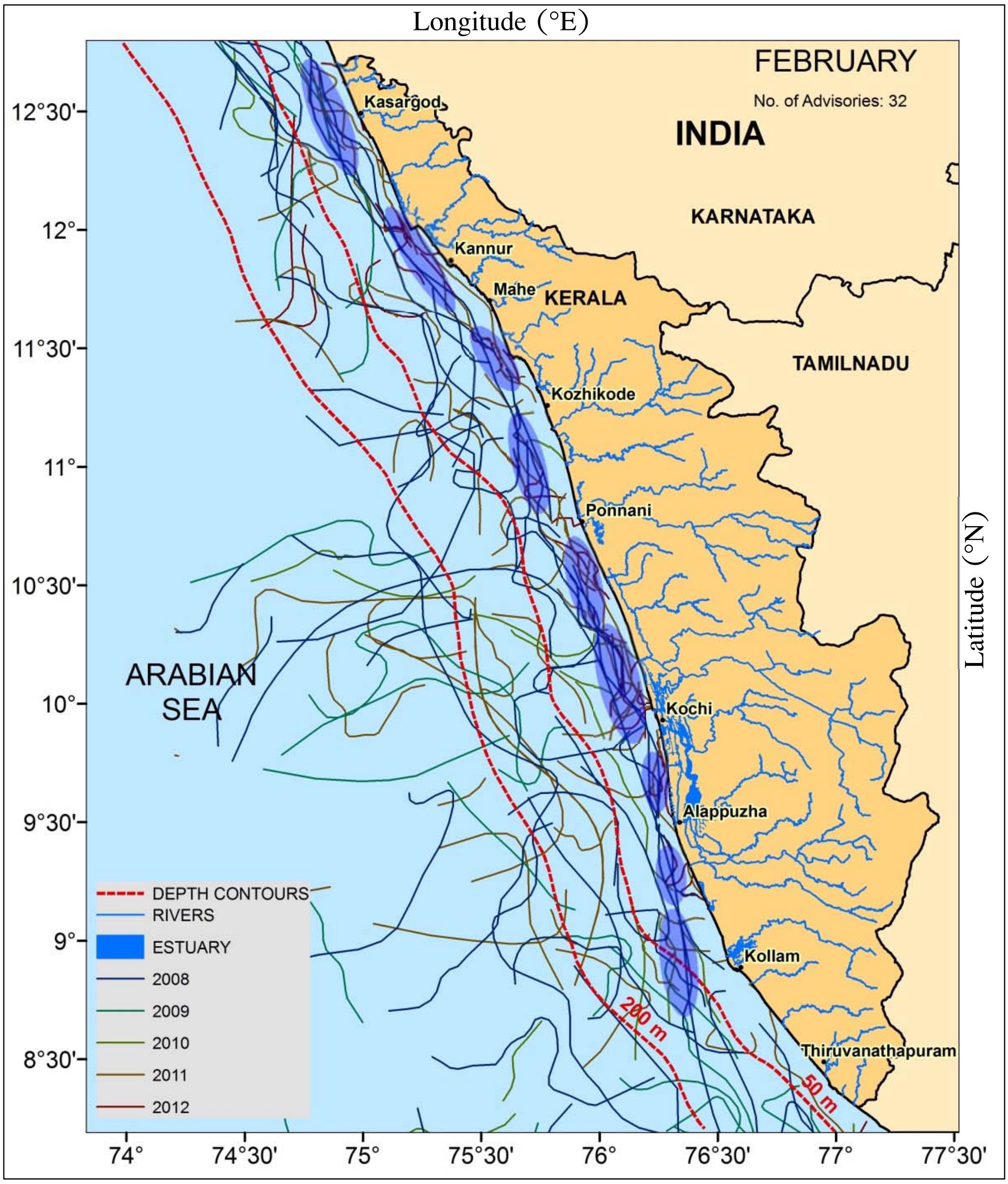


Figure 3.11 - Map showing the recurrent PFZ along the Kerala coast in February. The map is based on the PFZ advisories disseminated to the fisherman community during the five year study period (March 2008 – March 2012). The PFZ bands recorded during different years are indicated in various colours as shown in the figure legend. Rivers / estuaries draining into the study region are marked in blue colour. The depth contours (50 and 200 m) are shown as red dotted lines. The repeat PFZs are highlighted in blue circular/oval shape shading. Repeat PFZs were found off Kollam, Kochi, Kannur and Kasargod. Also a band of repeat PFZ was evident closer to the coastline between Kochi and Ponnani. Beyond 50 m depth contour, repeat PFZ was lower as compared to the inshore waters. However, waters beyond 50m between Kollam and Ponnani had higher concentration of PFZ bands as compared to the rest of the region in the same depth ranges. Nine repeat PFZs have been identified for February.

The results of the non- parametric ANOVA (Kruskal Wallis) to understand whether there is a statistically significant difference in the frequency of PFZ bands in advisories during different seasons are detailed below:

W	0.792
p-value	< 0.0001
alpha	0.05

Table 3.2 - The result of the normality (Shapiro-Wilk) test. The analysis showed P<0.05 which represents that the data sets rejects the null hypothesis (Ho- Normal distribution) and the samples are randomly distributed

K (Observed value)	13.546
K (Critical value)	5.991
DF	2
p-value (Two-tailed)	0.001
alpha	0.05

Table 3.3 - Over all results of Kruskal Wallis ANOVA test

Seasons	NEM	SWM	SIM
Northeast Monsoon (NEM)	1		
Southwest Monsoon (SWM)	0.108	1	
Spring Intermonsoon (SIM)	**0.0001**	0.034	1

Table 3.4 - Dunns multiple comparisons with Bonferroni corrected significance. Bold number indicate significant level of variation (Bonferroni corrected significance level, $p < 0.02$) in the frequency of PFZ bands between the Spring Intermonsoon and Northeast Monsoon periods.

Seasons	NEM	SWM	SIM
Northeast Monsoon (NEM)	1		
Southwest Monsoon (SWM)	NO	1	
Spring Intermonsoon (SIM)	**YES**	NO	1

Table 3.5 – Bonferroni corrected significance level ($p < 0.02$), which confirms the statistically significant variation in the frequency of PFZ bands in advisories during the Spring Intermonsoon and the Northeast Monsoon periods.

The data presented in Table 3.1 and the statistical analysis (ANOVA) presented in Tables 3.2 – 3.5 clearly show that the frequency of the PFZ bands in advisories during the Spring Intermonsoon was significantly lower than that during the Northeast Monsoon. It is generally believed that the rainfall and river influx have direct connection with the large fishery production along the Kerala coast (ICAR, 2011). This possible relationship has been verified in the present study by comparing the seasonal rainfall as well as the frequency of PFZ bands along the Kerala coast during study period. The seasonal rainfall pattern presented in Figure 3.13 clearly shows significantly higher rainfall during the Summer Monsoon and very low rainfall during the rest of the period as reported earlier by several authors (Qasim 2003).

This possible relationship has been verified in the present study by comparing the seasonal rainfall as well as the frequency of PFZ bands along the Kerala coast during study period. The seasonal rainfall pattern presented in Figure 3.12 clearly shows significantly higher rainfall during the Summer Monsoon and very low rainfall during the rest of the period as reported earlier by several authors (Qasim, 2003). The freshwater influx connection with the abundance of small pelagic fishes along the Kerala coast seems to be reasonable when considering the enormous water that reaches in the near shore marine waters of the Kerala during the Southwest Monsoon. Probably, the equator ward surface currents along the southwest coast of India during the Southwest Monsoon period facilitate the southward spreading of the freshwater plume from the 41 small rivers that empty into the Kerala coast (NIO Report 2008). However, this aspect need to be resolved based on more focused study considering a larger data sets of these aspects.

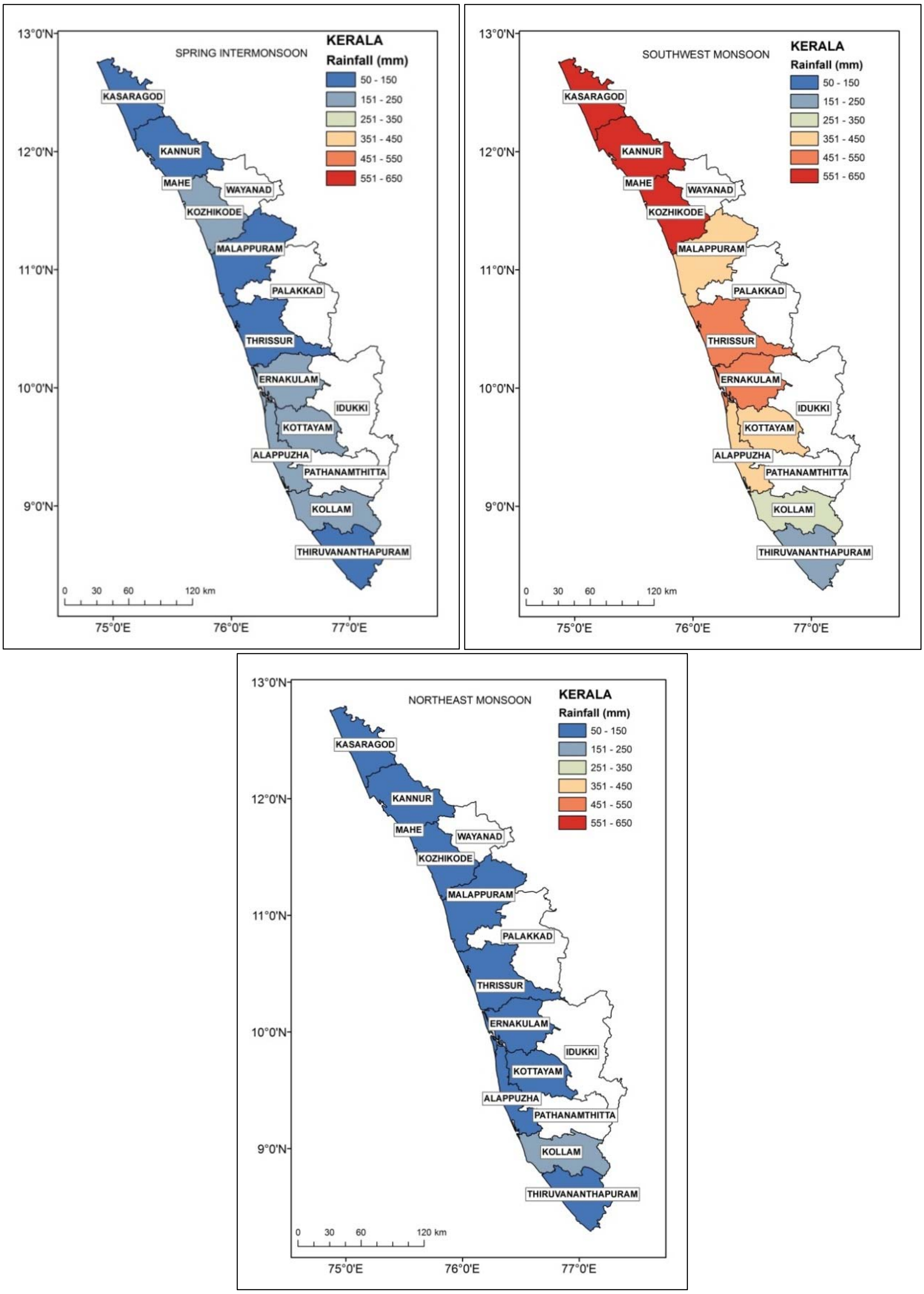


Figure 3.12 – Seasonal rainfall pattern along the Kerala coast line. Significantly high rainfall (~75%) during the Southwest Monsoon is evident. The rest of the annual rainfall is more or less equally contributed by the Spring Intermonsoon and Northeast Monsoon seasons.

In an earlier attempt, based on PFZ advisories along the Kerala coast during 2003 to 2007 period, Kripa et al., (2014) also showed that the near-shore waters with depths less than 50m host more PFZ bands than those in the continental shelf and slope waters. Considering the results of the present study, the traditional notion that the rainfall and the river influx are the major factors controlling the recurrent PFZs as well as high frequency of PFZ bands along the Kerala coast seems to be ambiguous. As shown clearly in the present study, repeat PFZs as well as the frequency of PFZ bands in advisories were significantly higher during the Northeast Monsoon when the rainfall was low and almost comparable with that during the dry Spring Intermonsoon period. On the other hand, the Southwest Monsoon season having the highest rainfall (~75% of the annual rainfall) had less frequency of PFZ bands than was expected. As the bands in the PFZ advisories are the regions of mesoscale/ sub-mesoscale ocean processes, reflected as gradients in SST and ocean colour, other ocean processes may likely to have prominent roles in the high frequency of PFZ bands along the Kerala coast during the Northeast Monsoon Period.

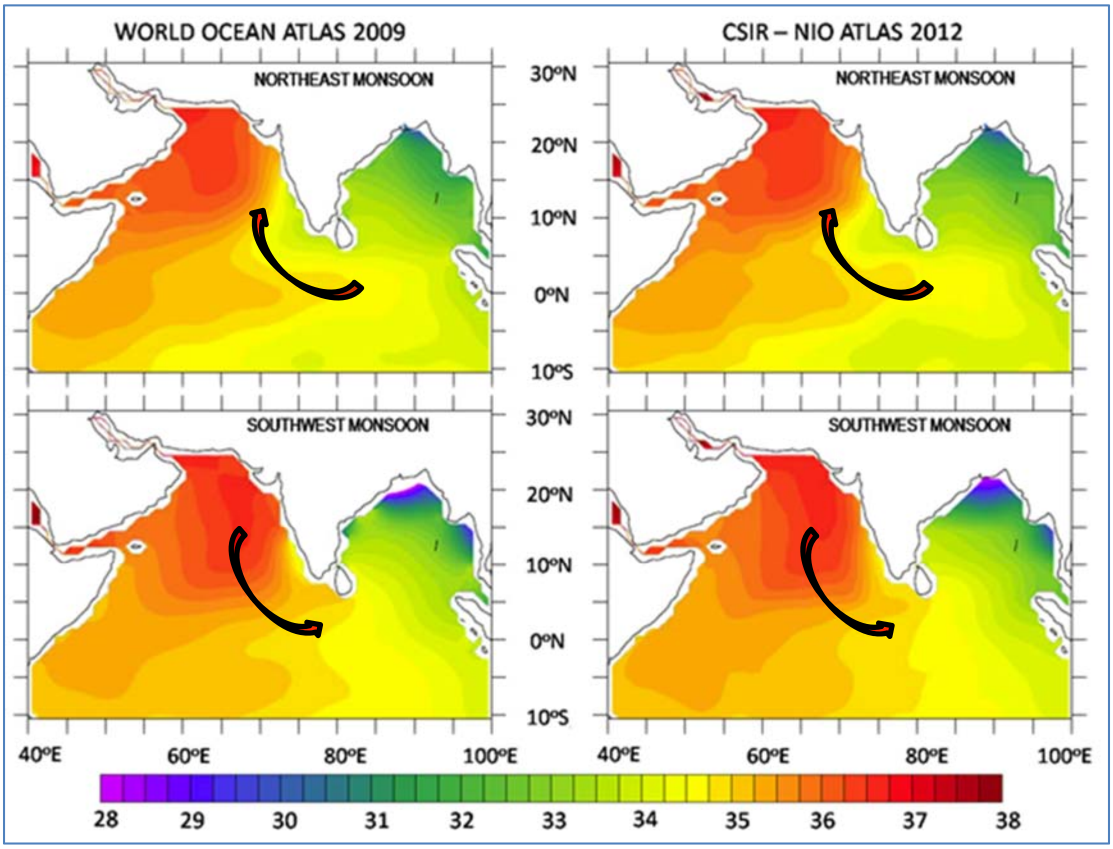


Figure 3.13 – The typical seasonal trend in the surface salinity distribution evident in the climatology atlases. It is clear that the entire South-eastern Arabian Sea has been significantly influenced by the low saline Bay of Bengal waters during the Northeast Monsoon season. The arrow marks indicate the direction of surface current (Shankar et al, 2002).

As presented in Figure 3.14, an important large scale ocean process operating in the South-eastern Arabian Sea during the Northeast Monsoon period is the intrusion of the low saline Bay of Bengal waters (Shankar et al., 2002; Jagadeesan et al., 2012). The impact of the low saline Bay of Bengal waters along the coastal waters of Kerala during the Northeast Monsoon have been described recently (NIO Report, 2008). The seasonal surface circulation brings low saline Bay of Bengal waters into the South-eastern Arabian Sea probably provides more chances for the formation of mesoscale and sub-mesoscale fronts and eddies in the region and this may be getting imprinted in satellite imageries as gradients in SST and ocean colour. However, this possibility needs further corroboration with filed as well as satellite data sets, which are beyond the scope of the present study.

3.4. Conclusion

Utilizing the PFZ advisories disseminated during the study period (April 2008 - April 2012), month-wise repeat PFZs have been demarcated for the Kerala coast. Large spatial and temporal variations were evident in the recurrent PFZs demarcated for various months. In general, most of the very prominent recurrent PFZs were found within the 50m depth contour. The highest number of recurrent PFZs, all along the Kerala coastline, was found in December, January and February. Similarly, the lowest number of recurrent PFZs was found in April, May and June. The overall results showed very prominent recurrent PFZs during the Northeast and Southwest Monsoon periods, whereas, such zones were sparse during the Spring Intermonsoon period. Similarly, the frequency of the PFZ bands in advisories was found to be significantly low during the Spring Intermonsoon as compared to the Northeast Monsoon. Analyses of the frequency of bands in PFZ advisories during different seasons showed that rainfall and river influx cannot be considered as the sole factor favouring the formation of the repeat PFZs along the Kerala coast. Therefore, it is suggested that other oceanographic processes may have a major role in causing prominent repeat PFZs along the Kerala coast, especially during the non-rainy (dry) period, as found in the case of the Northeast Monsoon.

The catch data from the Controlled Fishing Experiments during the Spring Intermonsoon shows equal percentage contribution (17% each) of Indian Mackerel and Oil Sardine. Therefore, Indian mackerel and oil sardine probably have equal chances to be caught from the Repeat PFZs demarcated for the Spring Intermonsoon period. Conversely, the fish catch data from the Controlled Fishing Experiments during the Southwest Monsoon presented significantly higher percentage contribution of Indian Mackerel (55%) followed by Oil Sardine (7%). This suggests that the repeat PFZs demarcated for the Southwest Monsoon may be more efficient to harvest the former species. Similarly, during the Northeast Monsoon, Oil Sardine contributed significantly (29%) compared to the Indian Mackerel (16%). This indicates that the recurrent PFZs demarcated for the Northeast Monsoon may be more useful to exploit the Oil Sardine resources compared with Indian Mackerel.

CHAPTER 4

FOOD AND FEEDING HABITS

4.1 Introduction

Concrete knowledge on the food and feeding habits of fishes is an important prerequisite for framing and practicing effective fishery resource management (Qasim, 1972; ICAR, 2011). Undoubtedly, the availability of suitable food in the natural environment directly influences the growth, fecundity and migration pattern of fishes and therefore, world over, the magnitude of fish stocks in a region is considered to be governed primarily by the availability of the preferred food in an environment (Pillay, 1952; Qasim, 1972). This suggests that any significant variations in the availability of the preferred food in a region can provide useful clues about the fluctuations in the associated fish stocks in the region (Pillay, 1952; Qasim, 1972).

The gut content of fishes is a true representative of the food materials they consume, which is believed to be the net result of their several ecological and physiological responses like behaviour, condition, energy requirements and inter/intra-specific interactions (Pillay, 1952; Qasim, 1972). The diet composition of fishes also provides clear indications about the trophic segregation among various fish stocks in a particular area. The food content in the stomach of fishes also indicates the seasonal fluctuations in the feeding habit as well as the availability of different kinds of food in the environment (Pillay, 1952; Ellis and Musik, 2007; Remya et al., 2013).

In fishery science, understanding the gut content is a standard practice as it provides important insight on the food and feeding habits as well as the physiological condition of the fish (Hyslop, 1980). The gut content study of fishes reveals the most frequently and recently consumed food and, hence, helps to determine the relative importance of different food types. The feeding behaviour of juveniles and adults may vary, and therefore, it is better if large number of samples with representation from all size classes is analysed.

Qasim (1972) discussed the practical difficulties faced while attempting gut content analysis of tropical fishes. However, even including all the limitations mentioned by Qasim (1972), it still remains to be the simplest, most direct, and effective tool to understand the feeding habits of fishes (Zachariah and Abdulrahiman, 2004). Food materials in the fish gut are often not intact due to their varying degrees of digestion. Even though all recently consumed feed items would be present intact in the foregut, only resistant items remain undigested in the hindgut due to the action of digestive enzymes. To avoid possible bias due to both digested and resistant food items in different parts of the gut, usually only the foregut is considered for analyses (Zachariah and Abdulrahiman, 2004).

The succeeding account deals with the food and feeding habits of Oil sardine (*Sardinella longiceps*), Indian mackerel (*Rastrelliger Kanagurta*) and Commerson's anchovy (*Stolephorus commersonii*). This accounts deals only with the plankton components in the diet as the present research topic is centred on the potential fishing zone advisories, which are derived from the plankton distribution patterns in the ocean. Probably, the first peer-reviewed research article on the food and feeding behaviour of Oil sardine was published by Hornell (1910), and since then, several authors presented their observations regarding this aspect (Nair, 1952; Noble, 1962, 1965; Kagwade 1964; Kutty, 1962, Dhulkhed, 1970). Studies in the past evidenced that Oil sardine is a plankton feeder, mainly feeding on phyto- and zooplankton. Studies on the food and feeding habits of Indian mackerel dates back to the 1940s and subsequently, several researchers recorded the gut content of Indian mackerel (Devenesan and Chidambaram, 1948; Bhimchar and George, 1952; Kuthalingam, 1956; Pradhan, 1956, Rao and Rao, 1957; Noble, 1962; Rao, 1962; Venkataraman and Mukundan, 1970; Sivadas and Bhaskaran, 2008, Ganga, 2010).

The general observation in these studies is that similar to Indian oil sardine, Indian mackerel also feeds on both phyto - and zoo - plankton. Compared to Indian oil sardine and Indian mackerel, information on the feeding habits of anchovies, even as a group, is very limited. The available literature on the food and feeding habits of various species of anchovies are contributed by Venkataraman (1960), Rao (1964), Anon (1974), Rao (1988a &b) and Nair (1985). These studies suggest that anchovies in general are carnivores, feeding mainly on planktonic crustaceans including copepods, ostracods, amphipods, cladocerans and mysids (Nair et al., 1985). However, there is no such information available specifically on Commerson's anchovy inhabiting the Indian coast.

Ocean research in the 1980s witnessed significant improvement in our fundamental understanding on the functional role of various plankton components in providing nutritional support to higher trophic levels (Azam et al., 1982). Based on this revised understanding, Cushing (1989) proposed two possible pathways of plankton food web providing nutritional support to fishes (Figure 4.1). The short 'traditional / classical food chain' (phytoplankton – fish, phytoplankton – zooplankton – fish) is proposed for nutrient-enriched environments and a 'microbial food web' (Smaller phytoplankton/bacteria, nanoflagellates - microzooplankton – mesozooplankton – fish) is reportedly common in low nutrient/ oligotrophic environments. Mann, (1993) summarised the above concept with emphasis on fisheries and suggested that world's major upwelling – linked fishery depends on the short, traditional plankton food chain. However, we are yet to know how relevant these concepts are in the Indian waters where there is a prominent change in the seasonal hydrography and plankton availability (Jyothibabu et al., 2006).

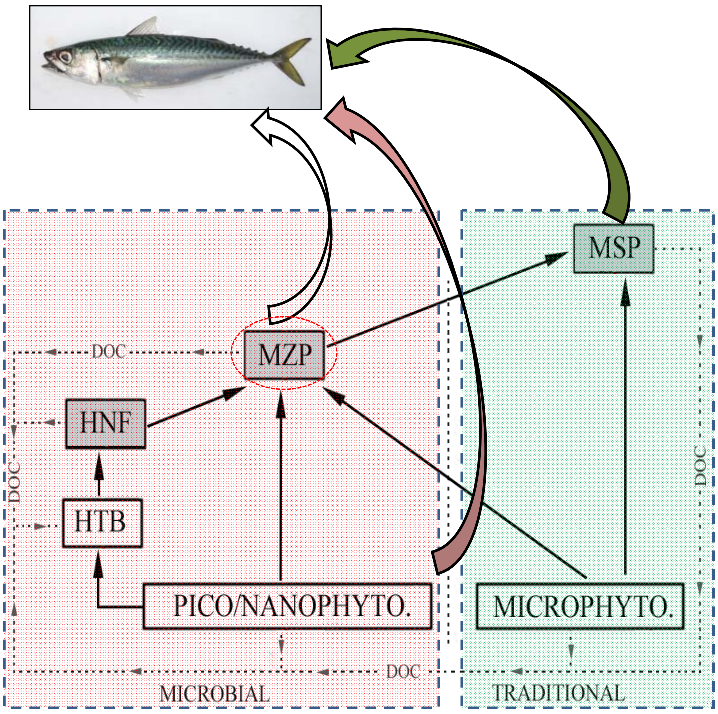


Figure 4.1 – The simplified schematic diagram of the two kinds of plankton food webs providing nutrition to fishes (Cushing, 1989; Mann, 1993). The highlight in green represents the traditional/classical food web, whereas the highlight in pink represents the microbial food web. The crucial/key role played by microzooplankton (MZP) in transferring the organic carbon from the microbial components to the fishes is evident (white dotted line circle). Abbreviations: HTB - Heterotrophic bacteria, HNF - Heterotrophic nanoflagellates, MZP - Microzooplankton, MSP - Mesozooplankton.

Considering the oceanographic environment in the south-eastern Arabian Sea, a larger domain of the present study display significant seasonal variations associated with monsoon winds and currents. Madhupratap et al., (1994) customised the original concept of Cushing

(1989) and Mann, (1993) and proposed that both 'traditional' and 'microbial' plankton food webs may have significance in supporting the pelagic fishery resources, probably in varying intensities during different seasons (Figure 4.2).

It is very clear in the figure that microzooplankton, consisting mainly of ciliates, heterotrophic dinoflagellates, radiolarians and crustacean nauplii play a crucial role in transferring organic carbon from the microbial food web to the higher trophic levels, including fishes. However, no comprehensive information is available so far on the role of microbial food web carbon as a source of nutrition to fishes from Indian waters.

