INTEGRATED APPROACH TO STUDIES ON TRAWL FISHERIES USING SEA- TRUTH AND REMOTE SENSING INFORMATION OFF MUMBAI COAST

Thesis submitted in partial fulfillment

of the requirements

for the degree of

Ph.D. (Fisheries Resource Management)

by

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CERTIFICATE

Certified that the thesis entitled "**INTEGRATED APPROACH TO STUDIES ON TRAWL FISHERIES USING SEA- TRUTH AND REMOTE SENSING INFORMATION OFF MUMBAI COAST**" is a record of independent bonafide research work carried out by **Mr. Karankumar Kishorkumar Ramteke** during the period of study from September 2016 to August 2020 under our supervision and guidance for the degree of **Doctor of Philosophy (Fisheries Resource Management)** and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title.

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सारांश

समुद्री मछली प्रजातियों पर महासागर की स्थितियों के प्रभाव का मूल्यांकन और आकलन करने के लिए एवं प्रभावी ढंग से मछली प्रग्रहण और समुद्री मछली पालन को तर्कसंगत रूप से प्रबंधित करने के लिए पर्यावरणीय परिवर्तनों का विश्लेषण महत्वपूर्ण है। मत्स्य प्रबंधन के लिए पारिस्थितिकी तंत्र का दृष्टिकोण प्रमुख रूप से मछलियों के सामयिक- स्थानिक वितरण पर पर्यावरण चर के प्रभाव को समझने पर आधारित है। पारंपरिक यथास्थान समुद्री- यथार्थता माप के साथ सुदूर संवेदन डेटा का एकीकरण क्षेत्रीय स्तर पर सुदूर संवेदन से प्राप्त पर्यावरणीय मापदंडों की स्थिति में बेहतर अंतर्दृष्टि प्रदान करता है। इस तरह की जानकारी की कमी के कारण, सितम्बर 2017- मई 2019 के दौरान सैटेलाइट पास के साथ मुंबई तट से प्रयोगात्मक तौर पर मछली पकड़ने के लिए ट्राल प्रग्रहण के दृष्टिकोण से एकीकृत जांच की गई । प्रायोगिक प्रग्रहण के लिये, 6-21 मीटर गहराई में पाक्षिक रूप से 18 ° 57'N से 19 ° 12'N अक्षांश और 72 ° 40 'E से 72 ° 43' देशांतर के बीच ICAR-CIFE, मुंबई के M.F.V NARMADA (IV) का उपयोग किया गया। मछली पकड़ने के लिए 35 मीटर का ट्राल(आनाय जाल- 35 मिमी कॉड एंड) का संचालन किया गया था। ट्राल संयोजन के मात्रात्मक विश्लेषण में वाणिज्यिक संघटन (20.12%) से अधिक उप-संघटन (79.43%) के प्रभुत्व का पता चला, जिसमें शेष मलबे थे(0.45%) । उप-संघटन एवं वाणिज्यिक संघटन क्रमश:3.44-61.34 kg/h और 3.80kg/h - 57.25kg /h अनुमानित किया गया , जिसमे 93 प्रजातियों कि मछलियाँ मुंबई तट से अवतरित पायी गयी, जिनकी संरचना में मछली (53), झींगा(13), उदरपाद(11), केकरा(4), कंदुकधर(4), रंध्रपद(3), उपास्थिमीन(3), लॉबस्टर(13), हर्मिट केकरा(1) शामिल थे। उप-संघटन में मुख्य रूप से स्क्विला (28%), सियानिड्स के किशोर (13%) और झींगा (11%) शामिल थे। ट्राल संसाधनों के स्थानिक वितरण में विविधताओं के विश्लेषण में 12-15 मीटर कि गहराई में अधिकतम प्रजाति(69) की संख्या में दर्ज की गई । तीन उपग्रह-व्युत्पन्न मापदंडों जैसेकि, क्लोरोफिल-ए, समुद्री सतह के तापमान , एवं लवणता के गुणवत्ता एवं यथास्थान मूल्यांकन ($n = 190$) तटीय जल की जटिलता और परिवर्तनशीलता के मद्देनजर किया गया था। तीनों क्लोरोफिल-a के प्रतिगमन समीकरणों के r^2 मूल्य इतने विशिष्ट नहीं थे, लेकिन MODIS (r2 = 0.36; p <0.001), OCM2 (r2 = 0.32; p 0.001) और VISSR (r2 = 0.19) के लिए एक सार्थक संबंध दर्शा रहे थे, जबकि MODIS और VIIR का स्पष्ट अधिमूल्यांकन पाया गया । समुद्र की सतह के तापमान के मामले में, यथास्थान अवलोकन की तुलना में दोनों प्रतिगमन समीकरणों के लिए r^2 मूल्यों में मजबूत संघ और महत्वपूर्ण परिवर्तनशीलता (MODIS के लिए 0.75 और SNPP VIIRS के लिए p <0.001) देखी गयी I MODIS (1.05) और SNPP-VIIRS (1.0) के लिए महत्वपूर्ण RMSE पाया गया जोकि उपग्रह व्युत्पन्न SST एवं यथास्थान SST के साथ अच्छी तरह से मेल खाते है। तुलनात्मक अध्ययन ने सैटेलाइट अवलोकनों से क्लोरोफिल-ए और लवणता माप के लिए कलन विधि के और विकास की आवश्यकता पर प्रकाश डाला। कैनॉनिकल सांगत्य विश्लेषण (CCA) और व्यापक योगज एडिटिव प्रतिरूपण (GAM) विश्लेषण ने सबसे महत्वपूर्ण पर्यावरणीय मापदंडों के समुच्चय की पहचान की जहां संसाधन प्रचुरता की उच्च संभावना है। समुद्री सतह क्लोरोफिल, तापमान, लवणता, सतह की ऊंचाई और जल धारा का मछलियों के प्रग्रहण पर अधिक है प्रभाव है । इन मापदंडों ने मछली की उपलब्धता में एक महत्वपूर्ण भूमिका निभाई, जो इन मापदंडों के सकारात्मक सहसंबंध के साथ यथास्थान प्रग्रहण के साथ संबंधित है। इस अध्ययन के निष्कर्षों से, कम प्रयास, समय और ईंधन की खपत के साथ मछली प्रग्रहण कि आवश्यक स्थितियों को समझने में मदद मिलेगी, और इन संसाधनों के स्थायित्व को बनाए रखने और स्थानिक प्रबंधन में सहयोग करेगी।

ABSTRACT

Analysis of environmental changes is crucial to evaluate and assess the impact of ocean conditions on marine fish species, to effectively harvest fish stocks and to rationally manage marine fisheries. Ecosystem approach to fisheries management is majorly based on understanding the effect of environment variables on spatio-temporal distribution of fishes. Integration of remote sensing data with traditional in-situ sea-truth measurements provide better insight into the status of environmental parameters derived from remote sensing at regional level. Due to paucity of such information, investigations were carried out by adopting an integrated approach through experimental trawl fishing off Mumbai coast in synchronization with satellite pass during Sep 2017- May 2019 to fulfil the following objectives: (1) to study the pattern of catch composition and their spatio-temporal distribution (2) to assess the quality of satellite-derived environmental parameters using in-situ data and (3) to correlate satellite-derived environmental data with in-situ trawl fish catch data. Experimental fishing was carried out fortnightly between 18°57'N to 19°12'N latitude and 72°40' E to 72°43' E longitude in the depth range 6-21m using *M.F.V NARMADA* of ICAR-CIFE, Mumbai. Fishing operations were conducted using 35 m bottom shrimp trawl with 35 mm mesh size cod end. Quantitative analysis of trawl catch composition revealed dominance of bycatch (79.43%) over commercial catch (20.12%) with marine debris forming the remaining 0.45%.The estimated bycatch ranged from 3.44-61.34 kg/h and commercial catch from 3.80kg/h - 57.25kg /h. Composition of trawl catch revealed that 93 species comprised the fish community off Mumbai coast. The species were categorised into finfishes (53), shrimps (13), gastropods (11), crabs (4), cephalopods (4), stomatopods (3), elasmobranch (3), lobster (1) and hermit crab (1). Sciaenids (37%), shrimps (21%) and coilia (17%) comprised the majority of commercial catch. Bycatch consisted of mainly squilla (28 %), juveniles of sciaenids (13 %) and shrimps (11%). Analysis of variations in spatial distribution of trawl resources revealed that the maximum number of species (69) was recorded in the 12-15m depth strata. The quality assessment of three satellite-derived parameters i.e. Chlorophyll-a, Sea surface temperature and Salinity with the *in-situ* observations (n=190) was statistically evaluated by applying strict match-up in view of complexity and variability of coastal water. The r^2 values observed for the three chlorophyll-a regression equations were not so strong, but showed a significant relationship for MODIS ($r^2 = 0.36$; $p<0.001$), OCM2 ($r^2 = 0.32$; $p<0.001$) and VISSR ($r^2 = 0.19$; $p<0.001$) with evident overestimation (MODIS and VIIRS) and in tune (OCM2) with the satellite-derived datasets. Comparison of retrieved chlorophyll-a with *in-situ* products showed lowest root-mean-square error (RMSE) of 0.32 for OCM2. In case of Sea surface temperature, r^2 values for both the regression equations in comparison with *in-situ* observation showed strong association and significant variability (0.75 for MODIS and 0.76 for SNPP VIIRS at $p<0.001$). The significant RMSE observed for the MODIS (1.05) and SNPP-VIIRS (1.0) showed that satellite-derived SST agreed well with *in- situ* observations. Comparison of SMAP satellite-retrieved salinity products with in-situ data showed r^2 value of 0.4; $p<0.001$ and a root-mean-square error (RMSE) of 2.04. The comparative study highlighted the need for further development of algorithm for Chlorophyll-a and Salinity measurement from satellite observations. Canonical correspondence analysis (CCA) and Generalized additive modelling (GAM) analysis identified the set of most important environmental parameters where there is high probability of resource abundance. Sea surface chlorophyll, Sea surface temperature, Sea surface salinity, Sea surface height and current speed have more influence on fish catch. These parameters played an important role in the availability of fish, which correlates with the positive correlation of these parameters with the in-situ catch. Findings of this study would help in understanding essential habitat conditions to achieve fishing with less effort, time and fuel consumption and in suggesting management measures like seasonal and spatial restrictions on resource utilization to conserve and maintain the sustainability of these resources.

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Introduction

Food, clothing and shelter are the universally accepted fundamental human needs for life and existence. According to the medium version of UN (2010) projections, the world population is projected to reach 9.3 billion in 2050. Globally, fish provides about 3.3 billion people with almost 20% of their daily animal protein intake, 4.3 billion people with around 15% of that protein and 7% of all proteins consumed globally. Fish is an important source of animal protein, essential amino acids, and minerals, particularly in food-deficit low-income countries (Easterling *et al*., 2007; FAO, 2009; Rice and Garcia, 2011). The degree to which fisheries sector are able to supply fish for future growing population and it will depend partly on climate-driven changes in productivity of the ecosystems (Brander, 2007; Cheung *et al*., 2008). World per capita fish consumption increased from an average of 9.9 kg in the 1960s to 11.5 kg in the 1970s. Likewise, world per capita consumptions has been constantly increases 12.6 kg, 14.4 kg ,17.0 kg,18.4 kg, 20.3 kg and 20.5 kg in the years of 1980s, 1990s, 2000, 2009, 2017 and 2018 respectively (FAO, 2020). As human population increases, the amount of fishing pressure also increases that causes the area and fishery to decline in catch per unit effort.

Fishing with vessel propelled by wind and sails was the original method of fishing untill 19th century. In the late 1800's, sailing boats were replaced by steamships. The era of steamers, however, was very short as it quickly replaced by motor-driven engine during the beginning of 20th century. An era of rapid technological development in vessel design began with the British factory trawler experiment in the late 1940's. It demonstrated the great advantage of large stern trawlers that processed their catch on-board. In the second half of the last century, increased in fish landings steadily due to rapid technological developments was occurred in the capture fisheries sector (Pauly *et al.,* 2000; Valdemarsen, 2001; Kennelly and Broadhurst, 2002).

India is endowed with a long coastline of 8129 km, Exclusive Economic Zone (EEZ) of 2.02 million sq.km and continental shelf area of 0.5 million sq.km. Annual marine fishery potential of Indian EEZ is estimated to 4.41 million tonnes (Ravishankar and Madhu, 2020) and India occupies seventh position in the world marine capture fish production. The estimated marine fish landings of India during 2019 was 3.56

million tonnes showing an increase of 2.1% in comparison to 3.49 million tonnes in 2018 (FRAD, CMFRI,2020).

Maharashtra is one of the dominant marine fish producing coastal states of India, with a coastline of 720 km extending along six maritime districts (from south to north), namely Sindhudurg, Ratnagiri, Raigad, Greater Mumbai, Thane and Palghar. The estimated marine fish landings of Maharashtra during 2018 was 2.95 lakh t. with 22.5% decrease from previous year (3.81 lakh t. in 2017-18). Due to the multi-species nature of the fishery, the resources of Maharashtra are mostly distinguished based on the type of gear used rather than the kind of species caught (Deshmukh, 2013). The fishery of Maharashtra is primarily contributed by the gears such as bag nets, purse seines, ring seines, shore seines, trawl nets, long lines and gill nets. In Indian marine fisheries, 37% of fishing craft are mechanized, 37% motorized and 26% non-motorized. Among the fully mechanized fishing craft, 29 percent comprise trawlers, 43 percent gill netters and 19 percent dol netters (CMFRI, 2010). In Maharashtra, total 17,362 fishing craft recorded, 2783 are non-motorized, 1563 motorized and 13,016 mechanized. Trawlers (43%), dol netters (31%) and gill netters (23%) are the main fishing craft in the mechanized sector (CMFRI, 2012).

The first profound effort to brought trawling in India were done by mechanized vessel S.T. Premier in 1900 off Bombay coast (Chidambaram, 1952; Mukundan and Hameed, 1993) and pearl Fishing Survey, Ceylon (Hornell, 1916). Subsequently, several experiments and survey fishing operations were conducted before the independence. The concerted efforts at development of Indian marine fisheries were initiated only after the country became independent in 1947. Afterwards, trawling has become widespread all along the Indian coast. Trawling has emerged as the most important method for exploiting demersal fisheries (Vivekanandan *et al.*, 2003). It usually requires dragging a cone - shaped bag net with wings as well as a cod end, based on the principle of filtration. Classification and description of trawling systems are described by several researchers (Hjul, 1972; Nedlec, 1982; Brandt, 1984; Sainsbury, 1996; Hameed and Boopendranath, 2000; Sreekrishna and Shenoy, 2001; Misund *et al.,* 2002; Meenakumari *et al.,* 2009). Trawls provide a major portion of the world's fish supply for direct human consumption (Sainsbury, 1996) and the trawling is considered to be a very effective method of catching demersal fish in terms of investment and yield (Scofield, 1948).

Trawlers are now the corner stone of the fisheries sector and 50% of total Indian marine catch comes from trawlers (Devaraj, *et al*., 1997; Devaraj and Vivekanandan, 1999). Mechanized crafts were first used for demersal trawling, targeting mainly shrimps. The highly profitable international market for shrimp exports in the 1960s due to the birth of a coastal trawler (Kurian, 1965). The national role in promoting exports gave further driving force to trawling. While numerous types modern of mechanized crafts have been adopted through various policy measures. whereas, most of the fishermen have strictly limited themselves to shallow-water fishing for varying reasons. Therefore, mechanised crafts directly or indirectly competing with the traditional sector which in turns to declining capture fisheries. Even though trawling is an effective technique for shrimps harvesting, but it also perceived as one of the most destructive and non-selective techniques of fishing.

In tropical nations such as India, the issue of by-catch is more convoluted due to multi-species nature of trawling. Bycatch is defined as the discarded catch of any living marine resource that retained incidental catch and unattended mortality due to a direct encounter with the fishing gear (NMFS 1998, 2003). The target catch is the catch of a fixed species, mainly obtained in a fishery and incidental catch is the retained catch of non - target organisms. Discarded catch would be the part of catch that returned into sea for maintaining cultural, legal or social considerations (McCaughran, 1992). Bycatch has been closely linked to fishing from initial stages of commercial fishing operations and lead to different challenges for fisheries managers. The efficiency of by-catch estimation is an important component to analyze spatial and temporal closures of fishing and ultimately it will helps gear technologists to develop mitigation strategy (Kennelly, 1999; Ortiz *et al.,* 2000; Lewison e*t al*., 2004). The need for bycatch assessment has been stressed by various authors (Alverson *et al.*, 1994; Alverson, 1997, 1998, 1999; Matsuoka, 1999; Ortiz *et al*., 2000; Cook, 2001; Sandra, 2003).

Knowledge on the climate change is necessary in order to take consideration of models and forecasting about the impact of ocean conditions on marine fish species. These will helps to harvest marine stocks effectively, and ultimately manage several marine fisheries rationally, rather than an average or mean ocean scenario (Kumar *et al.*, 2018). Deviations in the distribution of spatial fishes are crucial for environmental understanding otherwise it may result in overestimation of biomass and underestimation of fishing pressure, if not handled carefully (Crecco and Overholtz, 1990; Rose and Kulka, 1999). Fishing pressure also influences spatio-temporal changes in the composition of fish catches, mainly due to increased direct and indirect mortality of targeted fish, and in most circumstances also for non-target fauna. This would may negatively affect stock status, fish dynamics and marine ecosystem functioning (Jennings and Kaiser 1998; Blaber *et al.,* 1989; Beck *et al.,* 2003; Claridge *et al*., 1986; De Ben *et al.,* 1990; Ansari *et al*., 1995). Analysis of community spatial distribution and environmental variations with opposing environmental conditions may provide new information about the factors that influence and alter coastal ecosystem function as well as structure (Rouyer *et al.,* 2008; Link *et al.,* 2010; Aguzzi *et al*., 2015; Thiel *et al.,* 1995; Cheung *et al.,* 2013). Exploring the seasonal changes in catch composition and its abundance will also help to explain the impact of environmental factors on the coastal ecosystem (KronfeldSchor and Dayan 2003; Hut *et al.,* 2012).

Environmental variations affect recruitment, population increase, distribution, abundance and resource availability (Laevastu and Hayes, 1981). Thus, the assessment of environmental parameters which affect the abundance and distribution of the resource is important for fisheries management. It is not possible to quantify all these environmental parameters required to determine changes in marine environment. Specific conditions and processes affecting the fish population can often be deduced through remote sensing measurements (Shixin, 1993). Satellite remote sensing can be described as getting information from a distance about an object. The potential of remote satellite sensing technology for marine exploration and management has been accepted since the late 1960s when earth's first visible and infrared surface images were acquired from orbit. Nevertheless, important studies, development and expansion in the use of satellite remote sensing to address the requirements of fishery researchers for the assessment and monitoring of ocean conditions have been made mainly in the last decade.

Remote satellite offers the advantages of being synoptic on a broad scale, high spatial resolution, and regular exposure. The main drawbacks are that the satellite measurements are often limited to cloud-free regions and land contamination in near coastal region. The surface water conditions were found to be representative of those in most oceanic regions in the upper 100 to 200 metres. Evolving remote sensing technology from satellites, combined with sea-truth in-situ data collection techniques is a powerful tool for cost-effective management of living marine resources. While experimental fishing vessel-based in-situ sea-truth measurement offers high precision, it is an employment-intensive and time-consuming process and therefore it is not reasonable to provide a comprehensive regional water quality database for the region (Gholizadeh *et al.,* 2016; Hussein and Assaf,2020; Garg *et al.,* 2020). Moreover, in-situ sea-truth measurements are not easily able to identify the spatio-temporal variations over large regional scale environmental parameter quality which is vital for comprehensive assessment and management.

Global algorithm-based satellite remote sensing prediction sometimes suffers due to poor calibration of algorithm. In order to check the accuracy of such algorithm and suitability for regional condition, it is necessary to conduct quality assessment with the help of sea-truth data. The application of satellite remote sensing techniques is still needed to be validated and calibrated and requires detailed study at regional scale. It is therefore not entirely independent, but rather it is important to use remote sensing data in conjunction with traditional in-situ sea-truth measurements, as integration of the two provides better insight into the environmental parameters derived from remote sensing status at regional level.

The coastal waters off Mumbai are known to support rich fishery resources. Published literature on spatio-temporal pattern of catch composition, assessment of the quality of satellite-derived environmental parameters and influence of those parameters on trawl fish catches off Mumbai coast is scanty. Detailed understanding of the spatio-temporal scale of experimental trawl fishing and quality assessment of the satellite variables will help to improve an ecosystem-based fishery implementation plan across the area. With this background, the present study was formulated with the following objectives:

1. To study the pattern of catch composition and their spatio-temporal distribution

2. To assess the quality of satellite-derived environmental parameters using in-situ data

3. To correlate satellite-derived environmental data with in-situ trawl fish catch data

1 INTRODUCTION

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2. REVIEW OF LITERATURE

2.1. Trawl Fishery

The word trawl has Dutch origin as *Traghelen* and its meaning is to drag (Archibald, 2014). Trawl net is believed to have originated from the dredge nets used in the oyster fisheries. In their earlier type, the trawls had a robust rectangular frame, holding the bag on one edge and towing cables on the other (Bal and Rao, 1984). The trawl is a conical shaped net that is pulled across the sea bed. Rectangular boards, called otter boards, are placed on the wings of the trawl net to lift the entire net to the bottom and retain the lateral opening (Kurien and Wilman, 1982). Trawler is a fishing boat with sufficient power engines to pull the net at the appropriate trawling pace. They are armed with trawl winches and the proper accessories to carry the net on board and to lift the cod end over the deck (FAO, 1985). The design considerations of trawl are fairly simple, a mechanism for holding the mouth of the net open in horizontal and vertical aspects. There is a body of the net that further directs fish inwards and a cod-end of an appropriate mesh size, in which the fish are collected. The size and configuration of the net used is assessed by the species being pursued, the engine power and locally imposed regulations. Depending on the geographic origin, the type of fish the trawlers capture, the fishing technique used and based on their design, the trawlers vary in size, to small boats to large freezer and factory trawlers (FAO, 1985). Cod end is the part of the net that eventually catches the fish. The mesh in the end of the cod is determined by the size of the fish that the net catches. The regulation of mesh size is therefore a common way to control the mortality of juvenile fish in trawl (FAO, 1982).

Trawling represents one of the most common fishing practices along the coastal oceans of the world (Graham,1938). Bottom trawlers contribute around 19 million tons of fish and invertebrates annually, almost 25% of global (Amoroso *et al*., 2018) and 50% of Asian marine landings (Sumaila and Cheung, 2015). Historical records of this fishing practice date back to 1376, then called "*wondyrechaun"* (Roberts. 2007). Bottom trawlers had been powered by sail until the early 19th century. However, the advent of the railways from the 1830s increased of demand of fish which lead to rapid increase in bottom trawling(Knauss, 2005). The development of steam trawlers in the 18th century marked the beginning of a rapid expansion of fishing practices that increased endurance-enabled vessels to fish in deeper water and for longer duration (Robinson,1996; Thurstan *et al*., 2010). The first attempt at introduction of trawling in Indian waters was by the mechanized vessel S.T. Premier in 1900 off Bombay coast (Hornell, 1916; Chidambaram, 1952; Mukundan and Hameed, 1993). Introduction of commercial trawlers along the Indian waters started with the commencement of the Indo-Norwegian Project in 1953 (Dineshbabu *et al*., 2016).

Various studies have been conducted in several places worldwide on the complexity, catch composition and temporal variations of trawling fishing. Son and Thuoc (2003) studied the catch composition of trawl net used in coastal waters of Vietnam, accounted for capture of fish belonging to families of Carangidae, Scombridae, Engraulidae and Clupeidae. Diversity and abundance of fish assemblages in trawling ground from Mersin Bay, north-eastern Mediterranean were studied by Gökçe *et al*. (2016). Stobutzki (2001) recorded 437 species from Australia’s northern trawling ground. Taiwo and Olopade (2014) studied the catch composition of trawl fishery in Nigerian coastal waters. Catch composition of trawl fisheries that operated along Bushehr coastal waters, the Northern Persian Gulf was reported by Paighambari and Daliri (2012). Barua *et al*. (2014) reported the catch composition of trawl catch from Bangladesh marine waters. Patterns in the community structure of trawl catch along coastal area of the South China Sea has been reported by Hajisamae and Yeesin (2010). Shakir and Bano (1998) reported a pattern of target and bycatch utilization in trawl fishery from Pakistan. Zupanovic and Mohiuddin (1973) studied the available potential fishery resources in the north-eastern Arabian Sea of West Pakistan region. Catch rate and catch composition of trawl net operating along Sibolga, North Sumatera was studied by Widodo and Mahiswara (2011). Due to the steep decline of shallow coastal water resources in the last five decades (Robinson,1996; Thurstan *et al*., 2010; Worm and Tittensor, 2011; Pusceddu *et al*., 2014), offshore fishing continues to expand, and trawling is steadily expanding at increasing depths. (Roberts, 2002; Morato *et al*.,2006).

Numerous authors have studied the trawl fishery of the Indian coast, and several of them have suggested measures to improve the fishery as well as for the conservation of stocks by managing the bycatch, mesh size and selectivity. Deshpande and George (1965) reported improved effectiveness of trawls with heavy ground rope and less buoyancy on the head rope. The earliest study on the fisheries bycatch along Indian waters was conducted by George *et al*. (1981). Sukumaran *et al.* (1982) had reported contribution of annual trawl catches from Malpe and Mangalore during 1980-82. Negative impacts of bottom trawling, technologies for bycatch reduction, biodiversity conservation, and measures for minimisation of bottom impacts for Indian waters were discussed by Meenakumari *et al*. (2009) and Boopendranath (2012). The discarded and the incidental catches consist of juveniles of commercially important fishes and other bottom biota (Boopendranath *et al*., 2008; Gibinkumar *et al*., 2012; Dineshbabu *et al*., 2013; Madhu *et al*., 2015). The efficiency of trawl improves in the large-meshed net without much reduction in the catch (Nayak, 1991; Nayak and Sheshappa, 1993). Talwar (1997) compared the performance of square-mesh panel trawl with a conventional trawl and reported higher catch in improvised square-mesh net (Talwar and Hanumanthappa, 2006). The pattern of bycatch generated by trawlers was studied by Pravin and Manohardoss, 1996; Pillai, 1998; Jagadis *et al*., 2003; Dixitulu, 2003; Zynudheen *et al*., 2004; Zacharia *et al*., 2006; Prabhu *et al.*, 2013)

2.2. Spatio-temporal pattern of fish catch composition

Analysis of spatio-temporal distribution pattern of species is one of the fundamental aspects of ecological studies (Cagnacci *et al.,* 2010; Tomkiewicz *et al.,* 2010). Spatio-temporal distribution of catch, effort and catch composition provide invaluable insights into the productivity of an area which supports target species. Marine fauna displays differences in habitat niches due to changes in behavior in res ponse to tides, currents and other environmental conditions round the year (Kronfeld-Schor and Dayan 2003; Hut *et al.,* 2012). The variability of the fish catch composition depends among other factors, on organism’s availability, access and susceptibility to fishing gear (González *et al.,* 1995). Highly diverse fish communities occur in the tropical and subtropical coastal zone (Longhurst and Pauly 1987). Such populations are assembled by various species such as pelagic fish and bottom-associated species, or shelters such as demersal fish (Allen and Robertson, 1994), which include complex and functional interrelationships between fish fauna and environment (Auster, 1988).However, it has been proven that these fishing methods are very efficient in showcasing changes in the catch composition (De la Cruz-Aguero *et al*., 1994, Abitia-Cárdenas *et al*., 1994, González *et al*., 1995, Madrid-Vera and Sánchez, 1997).

When considering the species as a whole within a community, these behavioural changes determine the overall spatio-temporal functioning of ecosystems (Tan *et al*., 2013). Analysis of community spatial trends and differences in certain habitats with competing anthropogenic pressures and environmental conditions provide new insights into how these factors interact and alter marine ecosystem structure and functioning (Link *et al.,* 2010; Rouyer *et al.,* 2008). Studying community spatiotemporal characteristics can help classify natural changes and anthropogenic fluctuations within the community organization (Arrington *et al.,* 2005; Boschilia *et al.,* 2012). Shift in spatio-temporal pattern attributed as a sign of the beginning of a trophic cascading and signals of predation induced top down effect on the mid-trophic species (Vivekanandan *et al.,* 2005). According to Sanders *et al.* (2003) and Mouchet *et al.* (2013), seasonal assessment allows for stronger inferences about structures underlying trends of community organization. Spatial structuring that may result from individual behavior, population dynamics, habitat preference can also be observed in catch and effort data (Maynou, 1998). Changes in climate which affected the marine ecosystem were reported by several researchers (Brodeur and Ware, 1995; Francis *et al.,* 1998, Hollowed and Wooster, 1995). As a result, one of the most notable changes reported in the catch composition from several fisheries (Pravin and Manohardoss,1996; Pillai,1998; Sanders *et al.,* 2003; Jagadis *et al*.,2003; Dixitulu,2003; Zynudheen *et al*., 2004; Vivekanandan *et al.,* 2005; Zacharia *et al*., 2005; Prabhu, 2013; Mouchet *et al.,*2013). The composition of the fish fauna in the coastal regions usually undergoes significant temporal variation due to a certain organism's sequential immigration and emigration (Hyndes *et al*., 1999).

Fishermen typically seek for high yield fishing grounds where they can receive the maximum catch rates with the least expenditure. Fisheries management focuses on robust methods to increase the efficiency of fishing operations by improving economic returns and reducing fishing effort while ensuring sustainability of the resources. Precise assessment of the spatial distribution of fishing resources can benefit managers in assessing harvest strategies and to set catch limits for spatially organised fisheries.

It is a challenging task for ecologists to illustrate changes in behavioural responses to environmental change or variability that determine the abundance of observed species in any area (Sarda and Aguzzi, 2012). Lack of knowledge about the abundance and distribution of a species would not only harm our understanding of the ecological system but also impact conservation management policies (Maitland, 1995). Many marine species studied to date, including several fish, exhibit diel and seasonal inactivity trends at all depths associated with continental margins (Naylor, 2010; Aguzzi *et al.,* 2015). Biotic processes such as food availability, predation and competition may also be important in driving spatial and temporal fish assembly patterns (Lankford and Targett, 1994; Barry *et al.,* 1996).