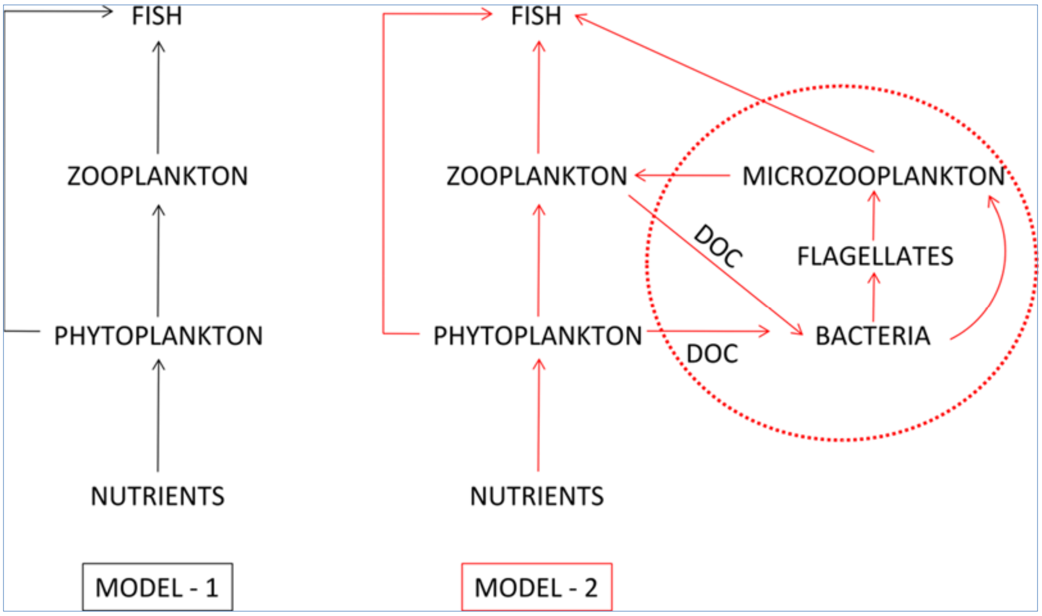


Figure 4.2 – Two possible plankton food webs providing nutrition to pelagic fishes along the southwest coast of India (adapted from Madhupratap et al., 1994). The dotted circle in model 2 represents the microbial food web in which microzooplankton (MZP) plays the crucial role in transferring the organic carbon from the microbial components to the fishes. DOC – Dissolved organic carbon

Careful analyses of the literature on gut content of Oil Sardine and Indian Mackerel show that microzooplankton like Tintinids (ciliate), *Protoperidinium*, *Ornithocercus* (heterotrophic dinoflagellates), radiolarians etc. were recorded priorly as part of the diet of these fishes. However, in earlier gut studies, these components were considered as a part of either the phytoplankton or the zooplankton group without understanding their ecological role in transferring microbial food web carbon to fishes.

It is relevant in this context to understand that more than 50% of the dinoflagellates, which were traditionally treated as phytoplankton, are obligate heterotrophs efficiently feeding on bacteria, autotrophic pico- and nanoplankton and even diatoms (Taylor, 1987; Stoecker, 1999; Sherr and Sherr, 2007). Therefore, a concerted effort to treat microzooplankton as a separate entity (as the representative of the microbial food web) has relevance as it helps to understand their role in providing nutritional support to fishes.

Alarming records of rising ocean temperature and ocean acidification are pointers of potential modifications in fish distribution and productivity of marine and freshwater systems (Cheung et al., 2010, 2013). Coastal and fishing communities and fishery-dependent countries are considered to be particularly vulnerable to climate change. However, the largest uncertainty in forecasting the effect of climate change on ecosystems is in understanding how it will affect the nature of interactions among different species (Winder and Schindler, 2004). Stenseth and Mysterud, (2002) suggested that climate change may cause perturbations to food webs if interacting species respond differently to shifting environmental conditions.

Scientific interest in understanding the climate-associated, long-term changes in marine ecosystem and its possible impact on the diet composition of small pelagics is relevant; already, indications on the northward habitat extension of Indian oil sardine along the west coast of India due to ocean surface warming have been reported (Vivekanandan et al., 2009). Environmental disturbance induced by coastal eutrophication and hypoxia along the shelf waters of the west coast of India are also of concern to the fisheries along the Kerala coast (Naqvi et al., 2000; Jayakumar et al., 2001). Discussions are also underway among the scientific community on the scientific belief that high abundance of phytoplankton (diatom) *Fragilaria oceanica* marks the region of high stocks of Indian Oil Sardine (Nair and Subrahmanyan, 1955). This scepticism is primarily because of the lack of *Fragilaria* in environmental samples even from the oil sardine fishing grounds (Remya et al., 2013).

Further, the gut content data of oil sardine from the west coast of India in the recent decades do not reflect abundant *Fragilaria*, and this situation may points towards a long-term change in the phytoplankton composition along the west coast of India (Remya et al., 2013). Based on this scientific background, the present study analyses the food and feeding aspects of Oil Sardine, Indian mackerel and Commerson's anchovy. This include (a) general composition, dominance and diversity of plankton food items in the diet composition (b) the role of microzooplankton/microbial food web as a food source (c) long-term changes, if any, in plankton diet content based on a comparison with the historic data.

4.2. Sampling and methods

4.2.1 Sampling

Sampling was carried out over a year (January - December 2010) and fish samples were collected once in a week from ring seine catches from Kalamukku and Munambam landing centres in Kochi, India (Figure 4.3). During the sampling period, specimens of 540 Oil sardine (size range 105-200 mm), 420 Indian mackerel (size range 125-275 mm) and 425 Anchovy individuals (size range 50-125 mm) were considered for the gut content analysis. Fresh specimens collected from the landing centres were used for the analysis.

In the laboratory, first, the basic morphometric measurements of the specimens such as the total length (mm) and wet weight (g) were taken, post which the samples were dissected to determine the growth stage. Subsequently, the gut was dissected and preserved in 5% formalin for microscopy with labels indicating all the necessary details of the specimen such as length, weight, sex, maturity stage and the date of sampling. The microscopy analyses of the gut preserved in formalin was carried out within the earliest possible time, and in any case, not later than a week's time.

Figure 4.3 – Ring seine landing centres sampled (a) Kalamukku and (b) Munambam. The bulk of the samples were collected from Kalamukku.

4.2.2. Methods

4.2.2.1. Gut content analyses

The foreguts of specimens were considered for the microscopy analysis. The gut content of 154 Oil Sardine, 96 Mackerel and 76 Anchovy were analysed. For the microscopic analysis, a longitudinal cut was made across the stomach and the content was transferred into a petri dish. The gut-contents, after making up to a known volume (say 10 ml), were well-stirred and an aliquot sample of 1 ml in triplicates were taken by means of a wide-mouth pipette; these were loaded on a counting slide and the quantitative estimation of the abundance of each food material were recorded under a binocular/inverted microscope with magnification from 100X - 400X (Number method). The plankton food contents were identified down to the genus/species level wherever possible.

4.2.2.2. Plankton diversity in the gut

The diversity of plankton in the gut content was represented using (a) Pielou's evenness (J') and (b) Shannon's diversity (H') indices. The basic purpose of Pielou's evenness (J') is to quantify the numerical homogeneity of a particular plankton (Pielou, 1969), and Shannon diversity (H') is used to represent the plankton diversity by taking into account the number of plankton groups/genera and their evenness in samples analysed (Shannon and Weaver, 1963).

4.2.2.3. Dominant plankton in the gut

The dominant plankton in the fish gut was analysed adopting the statistical method frequently used to analyse the dominance of a plankton group in the natural community (Yang et al., 1999, Lee et al., 2009, Lin et al., 2011; Jagadeesan et al., 2012).

$$Yi = (Ni / N) \times fi$$

Where, Yi is the dominance of a plankton i, Ni is the number of individuals of plankton i in all samples, N is the number of individuals of all plankton in all samples, and fi is the frequency of samples in which plankton i occurs. Plankton with a Y value of more than or equal to 0.02 were defined as the threshold for demarcating the dominant plankton (Yang et al., 1999, Lee et al., 2009, Lin et al., 2011).

4.3. Results and discussion

Snapshots of microscopic view of the gut content of Oil sardine, Indian mackerel and Commerson's anchovy are presented below (Figure 4.4). The plankton components in the foregut were usually found in a mixture of intact as well as partly deformed forms. Long chain-forming diatoms in the gut that become largely fragmented are rather more difficult to identify compared to those with only one cell (Figure 4.5).

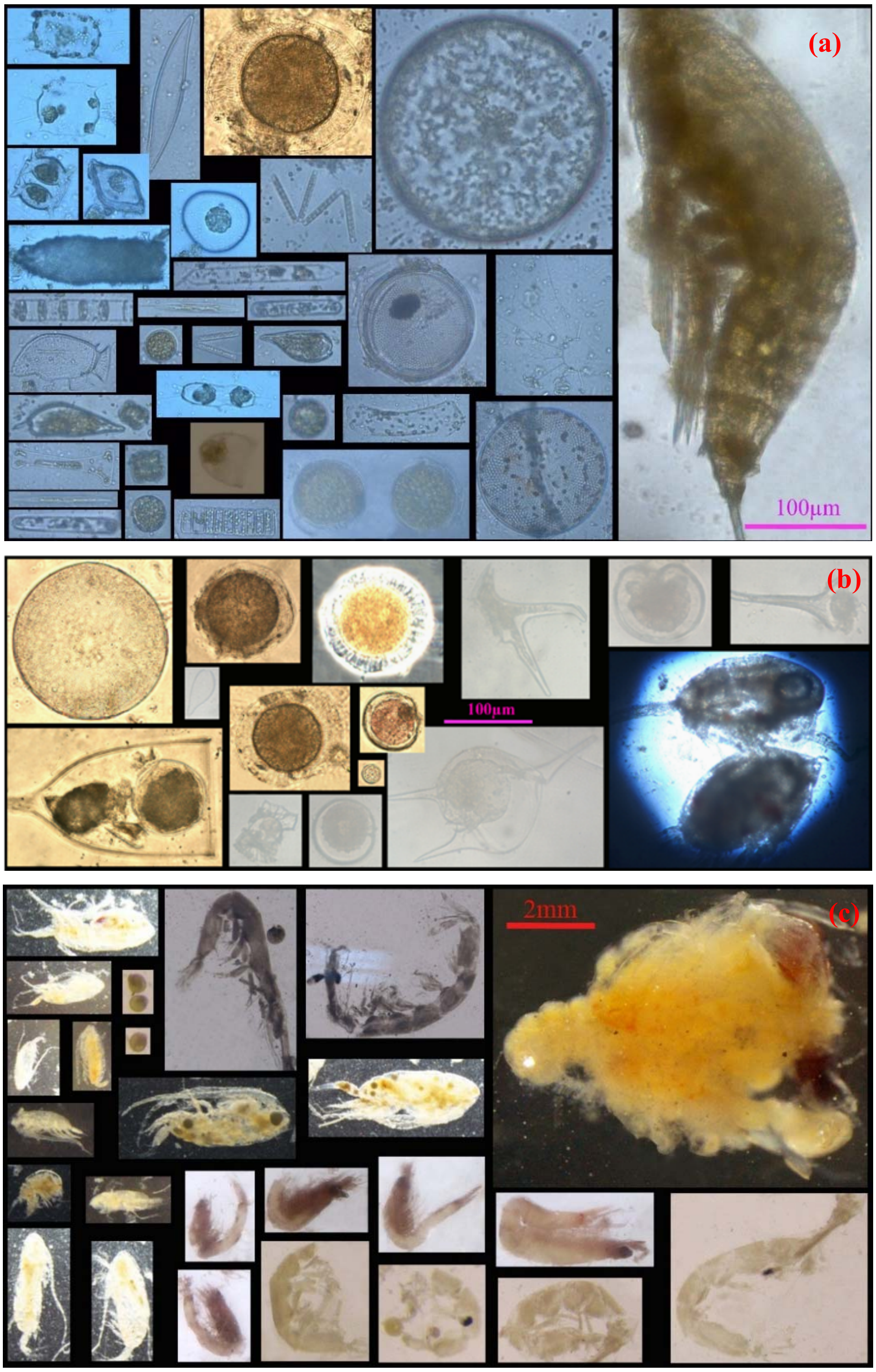


Figure 4.4 – Snapshots of the plankton in the gut content of (a & b) Oil Sardine and Indian mackerel and (c) Commerson's anchovy. It is clear in the image that oil sardine and Indian mackerel feed on both phytoplankton and zooplankton indicating omnivorous feeding habit, whereas Commerson's anchovy feeds predominantly on zooplankton indicating their carnivorous feeding habit.

The common plankton food in the foregut of oil sardine and Indian mackerel were (a) diatoms, (b) autotrophic dinoflagellates, (c) heterotrophic dinoflagellates (d) ciliates and (e) copepods. In the case of Commerson's anchovy, the plankton in the gut content was contributed chiefly by zooplankton such as copepods, sergistids, foraminifers etc, indicating the carnivorous diet of the species (Figure 4.4).

The plankton components present in the gut of fishes is usually a direct representation of the plankton components in the natural environment. During our gut content studies, we observed many instances where the fish gut contains predominance of a single species of phytoplankton, representing the blooming of those species in the natural environment.

Two such situations are presented below (Figure 4.5), wherein significantly high abundance of *Rhizosolenia* and *Fragilaria* were found in the gut content of Oil sardine during the Southwest monsoon season. Similarly, high abundance of *Pleurosigma* and copepods were found in the case of Indian mackerel and lucifers in the case of Commerson's anchovy during different periods, all indicating the high availability of the preferred food in the natural environment.

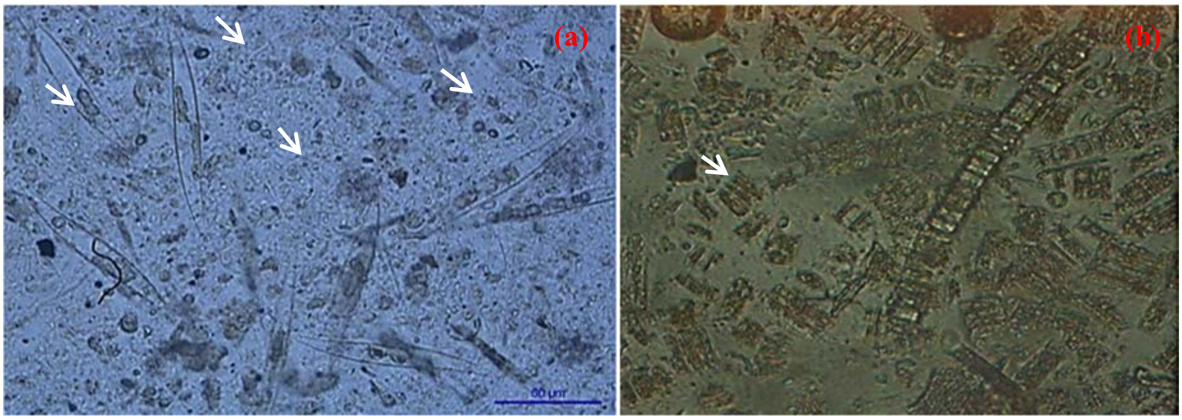


Figure 4.5 - The gut content of Indian Oil Sardine indicating large abundance of (a) *Rhizosolenia* and (b) *Fragilaria* probably indicating a blooming of these phytoplankton in the natural environment during the capture of the fish. Nair and Subrahmanyan, (1955) proposed that the presence of *Fragilaria* is an indication of the rich oil sardine stock in the region. Now discussions are underway among the scientific community on the above proposal that high abundance of phytoplankton (diatom) *Fragilaria oceanica* marks the region of high stocks of Indian Oil Sardine (Nair and Subrahmanyan, 1955). Literature suggests *Rhizosolenia* as a dominant plankton component in the diet of Indian oil sardine (Kuthalingam, 1961., Dhulkhed, 1962., Kagwade, 1964) and Indian mackerel (Noble, 1962, 1974). Microscopic images of the dominant plankton components in the gut content of the small pelagic fishes of interest are presented below (Figure 4.6) and the images are captured from the natural water samples collected from off Kochi.

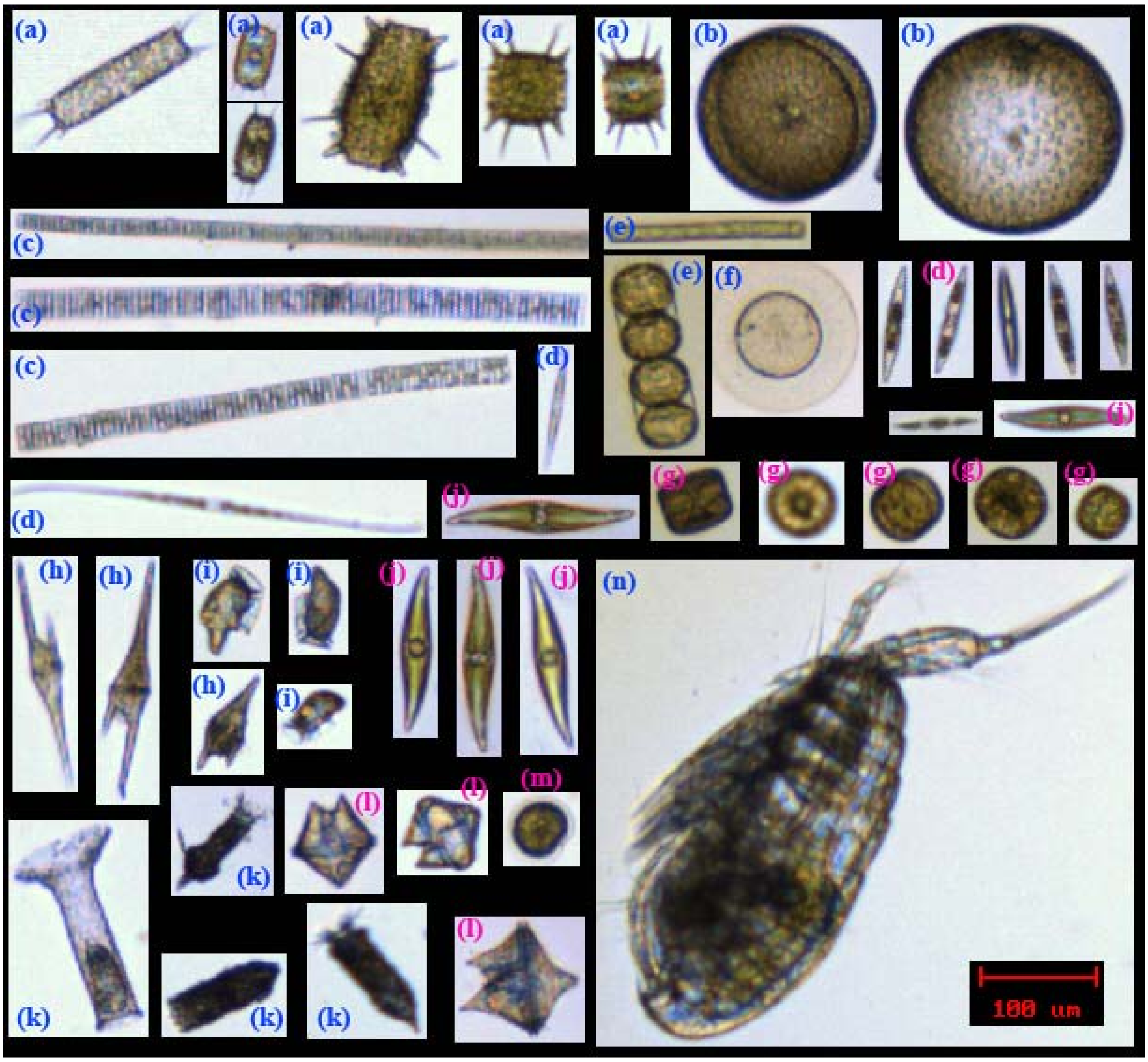


Figure 4.6 – Images of intact plankton which are found in the gut of Indian Oil Sardine, and Indian mackerel: (a) *Odontella*, (b) *Coscinidiscus*, (c) *Fragilaria*, (d) *Nitzschia*, (e) *Melosira*, (f) *Cyclotella*, (g) *Thalassiosira*, (h) *Ceratium*, (i) *Dinophysis*, (j) *Pleurosigma*, (k) *Tintinnopsis*, (l) *Protoperidinium*, (m) *Pyrophacus*, (n) Copepod.

4.3.1. Plankton in the gut content of Indian oil sardine

Altogether 34 group/genera of plankton components were identified from the gut of Indian Oil Sardine (Table 4.1). The phytoplankton component consists of 21 genera of diatoms and 4 genera of autotrophic dinoflagellates. Microzooplankton was composed of 3 genera of heterotrophic dinoflagellates, foaminifers, radiolarians and tintinnid ciliates. Mesozooplankton in the diet was composed of copepods, mysids and ostracods. *Coscinodiscus*, *Nitzschia*, *Pleurosigma*, *Thalassiosira*, Tintinnids and copepods were found in the gut of oil sardine almost throughout the year. Phytoplankton like *Bidulphia*, *Fragilaria*, and *Protoperidinium* were found to be present in the gut in the first half of the year, indicating a probable seasonal shift in the natural environment.

SL	Group/Genera	Jan.	Feb.	Mar.	Apr.	May	Jun.	Aug.	Sep.	Oct.	Nov.	Dec.
	Diatom (**Phytoplankton**)											
1	*Asterionella*	-	-	-	-	-	-	+	-	-	-	+
2	*Biddulphia*	+	+	+	+	+	+	+	-	-	-	-
3	*Chaetoceros*	+	+	+	+	+	+	-	-	-	-	-
4	*Coscinodiscus*	+	+	+	+	+	+	+	+	+	+	-
5	*Cyclotella*	-	+	+	+	-	-	+	-	+	+	-
6	*Ditylum*	-	-	-	-	+	-	-	-	-	-	-
7	*Eucampia*	-	-	-	+	-	-	+	-	-	-	-
8	*Fragilaria*	+	+	+	+	+	+	+	-	-	+	-
9	*Gyrosigma*	+	+	-	-	+	+	-	-	-	-	-
10	*Licmophora*	-	-	-	-	-	+	-	-	-	+	-
11	*Melosira*	-	+	+	+	+	+	-	-	-	-	-
12	*Navicula*	+	+	+	-	+	-	+	-	-	-	-
13	*Nitzchia*	+	+	-	+	+	+	+	+	+	+	-
14	*Pleurosigma*	+	+	+	+	+	+	+	+	+	+	-
15	*Pseudonitzchia*	-	-	+	-	-	-	-	-	-	+	-
16	*Rhiszosolenia*	+	+	-	+	+	-	+	-	+	-	-
17	*Skeletonema*	-	-	-	-	-	+	+	-	+	-	-
18	*Striatella*	-	-	-	-	-	-	-	-	-	+	-
19	*Thalassionema*	+	+	+	-	-	+	-	-	-	-	-
20	*Thalassiosira*	+	+	+	+	+	+	+	+	-	+	+
21	*Triceratium*	-	+	-	-	+	-	-	-	-	-	-
	Autotrophic Dinoflagellates (**Phytoplankton**)											
22	*Ceratium*	+	+	+	+	+	+	-	+	-	-	-
23	*Dinophysis*	+	-	+	+	+	-	+	+	+	+	+
24	*Gymnodinium*	-	-	-	-	-	+	-	-	-	-	-
25	*Porocentrum*	-	+	+	+	+	-	+	+	-	+	-
	Heterotrophic Dinoflagellates/Ciliates/Foraminifers/ Radiolarians (**Microzooplankton**)											
26	*Ornithocercus*	-	-	-	-	-	+	+	-	-	-	-
27	*Protoperidinium*	-	+	+	+	+	+	-	-	-	-	-
28	*Pyrophacus*	-	+	-	-	-	-	+	-	+	+	-
29	*Globigerina (Foram.)*	-	-	-	-	-	-	-	-	-	+	-
30	*Radiolarian*	-	+	-	-	-	-	+	-	-	+	-
31	*Tinitinnids (Cilia.)*	+	+	+	+	+	+	+	+	+	+	+
	Mesozooplankton											
32	*Copepod*	+	+	+	+	+	-	+	+	+	+	+
33	*Mysid*	-	-	-	+	-	-	+	-	-	-	-
34	*Ostracod*	-	-	-	-	-	-	-	+	-	-	-

Table 4.1 – Monthly variations in the composition of plankton in the gut of Oil sardine (juvenile and adult combined). The symbol + represents presence and - represents absence of a group/genera. Monthly variations in the composition of plankton in the gut of Oil sardine (juvenile and adult combined). The symbol + represents presence and - represents absence of a group/genera.

The dominant plankton components in the gut content of oil sardine based on statistical analysis of dominant value index is given in Table 4.2. This shows a general dominance of diatoms throughout the year and the dominance of the dinoflagellates, microzooplankton and copepods in the post-monsoon period (September - December). Even though the presence of *Fragilaria*, considered to be an indicator of oil sardine, was noticed in eight out of 12 months studied, they were found to be dominant in the oil sardine diet only in the April-June period. The highest dominance value was shown by copepods in December (0.84), followed by *Dinophysis* in October (0.62), and *Plerosigma* in January (0.59) and February (0.57). Copepods' contribution to the diet of Oil sardine in December was predominant compared to the other components.

SL	Group/Genera	Jan.	Feb.	Mar.	Apr.	May	Jun.	Aug.	Sep.	Oct.	Nov.	Dec.
	Diatom (**Phytoplankton**)											
1	*Biddulphia*	0.15	-	0.06	-	0.4	0.14	-	-	-	-	-
2	*Coscinodiscus*	+	+	+	0.05	+	0.08	-	0.06	0.16	0.03	-
3	*Cyclotella*	-	+	0.04	+	-	-	-	-	0.07	0.1	-
4	*Fragilaria*	+	+	0.08	0.02	+	-	-	-	-	+	-
5	*Melosira*	-	+	-	0.43	+	0.05	-	-	-	-	-
6	*Nitzchia*	0.05	0.03	-	+	+	0.03	0.07	0.32	0.02	+	-
7	*Pleurosigma*	0.57	0.59	0.16	+	0.12			+	+	+	-
8	*Thalassiosira*	0.08	0.07	0.07	0.24	0.11	0.14	0.09	0.09	-	0.02	+
	Autotrophic Dinoflagellates (**Phytoplankton**)											
9	*Ceratium*	+	+	+	+	0.05	-	-	+	-	-	-
10	*Dinophysis*	+	-	+	0.05	+	-	-	0.11	0.62	0.10	0.03
	Heterotrophic Dinoflagellates/Ciliates/Foraminifers/ Radiolarians (**Microzooplankton**)											
11	*Protoperidinium*	-	+	0.02	0.04	+	-	-	-	-	-	-
12	*Pyrophacus*	-	+	-	-	-	-	0.03	-	0.03	0.07	-
13	*Tinitinnids (Cilia.)*	+	+	+	0.02	+	-	-	0.28	0.06	0.04	0.02
	Mesozooplankton											
14	Copepod	+	+	0.04	0.05	+	-	-	0.16	+	0.14	0.84

Table 4.2 - Monthly fluctuation in the dominant plankton (dominance values ≥ 0.02) in the gut content of mature Oil Sardine. The symbol + represents presence and - represents absence of a group/genera

The evenness and diversity of plankton in the gut of oil sardine is presented in Figures 4.7 and 4.8. The evenness of plankton in the gut content of oil sardine was high in March April, May and December, whereas the diversity was high in April, May and June. The plankton diversity in the gut content of oil sardine was the lowest during December, when copepods dominated the diet composition. The gut composition of plankton components showed noticeable changes during various months indicating a corresponding change in the plankton components in the natural environment. *Nitzchia*, *Pleurosigma* and *Thalassiosira* were the most dominant diatoms in the gut content of Indian Oil Sardine, whereas microzooplankton was mostly dominant only during the October – December period.