Several researchers around the world have recorded the spatiotemporal dynamics of fish fauna along coastal waters. The scientific survey data from the 1994 to 2010 in the Mediterranean Sea was analyzed by Morfin *et al*., (2012). They could observe that the patterns in strong spatial distribution, which occupied each species with its abundance, were associated and that their size was consistent over the time scale observed. De Ben *et al.,* (1990) studied spatiotemporal variability in the abundance of fish in Yaquina Bay, Oregon. Tremain and Adams (1995) described seasonal variations in fish diversity and abundance in the Lagoon North Indian River, Florida. The fish composition and assembly mechanisms of the macrotidal estuaries of the Eastern English Channel were analysed by Selleslagh *et al*., (2008). They reported that structures of fish assemblies such as species richness and abundance in the salinity gradient are generally more variable than the seasons. The spatiotemporal features of fish assembly structure in the North Sea were identified by Fujii (2015). Brosset *et al.,* (2017) studied spatio-temporal distribution in Mediterranean coastal waters and study of the size, spatial and time-related patterns of fish (García-Ruiz *et al*., 2019). It was noted that the structural patterns of fishery are caused by the spatio-temporal variations in coastal ecological process. Composition and spatiotemporal variation in the fish community structure were also reported from various other coastal ecosystems: Alamitos Bay, Allen and Horn, (1975) in Colorado Lagoon, California, Newport Bay (Allen, 1982), Scottish Coast (Nash and Gibson, 1982), California Coast (Yoklavich *et al.,* 1991), Moriarty, and Winemiller, (1997) in Texas village creeks.

Several researchers have attempted studies of spatiotemporal variations in co astal in Indian fisheries (Bapat *et al.,* 1972; Prabhu and Dhawan, 1974; Radhakrishnan, 1974; Rao, 1988; Mathai *et al.,* 1998; Venkataraman and Wafar, 2005; Rajkumar *et al.,* 2005, Sujatha, 2005; Ramesh *et al.,* 2008; Sreekanth *et al.,* 2017).Spatio-temporal distribution of puffer fish along the south-eastern Arabian Sea was investigated and mapped (Saha *et al.,* 2019). Dineshbabu *et al.* (2012) analysed Spatio-temporal pattern of trawl bycatch of Karnataka coast. Abdul Azeez *et al.* (2016) investigated the spatio-temporal distribution and abundance of ribbonfish off Saurashtra coast. Jyoti *et al.* (2018) studied spatio-temporal distribution and fishing ground range of small sized and medium sized dolphinfishes along the Saurashtra coast. Manojkumar *et al.* (2019) mapped the spatio-temporal pattern of pelagic elasmobranchs from south-east coast of India. Selvaraj *et al*. (2007); Bhendekar *et al.* (2016); Ratheesh Kumar (2019) described the spatiotemporal distribution and ichthyofaunal diversity along the Mumbai coast of Maharashtra state.

2.3. Satellite-derived environmental parameters

The accuracy and quality of data from remote sensing is highly dependent upon the precision of algorithms used for atmospheric correction. It is based in the open sea upon this assumption that water-leaving radiance is negligible in the Near-Infrared (NIR) region. This hypothesis helps to estimate the contribution of atmospheric molecules and aerosols both to reflectance. Owing to higher concentrations of suspended matter (TSM) and colored dissolved organic matter (CDOM), the NIR Black Ocean hypothesis is invalid for coastal waters since these causes substantial backscattering in the Near - infrared. The standard data extraction based on algorithms will result in reduced errors, and the regional algorithms are needed to retrieve the bio-optical characteristics from satellite data. These algorithms are derived from in-situ sea-truth measurements. Remote sensing by satellite can resolve this deficiency, if appropriate algorithms are designed. Integrating open sea algorithms to the optical complexities of coastal waters is one of the main issues which will serve as standards for the development of algorithms in optically complex coastal waters. Comparison of remote sensing data along with sea-truth provides an opportunity to highlight existing instrumental biases and emphasis on future developments.

2.3.1. Sea Surface chlorophyll

Sea Surface chlorophyll (hereafter chlorophyll-*a*) is found inside the living cells of phytoplankton. Chlorophyl-a, an important factor in the mechanism in which life-sustaining oxygen is produced, is known for its role in photosynthesis. Chlorophyll-a is the key photosynthetic pigment of oceanic phytoplankton (Platt *et al*., 2010, Pettersson and Pozdnyakov, 2012). Phytoplankton plays a major role in deciding water colour. The most commonly used product extracted from the satellite ocean color is probably chlorophyll-a (chl a), a phytoplankton biomass index with various applications such as phytoplankton ecology and phenology (Vargas *et al*., 2009; Racault *et al*., 2012), carbon cycles (Siegel *et al*.,2014) climate change, transfer of energy to higher trophic levels, and water quality (Toming *et al*., 2017). Phytoplankton's influence on the color of the water has been investigated for many years. However, with the introduction of satellite, it has become possible to obtain many parameters which are otherwise not possible by research vessel-based analysis. Satellite data of ocean color from atmosphere began in 1978, when NASA successfully tested the Coastal Zone Color Scanner (CZCS). It was an exciting project that was intended to last for only a year, and the sensor continued to obtain valuable time-series data over specified test sites until early 1986.

After CZCS, SeaWiFS (Sea-Viewing Wide Field-of View Sensor) acquired chlorophyll-a from 1997 to 2010 for a global view at 4 km resolution and a 1 km local view. (Hooker *et al.,* 1992). As ocean biochemistry is strongly influenced by physical factors such as temperature, salinity, light and dynamics (mixing and upwelling), the reality that precise time series of geophysical factors such as sea surface temperature, wind speed, and sea level were readily available for correlation analyzes with SeaWiFS data meant a marked improvement for the ocean color (McClain, 2009).

Numerous findings have presented extensive empirical assessments of global variability in the context of physical dynamics. (e.g., Wilson and Adamec, 2002;Doney *et al*., 2003; Yoder and Kennelly, 2003; Uz and Yoder, 2004; Wilson and Coles, 2005; Hattab *et al.,* 2013). Since then, MODIS-Aqua (since 2002), MODIS-Terra (2000-present) and MEdium Resolution Imaging Spectrometer (MERIS) ENVISAT (2002-2012) have been made available. MERIS's main purpose is to investigate the color of the water, both in the open ocean and in coastal areas (Rast *et al*., 1999). VIIRS-SNPP (2011-present) have taken over missions with medium spatial resolutions in ocean-color monitoring. Sentinel- 3A, launched in 2016, and Sentinel-3B, which followed in 2018, work in a pair to cover the ground. Sentinel- 3C and Sentinel-3D are also planned to be launched from 2021 onwards. The Ocean Land Color Instrument (OLCI) onboard Sentinel-3 is an optical instrument that provides data continuity to the MERIS capability. OLCI and MERIS have similar spectral range and spatial resolution. This satellite provides improved spatial and spectral resolutions although the loss of temporal resolution will be counterbalanced as new satellites adhere to the configurations.

Satellite-derived chl-*a* concentration is a popular ocean colour commodity used not only by professionals in the field of bio-optics but also by numerous fisheries scientific organizations, including modelling, data assimilation (Natvik and Evensen, 2003), fisheries applications (IOCCG, 2009) and sustainable development (McIver *et al.*, 2018). Changes in water color are caused by variations in the nature of optically active substances (Morel and Prieur, 1977), suspended particulate matter, pigments (chlorophyll-a, b and c) in algae (Shengguang *et al*., 1991) and dissolved organic matter (Plass *et al*., 1978). The blue color of the oligotrophic oceans is caused by the strength of selective absorption and dispersion of water molecules. Marine ecosystems are controlled by bottom-up regulation, emphasizing the importance of phytoplankton as the bottom of the food chain web (Frederiksen *et al*., 2006). The link between phytoplankton and fish is affected by the type and chemical characteristics of the ecosystems (Schwartzlose and Alheit, 1999).

Chlorophyll-*a* (Chl-*a*) absorbs light from violet-blue and orange-red wavelengths and reflects green / yellow color, reflecting in the green color. It has become a well-established process used by different satellites for photosynthesis detection of chlorophyll. Sea Surface chlorophyll-a is extremely significant for fisheries, because it's the only remotely-sensed parameter directly measuring the ecosystem's biological basis (Wilson and Adamec, 2002; Wilson and Coles, 2005). Although Chl-*a* is the most abundant biological oceanic measurement, however, the data generated is scarce in comparison with the number of other physical observations studied (e.g., temperature and salinity). It is identified that several currently underway Chlorophyll-*a* validation efforts focus entirely on satellite-derived value extraction comparative analysis with regional in situ sets of data, several of which are linked to specific, or separate, field campaigns (Barbini *et al.*, 2005). Most ocean-colored satellites have space resolutions that range between 300 m and 1.1 km.

A large spectrum of in-situ spatio-temporal data measurements of high quality are highly significant in the discovery of novel and evaluation of current algorithms. The sea-truth measurement is faced with many hiccups like disparities in sampling protocols, spatial coverage, time management, huge cost, sampling errors, paucity of wide-ranging observations, etc. The global algorithms were developed for the ocean color products (SeaWiFS, MODIS Terra, MODIS Aqua, OCM2 and VIIRS), which provide a synoptic view of the globe. Presently there are few scattered sea-truth datasets available in the sphere of the globe, which are vital for the development of regional specific algorithms and support the validation of global ocean color missions. Chlorophyll-a calculated with raw data from satellite sensors is processed using different algorithms.

The algorithms for converting satellite observations into oceanic variables usually work based on the (Rrs) remote sensing reflectance (O'Reilly *et al*., 1998; O'Reilly, and Werdell, 2019). Two types of algorithm have been historically employed to derive chl-a concentration from satellite-derived radiance (Dierssen, 2010; Hu and Campbell, 2014). The first is the empirical algorithm, which works via regression, sequencing the blue-to-green wavelength ratio or the difference of Rrs against chl-a concentration (e.g., Kahru and Mitchell, 1999; O'Reilly *et al.*, 2000; Hu *et al*., 2012). The second is the semi-analytical algorithm, which operates by solving equations of chl-a concentration and water-leaving radiance established from models of the radiative transfer theory using certain bio-optical assumptions (e.g., Sathyendranath *et al*., 1989; Carder *et al*., 1999; Lee *et al*., 2002; Maritorena *et al*., 2002; IOCCG, 2006). In addition to these two algorithm types, hybrid or neural network (NN)-based algorithms have also been developed (e.g., Doerffer and Schiller, 2007; Hu *et al*., 2012, 2019). There are no accepted algorithms available to retrieve information from remote sensing reflection and light wavelengths so that chlorophyll-a value can be accurately detected.

The color of coastal water is influenced by human-induced contaminants, detritus that interfere with reflection therefore cannot function for both coastal and open waters. Validation studies indicate that coastal algorithms need to be modified to get the necessary precision. Case-I waters refer to the oceanic water whose optical properties are dominated by phytoplankton and their associated degradation products (Morel and Prieur, 1977). Case 2 waters refer to the coastal water which is influenced by the optical interference of both suspended particulate matter (SPM) and colored dissolved organic matter (CDOM) (Carder *et al*., 1991; Bukata *et al*., 1995; Hu *et al*., 2000; Pradhan *et al*., 2005; Tilstone *et al*., 2013). Unlike the oceans, coastal waters are affected by a large quantity of particulate material, land-derived yellow substance, river inputs, and land drainage. In general, global algorithms are only suitable for Case-I water, which is the open ocean. By contrast, Case- II water under the influence of continental discharge cannot match a global specific algorithm and a local algorithm is required (Ruddick *et al*., 2001; Gitelson *et al*., 2009; Moses *et al*., 2009). Therefore, it is important to develop and tune the appropriate chl-a retrieval algorithm depending on the spectral characteristics of each sea area studied and ocean color sensor used (Gitelson *et al*., 1996; Garcia *et al*., 2005; Hattab *et al*., 2013). A thorough comprehension of ocean color measurements including the specification of the ocean color sensors and bio-optical algorithms are required in order to extract accurate chl-a data from observations several hundred kilometers above Earth. The satellite sensor offers useful information about chlorophyll-a concentration. A number of algorithm-based methods have been developed to extract chlorophyll-a concentration.

The development of region-specific algorithms is based on the relationship between Blue and Green portions of satellite bands, electromagnetic radiation and chlorophyll-a concentration information about sea-truth. The estimation of Chl-*a* from ocean color satellites remains a difficult job in coastal waters, where the optical properties are affected not only by phytoplankton, but also by other water components, including TSM and colored dissolved organic matter (CDOM) (Morel and Prieur, 1977; Gordon and Morel, 1983; Tassan, 1994; Bukata *et al*., 1995; IOCCG, 2000; Ruddick *et al*., 2001; Pradhan *et al*., 2005; Siswanto *et al*., 2011; Tilstone *et al*., 2013). Therefore, the coastal water should have a regionally customized Chl-*a* algorithm framework modified after testing and tuning with in situ sea-truth datasets. (Gitelson *et al*., 1996; Garcia *et al.,* 2005; Hattab *et al*., 2013). Several Chl-*a* extraction methods based on improved algorithms were developed and evaluated for different coastal region (Moon *et al*., 2010; Siswanto *et al.,* 2011; Kim *et al*., 2016). These validation studies along coastal water showed that these Chl-*a* value extraction methods were not suitable because of the diverse bio-optical properties observed. With the help of the series of ocean color sensors from CZCS to Sentinel, there has been progress in understanding the changes in the marine ecosystem and the impact of rapid climate change on the oceanic biosphere environment based on the imageries of chl-*a* concentrations in the oceans and coasts (e.g., Smetacek and Cloern, 2008; Martinez *et al*., 2009; Racault *et al*., 2012; Siegel *et al*., 2013).

2.3.2. Sea Surface Temperature (SST)

Sea surface temperature is a measurement of the temperature at the top of the ocean's surface, preferably few (mm) millimeters (Luo *et al*., 2019). SST is an essential factor for the biological cycle, the exchange of heat and the atmospheric momentum (Karagali *et al*., 2012), ecological and biogeochemical processes; it controls water metabolism and specifies the habitat area for aquatic life (Ding *et al.,* 2015). Understanding of SST is essential for research, commercial and social use (Oke *et al*., 2015), such as weather forecasting, air-sea interaction, climate change studies, fisheries, and coastal zone management (Karagali *et al*., 2012; Alavipanah *et al*., 2016). SST is an integral component of coastal processes including biological activity, heat momentum, circulation and atmospheric interaction (Alavipanah *et al*., 2016).

Heat transferred from the oceans to the atmosphere, and interactions between the two processes make the surface of earth habitable (Marullo *et al*., 2010). The heat exchanges between the ocean and the atmosphere are determined by humidity, gases and sea surface temperature (Donlon *et al*., 2002; Minnett, 2019). The high-resolution SST maps will display currents and eddies on the ocean floor. Real time SST processing is important for fisheries and meteorological forecasts (Hasoda *et al*., 2007). Remote sensing collaboration with SST satellites has two major advantages. First, high-resolution global coverage by one or more sensors generating a reliable data set (Azmi *et al.,* 2015). Secondly, a physical attribute can be calculated with minimal effort. Satellite instruments can also determine the useful accuracy (Hasoda *et al*., 2007).

Advanced Very High-Resolution Radiometers (AVHRRs) on board National Oceanic and Atmospheric Administration (NOAA) have been operating the satellites since 1978 (McClain *et al*., 1985). The Visible Infrared Imaging Radiometer Suite (VIIRS), launched in 2011, is a modern, improved satellite to replace the AVHRRs satellite (Wolfe *et al*., 2013). VIIRS sensor started on the lines of NASA MODIS (Moderate Resolution Imaging Spectroradiometers) consisting of two sensors, Terra and Aqua since 1999 and 2002, respectively. VIIRS and MODIS are known for their identical spectral bands, which leads to better radiometric as well as spatial coverage every day (Kilpatrick *et al*., 2019). Findings of such sensors provide precise observation (Hillger, 2013; Hillger, 2014).

SST satellite sensors measure electromagnetic radiation (EMR) which is emitted from the sea surface (Hillger *et al*., 1993). Satellite sensor bands sensitiveness to record EMR helps to retrieve required observation from space. The reflected frequency computed in the form radiation leaving and converted into values to get SST by applying a nonlinear set of rules and algorithm. In addition, visible and near-infrared wavelengths are used in the production of satellite-derived SST to identify clouds and water vapor (Pinker *et al*., 2018). SST difference is linked with atmospheric and oceanic variations with a range of temporal and spatial scales (Willis *et al*., 2004). Due to its property of light to travel in waves, SST can be recorded via satellite sensors. Perhaps every wavelength corresponds to a particular frequency; the size of that frequency can be measured and any changes in the size can be correlated with a change in temperature. The wavelengths used for SST measurements are infrared (3.55 -12.5 μm) and microwave (6.9-89 GHz) because of their various attenuation lengths correspond to an SST at a depth of a few mm to infrared wavelength of 20 micrometers (Kusuma *et al*.,2017). Their unique characteristics are that infra - red measurements are available with high precision and sensitivity, but are prone to cloud coverage, while microwave measurements are available at lower resolution, but are capable of penetrating cloud cover due to the extremely low microwave emissions (Kennedy *et al*., 2011). Because of satellite sensor data showing some amount of uncertainty related to various factors like cloud cover, presence of aerosols, diurnal fluctuations, sensor and satellite drift, these measurements often used an algorithm or reference dataset to improve accuracy (Comiso and Kwok,1996). It is important that the satellite images have the correct temporal and spatial resolution to estimate the surface temperature. Remotely sensed thermal bands use radiative transfer equation relating to surface temperatures. Since its inception SST calculations using thermal infrared data sets began and measurement tools have been developed to improve the accuracy (Li *et al*., 2013).

Recovery of SST is only prevented in sun-glitter, rain or near-field regions. Since there is only a small percentage of unsuccessful retrievals, almost complete global coverage is attained constantly (Cronin *et al*., 2019). Small errors in the wind speed, water vapor or cloud liquid water recovered can create errors in the SST. The major problems in recovering satellite SST data are required corrections for atmospheric effects, especially water vapor absorption and emission (Gentemann, 2014).

Development of sensors with different algorithms in recent decades has resulted in improved surface temperature measurement using satellite data. (Hosoda and Qin, 2011; Kilpatrick *et al*., 2001; Liang and Ignatov, 2013). These algorithms is based on an assumption of radiation equation guesstimates. SST Algorithms are separated into three general categories (Li *et al*., 2013): a) Single-Channel method developed by Jiménez-Muñoz and Sobrino,(2003) which helps to reduce the error of the final retrieved value due to the error of the mean temperature measurement b) Split Window methods, developed by Mcmillin, (1975) which is useful for detecting relatively thin clouds and c) Dual Angle methods given by Prata (1993, 1994), using single wavelength channel at two different observation angles. As the number of drifting buoys for in-situ sea-truth data increased in the world's ocean, it became apparent that SSTs collected from these sources constituted a more accurate and less noisy set of data to use for the computation of the satellite-based SST algorithm coefficients (Reynolds *et al*., 2007; Reynolds *et al.,* 1989). Yokoyama *et al*., (1995) mentioned that in-situ sea-truth buoy derived SSTs became the reference system for the computation of satellite SST. To understand the accuracy and quality of satellite-derived SST, several researchers have attempted a multitude of validation efforts in coastal waters and open oceans by comparing with sea-truth data (McMillin and Crosby 1984; Strong and McClain 1984; McClain *et al.,* 1985: Walton 1988; Bates and Diaz 1991; Gong *et al*., 1992; Lin *et al.,* 1992; Liao *et al.,* 1997; Lee *et al*., 1999; Yokoyama *et al.,* 1995).

2.3.3. Sea Surface Salinity (SSS)

Salinity describes the concentration of dissolved inorganic salts (grams of salt per kilogram of seawater or parts per 1000 grams) in seawater (Rhoades, 1996). The use of conductivity, temperature and pressure measurements to estimate the ionic content of seawater contributed to the creation of the scale PSS-78 in 1978 (UNESCO, 1981). Since Salinity is a ratio of conductivity, temperature and pressure hence the value is actually dimensionless (no units) in PSS-78 scale. The suffix psu or PSU (denoting practical unit of salinity) is often applied to the calculated values of PSS-78. Quantifying variations in salinity in the sea and discovering its underlying processes is regarded as essential in physical oceanography (Telesh *et al.,* 2013). Historically, salinity is among the inadequately-sampled quantities of the time-varying sea process. Complete understanding of long-term changes in salinity in the seas still less known.

Salinity of the sea surface has been measured since the late 19th century (Bingham and Lee, 2017). The salinity analyses were undertaken for the given seawater sample using various chemical titration techniques (Durack, 2011). In the 1950s, Conductivity-Temperature-Depth (CTD) platforms were created, which provided an improvement in data quality but with small spatial distribution (Durack, 2011; Alory *et al.,* 2012).

First efforts to evaluate SSS from space started in 1968 on board the Soviet Cosmos 243 and Skylab S-194 satellite missions in 1973 (Lerner and Hollinger, 1977). It used highpoint-looking L band horizontal (HH) microwave radiometers with a beam width of 3 dB of 15° with ground footprint of ~110 km (Swift and McIntosh, 1983). Apparently, only a very limited amount of L-band radiometer data was gathered, and in situ sea-truth measurements weren't available at that time to verify observed SSS (Droppelman *et al.,* 1970). Nevertheless, the retrieved and observed SSS was found to be correlated with recently available sea-truth in situ salinity. Overall, these experiments showed that a promising early result could be calculated with a precision of roughly 2 pss.

Based on these initial aircraft and satellite tests, Swift and McIntosh (1983) proposed a revised satellite model with a footprint spatial resolution of ~100 km to achieve an ideal precision of about 0.25 pss. During that time research institutions were engaged in the surface temperature measurement missions (Advanced Very High Resolution Radiometers (AVHRRs) and Along Track Scanning Radiometers (ATSRs) Merchant *et al.,* 2019), wind stress (SEASAT A Scatterometer (SASS), Brown, 1983),surface dynamic topography (Geosat (GEOdetic SATellite), Cheney *et al*., 1989),ocean color (Coastal SATellite). Primarily due to the scientific challenges associated with the launch of large sized sensors required for high radiometric selectivity, salinity remote sensing was assumed too costly and not given utmost importance (Njoku *et al.*, 1999).

The European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) satellite mission, performing since the end of 2009, has been the first orbital radiometer to collect daily and regional measurements (Font *et al*., 2010). The National Aeronautics and Space Administration (NASA) Aquarius mission was launched with the main goal of providing global space-operated SSS readings from mid-2011 through mid-2015(Lagerloef *et al*., 2008). NASA's Soil Moisture Active Passive

(SMAP) program has been functioning since early 2015 (Entekhabi *et al.,* 2014), primarily dedicated to soil moisture measurements but also to tracking SSS.

SMOS and Aquarius SSS data validation experiments concentrating on warm waters with significant variability in salinity (Reul *et al.,* 2014). Banks *et al.,* (2012) used Argo and model data to validate the first SMOS SSS retrievals in the Atlantic Ocean from 60^0 to 60^0N. Boutin *et al.,* (2013) examined the impact of rainfall on sea surface salinity and compared SMOS and Argo measurements in the Pacific Ocean. Lee *et al.* (2012) utilized Aquarius data to identify complex SSS attributes associated with tropical depression waves in the eastern equatorial Pacific. Besides, modern surface-drifter observations of near-surface salinity were evaluated in the top 50 cm and SMOS measurements in heavy rainfall and tropical climates (Morisset *et al*., 2012). Boutin *et al.* (2013) described that the satellite retrieved SSS data capacity in tropical and subtropical regions of the world where the accuracy of SMOS SSS is approximately 0.3 on average over 10 days, whereas the accuracy in high latitudes will be even less than 0.5. In general, SMOS and Aquarius data are more impacted by Radio Frequency Interference (RFI) than SMAP data in a range of main oceanic regions (e.g. Asian coastlines, Bay of Bengal, Arab Sea, Mediterranean). Since the SMAP sensor is equipped with a solely devoted on-board RFI filtering device, the SSS from this device provides better results in intensely RFI contaminated areas such as the northern (BoB) Bay of Bengal (e.g. Fournier *et al*., 2016, 2017). The expected value of SMAP SSS would include biases of roughly to 0.2 pss in the open ocean from low to middle latitude (Fore *et al*., 2018).

The quantified accuracy of SSS from the SMOS over a 10-day cycle on a 200 km grid is 0.1 practical salinity units (psu). The SSS products from such a satellite have recently validated by Reul (2011), Subrahmanyam *et al*. (2013) and Ratheesh *et al.* (2013) with in situ measurements in the tropical Indian Ocean (TIO). They demonstrated that the root mean square error (RMSE) in SSS from the SMOS would be of the order of 0.3 psu with in situ measurements over the Southern and Equatorial Indian Ocean (EIO), but the error over the Northern Indian Ocean increases. SMOS SSS data is ideal for open ocean applications, the existing SMOS SSS retrievals are of low quality in the BoB area due to substantial radio frequency interference (RFI) pollution and land signals (Akhil *et al.,* 2016; Boutin *et al*., 2012; Subrahmanyam *et al.,* 2013). By contrast, Aquarius performs much better in tracking large-scale SSS trends in the BoB (Akhil *et al.,* 2016), but is not appropriate for tracking the freshwater plume due to its lower spatial resolution (110 km) and because measurements within 150 km of the coast are normally compromised with land signals (Aquarius User Guide, 2015). The SSS products from the satellite were extensively validated with in-situ sea-truth observations. Based on study it was observed that the SSS from the satellite was in good agreement with in-situ observations (Font *et al.,* 2009; Prakash and Gairola, 2013; Ratheesh *et al.,* 2013; Subrahmanyam *et al.,*2013; Menezes *et al*., 2014; Köhler *et al*., 2015; Fournier *et al.,* 2016; Tang *et al.,* 2017; Fournier *et al*., 2017; Garcia-Eidell *et al*., 2017; Olmedo *et al.,* 2018; Tang *et al.,* 2018; Vazquez-Cuervo *et al.,* 2018; Dinnat *et al.,* 2019; Grodsky *et al.,* 2018; Bao *et al.,* 2019; Grodsky *et al.,* 2019; Garcia-Eidell *et al*., 2019; Vazquez-Cuervo *et al.,* 2019; Menezes, 2020; Yu, 2020)

2.4. Influence of environmental factors on fishery

Knowledge of spatiotemporal changes in marine ecosystem environmental parameters is important for understanding the biological process, environmental health and biological integrity, since they reveal significant information about general hydrobiological interrelationships (Walther *et al.,* 2002; Limbu and Kyewalyanga, 2015). Fish production in nature, directly or indirectly is affected by critical factors such as an ecosystem and climate, fishing practices and anthropogenic events (Brander, 2007; Behera *et al*., 2017; Supraba *et al.,* 2016). Thus, spatial variations in marine fish abundance can be attributed mainly to environmental conditions, human pressure, physiological requirements and fishing (Glantz, 1990; Beamish *et al.,* 1999; Lotze *et al.,* 2006). Environmental variables are known to be crucial factors in assessing the structure, distribution, assembly and abundance of fish species in an aquatic environment (Whitfield and Elliot 2002; Mansor *et al.,* 2012). Individual fish species and communities are documented to have strong physiological and behavioural responses to environmental changes (Boesch and Turner, 1984). It is anticipated that marine ecosystems will change rapidly in response to spatiotemporal environmental variations (Biswas *et al.,* 2009). Physicochemical factor fluctuations have a profound impact on the periodic and seasonal variations in the structure of the fish community (Kawasaki *et al*., 1991).The biotic processes, such as food availability, predation and competition, are among other important factors in driving the occurrence of spatial and temporal patterns of fish assemblage (Ramos *et al*., 2011; Gjosaeter, 1988).

At a regional scale, effects of winds, tide and habitat (Tupper and Boutiller, 1995) have shown to influence the spatiotemporal distribution of fishes. It is reported that environmental variations in the coastal ecosystem also influenced by onset of rain which expected to affect the spatiotemporal distribution of aquatic species and thus, influence the movement, feeding, growth, spawning, diversity, and abundance of organisms (Qasim, 1973; James, 1992; Tremain and Adams, 1995; Roessig *et al*., 2004; Das *et al*., 1997). Spatiotemporal changes in physiological and oceans biogeochemical factors contribute to changes in physiology, phenology, distribution and assemblage of species (Perry *et al*., 2005; Rosa and Seibel, 2008; Portner, 2010). Salinity and turbidity on a spatial scale and temporal pattern in temperature are the best predictors for species abundance and spatio-temporal population structure in coastal ecosystems (Akin *et al*., 2005; Selleslagh & Amara, 2008; Whitfield 1999; Thiel *et al.* 1995; Marais 1982; Haedrich 1983; Jaureguizar *et al.* 2004;). Temperature (Peterson and Ross, 1991; Jaureguizar *et al*., 2004), salinity (Ansari *et al.,* 1995; Thiel *et al.,* 1995; Whitfield, 1999), turbidity (Blaber and Blaber, 1980; Sreekanth *et al.* 2017), pH (Dutta *et al*., 2016), nutrients and the area’s productivity, comprising both phytoplankton and zooplankton (Thomas *et al.,* 2016), are major environmental variables affecting species in coastal areas.

The subject of concern for many fisheries researchers is spatio-temporal changes in the distribution of aquatic species in relation to environmental variables. Salinity fluctuations due to heavy rainfall, variations in the temperature, pH, DO and availability of prey items were attributed to the seasonal variations in catch composition (Gjosaeter 1988; Tremain and Adams, 1995; Maravelias and Reid, 1997; Maravelias *et al*., 2000; Olukolajo and Oluwaseun, 2008; Ramos *et al*., 2011). Concentrations of dissolved oxygen, temperature, water velocity and composition of substratum have been reported to affect fish assembly (Daga *et al.,* 2012). Previous research found that minute changes in environmental parameters influence d ontogenic characteristics and movement patterns of many fishes (Lehodey *et al*., 2006; Schwartzlose and Alheit, 1999). Distributions, assemblage, behavioural change and pattern of distribution are apparent in fishes due to their long migration movements (Cheung *et al.,* 2013).