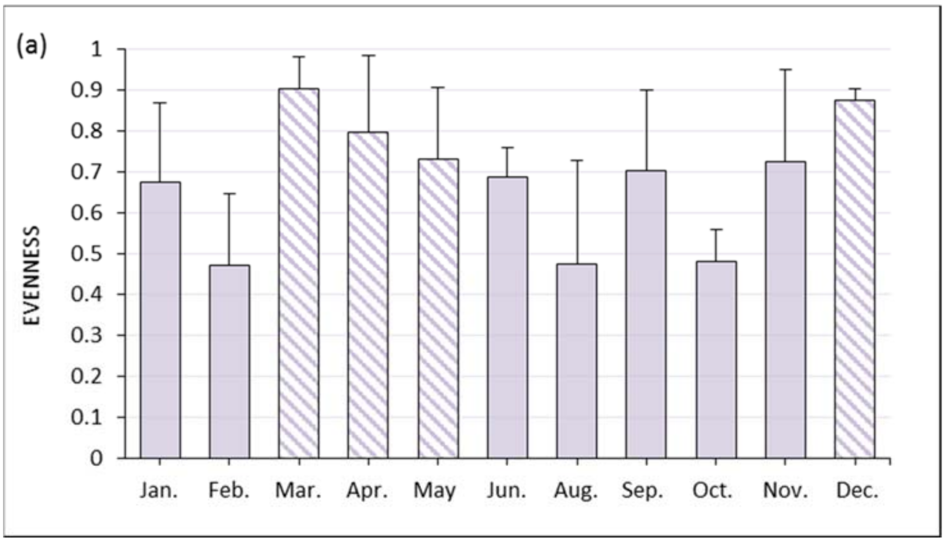


Figure 4.7 – Plankton evenness in the gut of Indian Oil Sardine. The evenness in plankton composition was high in March, April, May and December represented as bars filled with downward diagonal pattern

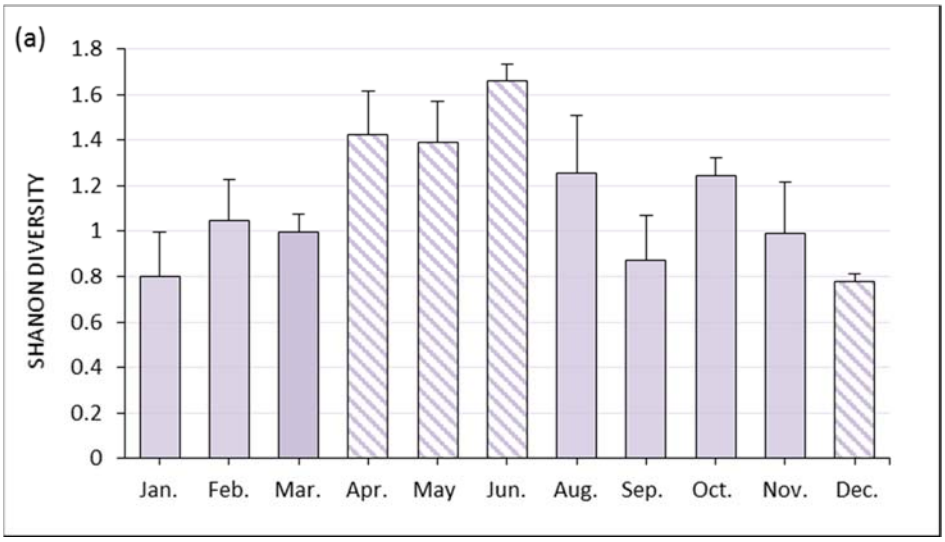


Figure 4.8 – Plankton diversity in the gut of Indian Oil Sardine. The evenness in plankton composition was high in April, May and June represented as bars filled with downward diagonal pattern.

4.3.2. Plankton in the gut content of Indian mackerel

Altogether 40 group/genera of plankton were identified from the gut of Indian mackerel (Table 4.3). The phytoplankton component consists of 21 genera of diatoms and 5 genera of autotrophic dinoflagellates.

SL	Group/Genera	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
	Diatom (**Phytoplankton**)												
1	*Asterionella*	-	-	-	-	-	-	+	-	-	-	-	-
2	*Bacillaria*	-	+	-	-	-	-	-	-	-	-	-	-
3	*Biddulphia*	+	+	-	+	+	-	+	-	+	-	+	-
4	*Chaetoceros*	-	-	+	-	-	+	-	-	-	-	-	-
5	*Coscinodiscus*	+	+	+	+	+	+	+	+	+	+	+	+
6	*Cyclotella*	+	-	+	+	+	-	+	-	-	+	+	-
7	*Ditylum*	-	-	-	+	-	-	-	-	-	-	-	-
8	*Eucampia*	-	+	-	-	-	-	-	+	-	-	+	-
9	*Fragilaria*	+	+	+	+	+	-	-	-	-	+	+	-
10	*Gyrosigma*	+	-	-	+	-	-	-	-	-	-	-	-
11	*Licmophora*	+	-	-	+	+	-	+	+	+	+	-	+
12	*Melosira*	+	-	-	+	+	-	-	+	-	+	-	-
13	*Navicula*	+	+	-	-	+	+	-	-	-	-	-	-
14	*Nitzchia*	+	+	-	+	+	-	+	+	+	+	-	+
15	*Pleurosigma*	+	+	+	+	+	-	-	-	+	+	+	-
16	*Rhiszosolenia*	+	+	-	+	-	-	-	-	-	+	-	+
17	*Skeletonema*	-	-	+	-	+	+	+	-	-	-	-	+
18	*Striatella*	-	-	-	-	-	-	-	-	-	-	-	+
19	*Thalassionema*	+	-	-	-	-	-	-	+	-	-	-	-
20	*Thalassiosira*	+	+	+	+	+	+	+	-	+	-	+	+
21	*Triceratium*	-	-	-	+	+	-	+	-	-	-	+	-
	Autotrophic Dinoflagellates (**Phytoplankton**)												
22	*Ceratium*	+	+	+	+	+	-	+	+	+	+	+	+
23	*Dinophysis*	+	+	+	+	+	+	+	+	+	+	-	+
24	*Diplosalis*	-	-	-	+	-	-	-	-	-	-	-	-
25	*Gonyaulux*	-	-	-	+	-	-	-	-	-	-	-	-
26	*Porocentrum*	-	-	-	+	-	-	+	+	+	+	+	-
	Heterotrophic Dinoflagellates/Ciliates/Foraminifers/ Radiolarians (**Microzooplankton**)												
27	*Noctiluca*	-	-	-	-	-	-	-	-	-	-	-	+
28	*Ornithocercus*	-	+	-	-	+	-	-	-	-	-	-	+
29	*Phalacroma*	-	-	-	+	-	-	-	-	-	-	-	-
30	*Protoperidinium*	+	+	+	+	+	-	+	+	+	-	+	+
31	*Pyrophacus*	+	+	+	+	+	-	-	+	+	+	+	-
32	*Globigerina (Foram.)*	-	-	-	-	-	-	-			-	+	-
33	Radiolarian	-	-	-	-	+	-	+	-	+	-	+	-
34	Tinitinnids (Cilia.)	+	+	+	+	+	+	+	+	+	+	+	+
	Mesozooplankton												
35	Copepod	+	+	+	+	+	+	+	+	+	+	+	+
36	Doliolum	-	-	-	-	-	-	-	-	-	-	-	-
37	Fish eggs	-	-	+	-	-	-	-	-	-	-	+	-
38	Medusa	-	-	-	-	-	-	-	+	-	-	-	-
39	Mysid	-	+	-	-	-	-	-	-	-	-	+	-
40	Ostracod	-	+	-	+	+	-	-	-	-	-	-	-

Table 4.3 – Monthly variations in the composition of plankton in the gut of Indian mackerel (juvenile and adult combined). The symbol + represents presence and – represents absence of a group/genera. The phytoplankton component consists of 21 genera of diatoms and 4 genera of autotrophic dinoflagellates. The microzooplankton is composed of 3 genera of heterotrophic dinoflagellates, foaminifers, radiolarians and tintinnid ciliates. The mesozooplankton component was composed of copepods, mysids and ostracods

Microzooplankton was composed of 5 genera of heterotrophic dinoflagellates, foaminifers, radiolarians and tintinnid ciliates. Mesozooplankton in the diet of Indian mackerel was composed of copepods, doliolids, medusae, mysids and ostracods. Coscinodiscus and tintinids were found in the gut content throughout the year. Similarly, *Thalassiosira*, *Ceratium*, *Dinophysis*, *Protoperidinium*, *Pyrophacus*, and copepods were found in the gut of indian mackerel almost throughout the year. Unlike Indian oil sardine, all components of plankton (phytoplankton, microzooplankton and mesozooplankton) were found to be present in the gut of Indian mackerel throughout the year. The increase in diversity of zooplankton components in the gut of Indian mackerel was significantly higher (6 groups) than that of the oil sardine (3 groups).

Group/Genera	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Diatom (**Phytoplankton**)												
1 *Biddulphia*	+	+	0.03	+	0.02	-	+	-	+	-	+	-
2 *Coscinodiscus*	+	+	+	0.04	+	+	+	+	0.06	0.16	0.03	+
3 *Cyclotella*	0.39	+	+	+	+	-	0.03	-	-	0.07	0.1	-
4 *Fragilaria*	+	+	0.08	+	+	-	-	-	-	0.04	+	-
5 *Licmophora*	+	-	-	0.03	+	-	+	+	+	0.02	-	+
5 *Melosira*	+	+	-	0.48	0.14	-	-	0.87	-	0.12	-	-
6 *Nitzchia*	0.39	0.04	-	0.03	+	-	+	0.85	0.43	0.11	-	0.28
7 *Skeletonema*	-	-	+	-	+	+	0.41	-	-	-	-	+
8 *Pleurosigma*	0.19	0.59	0.16	+	0.12	-	-	-	+	+	+	-
9 *Thalassiosira*	+	+	0.08	0.02	0.07	-	0.05	-	0.09	-	0.02	+
*Autotrophic Dinoflagellates (**Phytoplankton**)*												
10 *Ceratium*	+	+	+	0.02	+	-	+	+	+	0.07	0.01	0.02
11 *Dinophysis*	+	+	+	+	+	+	+	+	0.09	0.14	-	+
*Heterotrophic Dinoflagellates/Ciliates/Foraminifers/ Radiolarians (**Microzooplankton**)*												
12 *Protoperidinium*	0.29	+	+	0.04	+	-	0.03	+	+	-	0.02	+
13 *Pyrophacus*	0.07	+	0.03	+	0.03	-	-	+	+	0.03	0.07	-
14 Tinitinnids (Cilia.)	+	+	0.03	+	+	+	0.11	+	+	0.04	0.02	-
Mesozooplankton												
15 Copepod	0.11	0.05	0.62	0.08	0.26	+	+	0.12	0.21	0.46	0.85	0.33

Table 4.4 – Monthly fluctuation in the dominant plankton (dominance values ≥ 0.02) in the gut of Indian mackerel (juvenile and adult combined). The symbol + represents presence and – represents absence of a group/genera.

The dominant plankton components in the gut content of Indian mackerel based on statistical analysis of dominant value index is given in Table 4.4. This shows a dominance of phytoplankton, microzooplankton and copepods in the diet of Indian mackerel throughout the year, indicating their almost equal preference to both phytoplankton and zooplankton. *Fragilaria*, an indicator of oil sardine, was noticed in eight out of 12 months studied and they were found dominant in the diet of Indian mackerel only in March and October. The highest dominance value of plankton in the gut of Indian mackerel was shown by *Melosira* in August (0.87), followed by *Nitschia* in August (0.62), Copepods in November (0.85) and *Pleurosigma* in February (0.57). In general, Indian mackerel has more feeding preference to copepods as compared to Oil sardine as indicated by high dominant value index in almost all months sampled.

The evenness and diversity of plankton in the gut of Indian mackerel is presented in Figures 4.9 and 4.10. The evenness of plankton in the gut content of Indian mackerel was high in January, February and July, whereas, the diversity was high in April, May and October. The plankton diversity in the gut content of Indian mackerel was the lowest during August, when *Melosira* and *Nitszchia* dominated the diet composition.

The gut composition of plankton components showed noticeable changes during various months, which may indicate the change in the plankton components in the natural environment or the physiological status of the fish. Copepods, *Thalassiosira* and *Nitzschia* were the most dominant diatoms in the gut content of Indian mackerel. Similarly, the contribution of microzooplankton as a group to the diet of Indian mackerel was also significant, irrespective of seasons.

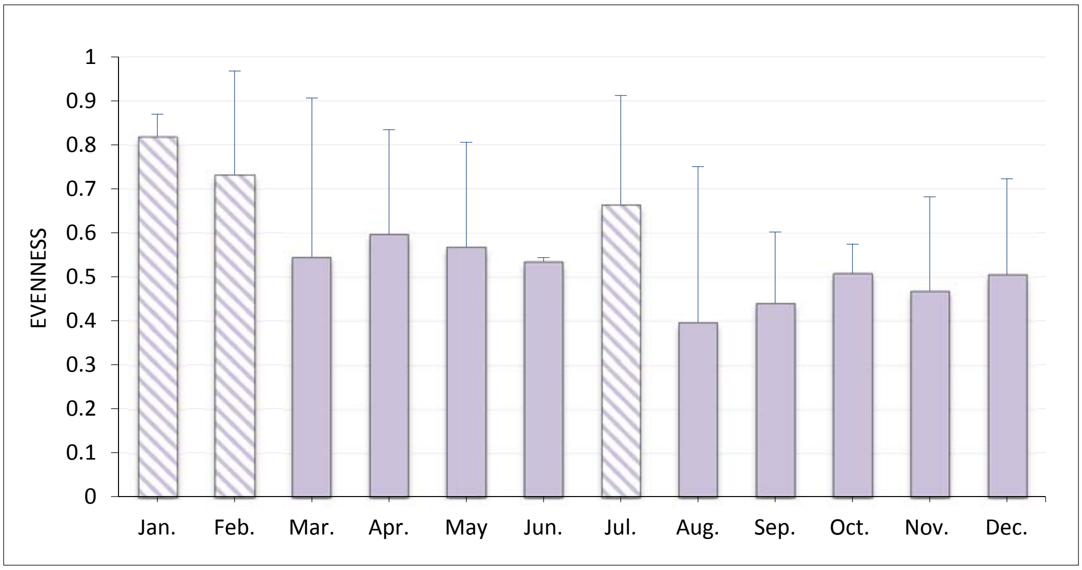


Figure 4.9 – Monthly variations in the plankton evenness in the gut content of Indian mackerel (juvenile and adult combined). The evenness in plankton composition was high in March, April, May and December, whereas the diversity was higher in April, May and June.

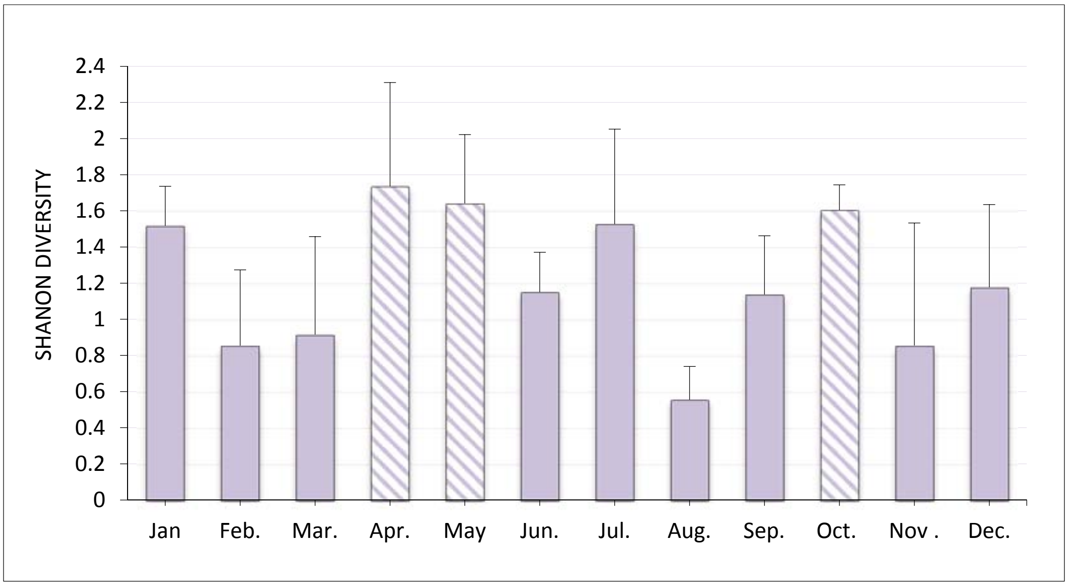


Figure 4.10 – Monthly variations in the plankton diversity in the gut content of Indian mackerel (Juvenile and adult combined). The diversity in plankton composition was high in March, April, May and December, whereas the diversity was higher in April, May and June.

4.3.3. Plankton in the gut content of Commerson's anchovy

The food items in the gut content of anchovy showed characteristic differences from both Oil Sardine and Indian mackerel. Altogether 12 groups/genera were identified from the gut content of Commerson's anchovy. The Commerson's anchovy was found to be a zooplankton feeder predominantly feeding on copepods, fish eggs, ostracods, and tintinids etc. The absence of diatoms in the diet composition was a striking feature, indicating the carnivorous diet of the fish. Other food items observed in the gut included acetes, bivalve, cladocera, decapods and mysids.

The dominant plankton components in the gut content of Commerson's anchovy based on statistical analysis of dominant value index is given in Table 4.5. This shows a clear dominance of copepods in the gut content throughout the year. Significantly, high dominance of single food item in the gut content was observed in several months, as in the case of Cladocera in December and lucifer/sergistids in June. The dominant plankton components in the gut content of Commerson's anchovy based on statistical analysis of dominant value index is given in Table 4.6. This shows a clear dominance of copepods in the gut content throughout the year. Significantly, high dominance of single food item in the gut content was observed in several months, as in the case of Cladocera in December and lucifer/sergistids in June.

SN	Group/genera	Feb.	Mar.	Apr.	Jun.	Jul.	Aug.	Nov.	Dec.
	Microzooplankton								
1	Tintinnids	+	+	-	+	+	+	+	-
	Mesozooplankton								
2	*Acetes*	-	-	-	+	-	-	-	+
3	Bivalves	-	-	-	-	+	+	+	-
4	Cladocera	-	-	-	-	-	-	+	+
5	Decapoda	-	-	-	-	-	+	+	+
6	Digested flesh	-	-	-	-	-	-	-	+
7	Dinophysis	-	-	-	-	-	+	-	-
8	Fish eggs	+	-	+	+	-	-	+	-
9	Lucifer	-	-	-	+	-	+	+	-
10	Mysid	-	-	-	-	+	-	+	-
11	Ostracods	+	-	-	-	+	-	+	-
12	Polychaeta	-	-	-	-	+	-	-	-
13	Prawn appendages	-	+	-	-	-	+	+	+
14	Siphonophora	-	-	-	-	+	-	-	-
15	Zoea	-	-	-	-	+	-	-	-
16	Copepods	+	+	+	+	+	+	+	-

Table 4.5 – Monthly variations in the composition of plankton in the gut of Commerson's anchovy (juvenile and adult combined). The symbol + represents presence and – represents absence of a group/genera.

SN	Group/genera	Feb.	Mar.	Apr.	Jun.	Jul.	Aug.	Nov.	Dec.
	Microzooplankton								
1	Tintinnid	0.05	0.03	-	-	-	-	-	-
	Mesozooplankton								
2	*Acetes*	-	-	-	0.03	-	-	-	0.02
3	Bivalve	-	-	-	-	-	0.16	0.03	-
4	Cladocera	-	-	-	-	-	-	0.05	-
5	Decapods	-	-	-	-	-	-	-	0.65
6	Fish scales	0.39	-	0.39	0.05	0.33	-	-	-
7	Lucifer	-	-	-	0.60	-	0.54	-	-
8	Mysids	-	-	-	-	-	-	0.03	-
9	Ostracods	0.03	-	-	-	0.45	-	0.09	-
10	Prawn appendages	-	0.12	-	-	-	-	-	-
11	Copepod	0.20	0.83	0.47	0.03	0.04	0.22	0.19	0.06

Table 4.6 – Monthly fluctuation in the dominant plankton (dominance values ≥ 0.02) in the gut of Commerson's anchovy (juvenile and adult combined). The symbol + represents presence and – represents absence of a group/genera.

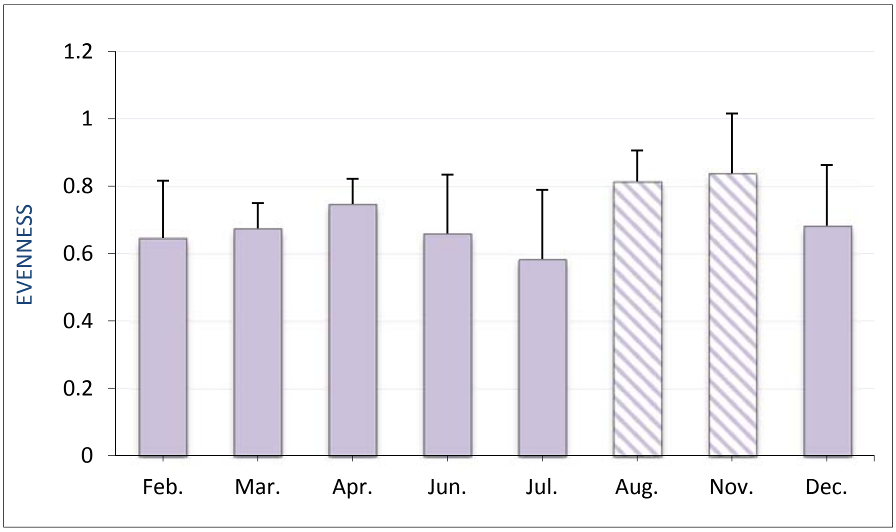


Figure 4.11 – Monthly variations in the plankton evenness in the gut content of Commerson's anchovy (Juvenile and adult combined). The evenness in plankton composition was high in March, April, May and December, whereas the diversity was higher in April, May and June.

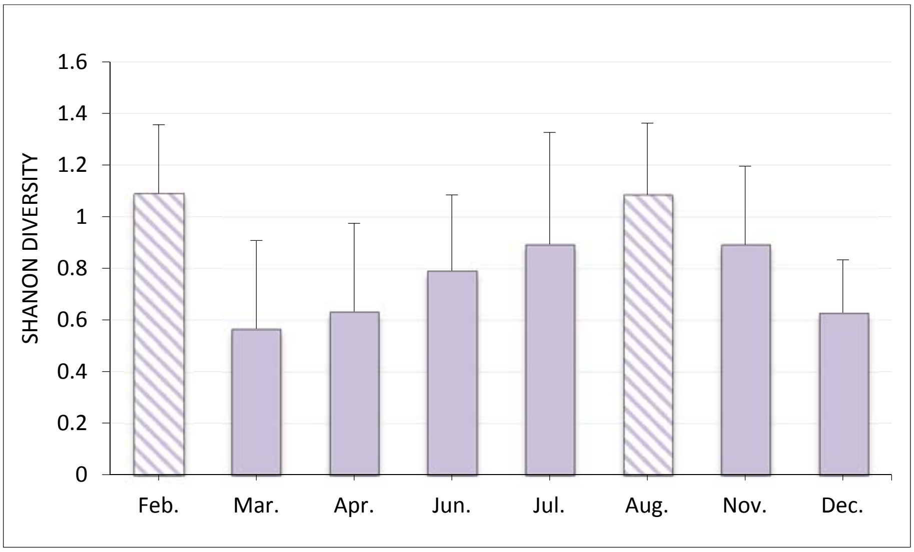


Figure 4.12 – Monthly variations in the plankton diversity in the gut content of Commerson's anchovy (Juvenile and adult combined). The diversity in plankton composition was high in March, April, May and December whereas the diversity was higher in April, May and June.

The evenness of the food items in the gut content of Commerson's anchovy was high in August and November whereas the diversity was high in February and August (Figures 4.11 and 4.12). The lowest evenness was found in July while lowest diversity was observed in March, April and December.

4.3.4. Comparison with earlier records of gut contents

4.3.4.1. Indian oil sardine

SL	Present observation	Historic observation
	Diatom (Phytoplankton)	
1	*Asterionella*	Kuthalingam,1961
2	***Biddulphia***	Dhulkhed,1962., Kagwade, 1964, Noble,1964
3	*Chaetoceros*	Dhulkhed,1962., Noble,1964
4	***Coscinodiscus***	Kuthalingam, 1961., Dhulkhed,1962., Kagwade,1964., Noble,1964
5	***Cyclotella***	No earlier records
6	*Ditylum*	No earlier records
7	*Eucampia*	No earlier records
8	***Fragilaria***	Dhulkhed,1962., Kagwade,1964., Noble,1964
9	*Gyrosigma*	No earlier records
10	*Licmophora*	No earlier records
11	***Melosira***	No earlier records
12	*Navicula*	Noble,1964
13	***Nitzchia***	Kagwade,1964
14	***Pleurosigma***	Dhulkhed,1962., Kagwade,1964., Noble,1964
15	*Pseudonitzchia*	No earlier records
16	*Rhiszosolenia*	Kuthalingam,1961., Dhulkhed,1962., Kagwade,1964
17	*Skeletonema*	Dhulkhed,1962
18	*Striatella*	No earlier records
19	*Thalassionema*	Kuthalingam,1961., Dhulkhed,1962., Bensam,1964
20	***Thalassiosira***	Dhulkhed,1962., Bensam,1964
21	*Triceratium*	Dhulkhed, 1962., Kagwade,1964., Noble,1964
	Autotrophic Dinoflagellates (**Phytoplankton**)	
22	***Ceratium***	Dhulkhed,1962., Kagwade,1964., Bensam,1964., Noble,1964
23	***Dinophysis***	Dhulkhed,1962., Kagwade, 1964., Noble,1964., Bensam,1964
24	*Gymnodinium*	No earlier records
25	*Porocentrum*	No earlier records
	Heterotrophic Dinoflagellates/Ciliates/Foraminifers/ Radiolarians (**Microzooplankton**)	
26	*Ornithocercus*	Bensam, 1964
27	***Protoperidinium***	Dhulkhed,1962., Bensam, 1964., Kagwade,1964
28	***Pyrophacus***	Bensam.,1964
29	Globigerina (Foram.)	No earlier records
30	Radiolarian	No earlier records
31	**Tinitinnids** (Cilia.)	Bensam, 1964
	Mesozooplankton	
32	**Copepod**	Kuthalingam, 1961
33	Mysid	No earlier records
34	Ostracod	No earlier records

Table 4.7 – Monthly variations in the plankton diversity in the gut content of Indian mackerel (Juvenile and adult combined). The diversity in plankton composition was high in March, April, May and December whereas, the diversity was higher in April, May and June. The plankton components found dominant in the gut of Indian mackerel are highlighted in bold.

4.3.4.2. Indian mackerel

SL	Present observation	Historic observation
	Diatom (**Phytoplankton**)	
1	*Asterionella*	Noble.,1962
2	*Bacillaria*	No earlier records
3	***Biddulphia***	Rao & Noble, 1962
4	*Chaetoceros*	Noble, 1962,1974
5	***Coscinodiscus***	No earlier records other than Sivadas, 2009., Rao
6	***Cyclotella***	No earlier records
7	*Ditylum*	Noble, 1962.
8	*Eucampia*	No earlier records
9	***Fragilaria***	Rao & Noble, 1962
10	*Gyrosigma*	No earlier records
11	***Licmophora***	No earlier records
12	***Melosira***	No earlier records
13	*Navicula*	Noble, 1962
14	***Nitzchia***	Noble, 1962,1974
15	***Pleurosigma***	No earlier records other than Sivadas, 2009
16	*Rhiszosolenia*	Noble, 1962, 1974
17	***Skeletonema***	No earlier records
18	*Striatella*	No earlier records
19	*Thalassionema*	Noble, 1974
20	***Thalassiosira***	Noble, 1962,1974
21	*Triceratium*	Noble, 1962
	Autotrophic Dinoflagellates (**Phytoplankton**)	
22	***Ceratium***	Kutty et al.,1962
23	***Dinophysis***	Rao & Noble, 1962
24	*Diplosalis*	No earlier records
25	*Gonyaulux*	No earlier records
26	*Porocentrum*	No earlier records
	Heterotrophic Dinoflagellates/Ciliates/Foraminifers/ Radiolarians (**Microzooplankton**)	
27	*Noctiluca*	No earlier records
28	*Ornithocercus*	Noble, 1962
29	*Phalacroma*	No earlier records
30	***Protoperidinium***	Rao & Noble, 1962
31	***Pyrophacus***	No earlier records
32	*Globigerina (Foram.)*	No earlier records
33	Radiolarian	No earlier records
34	**Tinitinnids** (Cilia.)	Kutty, 1962; Noble, 1962
	Mesozooplankton	
35	**Copepod**	Noble (1974), Rao & Kutty, 1962
36	Doliolum	No earlier records
37	Fish eggs	No earlier records other than Ganga, 2010
38	Medusa	No earlier records
39	Mysid	No earlier records
40	Ostracod	Kutty, 1962

Table 4.8 – Monthly variations in the plankton diversity in the gut content of Indian mackerel (Juvenile and adult combined). The plankton components found dominant in the gut of Indian mackerel are highlighted in bold.

The comparison of plankton components observed in the gut of Oil sardine and Indian mackerel with earlier studies presented in Table 4.7 and 4.8 showed the following results. It was clear in the above tables that almost all the dominant plankton components observed in the gut of the Oil sardine and Indian mackerel were recorded in the historical studies, suggesting no major changes in the diet composition of these small pelagic fishes due to long-term changes such as climate change. However, there are indications of increased diversity of plankton components in the diet composition of both oil sardine and Indian mackerel, which may be linked to the long-term changes in the abundance of these plankton in the natural environment. This study reports 14 group/genera of plankton identified from the gut of the Oil sardine, which were not recorded in earlier studies. Similarly, 17 group/genera of plankton were identified from the gut of the Indian mackerel in the present study, which were not recorded in earlier studies. Therefore, increased diversity in plankton in the diet composition observed in the present study deserves a much more intense analysis, including the long-term plankton data from the natural environment - an aspect that is quite elaborate and hence, not covered in the present study. Since there is no earlier data available on the diet composition of Commerson's anchovy, comparison of present data with historical data could not be attempted.

4.3.5. Role of micro-zooplankton (20-200 μm) as a food source

The present study probably forms the first of its kind, trying to understand the contribution of microzooplankton in the diet of small economically important pelagic fishes inhabiting Indian waters. This is particularly relevant in the context of the recent understanding on the trophic role of microzooplankton in Indian waters in supporting the higher trophic levels (Madhupratap et al., 1994, 1996; Gauns et al., 1996; Jyothibabu et al., 2008a &b). Microzooplankton are efficient consumers of smaller phytoplankton (pico-and nano-plankton), which are normally unavailable for the large zooplankton (Nival and Nival, 1976; Johnson and Sieberth., 1982) and act as a trophic intermediate between smaller phytoplankton and higher trophic levels (Robertson, 1983; Stoecker and Egloff, 1987; Stoecker and Capuzzo, 1990; Fukami et al., 1999). Tintinnid ciliates function as an important trophic link between detritus, bacteria, smaller phytoplankton and higher trophic levels (Rassoulzadegan and Etienne, 1981; Azam et al., 1983; Rassoulzadgan et al., 1988). It was observed in laboratory studies that addition of ciliates to the diet of copepod, *Acartia* *tonsa* enhanced egg production, indicating high nutritional value of the prey (Stoecker, 1987a). Suspension feeding animals in general, traditionally thought of as 'herbivores', in fact utilize the microbial food web in which microzooplankton is an important component (Sherr and Sheer, 1988).The ciliates are a potential food source of microzooplankton including fish larvae and copepods (Berk et al., 1997; Robertson, 1983). Direct evidences show that heterotrophic dinoflagellates efficiently fed on a prey size spectrum ranging from bacteria (Lessard and Swift, 1985) to large diatoms (Hansen, 1992), copepod eggs and even earlier naupliar stages of copepods (Sekiguchi and Kato, 1976).

The present study provided the base line information on the role of microzooplankton in the diet of oil sardine, Indian mackerel and Commerson's anchovy. It was evident in the present study that microzooplankton form a dominant food component in the diet of all the three small pelagic fishes studied and more so in the case of Indian mackerel and Commerson's anchovy (Tables 4.1-4.6). This indicates that the organic carbon from the microbial food web also provides nutritional support to the survival of the small pelagic fishes addressed in the present study. However, more concerted effort is required to understand the proportionate contribution of the microbial food web carbon in supporting these small pelagics along the Kerala coast. It was also observed that there were monthly variations in the presence of microzooplankton components in the diet of the small pelagics addressed, which could be the result of the physiological status of the fish species. Alternately, this could be linked with the fluctuations of these plankton in the environment itself, a facet that needs more elaborative studies. Nonetheless, it is evidenced in the present study that microzooplankton contribute significantly to provide nutritional support to small pelagic fishes of interest in the present study.

4.4. Conclusion

Plankton components in the diet of oil sardine, Indian mackerel and Commerson's anchovy based on analysis of the gut of fish samples collected fortnightly during a year period are presented. The analysis considered the recent understanding on various plankton food webs in supporting higher trophic levels. Attempts have also been made to understand the possible change in the diet composition of the fishes due to long-term change in the environment. In the case of Oil sardine, altogether 34 group/genera were identified in which phytoplankton component consists of 21 genera of diatoms and 4 genera of autotrophic dinoflagellates. *Coscinodiscus*, *Nitzschia*, *Pleurosigma*, and *Thalassiosira* were found in the gut of oil sardine almost throughout the year, whereas microzooplankton was mostly dominant only during October – December period. In the case of Indian mackerel, 40 group/genera of plankton were identified in which phytoplankton component consisted of 21 genera of diatoms and 5 genera of autotrophic dinoflagellates. *Coscinodiscus* and Tintinids were found in the gut content of Indian mackerel throughout the year. Similarly, *Thalassiosira*, *Ceratium*, *Dinophysis*, *Protoperidinium*, *Pyrophacus*, and copepods were found in the gut of Indian mackerel almost throughout the year. Unlike Oil sardine, all components of plankton (phytoplankton, microzooplankton and mesozooplankton) were found to be present in the gut of Indian mackerel throughout the year. Statistical analysis of dominant value index shows the dominance of phytoplankton, microzooplankton and copepods in the diet of Indian mackerel throughout the year, indicating their almost equal preference to both phytoplankton and zooplankton. The food items in the gut content of Commerson's anchovy showed characteristic difference from both Oil Sardine and Indian mackerel. Altogether 12 group/genera were identified from the gut content of Commerson's anchovy. It was found to be a zooplankton feeder, predominantly feeding on copepods, fish eggs and ostracods, tintinids etc.

The comparison of plankton components observed in the gut of Oil sardine and Indian mackerel with earlier studies showed that almost all the dominant plankton components observed in the gut of the Oil sardine and Indian mackerel in the present study were recorded in the historical studies, also suggesting a lack of major changes in the diet composition of these small pelagic fishes due to long-term environmental changes. However, there are indications of increased diversity of plankton components in the diet composition of both oil sardine and Indian mackerel, which may be linked to the long-term changes in the abundance of these plankton in the natural environment. The base line information on the role of microzooplankton in the diet of oil sardine, Indian mackerel and Commerson's anchovy showed that microzooplankton form an important food component in the diet of all the three small pelagic fishes studied and more so in the case of Indian mackerel and Commerson's anchovy. This indicates that organic carbon from the microbial food web also provides nutritional support to small pelagic fishes addressed in the present study.

CHAPTER 5

ENVIRONMENT IN THE PFZ OFF KOCHI

5.1. Introduction

The scientific logic behind PFZ advisory and its usefulness along the Kerala coast was presented in Chapter 2. It is expected that marine fishes tend to aggregate in regions where their food resources are available in optimum concentrations (Solanki et al., 2005). As discussed earlier in this thesis, the ocean processes enhancing biological production leave its imprints on the ocean surface parameters that can be mapped by satellite remote sensing techniques. It was clarified in Chapter 3 that PFZ bands vary spatially with time, but in some regions, its frequency of occurrence is higher than in other regions. One such region is off Kochi where PFZ bands occur quite regularly around 10m depth contours, especially during the Northeast Monsoon period.

As discussed in detail in Chapter 2, most of the PFZ bands have a close connection to the frontal systems, which may be more relevant in the coastal waters where such features are ubiquitous. Recently, Sarma et al. (2015) studied variations in the inorganic carbon components in the thermal fronts in the northeastern Arabian Sea and showed that biological and mixing effects were dominant factors controlling inorganic carbon concentration in fronts followed by thermal and flux effects. This study suggests that fronts act as a source or sink, depending upon the strength of the mixing process associated with the biological response and age of the front.

In order to characterize the hydrographical characteristics in the PFZ and non-PFZ regions off Kochi, monthly field sampling was conducted for a year (2010 - 2011) in these two regions. The primary objectives for such an attempt were to (a) understand the hydrographical setting in the PFZ and non-PFZ regions on a monthly basis and (b) search for any noticeable changes in these regions in terms of physico-chemical and plankton parameters.

5.2. Materials and methods

In order to understand the oceanographic environment in the PFZ region off Kochi as a test case, monthly hydrographical surveys were carried out in two locations (at 10m and 20m depth contours) off Kochi during 2010-2011. The locations selected off Kochi were based on previous reports that location at 10m often act as PFZ and at 20m non- PFZ zones. Water samples were collected from the surface and bottom waters using Nansen bottle for analyzing chemical and biological parameters. pH of the water samples was measured using a digital pH meter. Macronutrients (Nitrate, Phosphate and Silicate) were measured as per standard protocols (UNESCO, 1994). Chlorophyll *a* was measured fluorimetrically based on a Trilogy Turner lab fluorometer. During the sampling period, PFZ bands formed around 10m depth contours in January, February, May, September and November, which provided a chance to characterize the hydrographical features of PFZ and non-PFZ regions in the study domain. Pearson correlation coefficient was used to understand the relationship between various parameters. ANOVA was used to understand the significance of variance of parameters in the sampling locations.

Measurement of size-based phytoplankton stock is useful to understand the nature of the phytoplankton community in an environment (Rodriguez and Guerrero, 1994; Sin et al., 2000; Iriarte and Purdie, 1994; Madhu et al., 2010; Jyothibabu et al., 2013, 2014). As part of the present study, attempts have been made to quantify the size-based phytoplankton stock off Kochi along with the routine chlorophyll a measurements. Various size fractions of chlorophyll a were separated into picoplankton (0.2 - 2 µm), nanoplankton (2 – 20 µm) and microplankton (20 – 200 µm) following the serial filtration method (Rodriguez and Guerrero, 1994; Sin et al., 2000; Iriarte and Purdie, 1994; Madhu et al., 2010; Jyothibabu et al., 2013, 2014). It consists of the size-based separation of the phytoplankton from 2L water sample by serial filtration through 20 µm Nitex screen, 3 µm filter (Pal Gelman) and 0.2 µm flter (Millipore) under low suction (<150 mm Hg). Phytoplankton cells collected on the Nitex screen were back-flushed into 100ml filtrate and collected on GF/F Filters (Whatman). The chlorophyll present in phytoplankton fractions collected on different filters was measured using the same analytical procedure used for total chlorophyll as described in the above paragraph.

5.3. Results and discussion

The seasonal evolution hydrographical parameters were evident in the monthly data. The distribution of surface and bottom hydrographical parameters in 10 and 20m depth contours is presented in Figures 5.1 and 5.2. Air and surface water temperature in the two locations showed only very minor variations throughout the observations as these sampling locations were not significantly far away. Throughout the observations, salinity and pH were higher in 20m compared to 10m, which was due to the proximity of Cochin backwaters to location at 10m depth. In both locations, values of salinity and pH were higher in the bottom waters as compared to the surface. The lowest surface salinity values at 10 and 20m depth was found in July and August due to fresh water influx during the Southwest Monsoon.

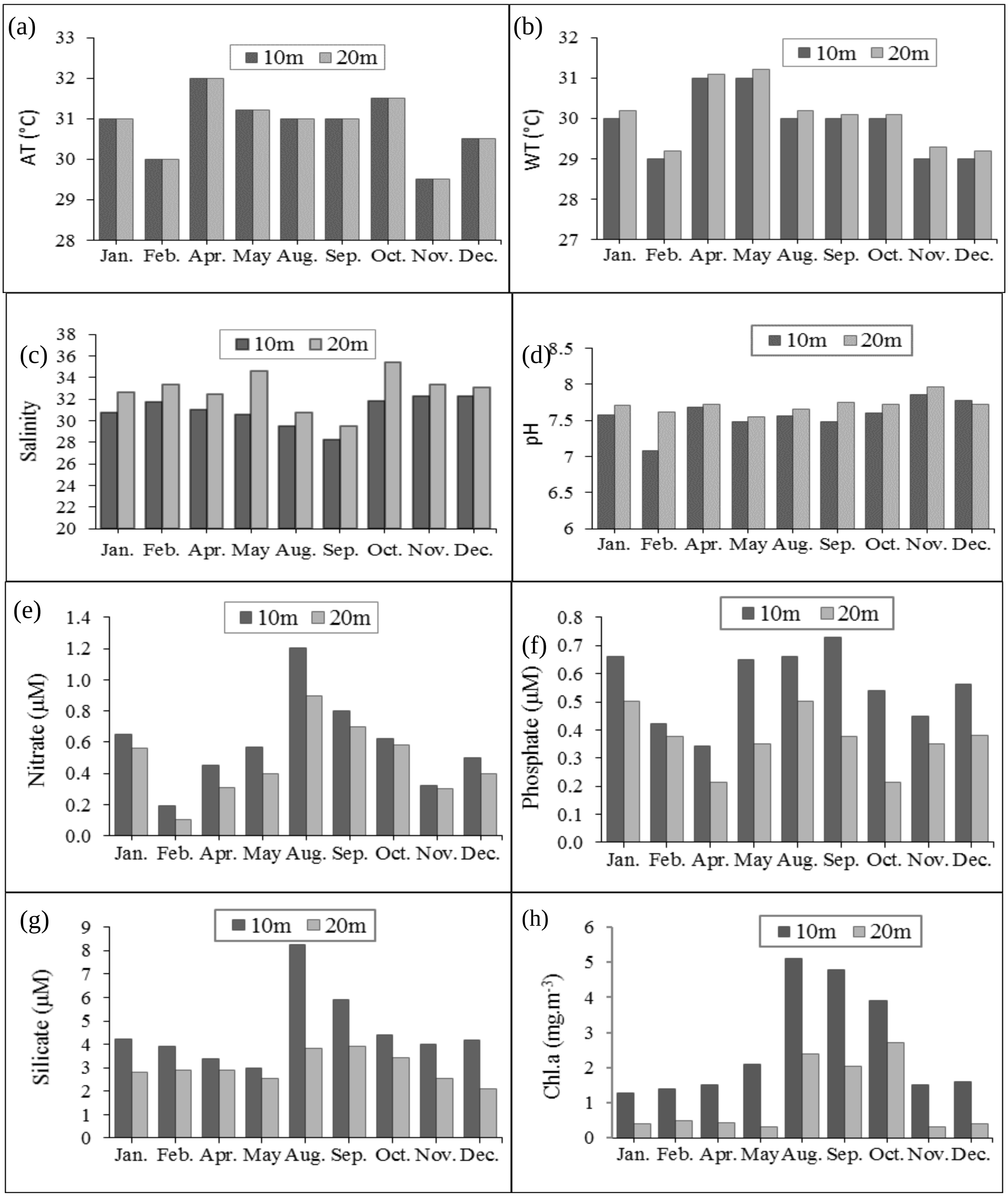


Figure 5.1- Distribution of surface physico-chemical parameters (a) atmospheric temperature (°C), (b) water temperature (°C), (c) salinity, (d) pH, (e) nitrate (µM), (f) phosphate (µM), (g) silicate (µM) and (h) chlorophyll *a* (mg. m^{-3}) distribution in 10m and 20m locations off Kochi during different months.

The macronutrients (nitrate and silicate) were found to be high in the surface waters during August and September followed by October, December and January. Nitrate concentration was in excess of 0.2 μM in both locations throughout the observations except in February. Similarly, the concentration of silicate was in excess of 2 μM in both locations throughout the observations. Phosphate concentration was the highest during May, August, September and January.

Relatively high concentration of macronutrients found in both locations during the present study is a typical feature of the coastal waters off Kochi due to its proximity to the Kochi backwaters and also due to the effect of coastal upwelling during the southwest Monsoon (Martin et al., 2013).

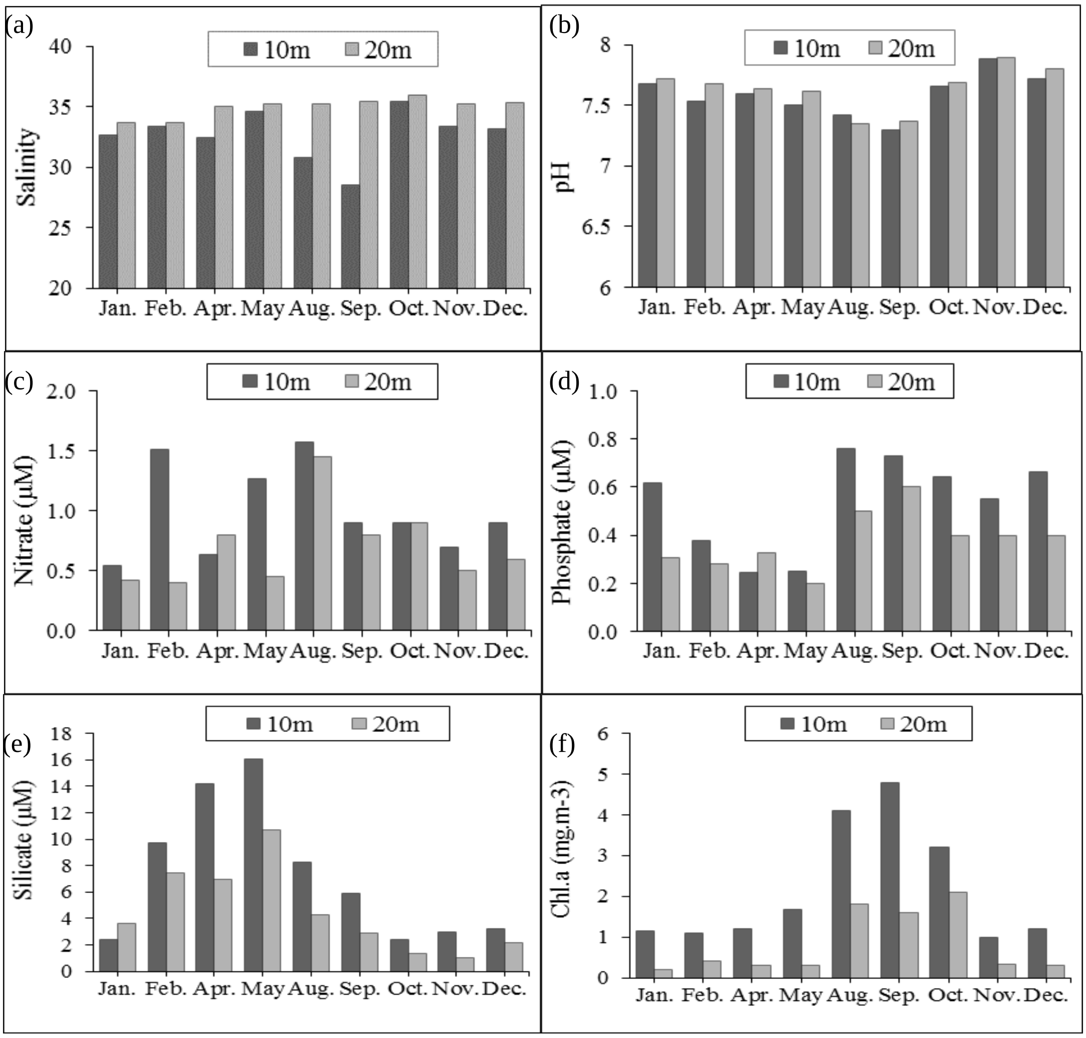


Figure 5.2 - Distribution of bottom physico-chemical parameters (a) atmospheric temperature (°C), (b) water temperature (°C), (c) salinity, (d) pH, (e) nitrate (μM), (f) phosphate (μM), (g) silicate (μM) and (h) chlorophyll *a* (mg. m^{-3}) distribution in 10m and 20m locations off Kochi during different months.

It was also observed earlier that the lowest nutrient concentration existed in the coastal waters of Kochi during the dry period (Feb-May), when the influx of the Cochin backwaters is minimum and thermal stratification dominates in the surface waters due to the highest level of solar radiation during the period (Martin et al., 2013).

The chlorophyll *a* concentration was moderate to high (>0.3mg m^{-3}) in both locations throughout the observations. High values of chlorophyll *a* (> 3mg m^{-3}) were found in August, September and October, which could be attributed to the combined effect of Cochin backwater influx and upwelling.

During the observation, the bottom waters showed noticeable decrease in chlorophyll concentration as compared to the surface except during August, September and October when both surface and bottom waters carried comparable level of chlorophyll biomass. It is also clear from Figures 5.1 and 5.2 that chlorophyll concentration was significantly higher in 10m (PFZ) than 20m (non-PFZ) throughout the study.

The size-based phytoplankton quantification using chlorophyll fractionation showed that nano-size fraction (2-20μm) of phytoplankton dominates in the study region except during August, September and October, when larger-sized (>20μm) phytoplankton also contributed significantly to the total chlorophyll biomass (Figures 5.3 and 5.4). Overall trend indicate and increase in biomass of larger phytoplankton components during the Southwest Monsoon period, which is a well-established seasonal feature of the coastal waters of the west coast of India during the Southwest Monsoon. The nutrient enrichment in the surface waters through coastal upwelling and river influx support the proliferation of the larger phytoplankton component leading to the blooming of such species in a later stage (Madhupratap and Parulekar, 1993; Banse et al., 1996)

The correlation analyses showed significant negative correlation between chlorophyll and salinity. Results of ANOVA showed significant difference in salinity, silicate and chlorophyll in the PFZ (10m) and non-PFZ (20m) locations (Table 5.1 – 5.3)

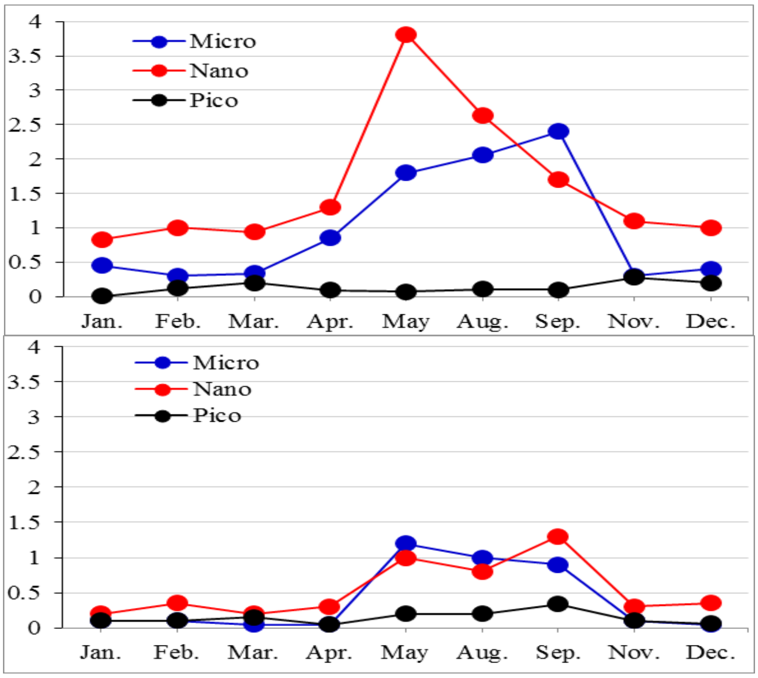


Figure 5.3 – Size-based phytoplankton quantification in surface waters in (a) 10m and (b) 20m contour locations during different months. The dominance of nanoplankton followed by microplankton is evident throughout. The peak values of micro- and nano-plankton were in May, August and September. Abbreviations: Micro- Microplankton, Nano- Nanoplankton, Pico – Picoplankton

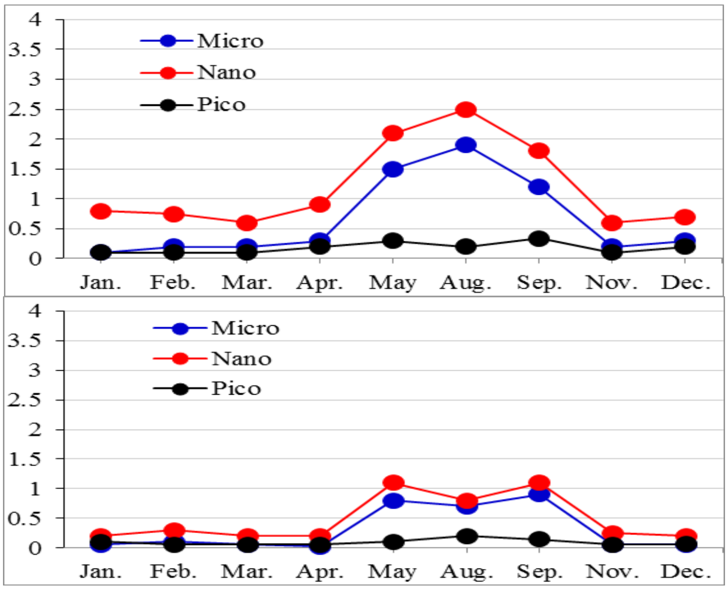


Figure 5.4 – Size-based phytoplankton quantification in bottom waters in (a) 10m and (b) 20m contour locations during different months. The trend was similar to the surface waters but the values were noticeably lower than the surface. Dominance of nano-plankton was evident throughout. Micro-plankton dominance was noticeable mostly during May, August and September. Abbreviations: Micro- Microplankton, Nano- Nanoplankton, Pico – picoplankton

SI.NO	Parameters	F	P
		Surface	
1	Water temperature	0.243	0.631
2	Salinity	6.087	**0.025***
3	pH	3.169	0.094
4	Nitrate	0.865	0.366
5	Phosphate	12.33	**0.003***
6	Silicate	7.81	**0.013***
7	Chlorophyll *a*	20.12	**0.001***
		Bottom	
1	Salinity	9.84	**0.006***
2	pH	0.399	0.536
3	Nitrate	2.975	0.104
4	Phosphate	4.231	0.065
5	Silicate	1.796	0.199
6	Chlorophyll *a*	0.901	**0.035***

Table 5.1 – ANOVA Comparison of physico-chemical parameters between 10m and 20m locations. Bold values show the significant differences between the locations. The difference in values of salinity, phosphate, silicate and chlorophyll *a* between 10m and 20m locations were statistically significant in the case of surface waters, whereas only salinity and chlorophyll a values in 10 and 20m waters showed statistically significant difference in the case of bottom waters.