Several researchers have studied the relationship between environmental parameters in relation to fisheries along the Indian coast (Shirodkar *et al*., 2012;

Sankaranarayanan and Qasim, 1969; Govindasamy *et al.,* 2000; Madhupratap *et al*., 2001., Kumar *et al.,* 2009; Kulshreshtha *et al*., 1989; Kalaiarasi *et al*., 2012; George *et al.,* 2012; Manjusha *et al*., 2013; Bharti *et al*., 2020). Marine fishes migrate to offshore waters from coastal waters during rainy season to avoid influx of low saline water which affects the catch contribution (Ratheesh Kumar *et al.,* 2019; Kunju,1968) Jayachandran *et al.* (2012) observed the influence of environmental factors on fish assemblage along south-west coast of India. Menon *et al*., (2019) reported that the weather and oceanographic factors including temperature, salinity, wind, current, water mass movement, upwelling and sunset affected the recruitment and abundance of numerous marine fish along the Indian coast. Mafalda and Rubín (2006) stated that the temperature is one of the main determining factors in seasonal distribution of marine organisms. Temperature variation is known to play a primary role in primary productivity by influencing the abundance of primary producers on which many organisms depend (Mercado *et al.,* 2006). Temperature played an important role in structuring fish assemblages on the northeast coast of the United States (Ayvazian *et al.,* 1992). Thiel *et al.* (1995) reported the temperature of the water as a significant predictor for the fish abundance of Elbe estuary.

Whitfield *et al.* (1994) reported the salinity characteristic, especially in coastal areas, has influenced spatio-temporal variations in fish populations. Salinity is an important element in a coastal environment affecting the abundance, distribution, and population structure of fish (Elliott and Dewailly, 1995; Emmerson, 1989; Lehtonen *et al.,* 2016). Variation of salinity affects survival and distribution at different life stages of fish (Sunde *et al.*, 2018). For optimum growth and survival, fish may detect their salinity range which in turn affect their distribution (Gross, 1991). The variation in salinity affects metabolism, growth, breeding and other physiological systems that then affect species distribution and abundance (Tibblin *et al.,* 2012; Huang *et al*., 2014; Glover *et al.,* 2012). Temperature and salinity changes affect the availability of habitat and feed timing, and performance of essential life events such as fish recruitment, development, and diel movements (Gunter, 1956; Glova and McInerney, 1977; Gillson, 2011; Morrongiello *et al*., 2014). Aquatic animals cannot tolerate minute pH changes because they have a detrimental effect on their growth and reproduction and in most instances, fish tend to move to a stable pH range (West *et al.*, 1977).

Dissolved Oxygen (DO) regarded as the most critical environmental variable affecting fish biology and its spatiotemporal distribution (Wannamaker and Rice, 2000; Maes *et al.,* 2004; Bell and Eggleston, 2005). The biota and the decomposition of organic matter extract DO from the natural waters by respiration. A vertical or horizontal shift of habitat is one of the important behavioral responses of fish to the reduced DO (Kramer, 1987; Altenritter *et al*., 2018). Several experiments indicate that fish exhibit avoidance responses to low rates of DO (Suthers and Gee, 1986; Birtwell and Kruzynski, 1989). Many fish rely on the water current to access to breeding sites and suitable habitat (Klemas, 2012). Currents are one of the most important factors influencing the variability in fish larvae and egg distribution (Kandler, 1950; Bishai, 1960; Johansson *et al*., 2014; Bashevkin *et al*., 2020). The marine fishery especially the pelagic fishery is readily influenced by currents in their initial stages. The dispersal of eggs, larval rearing, larval feeding, and migration of fishes are dependent on currents in the ocean. Recently it has been reported that the Japanese Eel catch have declined due to the potential impact of a change in ocean current pattern (Morgan,1995; Llopiz *et al.,* 2014; Solanki *et al.,* 2017; Chang *et al.,* 2018).

Many of these efforts highlight the fact that marine ecosystems, both pelagic and demersal, including the deep sea, have been changing constantly in their spatial and temporal patterns progressively influenced by their respective environment and ecosystem parameters (Barange *et al.,* 2014). Changes in the distribution and availability of environment-related fish often impact the fishing communities that harvest those fish resources. (Roessig *et al.,* 2004). Recognizing the spatio-temporal variations in the characteristics of the marine environment is important in order to manage fisheries effectively, since these characteristics play a crucial role in the access and availability of fish stocks (Kawasaki *et al*., 1991). The importance of species-specific environmental factors was long recognized across temperate regions (Brett and Groves, 1979; Jackson *et al.,* 2001) but least considered in tropical areas (Rainboth, 1996, Ficke *et al.,* 2007).

1 INTRODUCTION

2 REVIEW OF LITERATURE

3 MATERIAL AND METHODS

4 RESULT

5 DISCUSSION

6 SUMMARY

7 REFERENCES

3. MATERIAL AND METHODS

3.1. Location of the study

The state of Maharashtra is one of the major marine fish producing states of India. The Maharashtra coastline is approximately 720 kilometers long and includes six districts: Thane, Greater Mumbai, Raigad, Ratnagiri, Palghar and Sindhudurg. The state's marine fish production is estimated at 2.95 lakh tons. The coastal fishing fleet consists of 12154 mechanized and 2292 non-mechanized vessels (CMFRI, 2010). The state's major fisheries are trawling, bag net fishing, gillnetting and purse seining. The state of Maharashtra lies within 73° 15' to 80° 33'East longitude and 15° 44' to 21° 40' North latitude. The coastal fishing ground of Mumbai was selected as the study area for research work. The seven islands that make up Mumbai were home to fishing communities. The seven islands, along with most of the Salsette Island and Trombey Island, have been joined into one trapezoidal landmass over the centuries, forming the present Greater Mumbai Landmass, covering a total area of 469 km^2.

3.2. Experimental Fishing

Experimental fishing was conducted on M.F.V NARMADA (IV), training cum research vessel of ICAR-Central Institute of Fisheries Education, Mumbai from September 2017 to May 2019 to fulfil the objectives of research. The details of the vessel are provided in the Table 3.2.1. The experimental fishing operations were carried out between 18°57'N to 19°12'N latitude and 72°40' E to 72°43' E longitude (Map 1). Fishing was conducted using 35 m bottom trawl with 35 mm mesh size cod end. Specifications of the net are provided in the Table 3.2.1. The GPS on-board (GARMIN 420 S) was used to navigate to different locations (area-wise and depth-wise) along the Mumbai coast. All the trawling operations were carried out during day time and identical shooting and hauling procedures were adopted during the entire fishing operations. During the selectivity experiments, 46 hauls of 1-hour duration were carried out in the depth range of 6-21 m, at a trawling speed of 1.5-2.5 knots. The water depth was measured manually using a graduated nylon rope with an iron sinker.

3.3. Geospatial Analysis

Data regarding date, time, speed of boat and geospatial data of each point of shooting and hauling of all trawling operations along with the catch of each haul was collected. The total Catch Per Unit Effort and species level CPUE were calculated by using Microsoft Excel 2019. Base map of India with WGS84 coordinate reference system showing coastline was used for the study. The data were interpreted with GIS based software package (ArcGIS10.3 and QGIS 10.3) to spatially interpolate and demarcate the fishing ground and spatio-temporal variation in catch. For interpolation Inverse distance Weighted (IDW) method was used. The IDW interpolator assumes that each input point has a local influence that diminishes with distance. Use of this method assumes that the variable being mapped decreases in influence with distance from its sampled locations.

3.4. Taxonomic identification

Fish catch samples obtained during experimental fishing were collected, preserved in crushed ice and transported to laboratory for further analyses. Separated fish catch was classified up to the species level. Species identification was done using standard taxonomic methods such as morphology, colour, morphology and meristic counts (Fischer and Whitehead, 1974; Fischer and Bianchi, 1984; Talwar and Kacker, 1984), and internet websites such as WORMS (Eschmeyer and Fong, 2020), FishBase (Froese and Pauly, 2010) and Sealifebase (Palomares and Pauly, 2010). Digital camera was used for taking pictures of fish samples.

3.5. Estimation of catch composition

Total weight of fish catch and species abundance in biomass, numbers and quantity of plastic have been recorded for each haul. After separation of the catch, species wise biomass was measured using a weighing balance scale to estimate the composition of the catch. For sub-sampling, biomass was determined by multiplying the subsample weight by a rising factor dependent on the ratio of the subsample weight to the total catch (Rodrigues-Filho *et al*., 2020). The portion of by-catch during each sampling was quantified using a digital scale and combined along all seasons and depth to evaluate spatial-temporal variations. To understand the temporal variations in catch composition, data collected from experimental fishing were pooled into two pre-determined seasons following Sehara *et al.,* (1992) and Suseelan *et al*., (1992): Pre-monsoon (February - May) and Post-monsoon (September - January).

3.6. Chemicals, Plastic Wares and Glass Wares

The chemicals used for the chemical analysis were collected from the Merck Laboratories, Fisher Scientific and Hi-Media, Mumbai. The amount and classification of chemicals used complied with standard procedures (APHA, 2017). The glass wares and plastic wares used for sample collection and analysis were procured from Qualigens, Borosil, Merck and Fisher Scientific, Mumbai.

3.7. Estimation of environmental parameters

Water samples were obtained from the selected fishing location along with data on latitude and longitude. The samples were collected in the respective bottles after depth measurement while continuing with the shooting of net. The parameters such as temperature and salinity were measured onboard while sampling. On-site measurements were made for physical-chemical parameters such as temperature (°C) and salinity (‰). For the estimation of Chlorophyll-a, water samples were collected in 1L polyethylene bottles, transported in individual sample boxes to the laboratory and stored at 4^{o}C and further analyses was done in the laboratory according to standard protocol (APHA, 2017). For each parameter triplicates were used to reduce the error.

3.7.1. Temperature

Water temperature was measured on-site using a mercury-in-glass thermometer (Fisher Scientific, USA) calibrated up to 0.1°C.

3.7.2. Salinity

Portable Refractometer (WOS-RHS-10ATC, Hand held salinity Refractometer w/ Automatic Temperature Compensation, Westover Scientific, North America) was used to measure salinity of water samples. The water samples from each site were measured while collecting samples for other analysis.

3.7.3. Chlorophyll-a

The algae from the water samples of respective sites were concentrated using vacuum filter assembly of KnF Neuberger Laboport under 0.5 atmospheric pressure. Polycarbonate filters of 47mm, 0.4 µm diameter (Advantec membrane filter, ADVANTEC Toyo Roshi Kaisha, Ltd., Japan) were used to filter 500 ml of water. After filtration, the filters with algae concentrate were preserved in 90% acetone and stored at 4°C for 24 hrs. The pigments were extracted from the concentrate with the aqueous acetone, the extract was centrifuged in refrigerated centrifuge (Heraeus, Thermo fisher scientific, United States) at 5000 rpm for 10 minutes and the optical density was measured using fluorometer (TriologyTM Fluorometer, 720-000, Turner Designs, California, U.S.A) before and after acidification using 1 ml 1% HCl for the estimation of Chlorophyll-a as per the APHA (2017) guidelines. The results are expressed in mg m^{-3}.

3.8. Satellite Datasets

Satellite-derived environmental parameters were collected from Internet-based Earth Observation portals like NASA Internet servers Ocean Color Web (https://oceancolor.gsfc.nasa.gov/), Copernicus Marine Environment Monitoring Service (https://marine.copernicus.eu/) (CMEMS), Physical Oceanography Distributed Active Archive Center (https://podaac.jpl.nasa.gov/) and INCOIS live access server (http://las.incois.gov.in/). The value was extracted for each fishing geo-location by using Sentinel Application Platform (SNAP) software. These data were tabulated in Excel sheet making it compatible for analysis. Three environmental parameters Sea Surface Temperature (SST), Chlorophyll-a concentration (Chl-a), Sea Surface Salinity (SSS) Level 3 (i.e. inputs projected on standard space-time map scales) were used to assess the quality of Satellite-derived environmental data with in-situ sea-truth information.

For correlation of satellite-derived environmental data with in-situ trawl fish catch data, satellite-derived environmental parameters like Sea Bottom Temperature (BT), Sea Water Potential Temperature (SWPT), Ocean Mixed Layer (OMXL), Sea Surface Height (SSH), Dissolved Oxygen (DO), Bottom Chlorophyll (BCHL), Current Speed (CS) were obtained from the EU Copernicus Marine Environment Monitoring Service (CMEMS) (https://marine.copernicus.eu/). The

Copernicus Marine Environment Monitoring Service (CMEMS) provides Level-4 (i.e. variables generated from various measurements) reprocessed and multi-sensor merged satellite-derived environmental parameters.

3.8.1. Satellite/Sea-truth matchups

In all, 190 Sea-truth data points were collected in near synchronization with remote sensing satellite pass and mapped. Matchups between the sea- truth and various remote sensing parameters were compared with assorted available global algorithms to understand the correlation, variability in data, accuracy and error. The parameters like satellite to Sea-truth in-situ ratio, median satellite to *in-situ* ratio, semi-interquartile range (SIQR) for this ratio, median absolute percentage difference (MPD) were computed to make out the accuracy for satellite data sets.

- **Semi-interquartile range (SIQR)**

The SIQR provides an indication of the spread of the data and proclaim the measure of uncertainty and also provide additional information on how accurately the satellite retrieval agrees with *in-situ* measurements.

$$SIQR = \frac{Q_3 - Q_1}{2}$$

Where Q_1 is the 25th percentile and Q_3 is the 75th percentile (Q2 would be the median value). The median ratio provides an indication of overall bias.

- **Median absolute percentage difference**

The median absolute percentage difference (MPD) is calculated as the median of the individual absolute percentage differences and calculated as (Bailey and Werdell, 2006):

$$PD_i = 100 * \frac{|X_i - Y_i|}{Y_i}$$

where X is the satellite value and Y is the *in-situ* value

- **Root mean square error (RMSE) and Bias**

Principally, two estimates were used to assess the differences between the *in-situ* and satellite-derived data. First, the root mean square error (RMSE) and the mean difference (Bias) were defined as (Marrari *et al*, 2006):

$$RMSE = \sqrt{\frac{\sum\left[\left((S) - (I)\right)\right]^2}{n}}$$

$$Bias = \frac{\sum[(S) - (I)]}{n}$$

Where, *S* is the satellite data, *I* is in *situ-data*, and n is the number of data pairs.

3.9. Fish catch and environmental parameters

Season-wise pooled catch data was further divided into major fish resource group and summarised data were used for further analysis. Two-way ANOVA and post-hoc comparison using Tukey's HSD were carried out to determine significant difference between the seasons. Pearson's correlation coefficients were calculated to determine the significance of each satellite-derived environmental variable on fish abundance.

3.9.1. Canonical correspondence analysis

To visualise the variations in fish assemblages, and their relationship with the environmental variables, the data were subjected to canonical correspondence analysis (CCA) using PAST software (Hammer *et al.,* 2001). CCA was applied to the overall fish data matrix and environmental data matrix integrating the environmental variables and various biological groups. CCA is a direct analysis that selects a linear combination of environmental variables that maximises the dispersion of the species scores (Ter Braak, 1986; Jongman *et al.,*1987). The ordination output shows patterns that are directly related to the environmental conditions being examined. Separate CCA was performed for major plankton and fish groups with environmental variables.

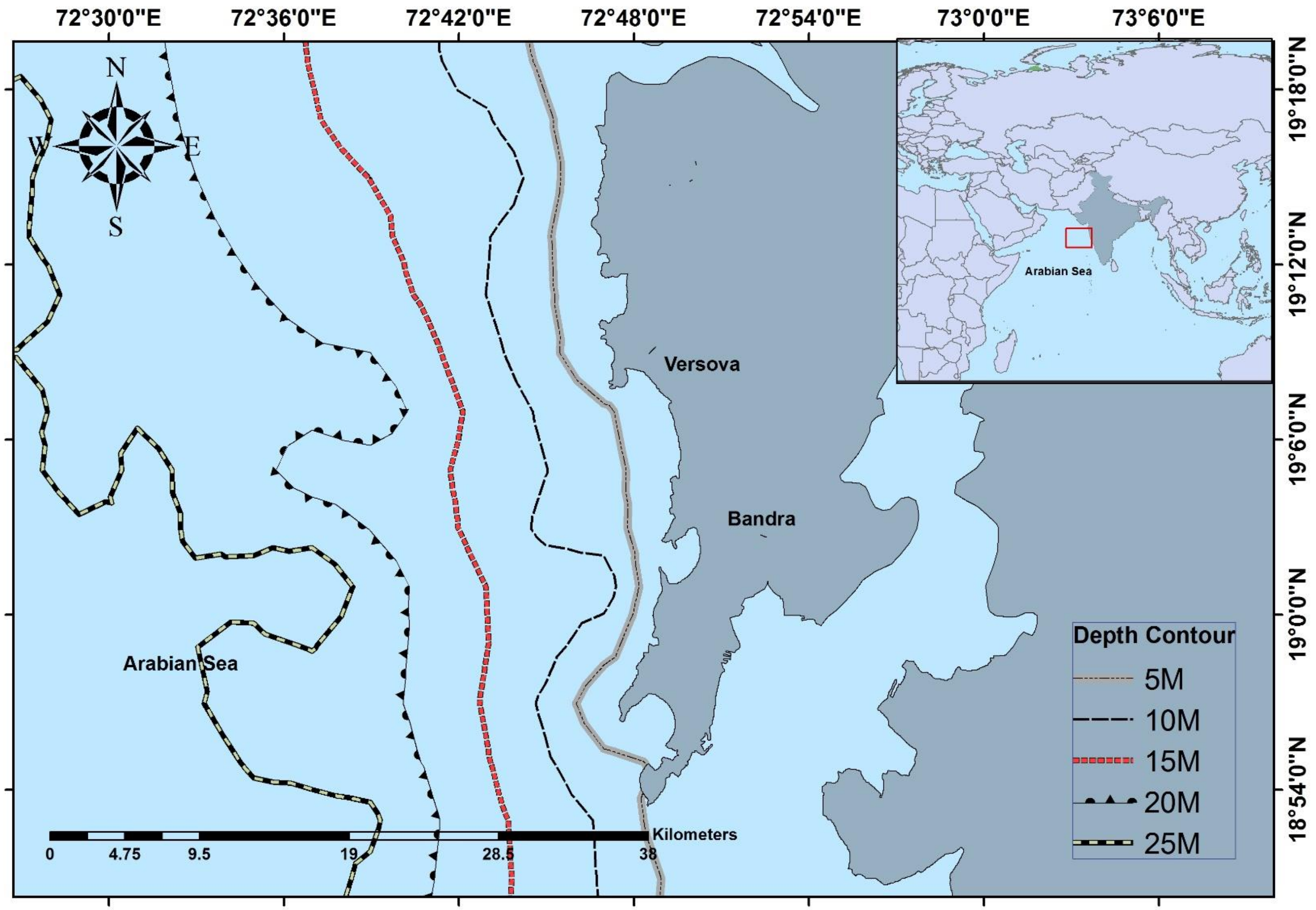
3.9.2. Similarity percentage analysis

The similarity in fish assemblages between seasons and stations were compared employing similarity percentage (SIMPER) analysis (Clarke, 1993) using the species abundance data. SIMPER analysis was performed using PAST software. Applying this method, species that contribute significantly to fish assemblages were measured and ranked. Percentage contribution of each species to the average dissimilarity among seasons were calculated.

3.9.3. Generalized additive modelling

Generalized additive modelling (GAM) was used to assess the relationship between catch and environmental parameters and to identify the most significant factors responsible for variation in the catch. The GAM has been considered a non-parametric generalization of multiple linear regressions, which is less restrictive in assumptions of the underlying statistical data distribution (Hastie and Tibshirani 1990). Model testing can help classify the important environmental variables and their respective impact extent (Drexler and Ainsworth, 2013). GAM analyses were conducted using the statistical package R (mgcv R package (R x64 4.0.1). The forward stepwise and shrinkage approaches were used in the final selection of model. This approach allowed avoiding collinearity among the explanatory variables. The choice of model was based on the lowest value of Akaike Information Creation (AIC), the level of Deviance Explained (DE) and inspection of residual plots. The degree of smoothing for each explanatory variable was chosen based on the Restricted Maximum Likelihood (REML). The thin plate spline was applied to models with a smoother regression, with the maximum degree of smoothing freedom (k) for the main effects limited to 3. The explanatory variables with significant levels of < 0.05 were retained for the final models.

Plate 1. *M.F.V. Narmada* (IV) used for experimental fishing



Map 1. Location of sampling site and study area

Table 3.2.1. Particulars of *M.F.V. Narmada* (IV)

Year and place built	**1979, Mangalore**
	Dimensions
Length (OAL)	10.06 m
Breadth	3.1 m
Depth	1.25 m
	Tonnage Capacity
Net Tonnage	12.38
Cabin	4.08
Gross Tonnage	16.46
	Cabin Dimensions
Length	4.27 m
Breadth	1.55 m
Width	1.8 m
	Engine Specifications
No:	ALMU 370/6059, Ashok Leyland
Power	86 HP, 6 cylinders, 4 stroke

Table 3.2.2. Specifications of fishing gear used in experimental fishing

Details of trawl net	
Head rope	35 m
Foot rope	40 m
Distance between Head rope and Foot rope	6.1 m
Sinkers (Chain)	25 kg
Floats	5 Nos; Diameter : 08 inches
Otter board	
Weight	40 kg (rectangular, flat)
Dimensions	Length- 125 cm, width- 70 cm, breadth - 1 inch (wood), 3 inches (metallic shoe)
Distance between brackets	50 cm
Distance between bridles	43 cm
Sweep line	15.5 m (upper) and 16.2 (lower)
Mesh size	
Upper panel	Wing-200 mm, Overhang-200 mm, Belly-150 mm, 100 mm, Throat- 75 and 35 mm, codend -30 mm)
Lower panel	Wing- 40 mm, Belly- 40 mm, Throat -35 mm, codend – 30 mm

4 RESULT

4. RESULTS

4.1 Extent of fishing operations

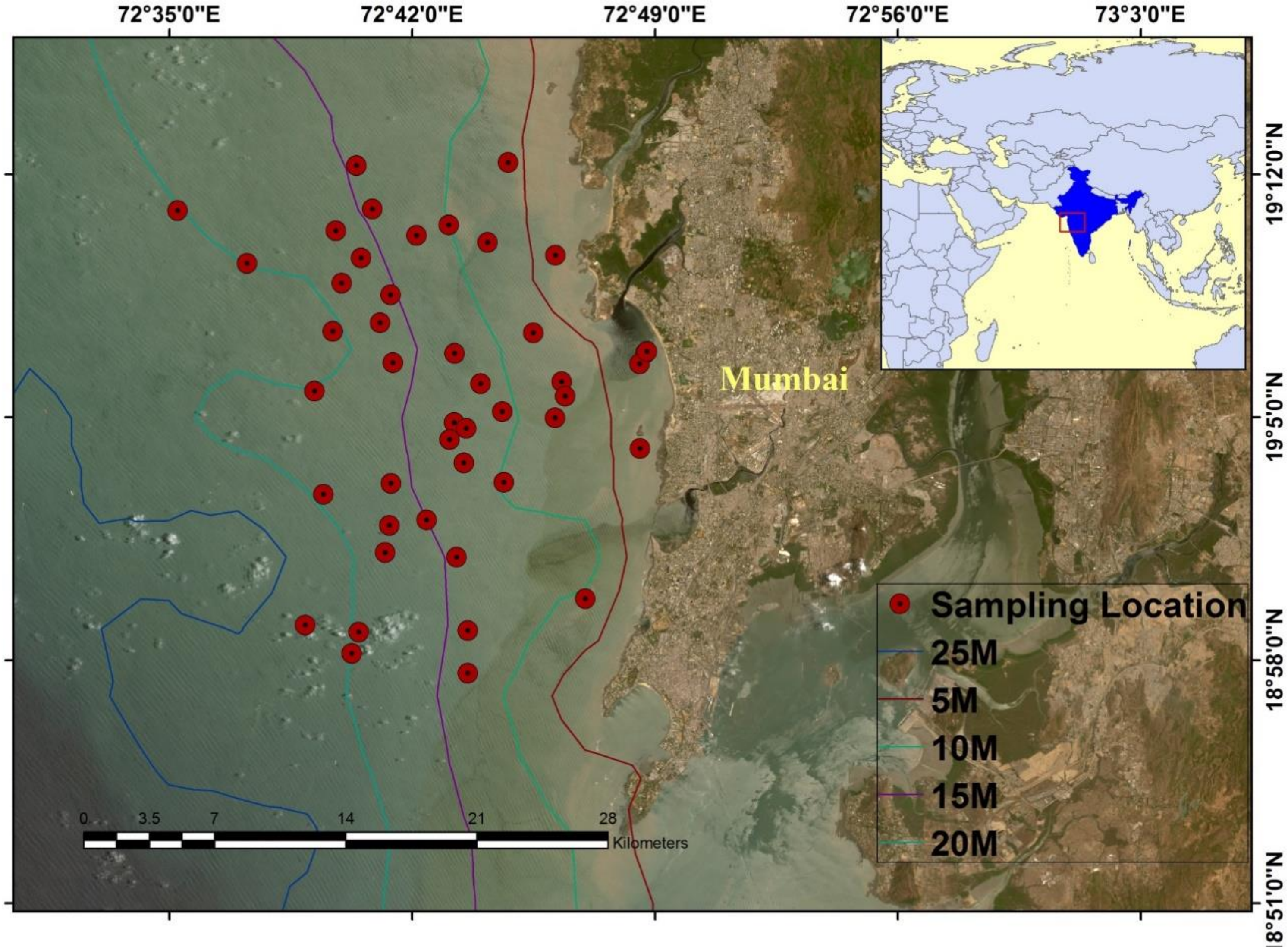
The primary data required to fulfill the objectives of the study was collected by experimental fishing along the Mumbai coast. In all, 46 experimental fishing trials were carried out from September 2017 to May 2019. The experimental fishing operations were carried out between 18°57'N to 19°12'N latitude and 72°40' E to 72°43' E longitude in the depth range 6-21m. The average duration of each haul was one hour. The details of all 46 fishing operations conducted are given in Table 4.1.1. The selected sampling points of experimental fishing operations are shown in Map 2.

4.2 Catch composition

4.2.1 Group-wise trawl catch composition

The overall trawl catch was grouped into three to study the category-wise contribution. Commercial catch which includes shrimp and other fishes which have commercial value; bycatch which includes low value fish catch, non-edible catch as well as juveniles of commercially important fishes; and marine debris including plastics and other debris. The overall percentage contribution of these categories was calculated based on the data collected during the experimental fishing throughout the study period. Monthly catch per hour for each category was calculated separately for more accuracy. The results showed that the bycatch contributed maximum (79.43%), commercial catch (20.12%) and marine debris (0.45%) to the total catch. The percentage contribution of bycatch, commercial catch and debris are depicted in the Figure. 4.1.1 and Table. 4.2.1

The monthly category-wise catch percentage revealed that bycatch was significantly higher than commercial catch during the year 2017 for the months of September, October, and November while it was January and April during 2018. Highest bycatch was recorded in February followed by January in 2019. The marine debris was maximum during March 2018 followed by March 2019.



Map 2: Extent of experimental fishing operations conducted along the Mumbai coast

Table. 4.1.1: Details of the experimental fishing operations conducted from September 2017 to May 2019

Sl. No	Date of sampling	Condition of the sea	Speed (knot)	Duration of trawl	Shooting depth (m)	Shooting geo-location	Hauling depth(m)	Hauling geo-location	Total catch (kg)
1	28.09.2017	Very Rough	1.5-2.5	01:00 - 2:00	11	19°06’35.3”N 72°44’19.5”E	11	19°05’09.4”N 72°44’35.6”E	18.013
2	25.10.2017	Calm	1.5-2	10.45-11.45	11.05	19°06’35.3”N 72°44’03.5”E	12.05	19°06’50.5”N 72°43’13.3”E	1000
3	10.11.2017	Calm	1.75-2.25	11.25-12.15	11.25	19°09’44.5”N 72°42’03.5”E	12.15	19°09’35.05”N 72°40’31.2”E	70.668
4	28.11.2017	Calm	1.5-2.5	10:35-11.35	10	19°10’03.01”N 72°45’37.05”E	8	19°10’02.04”N 72°44’10.06”E	116.47
5	13.12.2017	Rough	1.5-2.5	10:30-11:31	13	19°09’50.72”N 72°44’19.04”E	15	19°12’15.09”N 72°40’23.2”E	27.802
6	13.12.2017	Rough	1.5-1.75	12:25-1:26	11	19°11’34.07”N 72°36’30.03”E	11	19°10’57.02”N 72°35’14.08”E	16.376
7	28.12.2017	Calm	1.5-2.5	10:50-11:50	14	19°10’25.2”N 72°41’34.5”E	15	19°10’22.5”N 72°39’48.0”E	35.752
8	28.12.2017	Calm	1.5-2.5	12:20-1:20	16	19°08’59”N 72°39’57.9”E	15	19°08’51.9”N 72°39’57.9”E	9.869
9	08-01-2018	Rough	1.5-2	10.35-11.35	11	19°00’09.8”N 72°40’34.9”E	11.5	18°58’11.9”N 72°40’15.2”E	16.1
10	08-01-2018	Rough	1.5-2.5	12.10-1.40	12	18°56’54.4”N 72°40’30.9”E	12	18°57’37.5”N 72°43’35.6”E	17.263
11	30-01-2018	Calm	1.5-2	10.20-11.20	19	19°03’00.5”N 72°41’07.4”E	20	19°01’53.08”N 72°41’20.03”E	19.389
12	30-01-2018	Calm	1.5-2	11.45-12.45	12	19°01’01.0”N 72°41’0.13”E	18	19°01’06.1”N 72°41’12.8”E	5.096
13	06-02-2018	Rough	1.5-2	11.30-12.35	9	19°10’29.1”N 72°40’02.7”E	12	19°10’14.3”N 72°42’07.6”E	23.195
14	15-02-2018	Calm	1.5-2.5	10.35-11.35	16	19°03’07.4”N 72°42’49.9”E	18	19°02’02.2”N 72°42’24.8”E	16.082