Variables	AT	WT	Salinity	pH	Nitrate	Phosphate	Silicate	Chl. *a*
AT	**1**							
W.T.	**0.855**	**1**						
Salinity	-0.146	-0.161	**1**					
pH	-0.126	-0.151	0.247	**1**				
Nitrate	**0.520**	0.420	**-0.493**	0.117	**1**			
Phosphate	-0.073	-0.033	**-0.700**	-0.263	0.348	**1**		
Silicate	0.210	0.086	-0.059	-0.076	0.140	-0.389	**1**	
Chl. *a*	0.257	0.117	**-0.605**	-0.185	**0.600**	**0.577**	0.135	**1**

Table 5.2 – Pearson correlation co-efficient (r) between the physico-chemical parameters in the surface waters of 10m and 20m locations. Bold represents the significance level $P<0.05$. Significant negative relationship between salinity and nitrate, salinity and phosphate, and salinity and chlorophyll a indicate the influence of Cochin backwater influx in the study region, especially at 10m location. The positive linkage between concentration of nitrate and phosphate with chlorophyll *a* in the surface waters was also evident.

Variables	Salinity	pH	Nitrate	Phosphate	Silicate	Chl. *a*
Salinity	**1**					
pH	0.288	**1**				
Nitrate	-0.189	-0.082	**1**			
Phosphate	-0.462	-0.423	0.206	**1**		
Silicate	-0.219	-0.217	0.216	**-0.478**	**1**	
Chl. *a*	**-0.595**	-0.363	**0.503**	**0.552**	0.123	**1**

Table 5.3 - Pearson correlation co-efficient (r) between the physico-chemical parameters in the bottom waters of 10m and 20m locations. Bold represents the significance level P<0.05. Significant negative relationship between salinity and chlorophyll a indicates the influence of Cochin backwater influx in the study locations, especially at 10 m location. As in the case of surface waters, a positive linkage between concentration of nitrate and phosphate with chlorophyll a was evident in the bottom waters also.

The phytoplankton ecology associated with seasonal nutrient concentrations in the Kochi backwaters and off Kochi has been reviewed recently (Marin et al., 2013). Being the largest estuarine system along the southwest coast of India, Kochi backwaters carry high levels of nutrients throughout the year (NO_3>8, PO_4>3, SiO_4>5 μM), which peaks during the Southwest Monsoon (NO3>50 μM, PO4>50 μM, SiO4>125 μM) (Saraladevi et al. 1983, 1991; Sankaranarayanan et al. 1986; Jyothibabu et al. 2006; Martin et al. 2008). The Arabian Sea waters in the proximity (off Kochi) receive the nutrient influx of seven rivers that empty into the backwater, and dilute it through mixing with marine waters (Sankaranarayanan and Qasim 1969; Saraladevi et al., 1991; Lierheimer and Banse 2002). This feature was found to be true in the case of nutrients and chlorophyll in the present study also and there was a noticeable dilution of these parameters in 20m locations as compared to 10m locations.

Studies based on advanced instruments in the recent decades evidenced that smaller plankton nano- and pico-plankton) are abundant in estuarine and marine environments (Li et al., 1983, 1988, 1992; Burkill et al., 1993; Veldhuis et al., 1993; Landry et al., 1996; Garrison et al., 2000; Brown et al., 2002). They contribute majority of the phytoplankton biomass and primary production in marine and estuarine environments (Detmer and Bathmann, 1997; Hickel, 1998; Tarran et al., 2001; Zhang and Zhang., 2007; Madhu et al., 2010., Jyothibabu et al., 2015). They are mainly composed of smaller algae and flagellates, which form the main source of dissolved organic matter (Lugioyo et al., 2007).

The chlorophyll *a* fractionation carried out in the present study strongly supports the above view and suggests the need for quantizing the smaller phytoplankton in relation to the fishery resources. This is particularly important as the PFZ bands of chlorophyll generated by the present satellite remote sensing techniques do not have the ability to distinguish the contribution of smaller and larger components of the phytoplankton community

It was clear in the present study that there was a significant variation in chlorophyll *a* concentration between 10m and 20 m depth locations throughout the observations. It is important to note that 10m depth contour locations showed PFZ bands in most of the months sampled. Considering that the PFZ bands represent large gradients in temperature and chlorophyll, a significant variation in chlorophyll level was expected in the two locations sampled in the present study. However, the intricacy in the present observation is that the observed difference in chlorophyll level in 10m and 20m locations could be partly imparted by the normal coastal offshore variation rather than any physical processes such as fronts or eddies as envisaged in the general PFZ concept. Unfortunately, this intricacy cannot be addressed by the present sampling resolution and remains a scientific problem to be addressed in the future.

5.4. Conclusion

The environmental observations based on monthly field sampling carried out at two locations (10m and 20m) situated off Kochi are presented. During seven out of nine observations, PFZ bands were observed around 10m locations. The chlorophyll *a* concentration was moderate to high (>0.3mg m^{-3}) in both locations throughout the observations. High values of chlorophyll (> 3mg m^{-3}) were found in August, September and October, which could be attributed to the combined effect of Cochin backwater influx and upwelling. The seasonal evolution of hydrographical parameters showed significantly higher concentration of nutrients and chlorophyll during the Southwest Monsoon period compared to the rest of the sapling. The size-based phytoplankton quantification showed that nano size fraction (2-20μm) of phytoplankton dominates all the year round except during August, September and October, when the larger fractions (>20μm) also contributed significantly. The chlorophyll *a* concentration was found to be significantly higher in 10m location (PFZ) as compared to the 20m location (non-PFZ), and the ANOVA results showed significant difference in chlorophyll between these locations.

CHAPTER 6

LENGTH -WEIGHT RELATIONSHIP AND CONDITION FACTOR

6.1. Introduction

Length – Weight Relationship (LWR) studies of fishes provide a mathematical relation between the two variables, which is useful to assess the quality (well-being) of individuals in a population. It helps to estimate the weight corresponding to a given length of a fish and to convert the catch data of a species from weight to numbers in order to obtain the abundance of the stock in space and time (Froese, 2006). In general, an increase in length of the fish implies that there is an increase in the body weight. LWRs of fish can be used to estimate the weight from the length of individuals, length classes or length frequency distribution in a population (Petrakis and Stergiou, 1995; Martin-Smith, 1996). Pauly (1983) used the LWR of fishes in stock assessment models to convert growth-in-length equations to growth-in-weight equation for predicting the weight of a fish in a particular age.

The LWR expressed in cube law was originally proposed by Galileo Galelei as pointed out recently by Froese (2006). Le Cren (1951) modified the cube law to precisely follow under isometric growth condition (Rounsefell and Everhart, 1953; Ricker, 1958). Usually, LWR shows variation from cube law (isometric growth) due to the influence of environmental factors or condition of fish (Le Cren, 1951). Change in the body proportion of a fish with ageing is a natural process and the form and specific gravity of fishes do not remain constant throughout their life. This often leads to changes in the allometric weight coefficient value ($b = 3$), which may vary from 2.5 - 4 (Hile, 1936; Martin, 1949). Assessment of variations from the general LWR is useful to understand the condition (quality) of a particular fish, which is usually represented by means of 'condition factor'.

Basically, 'condition factor' represents the quality of individuals, which is actually the result of the interactions between biotic and abiotic factors and their effect on the physiological condition of fish. Therefore, 'condition factor' represents the status of well-being of individuals in a fish population (Angelescu et al., 1958). Studies have evidenced that 'condition factor' is capable of providing useful information on the physiological status of fishes living in certain climatic conditions (AlhadiIghwela, 2011). It is usually expressed as 'coefficient of condition', denoted by 'K' (also known as Fulton's condition factor, or length-weight factor, or Ponderal Index). Greater 'K' value indicates better growth condition of the fish. Condition of a fish varies depending on its age, sex and season, and considering all these, Le Cren (1951) suggested the calculation of the relative condition factor 'Kn' to accommodate the effect of age, sex and season on 'K' value. The 'K' value measures the variations in an ideal case in which the fish obey the cube law while 'Kn' helps to measure the variation from the estimated weight from the LWR. Thus, relative condition factor ('Kn') provides an important measure of different life cycle stages of fishes and valuable for the management of fishery resources in an ecosystem.

Several studies in the past have attempted to explain the condition factor with maturity, feeding intensity and spawning of fishes (Menon, 1950; Le Cren, 1951; Pillay, 1954; Sarojini, 1957). LWR studies of Indian mackerel are available representing different time periods (Rao, 1967; Noble, 1974; Yohannan, 1982; Ganga, 2010). Noble (1992) made a comparative study on the LWR of Indian mackerel from Goa in the west coast and Visakhapatnam in the east coast of India. Sivadas et al, (2006) studied the L-W relationship, condition factor and length at first maturity of Indian mackerel from Calicut region, Kerala.

The length frequency study of Oil sardine showed that the mature fish attains the maximum length of 19.5 cm (Annigeri et al., 1992). Several researchers studied the LWR of oil sardine from the Kerala coast (Jhingran, 1952., Pillay, 1954., Raja, 1967). Oil sardine grows at a rapid rate during the first twelve months, with the growth rate being the highest during the initial two-three months (Balan, 1984). Devanesan (1943) reported the sizes of different year-classes of oil sardine based on the growth rings on the scales and recently, Rohit and Uma (2003) carried out a detailed study regarding the biology of oil sardine from the Mangalore - Malpe coast.

Commerson's anchovy (*Stolephorus commersonii*) is the second major species in the anchovy group (Genus - *Stolephorus*) exploited along the Kerala coast. Their body length ranges from 67 - 147 mm, the dominant size range being 112 - 127 mm (Luther, 1979). Several studies have dealt with the fishery and LWR of anchovies such as *Enchrasicholina devisi*, *Stolephorus* *bataviansis* from Indian waters (Puthran, 1990; Luther et al, 1992; Rao, 1988b; Nair, 1998; Goapkumar et al, 2000). However, there is no information available so far on the L-W relationship of *S.commersonii* and the present study forms first from the Kerala coast.

Globally, it is noticed that due to changes in climatic conditions and heavy exploitation, many fish stocks have displayed a marked reduction in their abundance /changes in age or size at first maturation (Agnalt, 1989; Vivekanandan, 2011). Fishes have evolved physiologically to live within a specific range of environmental variation, and existence outside of that range can be stressful or fatal (Arístegui et al., 2004). Climate change will impact fish and shellfish, their fisheries, and fishery-dependent communities through a complex suite of linked processes (Hollowed et al., 2013). Studies indicate that the shelf waters of the Indian west coast have undergone noticeable changes in the environmental quality due to natural and anthropogenic caused, leading to coastal hypoxia and increased methane production (Naqvi et al., 2000; Jayakumar et al., 2001). Many studies also indicate changes in the distribution of pelagic fisheries along the coasts of India in the recent decades (Vivekanandan, 2011). All these observations are also important in the context of global issues such as climate change and ocean acidification and their proposed impact on the fisheries (FAO, 2008; Hollowed et al., 2013). In this context, the present L-W study of oil sardine and Indian mackerel along the Kerala coast is significant, as it attempts to compare the present data with the historical data of these fishes for assessing any possible long term change in LWRs and condition factors. The objectives addressed in this chapter are (a) to understand the L-W relationship and condition factor of oil sardine, Indian mackerel and Commerson's anchovy along the Kerala coast and (b) to assess the long term changes in the L-W relationship and condition factor, if any, by comparing the present data with historical data of Oil sardine and Indian mackerel.

6.2. MATERIAL AND METHODS

During 2010 - 2011 period, fortnightly samples of Indian mackerel (*Rastrelliger kanagurta*), Oil sardine (*Sardinella longiceps*) and Anchovy (*Stolephorus commersonii*) were collected from the same fish landing centres in Kochi described in Chapter 4. During the present L-W study, 790 samples of Indian mackerel (male - 403, female - 387), 1395 samples of Oil sardine, (male 604 and females 791) and 1180 samples of Commerson's anchovy (male 575 and female 605) caught by 'Ring seine' and 'Purse seine' were collected and analysed. The total length of the specimens were taken from the tip of the snout to the tip of the caudal fin using a half meter measurement scale and the weight was taken using a measuring balance (0.1g accuracy) after removing the water content of the fishes with a blotting paper.

6.2.1. Length – Weight relationship (LWR)

LWR of fishes was calculated by cube law, separately for male and female fishes. The cube law explains the LWR as $W = CL^3$. Faulton (1904) showed that cube law is not precise for most of the fishes and concluded that most fish species display a higher increase in their weight than in their length. Later, Le Cren (1951) modified the cube law as $W= aL^b$, where W = weight of fish in grams, L = total length of fish in centimetres, a = exponent describing the rate of change of weight with length (intercept in the Y axis), and b = slope of the regression line (also referred to as allometric coefficient).

Graphically, the length-weight relationship can be expressed by plotting the observed lengths and weights of a fish as a dot diagram. The diagram will be a straight line for the fish having the same LWR with some scatter dots due to individual variation. This line represents the logarithmic form of equation. When expressed logarithmically, the above equation becomes a straight line of the formula $\log W = \log a + b \log L$, which indicates that a plot of weight against the logarithm of length gives a straight line.

The constant 'a' represents the point at which the regression line intercepts the y-axis and 'b' the slope of the regression line (allometric coefficient) estimated by the method of least square (Snedecor and Cochran, 1967). The data were analysed with Analysis of Covariance (ANCOVA) to test the significance of difference between the male and female (Snedecor and Cochran, 1967). Significance of differences in the 'b' value from the expected isometric growth value of 3 was tested by Bailey's t-test (Zar, 2005), using the formula

$$t = \frac{b - 3}{sb}$$

b = regression coefficient of log transformed data

sb = standard error of b

6.2.2. Relative condition factor (Kn)

The relative condition factor (Kn) was introduced by Le Cren (1951).

It is calculated using the formula: Kn = W/WA

Where W is the observed weight and WA the estimated weight.

Kn was calculated for different months for both sexes and the average value in each month, irrespective of sizes, was considered.

6.3. Results

6.3.1. Length – Weight Relationship (LWR)

6.3.1.1. Indian mackerel

The length of male Indian mackerel (*Rastrelliger kanagurta*) ranged from 11.4 - 26.8 cm (av. 19.2 ± 3.3 cm) while that of the female was from 10 - 27.5 cm (av. 19.7 ± 3.5 cm). The total weight of male varied from 13 - 200 g (av. 83.47 ± 45.2 g) while the females' weight ranged from 8 - 210 g (av. 90.88 ± 49.31g). The length-weight relationship plot of male and female mackerel has been presented in Figures 6.1a and b, and the regression equations for each treatment are:

Male: Log W = -5.4606 + 3.3067 log L (R^2 = 0.9694)

Female: Log W = -5.3765 + 3.2726 log L (R^2 = 0.972)

The length-weight relationships for male and female based on $W = aL^b$ are:

Male: $W = 0.0042506\ L^{3.31}$, Female: $W= 0.004625\ L^{3.27}$

The LWR of Indian mackerel (male, female & pooled) is presented in Figure 6.1. The coefficient of determination (R^2) for male is 0.969 and the female is 0.972, which shows a significant positive correlation between length and weight ($P<0.05$). The Analysis of Covariance

(ANCOVA) presented in Table 6.2 shows that there is no significant difference in L-W relationship in male and female (P>0.05). It indicates that there is no need for separate curve fit for male and female, and hence, a common equation was derived by pooling the data (Figure 6.1c)

Pooled: Log W = -5.6623 + 3.371 log L (R^2 = 0.9726), Pooled: W = 0.003474 $L^{3.37}$

The allometric coefficient values for male, female and pooled mackerel are 3.31, 3.27 and 3.37, respectively (b > 3, P <0.05), which indicate positive allometric growth. The significance of variation in the estimates of regression coefficient value 'b' from 3 was analysed for significance using t-test (Tables 6.1 and 6.2).

	N	Log a	b	sb	R^2	t	p
Male	403	0.00425	3.3	0.02748	0.969	11.6	>0.05
Female	387	0.00462	3.2	0.03688	0.972	7.39	>0.05
Pooled	790	0.0034	3.3	0.01904	0.973	19.48	>0.05

Table 6.1 - Statistical details showing number of Indian mackerel studied (n), intercept (Log a), allometric coefficient (b), standard error of b (sb), coefficient of determination (R^2) and results of Bailey's t-test on b for significance.

				Deviation from regression			
	Df	b	df	SS	MS	F	P
Male	403	3.29	402	4.529	0.0114		
Female	387	3.285	386	4.22	0.010		
Pooled	790	3.289	789	8.757	0.0111		
Difference between slopes			1	0.00038	0.00038	0.27306	0.60142
Difference between adjusted means			1	0.0288	0.0288	14.37	0.00016

Table 6.2 - Analysis of co-variance (ANCOVA) on the regression of length-weight relationship in male and female of Indian mackerel. P value < 0.05 and < 0.01 indicate significance at 5% and 1%, respectively.

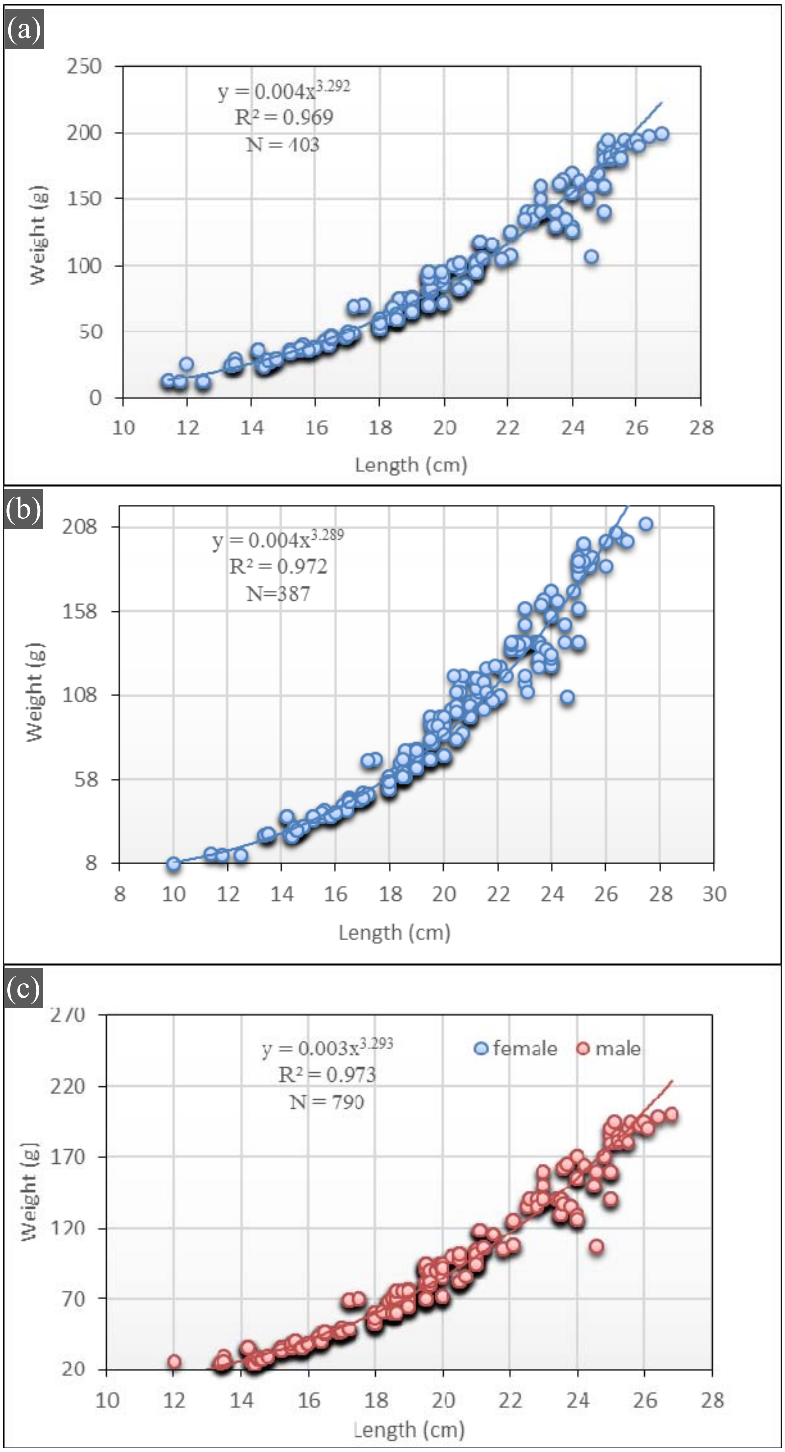


Figure 6.1 – LWR of Indian mackerel (a) male, (b) female and (c) pooled

6.3.1.2. Indian oil sardine

The length of the male Oil sardine (*Sardinella longiceps*) ranged from 10.9 - 20 cm (av. 15.6 ± 2.3 cm) and that of the female was observed to be 8 - 80 g (av. 36.46 ± 16.34 g).. The length of the female varied from 11 - 21 cm (av. 15.72 ± 2.25 g) and the weight from 7 - 88 g (av. 36.53 ± 18.291g). The LWR of male and female showed the relationship presented in Figures 6.2.

Male: Log W = -6.0186 + 3.46 log L (R^2 = 0.904)

Female: Log W = -6.017 + 3.45 log L (R^2 = 0.917)

The length-weight relationship for male and female fishes is as follows:

Male: W = 0.0024 $L^{3.4}$, Female: W = 0.0024 $L^{3.4}$

The details of LWR of oil sardine are presented (Table 6.3), which shows that the fish has not followed the typical cubic law, thus, indicating allometric growth. The coefficient of determination for male was 0.904 and that for female was 0.917, which were significant ($P<0.05$). Analysis of co-variance shows no significant difference in L-W relationship between male and female (Table 6.4). Hence, the data were pooled and a common equation was generated for oil sardine (Figure 6.2c).

Pooled: Log W = -5.88 + 3.4 log L (R^2 = 0.934),

Pooled: W = 0.0027 $L^{3.4}$

The values of male, female and pooled oil sardines are given in Table 6.3, which depict that the allometric coefficient is greater than 3. This confirms a positive allometric growth of the fish body dimensions. The significance of variation in the estimates of allometric coefficient value ‘b’ from 3 was tested using t – test (Table 6.4)

	n	Log a	b	sb	R^2	t	p
Male	604	0.0024	3.4	0.045	0.904	10.13	>0.05
Female	791	0.0024	3.4	0.0368	0.917	12.35	>0.05
Pooled	1395	0.0024	3.4	0.0224	0.934	18.17	>0.05

Table 6.3 – Statistical details showing number of oil sardines studied (n), intercept (log a), regression coefficient (b), standard error of b (sb), coefficient of determination (R^2) and results of Bailey's t-test on 'b'

			Deviation from Regression				
	df	b	df	SS	MS	F	Prob.
Male	604	3.43	603	11.17	0.024		
Female	791	3.49	790	11.88	0.024		
Pooled	1395	3.41	1394	23.06	0.023		
Difference between slopes			1	0.005	0.005	0.273	0.646
Difference between adjusted means			1	0.3	0.3	12.92	0.001

Table 6.4 – Analysis of co-variance (ANCOVA) on the regression of length-weight relationship in male and female of oil sardine. P – Values <0.05 and <0.01 indicate significance at 5% 1% levels, respectively.

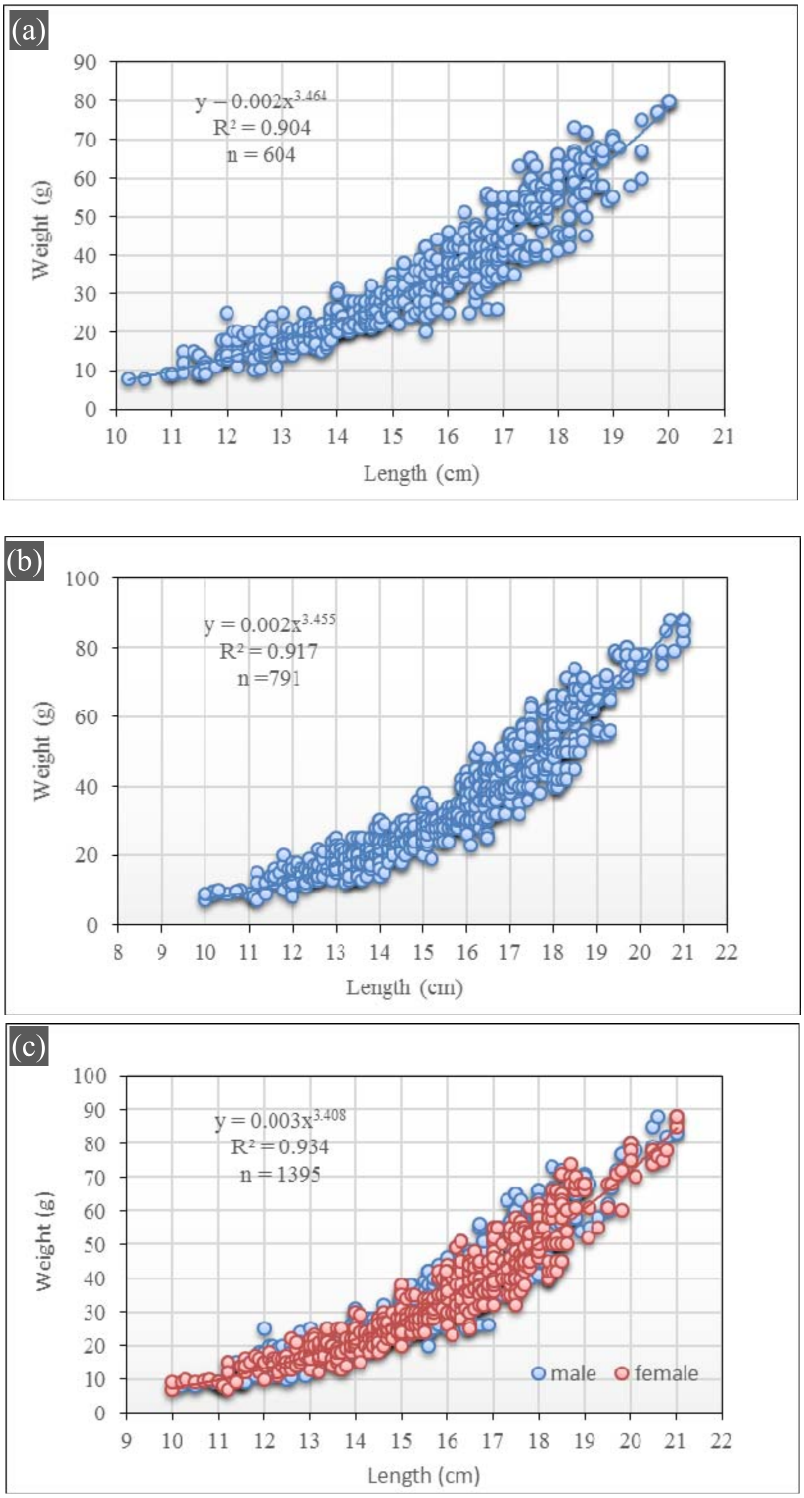


Figure 6.2 – LWR of Oil Sardine (a) male (b) female and (c) pooled.

6.3.1.3. Commerson's anchovy

The difference in length and weight of male and female Commerson's anchovy (*Stolephorus commersonii*) was found to be minor. Length and weight of the fish varied from 5 - 14.6 cm (av. 9.24 ± 1.83 cm) and 1 - 25g (av. 6.64 ± 3.96 g), respectively. The LWRs of Commerson's anchovy were as follows:

Male: Log W = -4.95 + 3.02 log L (R^2 = 0.893)

Female: Log W = -4.88 + 2.99 log L (R^2 = 0.896)

The LWR for male and female *S.commersonii* are as follows:

Male: $W = 0.0070\ L^{3.02}$

Female: $W = 0.\ 00756\ L^{2.99}$

The curves for LWR were calculated separately for male and female and are presented in Figures 6.3, which display a linear relationship between the length and weight. The coefficient of determination for males and females was 0.893 and 0.896, respectively, which indicates a significant relation between the length and weight of Commerson's anchovy ($P<0.001$). The L-W relationship was found to be highly significant for both the sexes ($P<0.001$).The regression coefficient (b) was 3.02 for male and 3.04 for female, and their growth can be considered as isometric type (b = 3). Significance of difference tested at 5% level between the regressions coefficients of both male and female revealed only insignificant variation and hence, the data were pooled and the following relationship was obtained (Figure 6.3 and Table 6.5).

Pooled: Log W = -4.915 + 3.006 log L (R^2 = 0.898)

Pooled $W = 0.\ 0073\ L^{3.006}$

The significance of variation of the estimates of regression coefficient value 'b' from 3 was tested using t – test (Table 6.6). The b values were very close to 3 and the variations were insignificant, confirming the isometric growth of the fish.

	n	Log a	b	sb	R^2	t	p
Male	575	0.00523	3.1	0.045	0.893	3.6	>0.05
Female	605	0.0075	2.9	0.041	0.896	0.146	>0.05
Pooled	1180	0.0073	3	0.029	0.898	0.228	>0.05

Table 6.5 – Statistical details showing number of Commerson's anchovy studied (n), intercept (log a), regression coefficient (b), standard error of b (sb), correlation coefficient (R^2) and results of Bailey's t-test on 'b'

			Deviation from Regression				
	df	b	df	SS	MS	F	P
Male	575	3.03	574	19.75	0.0398		
Female	605	3.04	604	21.2	0.045		
Pooled	1180	3.03	1179	40.96	0.042		
Difference between slopes			40.96	0.0003	0.0003	13.28	0.00028
Difference between adjusted means			1	0.0014	0.0014	21.67	0.00004

Table 6.6 – Analysis of co-variance (ANCOVA) on the regression of length-weight relationship in male and female of Commerson's anchovy. P-value <0.05 and <0.01 indicate significance at 5% and 1% levels, respectively.

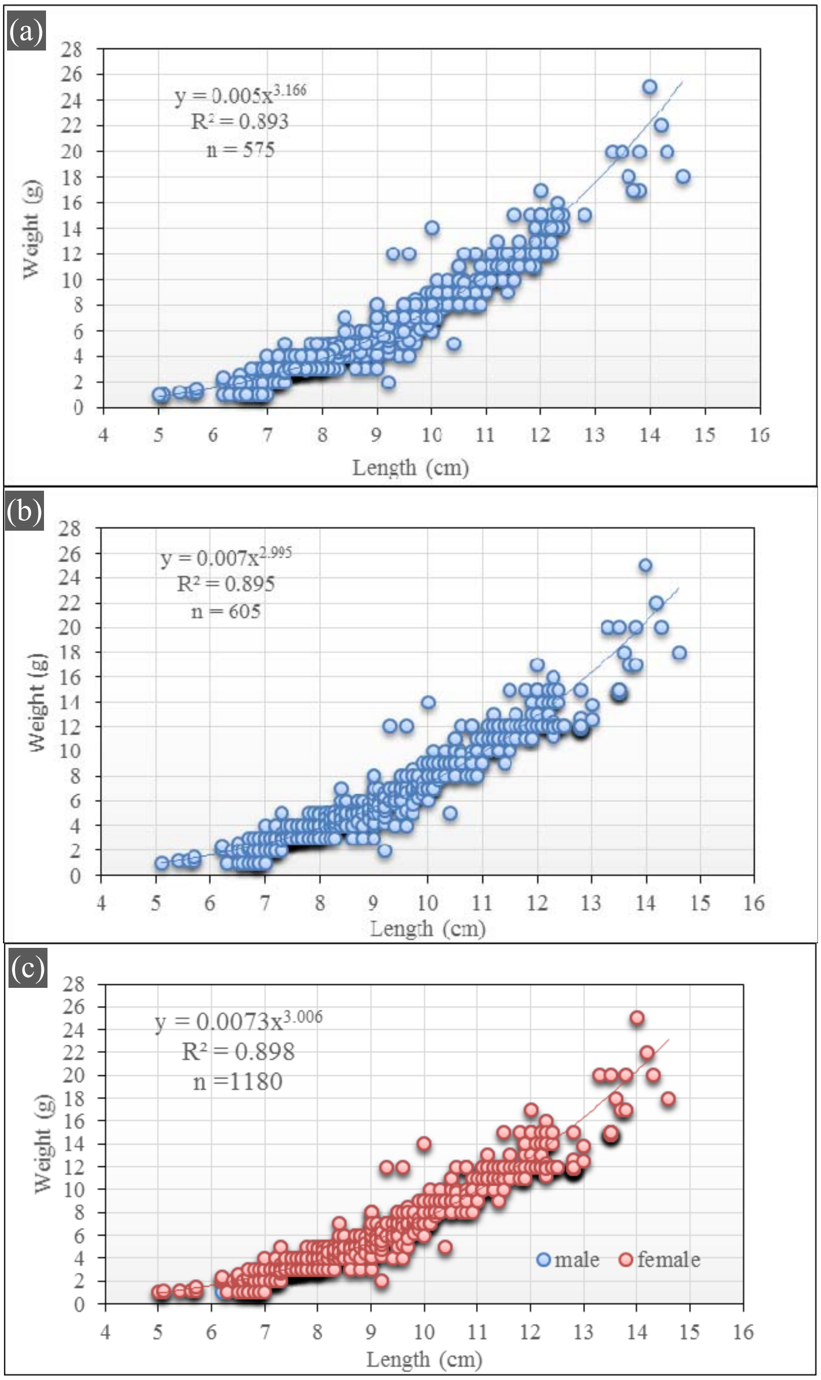


Figure 6.3 – LWR of *S. commersonii* (a) male, (b) female and (c) pooled

6.3.2. Relative condition factor (Kn)

6.3.2.1. Indian mackerel

The relative condition factor of Indian mackerel during 2010-2011 is presented (Figure 6.4). Both the males and females show the highest Kn value in January (1.8 and 1.44, respectively) and lowest in April (0.628 and 0.61, respectively). In males, the Kn value was less than 1 in February, March, April and June, whereas in females, such was the case in February, April, May, June and July.

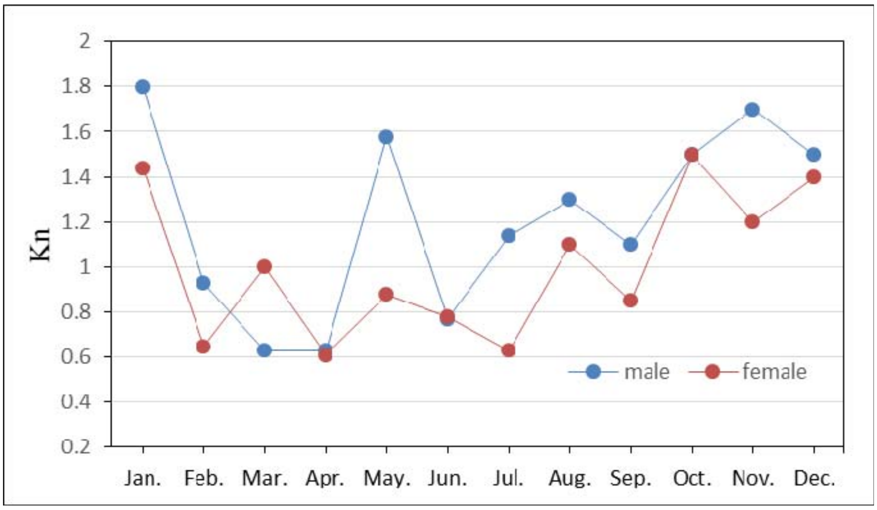


Figure 6.4 – Month-wise relative condition factor (Kn) of Indian mackerel in 2010 -2011

6.3.2.2. Indian oil sardine

The relative condition factor value of oil sardine was above 1 in almost all months (Figure 6.5). Overall condition of the fish was good in all the months. In female sardines, Kn values were the highest in March and August (1.6 and 1.5, respectively), while in male sardines, it was in January and August (1.4). The lowest Kn value for males (0.95) was found in February and for females, this was observed in March (0.85). The month-wise fluctuation in Kn value of oil sardine was noticeably smaller than that of Indian mackerel

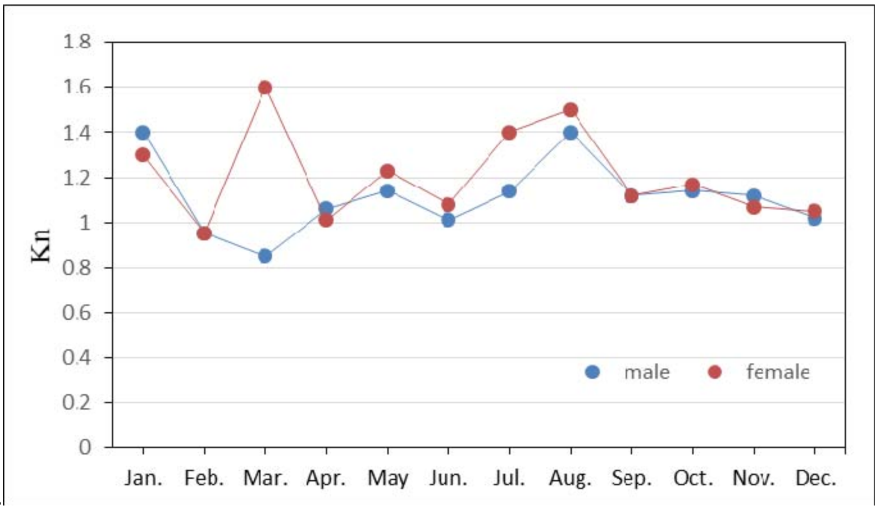


Figure 6.5 – Month-wise relative condition factor of oil sardine

6.3.2.3. Commerson's anchovy

The monthly values of relative condition factor (Kn) of male and female Commerson's anchovy are presented in Figure 6.6. The (Kn) showed the highest value of male and female in February (1.19 and 1.18, respectively) and August (1.18 and 1.95, respectively) and the lowest in June (0.88 and 0.78, respectively). For both sexes, Kn value was found to be less than 1 in March, April, September and November.

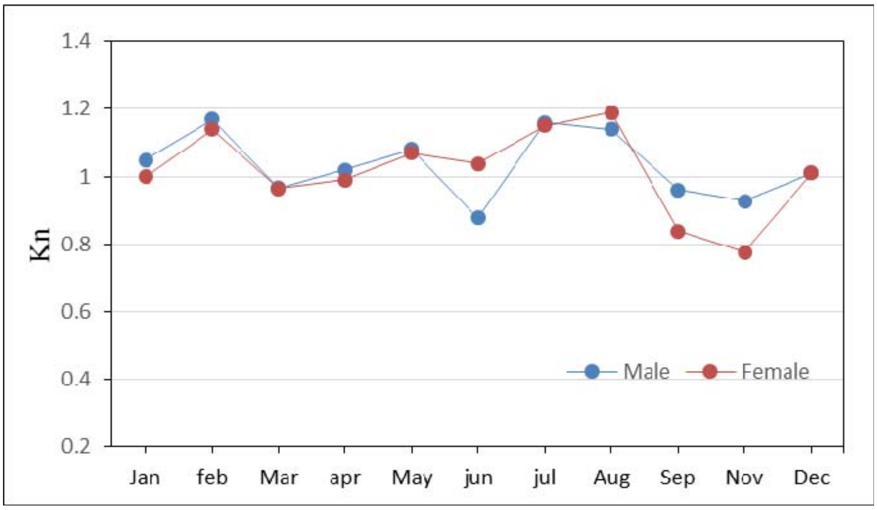


Figure 6.6 – Month-wise relative condition factor (Kn) of Commerson's anchovy

6.4. Discussion and Conclusion

The LWR of an ideal fish precisely follow the cub law, and according to Wootton (1990), the value of exponent 'b' in the cube law will become exactly 3 if the fish retains the same shape and specific gravity and grows isometrically during their life time. Allen (1938) reported that such an ideal fish with a b value 3 is very difficult to observe in the natural environment. In other words, a majority of fishes for which LWRs were calculated in the past, b value was either less than or greater than 3, representing negative or positive allometric growth, respectively.

The change in 'b' value mostly reflects the change in the body form when the weight of the fish gets affected by environmental factors like temperature, food supply, spawning conditions and other factors like sex, age, fishing time and area and fishing vessels (Ricker, 1973; Bagenal and Tesch, 1978). Wootton (1990) showed that 'b' value less than 3 indicates that the fish becomes lighter (negative allometric) while values greater than 3 indicate that the fish becomes heavier (positive allometric). In essence, the change in specific gravity and body form during growth are found to cause a deviation from the isometric growth of the fish.

In the present LWR study on Indian mackerel, it was found that the coefficient of determination (R^2) ranged from 0.969 - 0.972 and allometric coefficient (b) from 3.2 - 3.3. This represents a significant correlation between the length and weight for both sexes, indicating that Indian mackerel has a positively allometric growth. The 'b' value was very close to 3 and its variation from the ideal value confirmed by t - test showed only insignificant deviation from the cube law. Yohannan and Sivadas (2003) reported that Indian mackerel attains an average length of 11 15 cm and 12- 21cm along the west and east coast of India, respectively. In recent years, mackerel fishery has undergone noticeable changes due to the expansion of fishing ground and introduction of new gears.

The LWR generally differs between and within fish species due to their body shape in the former case and the growth condition in which the species exist in the latter case. In the present study, b value of Indian mackerel was found to be close to the observation of Sivadas et al, (2006), who reported a positive allometric growth for Indian mackerel from Calicut region. Sekharan (1958) compared the LWRs of Indian mackerel between the day and night landings, which were found to be similar to the observations in the present study and close to the ideal cube law. Abdusamad et al (1988) reported LWR of Indian mackerel form Kakinada region and showed that the females are heavier than the males (b = 3.4 for pooled data). Yohannan et al (2000) estimated the LWR of mackerel from the west and east coast of India and reported b values very close to the present study.

The LWR study of oil sardine showed the coefficient of determination in the range of 0.90 - 0.94 and b value from 3.40 -3.46, indicating a positive allometric growth. Raja (1967) studied the LWR of Oil sardine based on seasons, sex and maturity and reported the b value from 2.5 – 3. He also noticed an insignificant difference in b value between male and female in mature stage. Along the Mangalore-Malpe coast, Rohit and Bhat (2003) noticed the size variation of oil sardine from 4 - 22cm with a 'b' value of 2.86. Oil sardine females were found to be slightly thinner than the males in the immature stage, but they become heavier than the male when mature. Based on several years' data, Raja (1969) reported the lack of any sequence in the fluctuations of b value of male and female oil sardine. Annigeri (1992) observed a positive allometric growth for both sexes and negative allometric growth for unsexed fish from the Karwar region. Desmukh (2010) reported negative allometric growth for oil sardine with 'b' value 2.5 along the Ratnagiri coast. Aljujaili (2012) estimated the 'b' value of Omani Oil sardine as 2.9, indicating the isometric growth of the fish. Study of L-W relationship of oil sardine from Mangalore area reported a positive allometric growth (Dhulkhed, 1963) and similar conclusion was drawn by Kumar and Balasubrahmanyan (1987) based on studies conducted in the coastal waters of Tamil Nadu.

The present LWR study on Commerson's anchovy showed a significant coefficient of determination (R^2) varying from 0.893 - 0.898. The b value of male, female and pooled data were 3.16, 2.99 and 3, showing that Commerson's anchovy follows the cube law and isometric growth. The maximum length of Commerson's anchovy recorded in the present study was 14.6 cm. Hoedt (1994) reported that Commerson's anchovy attains a maximum length of 15.8 cm from Clevel and Bowling green Bays. Similar to the present study, Rao (1988a) observed no significant difference in length between the male and female of *Enchrasicholina devisi*, and suggested a combined LWR. Rao (1988b) reported a significant difference in the slope between sexes in *S. bataviensis* and concluded that the weight of the fish increases at a rate lower than the cube of its length.

Nair (1998) described the biology of *E. devisi*, *S. waitei* and *E. punctifer* along the Kerala coast and reported a significant difference in the length-weight relationship between males and females in *E. devisi*, and *S.waitei*. He also reported an isometric growth pattern in *E.devisi* and *S.waitei* and a significant variation in 'b' value in the case of the first two species. Doddamani et al (2001) reported an allometric growth for *S. bataviensis* from the Mangalore area. The relative condition factor (Kn) equal or greater than 1 indicates that the fish is in good growth condition, which is usually employed as a tool to assess the growth status of a fish (Sachidanandamurthy and Yajurvedi, 2008). The fluctuations in the monthly Kn values depend on several factors like feeding, environmental condition, maturity and spawning. Decline in Kn values of Indian mackerel in February, April, June and July coincided with their peak spawning period.

Low feeding intensity was noticed earlier in spawners, so the relative condition factor is believed to decrease during the spawning period (Chidambaram et al, 1952). In the present study, Kn value was found to be less than 1 in the case of female mackerel in February, March, April and June, which may be attributed to the decreased feeding intensity at advanced stage of maturity along the west coast of India. In the present study, condition of the male mackerel (Kn = 1.14, R^2 = 0.928,) was found to be better than the female (Kn = 0.6636, R^2 = 0.654) in February and July, which could be attributed to the fact that the females reduce their growth after first maturation and use large amount of their energy for reproduction while the males continue their growth with insignificant energy loss in reproduction. Comparable results were obtained in the case of *Amphychthys cryptocentrus* (Granado and Gonzales, 1988). It was also observed that Indian mackerel has low feeding intensity during the advanced stages of maturity (Chidamabram et al, 1952; Bhimachar and Geoge, 1958; Pradhan, 1956; Rao, 1962).

The relative condition factor of the oil sardine was more than 1 in almost all months, including the peak spawning period. Therefore, decrease in condition factor of oil sardine during certain months could not be linked to the spawning period, but could be linked to the plankton richness in the upper water column. Saud, (2011) reported an inverse relation between the Kn value and gonado-somatic index (GSI) of Indian Oil sardine from the Oman coast. He concluded that the

Omani Oil sardine feed well before the spawning period and use the stored energy for spawning. Annigeri et al., (1992) observed a low Kn value in oil sardine during its size at first maturity from the Karwar region. However, there are no published reports from the Kerala coast on the relative condition factor of Oil sardine during different months

The present study showed fluctuations in Kn values of Commerson's anchovy during different months. Rao (1988a) obtained low Kn values for *Encrasicholina devisi* at Mangalore in October and February, which coincided with the commencement and completion of their major spawning period. Nair (1998) observed random fluctuations in Kn values for *Encrasicholina devisi*, *Stolephorus waitei* and *E. punctifer* in different months even within the peak spawning season, indicating no correlation with spawning activity and fluctuation in the Kn values. The observed irregular fluctuation in Kn value of anchovy could be due to their protracted spawning period, as indicated in the study of Nair (1998). May- August are the peak spawning period of Commerson's anchovy, but in the present study it was observed that the Kn value of the female during these months were greater than 1. This conveys that the decrease in the relative condition factor of the species cannot be linked to the spawning period, as observed by Basilon et al (2006) in the case of European anchovy along the Strait of Sicily.

This chapter presents the status of the LWR and condition factor of three commercially important small pelagic species along the Kerala coast, which will be beneficial for fishery biologists and conservationists for sustainable fishery management and conservation. The LWR of Commerson's anchovy is the very first detailed report from this region. The variation in climatic factors, fishing ground and fishing gear are considered to be to the driving factors causing change in the structure of the fishing stock and early maturity of the pelagic fishes. It is reported that the mean length and mean weight of North Sea mackerel increased over a 20 year period due to the increasing sea surface temperatures (Agnalt, 1989). Vivekanandan et al (2008) reported the northward extension of distributional range of oil sardine in the west and east coasts of India due to increase in sea surface temperature. However, LWR and condition factor values of Indian mackerel and Oil sardine were not significantly different from the values reported in the historical studies, indicating that these parameters are not affected by the expected long-term environmental changes.

CHAPTER 7

GROWTH AND MATURITY

7.1. Introduction

Growth and maturity are two important biological characteristics used to study fish stock dynamics. The determination of sex and the maturity stage provides valuable and basic knowledge of the reproductive biology of a fish stock. The information derived from such studies is indispensable to understanding the spawning potential and recruitment forecast of a fish stock (Carvalho and Nigmatullin, 1998).

The studies on age and size at which fish attain sexual maturity, the time and place of spawning and the duration of the reproductive cycle beginning from the development of the ovary to the final release of eggs are essential for the realistic understanding of the stocks and also for implementing useful management practices for their sustainable utilization.

Growth parameters are important for fishery stock management and understanding on the maximum length of fish is a strong predictor of many growth parameters (Bluewiess et al., 1978). Qasim (1973) pointed out the relevance of growth studies to determine the total recruitment of fish with respect to time. The growth parameters may differ from species to species, stock to stock and one sex to the other (Vivekanandan, 2005).

Knowledge of age and length at first maturity (L_m) is essential to assess the spawning stock. The length at first maturity (L_m) or size at first maturity is defined as the length/size at which 50% of the population become sexually mature for the first time, which is an important biological parameter used in fisheries management.

Electronic Length Frequency Analysis (ELEFAN) is a software used to analyze the growth parameters and to predict fishery yield or stock-related attributes. Annigeri et al., (1992), Abdusamad et al., (2006, 2010), Rao, (1998) and Nair, (1998) have studied the growth rates of sardine, mackerel and anchovy, respectively, using ELEFAN. The growth of an individual fish can be calculated by using von Bertalanffy Growth Formula (Bertalanffy, 1934). George and Banergi (1964) studied age and growth of Indian mackerel along the Kerala coast using length frequency data.

It is well accepted that the frequent analysis of parameters of growth, mortality and maturity is important to understand any fluctuation in population size, structure, and distribution due to long-term environmental change (McRae and Diana, 2005). It is also known that the life history traits of fishes determine the productivity of the fishery resources, which should be integrated with the scientific advisories for fisheries management including the size/age at first maturity, sex ratio, fecundity, spawning periods and spawning behaviour (Katsukawa, 1997; Morgan, 2008).

In this chapter, using length frequency data of oil sardine (*Sardinella longiceps*), Indian mackerel (*Rastrelliger kanagurta*) and Commerson's anchovy (*Stolephorus commersonii*), attempts have been made to assess their growth parameters like Length at infinity (L_∞), Growth coefficient (K), Length at 0 age (t_0), Length at age (L_t), Recruitment pattern, Probability of capture, and Size at maturity (L_m). The values obtained for various parameters in the present study were used to compare with the data available from the past studies for understanding whether there is any long-term change in these parameters.

7.1.1. Indian oil sardine

Along the west coast of India, the growth and maturity aspects of Indian Oil Sardine have been relatively less studied as compared to their fishery aspects (Chacko, 1955; Raja, 1970, 1971; Balan, 1964, 1965, 1971; Bensam, 1970; Raja, 1970; Annigeri et al, 1992). Raja (1970) noticed that sardines grow rapidly during the first few months and attain 15 cm length at first year, 17 to 18 cm in the second year and then grow slowly. Oil sardine spawns during the month of June and attains first maturity at the length of 15 cm, though juveniles have also been observed during the spawning season.

In the past, the spawning season of oil sardine has been variously recorded by several workers as May to August (Hornell and Nayudu, 1924), June to September (Nair, 1959; Dhulkhed, 1968), June to October (Raja, 1967, 1969), and June to December (Prabhu and Dulkhed, 1970). In general, it is believed that the monsoon season is the best suited for spawning and larval survival of oil sardine (Bal and Rao, 1984). Raja (1970) reported that the oil sardine of west coast of India spawns at the end of the first year and second year and their life span is 2½ years. Balan (1965) studied maturity, spawning, growth parameters while Bensam (1964) observed the seasonal growth variations in oil sardine from south west coast of India. The maturation in fishes is reported to be influenced by environmental factors such as rainfall (Pillai et al, 2003).

7.1.2. Indian mackerel

Noble et al, (1974) studied the biology and population parameters of Indian mackerel in the Indian coasts. Venkataraman and Mukundan (1970) studied the spawning behavior of Indian mackerel, whereas Abdusamad et al, (2006, 2010) attempted the population parameters of the species from the Kakinada and Tuticorin coasts. Qasim (1973) showed a close relation between the spawning /recruitment of major pelagic fishes and the South-west/ North-east monsoons. Past biological oceanographic studies along the west coast of India suggest the possible role of microbial loop in the coastal waters providing nutritional support to mackerel and oil sardine reproduction and recruitment (Madhupratap et al., 2001).

Along the west coast of India, the spawning of mackerel is reported to be from April to September and the optimum temperature for spawning is around 27°C, thermocline being be the their lower distribution limit (Devansan and Chidamabaram, 1948, Chidamabaramet al., 1952; Bhimachar and George, 1952; Sekharan, 1958; Balakrishanan et al, 1967; Yohannan, 1997). Venkataraman, (1970) noticed that a large number of young mackerel occur along the west coast of India during the Southwest Monsoon period. Peak spawning and recruitment is reported to coincide with the southwest and northeast monsoon seasons along the west and east coast of India, respectively (Qasim, 1973). The lifespan of mackerel is about two years; they grow very fast during early life stages and reach the length of about 19 cm by the end of the first year (Devaraj et al, 1997).