15	15-02-2018	Calm	1.5-2.5	11.50-12.52	17	19°01’44.0”N 72°42’25.5”E	18	19°00’58.0”N 72°43’16.2”E	14.388
16	15-03-2018	Very Rough	1.5-2	11.45-12.45	7.5	19°06’33.6”N 72°48’24.8”E	7.5	19°06’51.1”N 72°48’42.9”E	15.82
17	22-03-2018	Very Rough	1.5-2	10.30-11.30	6.5	19°10’40.2”N 72°42’25.7”E	8	19°11’00.0”N 72°40’51.0”E	12.217
18	26-03-2018	Moderately Rough	1.5-2.5	10.30-11.35	17	19°02’43.2”N 72°41’7.7”E	19	19°02’46.7”N 72°39’26.0”E	21.032
19	26-03-2018	Moderately Rough	1.5-2.5	12.05-1.05	20	19°00’46.3”N 72°38’31.3”E	21	18°59’00.7”N 72°38’54.9”E	20.262
20	04-04-2018	Rough	1.5-2	10.20-11.30	8	19° 03’4.59”N 72°48’4.28”E	9	19°06’32.34”N 72°48’33.31”E	4.4
21	23-04-2018	Rough	1.5-2.5	10.20-11.30	18	19°00’52.2”N 72°40’48.1”E	20	18°58’48.3”N 72°40’27.4”E	18.397
22	04-05-2018	Moderately Rough	1.5-2.5	10.10-11.10	14	19°06’34.3”N 72°41’26.6”E	16	19°06’34.3”N 72°41’26.6”E	37.152
23	04-05-2018	Moderately Rough	1.5-2.5	12.05-1.05	20	19°07’44.8”N 72°38’16.7”E	18	19°07’28.7”N 72°39’42.6”E	15.667
24	14-05-2018	Moderately Rough	1.5-2.5	10.00-11.00	8	19°00’51.28”N 72°47’51.28”E	9.5	18°59’46.50”N 72°46’59.01”E	21.083
25	14-05-2018	Moderately Rough	1.5-2.5	12.00-1.00	12	18°59’24.04”N 72°48’46.77”E	14.5	18°58’51.48”N 72°43’35.77”E	21.275
26	29-09-2018	Calm	1.5-2.5	09.30-10.30	8	19°05’36.38”N 72°45’90.59”E	9	19°04’06.2”N 72°47’94.00”E	81
27	29-09-2018	Calm	1.5-2.5	10.50-11.53	9	19°04’08.00”N 72°47’00.9”E	11	19°04’58.7”N 72°46’06.9”E	41.641
28	15-10-2018	calm	1.5-2.5	09.00-10.00	5	19° 9'4.14"N 72°38'41.64"E	5	19° 9'26"N 72°37'14.3"E	1.23
29	15-10-2018	Moderately Rough	1.5-2.5	10.20-11.20	14	19°04’13.7”N 72°43’52.7”E	10	19°03’41.1”N 72°43’29.4”E	59.769
30	15-10-2018	Moderately Rough	1.5-2.5	11.40-12.40	15.2	19°03’58.1”N 72°42’10.6”E	18	19°03’05.3”N 72°41’23.0”E	18.748
31	27-10-2018	calm	1.5-2.5	10.10-11.10	12.7	19°05’42.50”N 72°43’20.4”E	14.6	19°04’50.90”N 72°43’12.50”E	24.12

32	27-10-2018	calm	1.5-2.5	11.30-12.30	15	19°05’03.50”N 72°42’57.5”E	17.5	19°04’21.50”N 72°43’04.1”E	20.39
33	20-11-2018	calm	1.5-2.5	9.50-10.50	14	19°07’16.00”N 72°42’57.5”E	17	19°07’43.00”N 72°41’04.0”E	50.912
34	20-11-2018	calm	1.5-2.5	11.30-12.35	18	18° 58'38.25"N 72°42'5.42"E	17	18° 57'32.75"N 72°41'43.59"E	35.985
35	30-11-2018	calm	1.5-2.5	11.30-12.45	18	19° 5' 47.66"N 72°40'38.09"E	17	19° 5'45.22"N 72°39'10.75"E	36
36	13-12-2018	Rough	1.5-2.5	10.15.-11.16	15	19°03’64.05”N 72°43’14.77”E	9	19°04’41.03”N 72°43’33.3”E	40.845
37	29-12-2018	calm	1.5-2.5	09.50-10.50	9	19°04’53.00”N 72°46’26”E	10	19°07’26.00”N 72°45’29”E	50.443
38	29-12-2018	calm	1.5-2.5	11.15-12.15	12	19°04’11”N 72°44’06”E	13	19°05’58.00”N 72°43’58”E	48.895
39	09-01-2019	calm	1.5-2.5	11.45-12.45	11	19°06’78”N 72°45’74”E	14	19°06’1.2”N 72°45’78”E	15.238
40	10-01-2019	calm	1.5-2.5	10.15-11.15	11	19°07’54.10”N 72°43’59.87”E	13	19°08’31.80”N 72°41’22.33”E	14.094
41	10-01-2019	calm	1.5-2.5	12.10-1.10	15	19°10’47.54”N 72°41’28.09”E	17	19°10'32.30”N 72°43’02.9”E	10.715
42	13-02-2019	calm	1.5-2.6	12.10-1.10	15	19° 11'44.29"N 72°45'21.93"E	14	19° 12'20.68"N 72°44'45.54"E	28.246
43	14-03-2019	calm	1.5-2.5	12.10-1.12	15	19° 3' 29.34"N 72°45'57.68"E	15	19° 3' 7.54"N 72°44'38.26"E	32.894
44	06-04-2019	calm	1.5-2.5	10.45-11.45	11	19°05’77.5”N 72°45’96.4”E	15	19°05’36.6”N 72°46’24.3”E	29.15
45	12-04-2019	calm	1.5-2.5	10.45-11.45	8	19°07’19.64”N 72°45’43.43”E	11	19°09’40”N 72°46’7.82”E	22.988
46	03-05-2019	calm	1.5-2.5	10.45-11.45	8	19° 3' 22.1”N 72°46’56.55”E	12	19° 2' 31.15"N 72°46'49.27"E	28.169

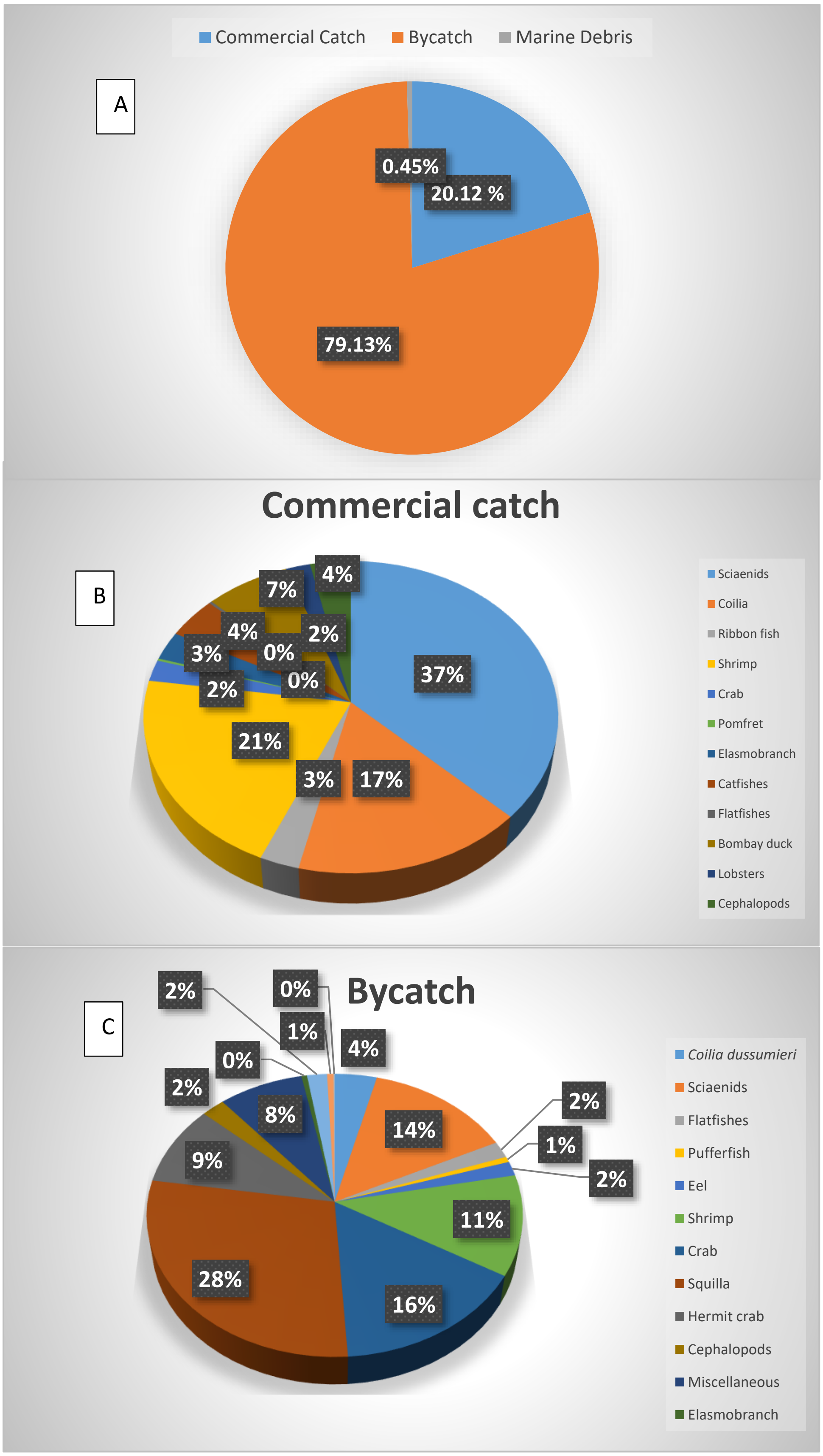


Figure. 4.1.1. Percentage contribution of three categories to the overall catch (A-C)

A-Major category, B- Commercial catch and C- Bycatch

Analysis of season-wise contribution revealed that highest commercial catch was observed in pre-monsoon while post-monsoon recorded highest bycatch. Category-wise monthly catch and catch per haul are given in Table 4. The commercial catch per hour was maximum (35.21 kg) during December 2018. The bycatch per hour was minimum during October 2018 and maximum during October 2017 and November 2017 (61.34 kg/hr) which was mainly due to jellyfish bloom during October 2017 and catch of *Trypauchen vagina* (110 kg) in November 2017 respectively. The maps highlighting the total catch per hour, bycatch per hour and commercial catch per hour are shown in Map 3, Map 4 and Map 5 respectively.

4.2.2. Group-wise contribution to total catch

The group-wise contribution was studied for both commercial and bycatch (Figure. 4.1.1). Resource groups contributing to the commercial catch from trawlers along the Mumbai coast consists of sciaenid's (37%), shrimp (21%), *Coilia* (17%), Bombay duck (7%), ribbonfish (3%) and elasmobranch (3%), crab (2%), cephalopods (3%) and catfishes (4%), lobsters (2%) and the rest miscellaneous. Details of contribution of groups to commercial catch are provided in Figure. 4.2.1 and Table 4.2.1. In case of bycatch, the major groups were Squilla (28.4%), sciaenids (13%), shrimp (11.4%), hermit crab (9.1%) and miscellaneous (8%), crab (15.5%), cephalopods (2.2%),flatfishes (1.8%), Lobsters (2%), Eel (1.6%), Elasmobranch (0.5%) and Ribbon fish (1.8%). A jellyfish bloom (approx.1000 kg) during October 2017 and a huge catch of approx.110 kg of *Trypauchen vagina* during November 2017 was recorded. Details regarding contribution of groups to by-catch are provided in Figure. 4.2.2 and Table. 4.2.3. A dominant group recorded in almost all the hauls was squilla. Month-wise contribution of species to total catch is presented in the form of pie diagrams in Figure. 4.2.3 - 4.2.36.

4.2.2.1 Sciaenids

This group was present in all the hauls. Nine species were recorded in this group and the major species contributing to the total catch include *Johnius borneensis, J. belangerii , J.dussumieri , J. elongates ,J. glaucus , J. macrorhynus , O.cuvieri , O. biauritus* and *Protonibea diacanthus*. The highest contribution of the group recorded was 22.5 kg/hr and lowest was 1.95 kg/hr.

Table. 4.2.1: Details of monthly category-wise and catch per haul

Catch (kg)						Catch per haul (kg/hr)			
Month	**No. of Hauls**	**Commercial catch**	**Bycatch**	**Plastics**	**Total catch**	**Commercial catch**	**Bycatch**	**Plastics**	**Total catch**
September-2017	1	0	17.64	0.37	18.0	0	17.64	0.37	18.01
October	1	0	1000	0.00	1000.0	0	1000	0.00	1000
November	2	63.26	122.67	1.21	187.1	31.6	61.34	0.60	93.57
December	4	47.87	40.12	1.81	89.8	12.0	10.03	0.45	22.45
January-2018	4	24.20	32.87	0.79	57.8	6.0	8.22	0.20	14.46
February	3	28.22	25.13	0.31	53.7	9.4	8.38	0.10	17.89
March	4	43.83	20.01	5.50	69.3	11.0	5.00	1.37	17.33
April	2	7.6	15.02	0.18	22.8	3.8	7.51	0.09	11.40
May	4	52.17	41.75	1.25	95.2	13.04	10.44	0.31	23.79
September	2	114.5	7.96	0.45	122.9	57.25	3.98	0.23	61.46
October	5	64.5	17.20	1.76	83.5	12.9	3.44	0.35	16.69
November	3	98.96	22.72	0.68	122.4	32.99	7.57	0.23	40.79
December	3	105.62	32.97	1.69	140.3	35.21	10.99	0.56	46.76
January-2019	3	19.52	19.94	0.55	40.0	6.51	6.65	0.18	13.34
February	1	12.09	16.08	0.08	28.2	12.09	16.08	0.08	28.25
March	1	21.82	9.73	1.50	33.0	21.82	9.73	1.50	33.05
April	2	37.5	14.69	0.16	52.4	18.75	7.34	0.08	26.18
May-2019	1	20.2	7.98	0.07	28.3	20.2	7.98	0.07	28.26
Total	**46**	**761.9**	**1464.5**	**18.3**	**2244.7**	**304.6**	**1202.3**	**6.8**	**1513.7**

4.2.2.2 Shrimps

Shrimps contributed considerably to the total catch of catch in almost all the hauls. The major non-penaeid and penaeid shrimp species in the catch were represented by Metapenaeus affinis, *M. brevicornis, Parapenaeopsis hardwickii, P. sculptilis, P. stylifera, Penaeus merguiensis, P. monodon, P. semisulcatus, Exhippolysmata ensirostris, Nematopalaemon tenuipes and Acetes indicus*. The significant seasonal variation in the mean catch composition was observed for shrimp group with the highest catch during pre-monsoon while the catch was significantly lower ($P<0.05$) in post-monsoon (Table. 4.2.4).

4.2.2.3. *Coilia dussumieri*

This species was present in all the hauls along with sciaenids. The highest percentage contribution to commercial catch was 12.5 kg/hr and the lowest was 1.0 kg/hr and it ranged from 0.03 to 1.86kg/hr in bycatch. Among the seasons, significantly ($P<0.05$) higher catch (3.45±0.48) was observed during pre-monsoon period (Table. 4.2.4).