7.1.3. Commerson's anchovy

The dominant species of anchovies available along the Indian coast are *Encrasicholina devisi*, *Stolephorus bataviensis*, *Encrasicholina punctifer*, *Stolephorus commersonii*, *Stolephorus indicus*, *Stolephorus baganensis* and *Stolephorus macrops*. Among these, *Stolephorus commersoni* (Commerson's anchovy) has the second position (27%) in landing with a size range 7.5-15.5 cm (CMFRI, 2013). Even though sufficient information is available on the growth and maturity parameters of most of the species of anchovies (Venkataraman, 1956; Marichamy, 1970, 1972;

Rohit, 1993; Gopakumar et al., 2000), virtually no such information is available on Commerson's anchovy from the Kerala coast.

7.2. Materials and methods

During 2010 and 2011, fortnightly sampling of oil sardine, Indian mackerel and Commerson's anchovy were carried out at two major fish landing centers in Kochi (Kalamukku and Munambam). *In toto*, 790 Indian mackerel, 1395 *Sardinella longiceps*, and 1180 *Stolephorus commersonii* caught by ring seine and purse seine were considered for the present study. The total length was taken from the tip of the snout to the tip of the caudal fin using a measuring scale and the weight was taken using a weighing balance after removing the water content of the fishes. Maturity was estimated by the observation of male and female gonads after the dissection of the specimens (Figures 7.1 – 7.3). Specimens with I and II gonad stage were considered as juveniles while those from III to VI were deemed mature (Bensam, 1964).

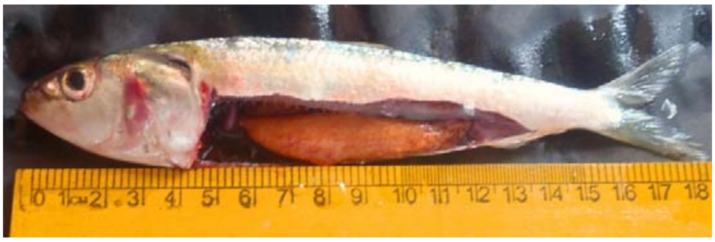


Figure 7.1 – Female Indian oil sardine with mature ovary

Figure 7.2 – Female Indian mackerel with mature ovary

Figure 7.3 - Female Commerson's anchovy with mature ovary

7.2.1. Growth parameters

Growth parameters like L Infinity ($L\infty$), Growth Coefficient (K), Length at 0 year class (t0), life span, length at age (Lt), recruitment pattern and probability of capture were estimated from length frequency data of the species using ELEFAN I module in FiSAT software (Gayanilo and Pauly 1997). Length frequency for each species was taken in 10 mm class intervals and the data of different classes were used to determine the stock structure and growth. Growth was explained by calculating the $L\infty$ and K in ELEFAN I programme and Powell-Wetherall plot (Wetherall, 1986)

7.2.1.1. L infinity ($l\infty$)

L-infinity ($L\infty$) is the length that the fish of a population would reach if they were able to grow indefinitely (also known as asymptotic length). It is one of the three parameters of the von Bertalanffy growth function. $L\infty$ can be calculated by ELEFANI programme and Powell-Wetherall method (Wetherall, 1986).

7.2.1.2. Growth coefficient (k)

Growth coefficient (K) is a parameter of the von Bertalanffy growth function also known as growth coefficient, expressing the rate (1/year) at which the asymptotic length is approached and was calculated by the ELEFAN I program .

7.2.1.3. Length at 0 year class (t_0)

This is another parameter of the von Bertalanffy growth function that is defined as the hypothetical age (in years) the fish would have had at zero length. It is calculated from Pauly's empirical equation (Pauly, 1979)

$t_0 = -(EXP((-0.392-0.275*LN(L\infty)-1.038*K)$

7.2.1.4. Life span

Life span is the approximate maximum age (t_{max}) that fish of a given population would reach. Following Pauly (1983), it was calculated using the parameters of the von Bertalanffy growth function as estimated above,

$t_{max} = 3 / K.$

7.2.1.5. Length at age (l_t)

Length of fish at age t was calculated by the Von Bertalanffy growth equation (1938).

$Lt = 302 (1-e-(0.45) [t-(-1.2)])$

7.2.2. Recruitment pattern

Recruitment pattern is the process by which the young one enters the population in a given year. It is obtained by back-projecting into the time axis by means of a single set of growth parameters (Pauly, 1982). Recruitment patterns have a bell-shaped normal distribution when recruitment occurs as a single event. When annual recruitment occurs as two major events, however, this results in a strongly asymmetric graph with a single mode or in a bimodal pattern. For most of the stocks, the recruitment pattern suggests that two pulses of recruits are generated each year (Pauly and Navaluna 1983; Pauly and Ingles 1981).

7.2.2.1. Probability of capture

The probability of capture by length (Pauly, 1984) is used to estimate length at first capture (Lc) and was calculated by the ratio between the points of the extrapolated descending arm of the length-converted catch curve using the FiSAT software. The length at which 50% of fish are retained is known as length at first capture.

7.2.2. Size/length at first maturity

In order to estimate the size/length at first maturity (L_m), male and female fishes were grouped separately into 5 mm class interval and the fishes with gonad stage III and above were considered as mature (King, 2007) .

7.3. Results

7.3.1. Growth parameters of Indian oil sardine

The growth parameters L∞, K, and age at zero length (t_0) were calculated in FISAT1 as 19.8 cm, 1.14yr^{-1}and -0.0464.The L∞ calculated by Powell-Wetherall method was 20.10 cm (Figure 7.4). Different size classes of oil sardine is shown in Figure 7.5 and their Z/K was 2.42 (Figure 7.6). The maximum life span of oil sardine was estimated to be 2.63 years and growth of the species followed the equation Lt = 302 (1-e-(0.45) [t-(-1.2)]), which confirms that the species grows faster during the early stages of its life. They attain the length (Lt), 13.9, 17.9 and 19.8 cm by the end of 1, 2, and 2.6 years, respectively (Figure7.7).Two peaks of recruitment of juveniles to the fishery was observed: a large peak during July-August and a small peak in February-March (Figure 7.8).The calculated values of probability of capture (Figure 7.9) were L_{25} = 13.69 cm, L_{50} = 15cm and L_{75} = 16.04cm. The length/size at first maturity was calculated as 15.7 cm and the length at first capture was 15 cm. It indicates that the peak exploitation of the species occurs before they attain sexual maturity.

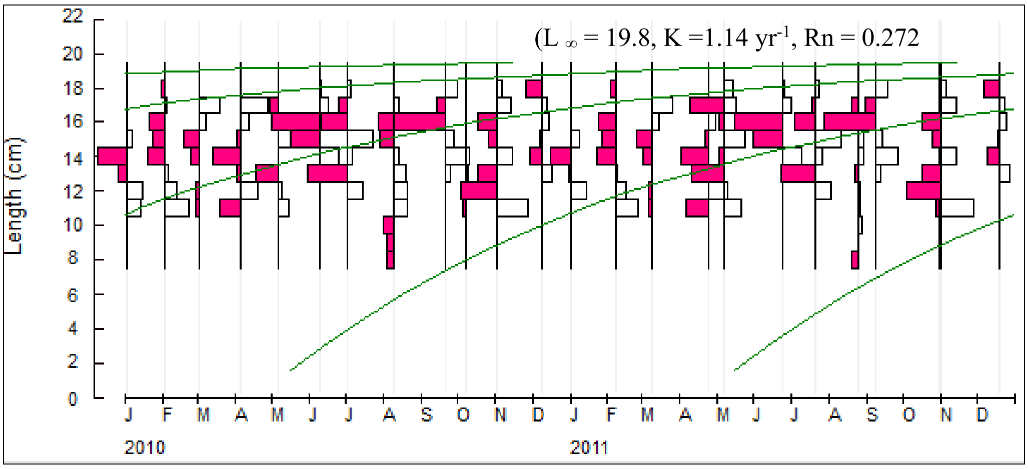


Figure 7.4 - Length - frequency curve of oil sardine (2 years pooled data) using ELEFAN I (VBGF and length frequency plot)

Figure 7.5 – Size classes of Indian oil sardine

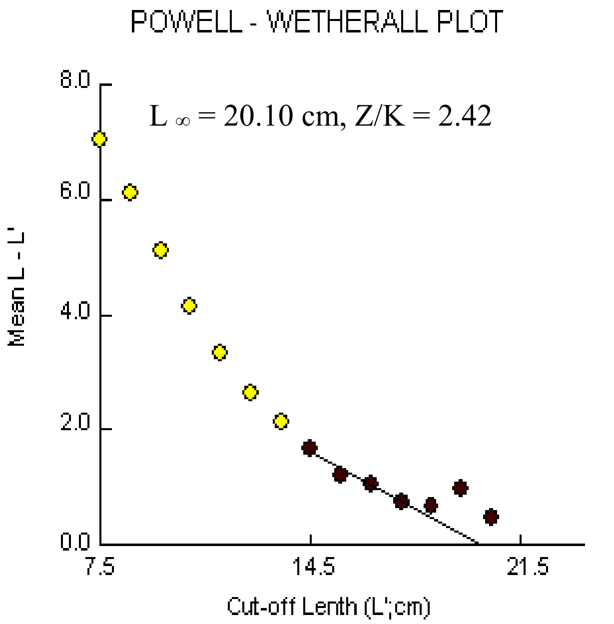


Figure.7.6 – Powell and Wetherall estimation of L∞ and Z/K of oil sardine

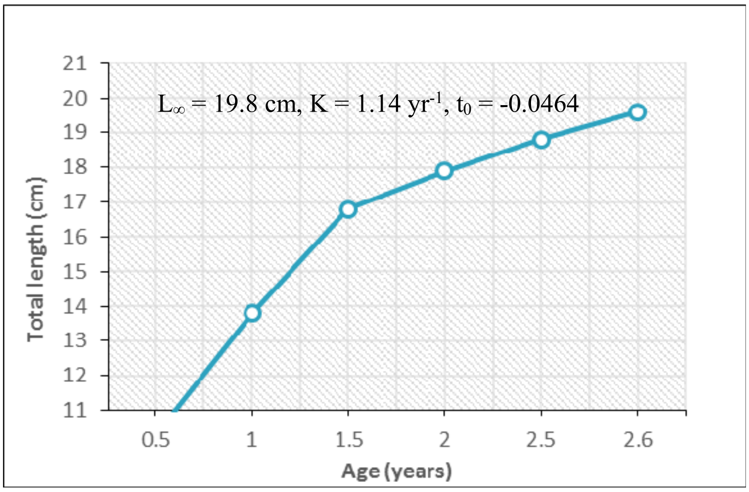


Figure 7.7– Average length attained by oil sardine at different ages

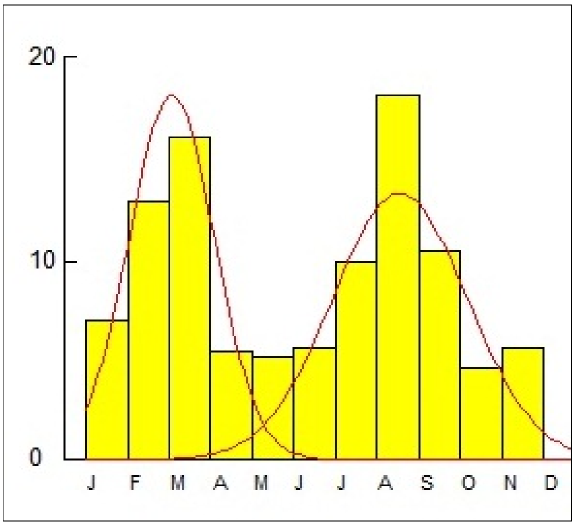


Figure 7.8 – Annual recruitment pattern of oil sardine based on ELEFAN programme. Two recruitment peaks are evident, a major peak during June – August and a minor peak during February – March

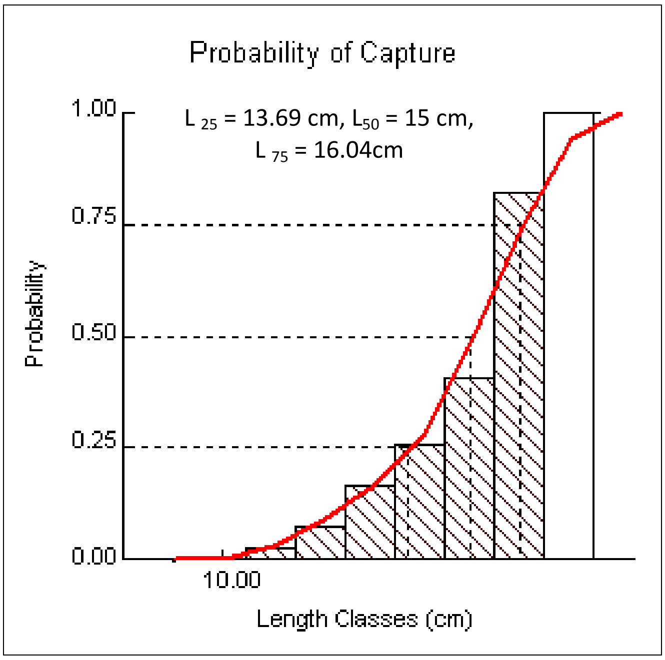
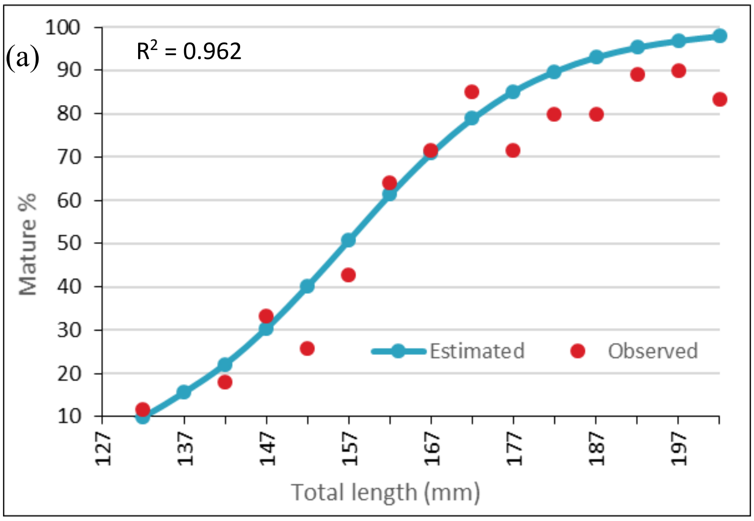


Figure 7.9 – Probability of capture of oil sardine for L_{c50}. The probability of capture was 15 cm suggesting peak exploitation before attaining sexual maturity at 15.7 cm.

7.3.2. Length / size at first maturity of oil sardine

Length at first maturity of Oil sardine was found to be 157 mm and 152 mm for male and female, respectively. This showed that male oil sardine attains its first maturity at 157 mm while the female does so at 152 mm (Figure 7.10).



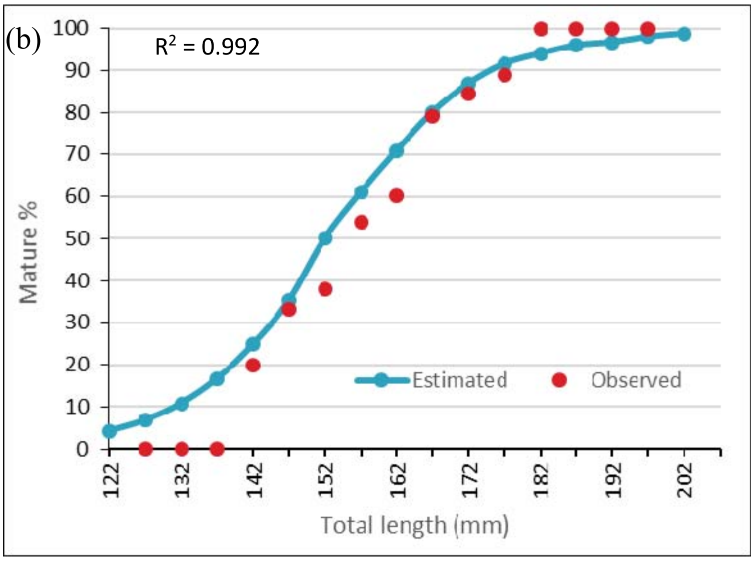


Figure 7.10 – Length at first maturity of oil sardine (a) male and (b) female

7.3.3. Growth parameters of Indian mackerel

Different size classes of Indian mackerel is presented in Figure 7.11. Their length at infinity ($L\infty$), K and t_0 were 27.8 cm, 1.5 yr^{-1} and -0.0565, respectively (Figure 7.12). The $L\infty$ and Z/K of Indian mackerel obtained by Powell and Wetherall method were 25.86 cm and 1.24 (Figure 7.13).The life span of the species estimated by calculating K in ELEFAN I using the equation t_{max} = 3/k is 2 years (Figures 7.14). The estimated values of $L\infty$ and K were substituted in the von Bertalanffy growth equation to calculate the length at age. The results showed that mackerel attained maximum growth in the first year (up to 22 cm) and after that the growth rate decreased and reached 26.5 cm. This indicates that mackerel spawns before they complete one year growth. In the life cycle of the species, two growth phases were evident: faster growth during the immature phase and a relatively slow rate of growth in the mature stage.

Figure 7.11 – Size classes of Indian mackerel

Using the values of L∞ (27.8), K ($1.5yr^{-1}$) and t_0 (-0.0565), recruitment pattern of mackerel has been analyzed (Figure 7.15), which showed the presence of matured mackerel in all months indicating that their spawning and recruitment occur throughout the year. Two recruitment peaks were also evident: a major recruitment peak from June to August and a minor peak during February to March, with the highest recruitment in July (28%). Probability of capture (Lc) of mackerel was 22.43 cm (Figure 7.16), which was higher than L_m (17.7 cm), indicating that the mackerel get exposed to peak exploitation after attaining sexual maturity.

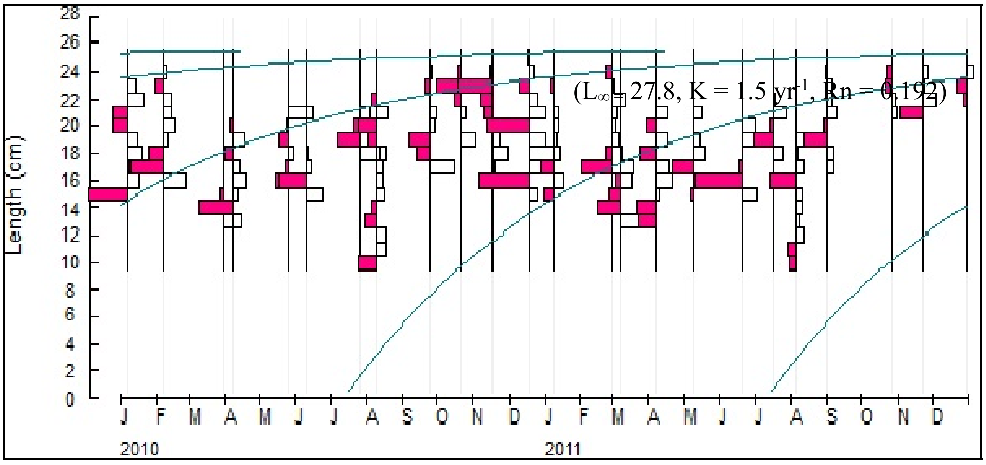


Figure 7.12 – Length – frequency curve of Indian mackerel (pooled data) using ELEFAN I

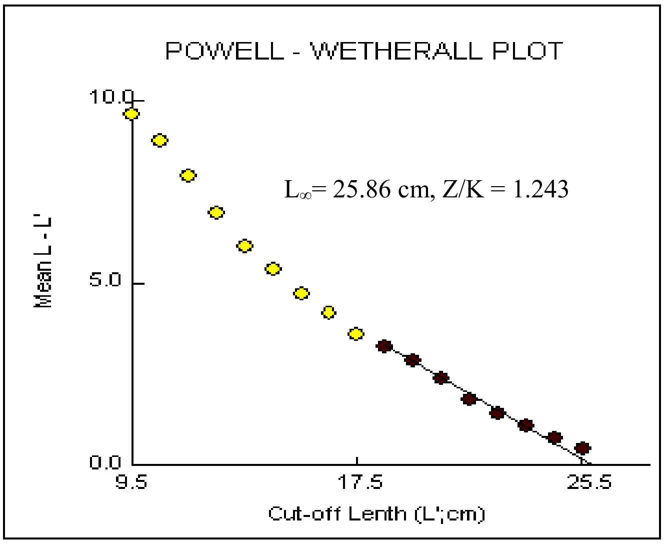


Figure 7.13 – Powell and Wetherall estimation of L∞ and Z/K of Indian mackerel

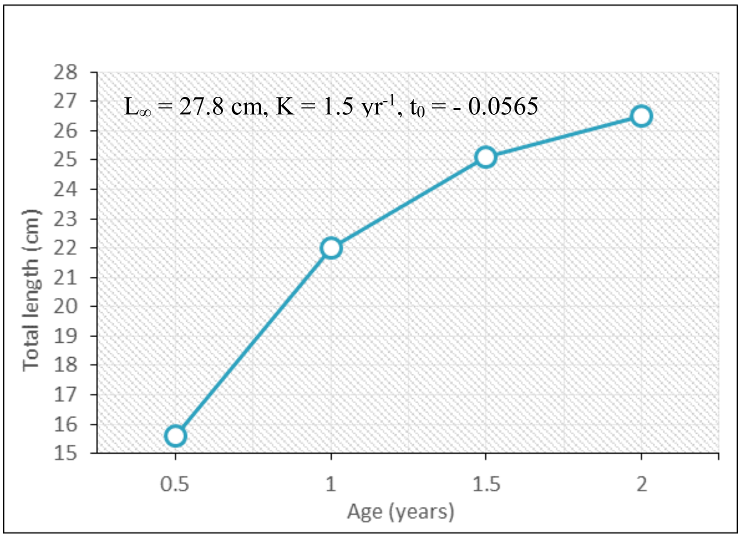


Figure 7.14– Average length at age of Indian mackerel. Mackerel showed maximum growth in the first year (up to 22 cm) and subsequently the growth decreased with time

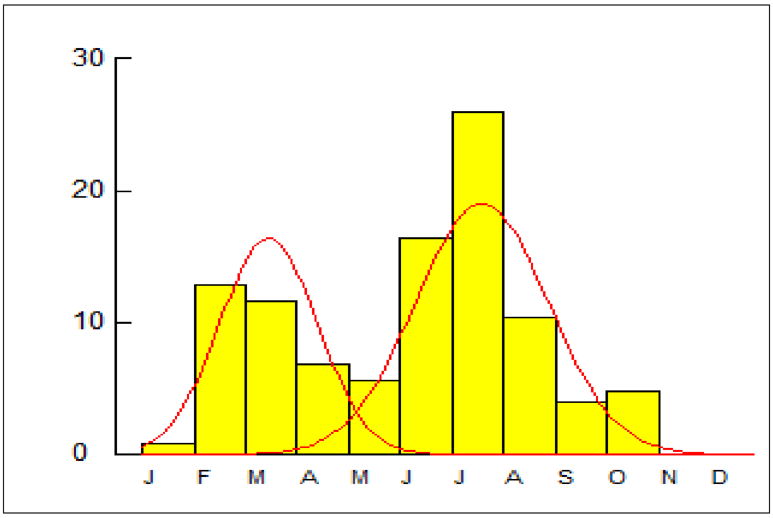


Figure 7.15 – Recruitment pattern of Indian mackerel. Two recruitment peaks are evident, a major peak during June – August and a minor peak during February – March

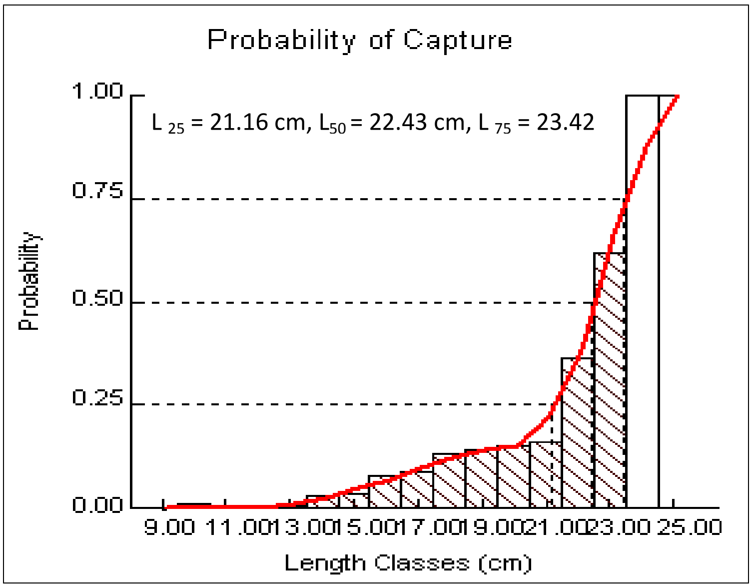


Figure 7.16 – Probability of capture of Indian mackerel for L_{c50}. The probability of capture was 22.43 cm suggesting peak exploitation after attaining sexual maturity at 17.7 cm.

7.3.4. Length / size at first maturity of Indian mackerel

Analysis of length / size at first maturity of male and female showed a mean length of 177 mm and 172 mm, respectively. This conveys that male mackerel attains its first maturity at 177 mm while the female does so at 172 mm (Figures 7.17 and 7.18).

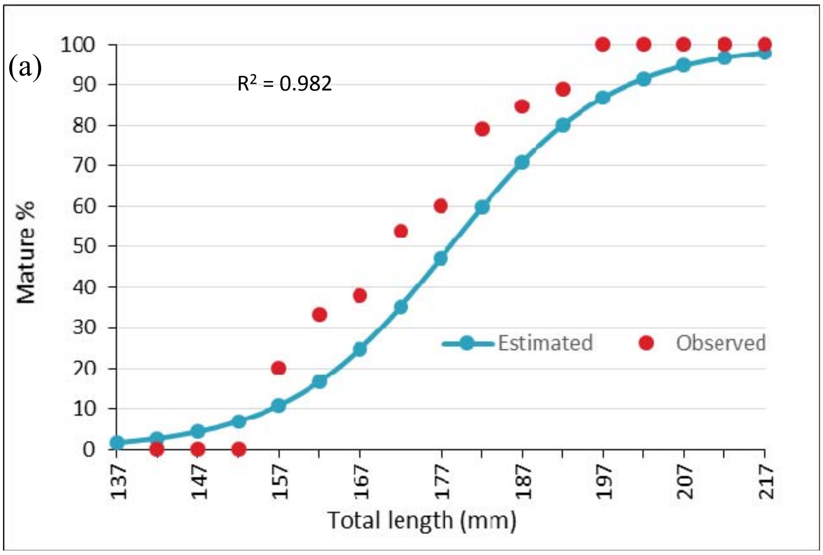


Figure 7.17 – Length at first maturity of Indian mackerel male

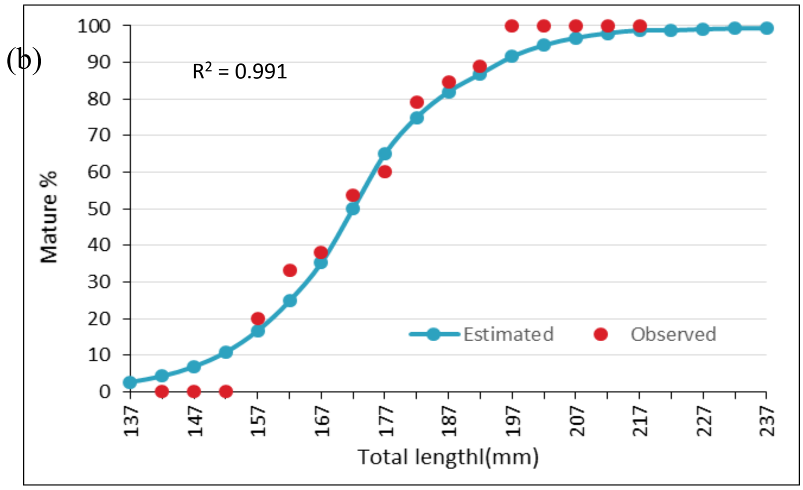


Figure 7.18 – Length at first maturity of Indian mackerel female

7.3.5. Growth parameters of Commerson's anchovy

The growth parameters of Commerson's anchovy obtained from von Bertalanffy growth equation showed that Length at infinity (L_∞) = 15.4 cm, K = 0.98 yr^{-1} and t_0 = -0.1152. The parameters L_∞ and Z/K of Commerson's anchovy calculated from Powell and Wetherall method were 18.87 cm and 4.8, respectively (Figure 7.19). Different size classes of Commerson's anchovy is presented in Figure 7.20. The present data suggests that Commerson's anchovy along the Kerala coast attains a length of 10.2 cm in the first year, 13.5 cm in the second year and 14.7 cm in the third year, with a maximum life span of 3.061 years.

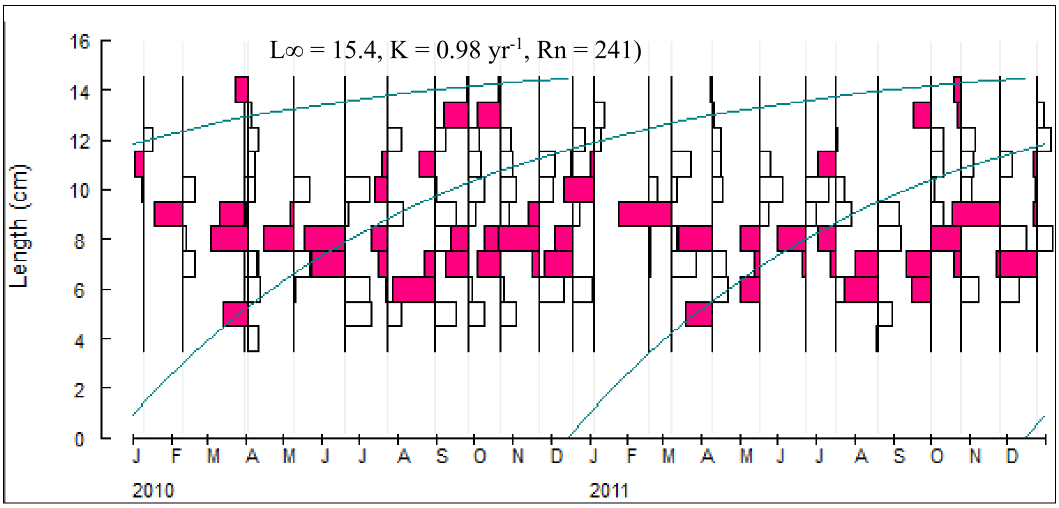


Figure 7.19– Length frequency curve of Commerson's anchovy (pooled data) using ELEFAN I

The recruitment pattern of Commerson's anchovy showed two peaks: a small one during February – March and a second one during June - July. The values of probability of capture were L_{25} = 7.22 cm, L_{50} = 8.2 cm and L_{75} = 9.61cm (Figures 7.21 to 7.24). The length frequency histogram for the probability of capture showed the length at first capture of Commerson's anchovy as 8.2cm, indicating that the fish get exposed to maximum exploitation after they attain the first maturity (7.1 cm).

Figure 7.20 - Size classes of Commerson's anchovy

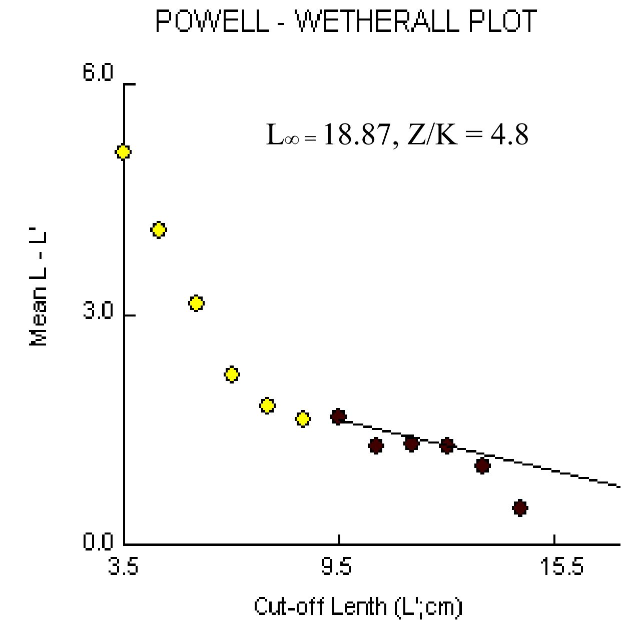


Figure 7.21 – Powell and Wetharall estimation of L∞ and Z/K of Commerson's anchovy

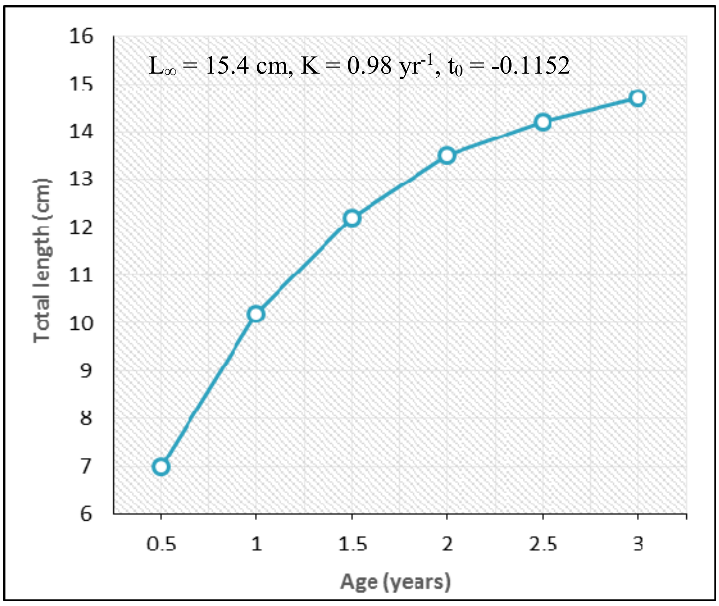


Figure 7.22 – Average length attained by Commerson's anchovy at different ages

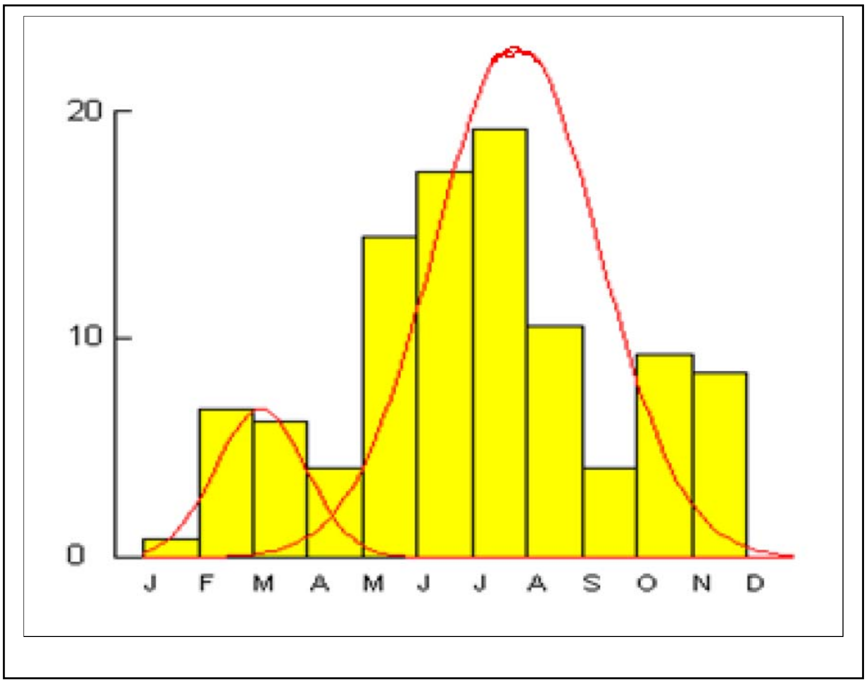


Figure 7.23 – Annual Recruitment pattern of Commerson's anchovy during 2010–2011

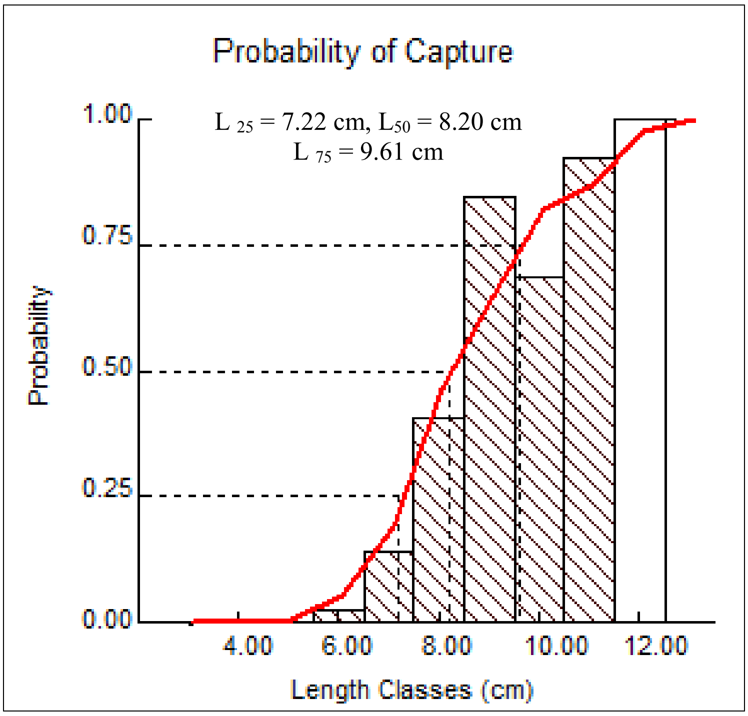
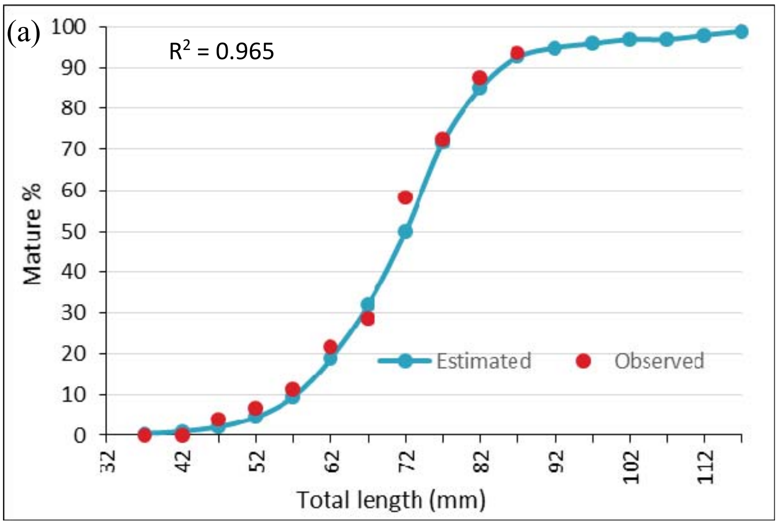


Figure 7.24 – Probability of capture of Commerson's anchovy for Lc 50

7.3.6. Length / size at first maturity of Commerson's anchovy

The Length at first maturity of Commerson's anchovy showed values of 71 mm and 72 mm for male and female, respectively. It is indicated that male Commerson's anchovy attains its first maturity at a length 71 mm and the female at 72 mm (Figure 7.24 & 7.25).



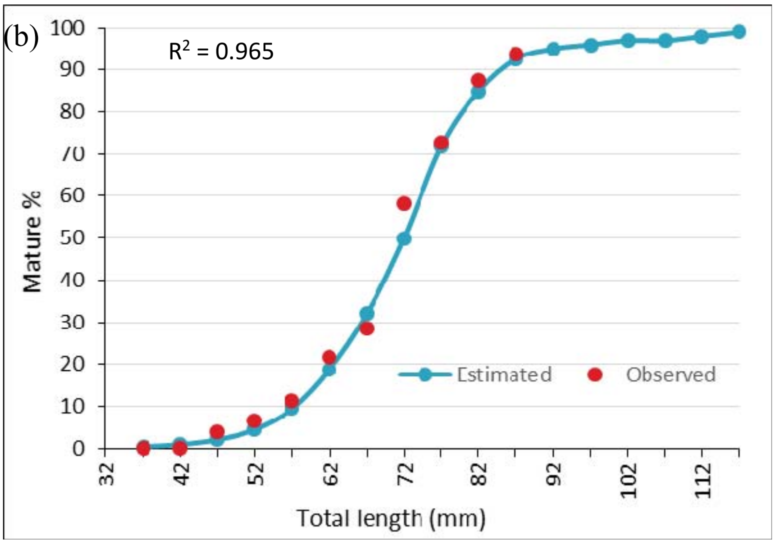


Figure 7.25 – Length at first maturity of Commerson's anchovy (a) male and (b) female

7.4. DISCUSSION

The coastal waters of Kerala have high plankton production due to large quantities of nutrients being introduced into the surface waters through large land/river input and upwelling (Madhupratap et al., 1996). Most of the small pelagic fishes in this environment live for only about two years and are exploited at less than one year before they get a chance to reproduce even once (ICAR 2011). The recruitment of juveniles to the stock is thought to be influenced by the annual fluctuations in the intensity and duration of upwelling and plankton bloom in the coastal waters (ICAR 2011). Pauly (1982) has shown that recruitment even in tropical fishes generally oscillates seasonally and is often normally distributed with one or two peaks per year. This situation influences the availability of different varieties of fish for exploitation. The daily rainfall along the southwest coast during monsoon has been considered useful for good recruitment to the fishery (ICAR 2011). The success of the commercial fishery during each season is determined by the number of juveniles recruited at the beginning of the season, which, in turn, is influenced by several environmental factors such as rainfall and plankton abundance (ICAR 2011).

7.4.1. Indian oil sardine

In the present study, Indian oil sardine was found to have a maximum length (L_∞) of 19.8 cm and K 1.14 yr^{-1}, which was lower than the values of 20.8 cm and 0.6yr^{-1} reported by Raja (1972). In the present study, Indian oil sardine attained the lengths of 13.9 cm, 17.9 cm and 18.8 cm during their first, second and third year, respectively. This was lower than the values reported by Hornell and Nayudu (1924), who showed a length 15 - 17 cm in the first year, 19 cm in the second year and 23 cm in the third year. Instead, the present growth values of Oil sardine obtained was higher than the values reported by Nair (1958), who reported a size of 10cm, 15cm and 19 cm in the first, second and third years, respectively. The life span of oil sardine in the present study was found to be 2.6 years, which was comparable with Nair (1958), who reported it as 2.5 years. It was also found in the present study that Oil sardine follows a two-year cycle in their life from recruitment to maturity and attains first maturity at the age of one.

The spawning season of oil sardine has been variously recorded by several workers as May to August (Hornell and Nayudu, 1924), June to August (Kumaran, 1988), June to October (Raja, 1967, 1969), June to September (Nair, 1953; Dhulkhed,1967) and June to December (Prabhu and Dulkhed, 1967).The present study shows two peak recruitment periods, one in February and March and the other in May to August, which indicate spawning during these months or just before these months. Pillai et al (2003) reported that oil sardine grows rapidly during the first few months and the length at first maturity is 15 cm, which was slightly lower than the value obtained in the present study (15.2 cm). Length at first capture of Oil sardine estimated in the present study was 15 cm, which is very close/lower than the length at first maturity. Hence, the results indicate that the oil sardine exploitation started before they attained their first maturity (Lm = 15.2cm). The maximum level of exploitation estimated in the present study was 16.04 cm while the corresponding age was 1.5 years. The total life span of oil sardine estimated in the present study was 2.6 years while the corresponding length was 18.8 cm. This indicates that most of the individuals in the stock do not get a chance to grow to their maximum size, getting exploited much before.

7.4.2. Indian mackerel

Along the west coast, a regular annual movement of mackerel from the deeper to the shallow waters associated with upwelling and deepening of thermocline has been reported (Yohannan and Abdurrahman, 1998). In the present study, the values of length at infinity (L_∞) were 27.8 cm, K was 1.5yr^{-1} and t_0 was 0.0565. An earlier study on mackerel from the Mangalore – Malpe region reported L_∞ as 30.7 cm and K as 1.8/ yr (Rohit and Gupta, 2004).Yohannan et al, (1982) also reported a length at infinity of mackerel as 26.5 and value of K as 2.4 yr^{-1}. High values of K normally indicate short life span of fish (Noble, 1986). In the present study, the K value is 1.5 and the calculated life span was 2 years. Noble (1986) reported the K value of mackerel to be 0.5 and life span as 5 years.

During the study period, mackerel attained a length of 22 cm in the first year and 26.5 cm in the second year. Pradhan (1956) reported that mackerel measuring 18 cm was one year old while above 18 cm was two years old. According to Sekaharan (1958), mackerel reaches a length of 12-15 cm in the first year and 21-23 cm at the end of the second year, based on the data from Malpe. The present observation on the growth of mackerel was similar to those of Yohannan (1979) who reported two distinct patterns in mackerel growth - one during the premature phase and another one in the mature phase. During the first phase, the growth in length was pronounced whereas in the second phase, growth in weight predominated.

Recruitment pattern of Indian mackerel observed during the present study was comparable with the observation of Venkataraman (1970), who reported the maximum recruitment during June to September period. Noble (1974) reported the presence of young ones of Indian mackerel in the Cochin backwaters during June month, clearly showing that the recruitment started by the onset of the Southwest Monsoon. During the present study, the maximum recruitment of mackerel young ones to the fishery was in February and July-August, indicating the spawning that took place prior to these months.

Several earlier studies have also reported that the mackerel juveniles get recruited to the fishery by March/April, July and September (Yohannan and Abdurrahman, 1998; Yohannan et al, 1999). This was supported by a few earlier researchers who examined the maturity stages of mackerel from Calicut coast and observed that spawning season of mackerel coincides with the monsoon period (Devanesan & John, 1940; Devanesan and Chidambaram, 1948).

The results of the present study was in general agreement with Ganga (2010), who reported that mackerel spawners are present throughout the year along Cochin coast and the maximum spawning activity reported during the period May to June and a small minor peak during November. Many earlier workers shared the view that the major spawning and recruitment of all pelagic fishes along the southwest coast of India is linked to the intensive coastal upwelling during the Southwest monsoon period.

As upwelling triggers phytoplankton bloom and zooplankton swarms throughout and later part of the Southwest monsoon, respectively, conditions this favor the fast growth of fishes and better survival of the planktivorous fish larvae (Yohannan et al, 1999, 2000, Madhupratap et al., 2001). All the discussion presented above conclude that Indian mackerel has a prolonged spawning season, which extends approximately four to five months. It was observed in the present study that the length at first capture of the Indian mackerel along the Kerala coast was 22.43cm, indicating that the species get peak exploitation after they attain first maturity at 17.7 cm.

7.4.3. Commerson's anchovy

The growth and maturity parameters of Commerson's anchovy inhabiting Indian waters are hitherto unavailable. The L_∞ Commerson's anchovy obtained in the present study was 15.4 cm, which is comparable with the value of Hoedt (1994), who reported the L_∞ of Commerson's anchovy from north Queen Island to be 15.5 cm. However, a few growth and maturity studies of other anchovies are available from the Indian coast, which include the work of Rao (1988 a), who reported L_∞ of *E.devisi* as 11.3 cm and Luther et al (1992), who reported L_∞ of *E. devisi* and *S. waitei* as 10.25 cm and 13.46 cm, respectively.

In the present study, using von Bertalanffy growth equation, it was found that Commerson's anchovy attains a length of 10.2 cm in the first year; subsequently, growth slows down and it reaches 13.5 cm, 14.7 cm in the second and third years, respectively. Life span of Commerson's anchovy was found to be 3.06 years, with a comparable life span (3 years) being reported for another anchovy *Engraulis encrasicolus* from Turkish waters (Aka et al, 2004). Probability of capture of Commerson's anchovy was found to be 8.5 cm, indicating that the species gets exploited after attaining sexual maturity at 7.1 cm size.

The recruitment pattern of Commerson's anchovy observed in the present study suggests two peak recruitment periods: one in June –July and a minor peak in March –April. Luther et al, (1992) reported similar observation of two peak recruitment periods for the anchovy group along the west coast. The spawning studies by Nair (1991) reported that anchovies as a group spawn throughout the year, an observation supported by the present study that reports the recruitment of Commerson's anchovy throughout the year. Supporting evidences have been provided by George (1989), who showed that larvae of *Stolephorus* sp. occurred in all the months, peaking in the March-July period and with a secondary dominance around November.

7.4.4. Long-term trends in the length / size at first maturity

The length / size at first maturity of fishes can fluctuate due to changes in the climatic conditions, food availability, fishing removals and growth rates (Chapman et al., 1996; Hood and Johnson., 2000; Potts and Manooch, 2001). Considering these factors, attempts have been made to analyze the long-term changes in the length/size at first maturity of the Oil sardine, Indian mackerel and Commerson's anchovy for which the present data has been compared with the past data.

The past reports of length at first maturity of oil sardine are as follows: Hornell and Nayudu (1924) reported this to be 15.0 cm, Dhulkhed (1967) reported 16.0 cm, Raja (1967) reported 15.0-16.0 cm while Kumar and Balasubramanian (1987) reported 15.6 cm for male and 15.5 cm for female. In the present study, the length at first maturity of oil sardine was 15.7 cm and 15.2 cm for male and female respectively, suggesting only minor variations with the past data.

The past reports of length at first maturity of Indian mackerel are presented below (Figure 7.26). Devanesan and John, (1940) reported it to be 19.0 cm, while Chidambaram and Venkataraman (1946) reported a length of 20.0 cm. Pradhan (1956) reported 22.4 cm, Radhakrishnan (1965) reported 21.0 - 22.0 cm and Rao et al. (1965) reported 20.0 cm. In recent times, Rohit and Ali, (2004) reported 18.2 cm, Sivadas (2006) reported 17.0 cm and Abdusamad et al, (2006) recorded 18.2 cm for male and 18.5 cm for female. In the present study the values were found to be 17.7cm for male and 17.2 cm for female indicating a long term change in length at first maturity presented in Figure 25.

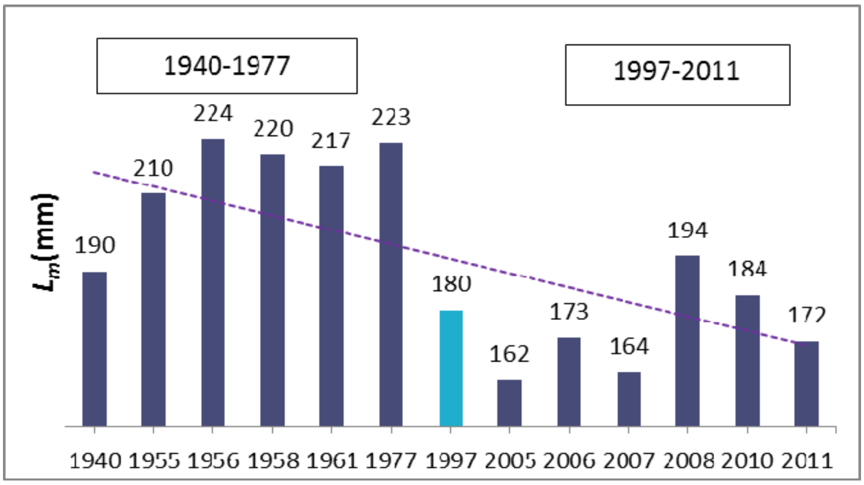


Figure 7.26 – Long-term changes in length at first maturity (L_m) of Indian mackerel. The trend line (dotted line) indicates a prominent decrease in length at first maturity of the species in the recent decades probably representing a long term shift.

The length / size at first maturity of Commerson's anchovy in present study were found to be 7.1 am for male and 7.2 cm for females. As there is only very scanty past data available on the Commerson's anchovy, attempts have been made here to see the present data with respect to the closely related other species of anchovies as well. Based on studies elsewhere, Hardenberg (1934) reported the following length at first maturity values for *Anchoviella tri* – 9.0 cm, *A. baganensis* – 7.0 cm, *A. indica* – 14.0 cm, *A. commersonii* – 10.0 cm, *A. heteroloba* – 6.5 cm, *A. zollingeri*– 70 cm and *A. bataviensis* – 7.0 cm. If we consider *Anchoviella Commersonii* equivalent to *Stolephorous Commersonii* (Commerson's anchovy), a prominent change in Commerson's anchovy is evident when compared with the values obtained in the present study and Hardenberg (1934). However, the results of this comparison probably involve large ambiguity as both studies are from temporally and spatially well-separated areas and, therefore, omitted from the highlight of the present study.

7.5. CONCLUSION

The results of the growth and maturity studies of Indian oil sardine, Indian mackerel and Commerson's anchovy inhabiting the Kochi coast have been discussed. The analyses were based on fortnightly sampling carried out in two major landing centers during a two-year period (2010 and 2011). The maximum life span of Indian oil sardine was estimated to be 2.63 years. Two peaks of recruitment of juveniles to the fishery were observed: a large peak during July-August and a small one in February-March. The length/size at first maturity was calculated as 15.7 cm while the length at first capture was 15 cm, suggesting that the peak exploitation of the species occurs before they attain sexual maturity. Comparison of length at first maturity of oil sardine in the past and present shows only minor variations between the two. The life span of Indian mackerel is estimated to be 2 years. The recruitment pattern showed the presence of mature mackerel all year round, concurring with the results of a few other recent studies. However, two recruitment peaks of Indian mackerel were evident: June to August and February to March with the highest recruitment in July (28%). Probability of capture of mackerel showed higher values (22.43 cm) than length at first maturity (17.7 cm) indicating their peak exploitation after attaining the sexual maturity. Long-term changes in length at first maturity of Indian mackerel indicated a prominent decrease in length in the recent decade, probably indicating environmental changes. The present study on the growth and maturity parameters of Commerson's anchovy forms the first such study from Indian waters and the life span of the species was found to be 3.06 years. Two recruitment peaks of Commerson's anchovy were observed, first during February – March and a second during June – July. The probability of capture of Commerson's anchovy showed that they get exposed to maximum exploitation after they attain maturity. Lack of past data on length at first maturity of Commerson's anchovy from the Indian coast hindered a possible comparison with the present data.

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