4.2.2.4. *Harpodon nehereus*

Catch of *Harpodon nehereus* obtained during experimental fishing ranged from 0.10 to 15 kg/hr. Significant ($P<0.05$) seasonal variation was observed in the mean catch composition of Bombay duck with the highest mean catch during post-monsoon period (Table. 4.2.4).

4.2.2.5. Cephalopods

The major contributors were Octopus (*Octopus vulgaris*) among the cephalopods, but only seen in some hauls. The cuttle fishes (*Sepiella inermis*) were also seen in some hauls in small quantity. The highest percentage contribution to bycatch was 0.70 kg/hr and the lowest was 0.01 kg/hr and it ranged from 0.58 to 2.60 kg/hr in commercial catch. Significant ($P<0.05$) seasonal variation was observed in the mean catch composition of *Sepiella inermis* with the highest mean catch during pre-monsoon period (Table. 4.2.4).

4.2.2.6. Elasmobranchs

The major contributors to elasmobranchs were *Scoliodon laticaudus*, *Chiloscyllium arabicum* and *Himantura imbricata* in few hauls. But it was observed that most of the rays and sharks obtained were juveniles. Their contribution ranged from 0.05-0.33 kg/hr to the bycatch and 0.13-1.78 kg/hr to the commercial catch. *Scoliodon laticaudus* from this group showed Significant ($P<0.05$) seasonal variation in the mean catch which was highest in pre-monsoon period (Table. 4.2.4).

Table 4.2.2: Details of monthly landing of major groups in the commercial catch from experimental fishing

Month-Wise Commercial Catch																		
	SEP- 2017	**OCT**	**NOV**	**DEC**	**JAN-** 2018	**FEB**	**MAR**	**APR**	**MAY**	**SEP**	**OCT**	**NOV**	**DEC**	**JAN-** 2019	**FEB**	**MAR**	**APR**	**MAY**
Groups	**Catch (kg/hr)**																	
Sciaenids	0	0	22.50	5.41	2.27	2.83	2.31	2.25	1.95	21.25	5.72	16.53	14.37	2.73	3.95	4.62	3.00	4.50
Coilia dussumieri	0	0	2.00	1.75	1.30	2.57	2.58	0.50	2.80	12.50	4.50	1.37	3.77	1.00	2.70	2.40	5.50	4.50
Ribbon fish	0	0	0.75	0.00	0.00	1.07	0.50	0.00	0.74	1.75	0.29	0.50	0.00	0.00	0.80	0.00	0.45	2.00
Shrimp	0	0	1.50	3.25	1.23	1.23	3.66	1.05	4.80	6.75	1.74	5.65	9.13	0.58	2.60	10.24	4.50	6.90
Crab	0	0	1.04	0.00	0.00	1.05	0.63	0.00	0.00	0.00	0.68	0.72	0.69	0.00	1.73	0.35	0.00	0.00
Pomfret	0	0	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.08	0.06	0.00	0.00	0.00	0.00	0.00
Elasmobranch	0	0	1.75	0.13	1.05	0.57	0.37	0.00	0.00	0.00	1.78	0.00	0.93	1.40	0.31	0.96	0.00	0.00
Catfishes	0	0	2.00	0.50	0.00	0.00	0.00	0.00	0.44	0.00	5.12	2.63	2.30	0.00	0.00	0.00	0.50	0.00
Flatfishes	0	0	0.00	0.06	0.00	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.15	0.27	0.00	0.20	0.00	0.00
Bombay duck	0	0	0.00	0.25	0.00	0.00	0.00	0.00	0.10	15.00	0.68	5.50	0.60	0.00	0.00	0.00	0.40	0.00
Lobsters	0	0	0.00	0.63	0.20	0.00	0.30	0.00	0.45	0.00	0.05	0.00	1.67	0.53	0.00	0.95	1.80	0.00
Cephalopods	0	0	0.00	0.00	0.00	0.00	0.58	0.00	1.78	0.00	0.00	0.00	1.53	0.00	0.00	2.10	2.60	2.30

Table 4.2.3. Details of monthly landing of major groups in the bycatch from experimental fishing

	Sep-17	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May-19
GROUPS	**CATCH (kg)/hr**																	
Coilia dussumieri	0.00	0.00	0.05	0.24	0.06	0.21	0.14	0.23	1.86	0.90	0.03	0.29	0.18	0.03	0.50	0.35	0.23	0.38
Sciaenids	1.95	0.00	1.31	0.98	0.25	1.33	0.25	0.42	2.45	0.33	0.83	2.08	1.04	0.18	3.80	0.13	0.42	1.96
Flatfishes	0.70	0.00	0.08	0.08	0.04	0.15	0.02	0.07	0.12	0.26	0.20	0.00	0.22	0.07	0.45	0.09	0.07	0.08
Pufferfish	0.00	0.00	0.00	0.05	0.01	0.10	0.13	0.20	0.00	0.03	0.02	0.25	0.00	0.00	0.00	0.03	0.04	0.06
Goby	0.38	0.00	55.00	0.18	0.97	0.10	0.01	0.02	0.04	0.05	0.00	0.00	0.22	1.31	0.35	0.01	0.03	0.02
Eel	0.47	0.00	0.68	0.01	0.00	0.02	0.03	0.07	0.00	0.20	0.19	0.16	0.39	0.00	0.05	0.03	0.04	0.00
Shrimp	3.00	0.00	0.25	0.29	0.21	0.72	0.79	0.21	3.43	0.58	0.32	1.80	0.92	0.37	0.65	0.34	0.22	2.33
Crab	3.35	0.00	0.08	1.81	1.29	0.76	0.82	2.11	1.00	0.66	0.14	0.87	1.82	1.40	0.60	2.18	2.08	1.30
Squilla	7.00	0.00	3.00	1.81	4.88	2.01	1.50	3.48	0.22	0.04	0.46	0.85	3.83	2.58	3.79	0.96	3.48	0.81
Hermit crab	0.00	0.00	0.00	0.32	0.46	2.65	0.61	0.45	0.13	0.00	0.00	0.00	0.08	0.62	5.65	1.71	0.45	0.00
Cephalopods	0.31	0.00	0.14	0.10	0.03	0.01	0.13	0.03	0.54	0.16	0.27	0.00	0.46	0.05	0.01	0.18	0.06	0.70
Miscellaneous	0.49	0.00	0.16	0.11	0.03	0.06	0.14	0.09	0.27	0.68	0.81	0.78	2.23	0.23	0.11	4.85	0.20	0.21
Jellyfish	0.00	1000.00	0.00	4.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Elasmobranch	0.00	0.00	0.33	0.00	0.00	0.08	0.05	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.05	0.08	0.00	0.00
Ribbon fish	0.00	0.00	0.28	0.00	0.00	0.02	0.32	0.11	0.16	0.20	0.37	0.72	0.00	0.00	0.04	0.25	0.11	0.13
Catfishes	0.00	0.00	0.00	0.00	0.00	0.14	0.01	0.00	0.17	0.13	0.00	0.00	0.17	0.00	0.10	0.06	0.00	0.08
Shells	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

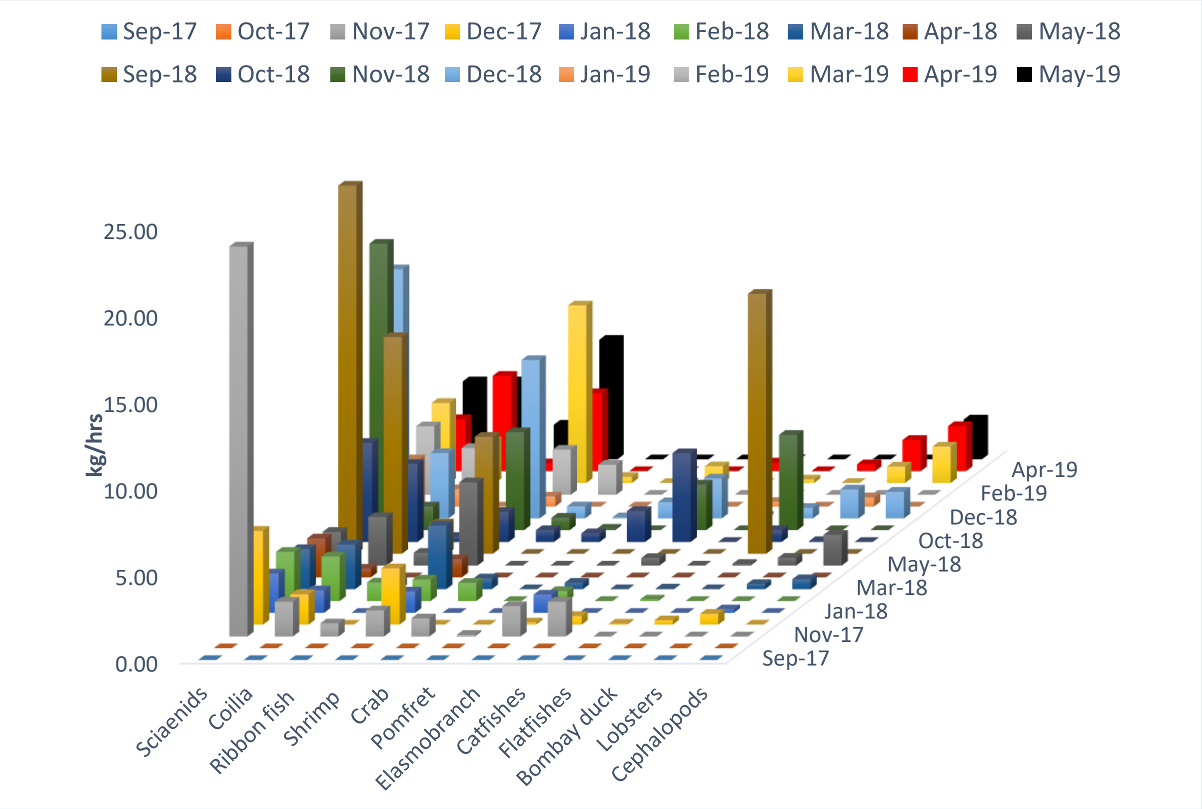


Figure. 4.2.1: Group-wise monthly contribution to commercial catch

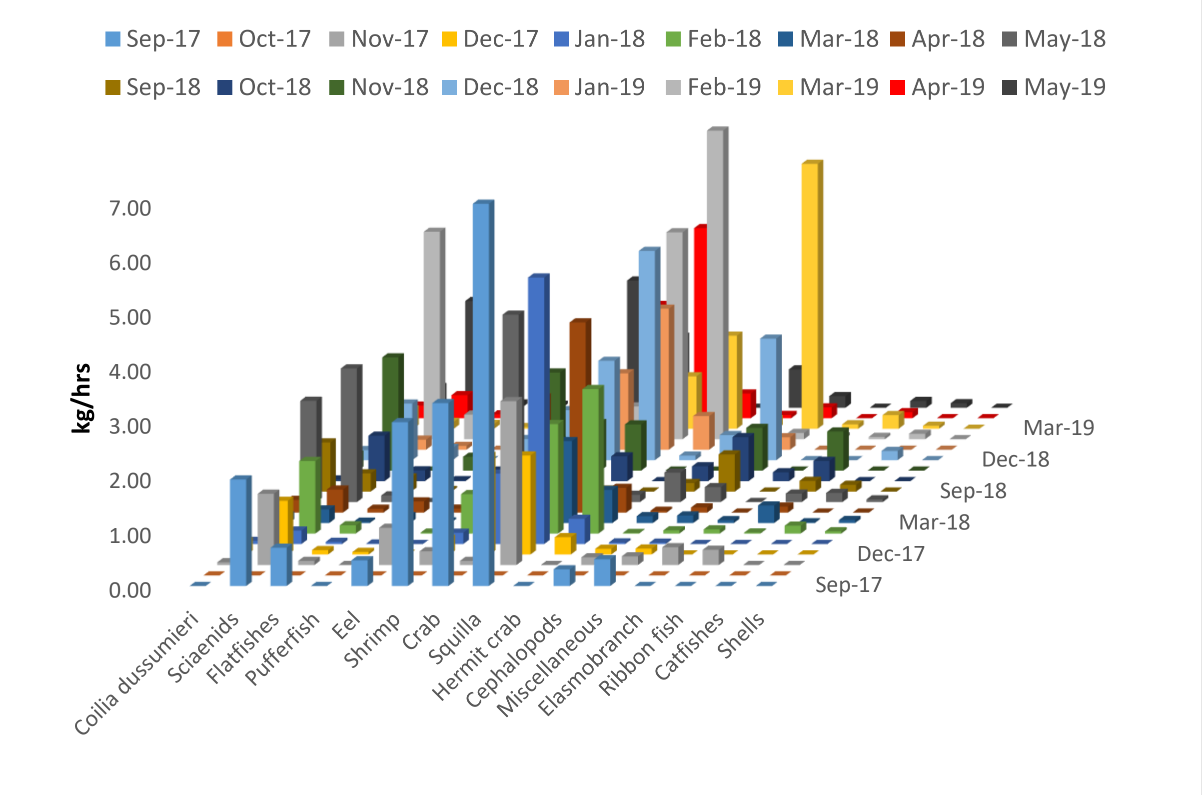


Figure. 4.2.2: Group-wise monthly contribution to the bycatch

4.2.2.7. Flatfishes

Fishes belonging to this group were seen in some hauls. The main species that contributed to the catch were *Cyanoglossus arel* and *Bothus myriaster.* Flatfishes contributed from 0.15-0.27 kg/hr to the commercial catch and 0.02-0.70 kg/hr to the bycatch. Significant (P<0.05) seasonal variation was observed for *Cyanoglossus arel* which was highest in post-monsoon.

4.2.2.8. Crabs

These were found in almost all the hauls; in some it was available in comparatively large quantity. Six species of crabs belonging to two families were recorded during the study period, those were *Panulirus polyphagus, Charybdis callianassa, Charybdis feriatus, Portunus pelagicus* and *Portunus sanguinolentus.* In commercial catch, their contribution ranged from 0.35-1.73 kg/hr and 0.08-3.35 kg/hr in bycatch. Significant (P<0.05) seasonal variation was observed for *portunus sanguinolentus* in the mean catch which was highest in pre-monsoon.

4.2.2.9. Ribbon fishes

Juveniles comprised the majority of ribbon fish catch in most of the hauls. This group contributed about 0.02 kg/hr and 0.72 kg/hr as highest and lowest contribution respectively to bycatch and 0.45-12.5 kg/hr in commercial catch. A significant seasonal variation in the mean catch of ribbon fishes was observed with highest catch during pre-monsoon period (Table. 4.2.4).

4.2.2.10. Catfishes

Catfishes were found in few of the hauls; in some it was available in comparatively small size. Three species of Catfish: *Nemapteryx caelata, Osteogeneiosus militaris* and *Plotosus lineatus* belonging to two families were recorded. It contributed 0.50 - 5.12 kg/hr in commercial catch and 0.01 - 0.17 kg/hr in bycatch.

4.2.2.11. Squilla

These were found in almost all the hauls. Three species recorded during study were *Harpiosquilla raphidea, Miyakella nepa* and *Oratosquillina perpensa.* It contributed from 0.22 kg/hr to 7.0 kg/hr. A significant seasonal variation in the mean catch of *Harpiosquilla raphidea* and *Oratosquillina perpensa* was observed with highest catch during post-monsoon period (Table. 4.2.4).

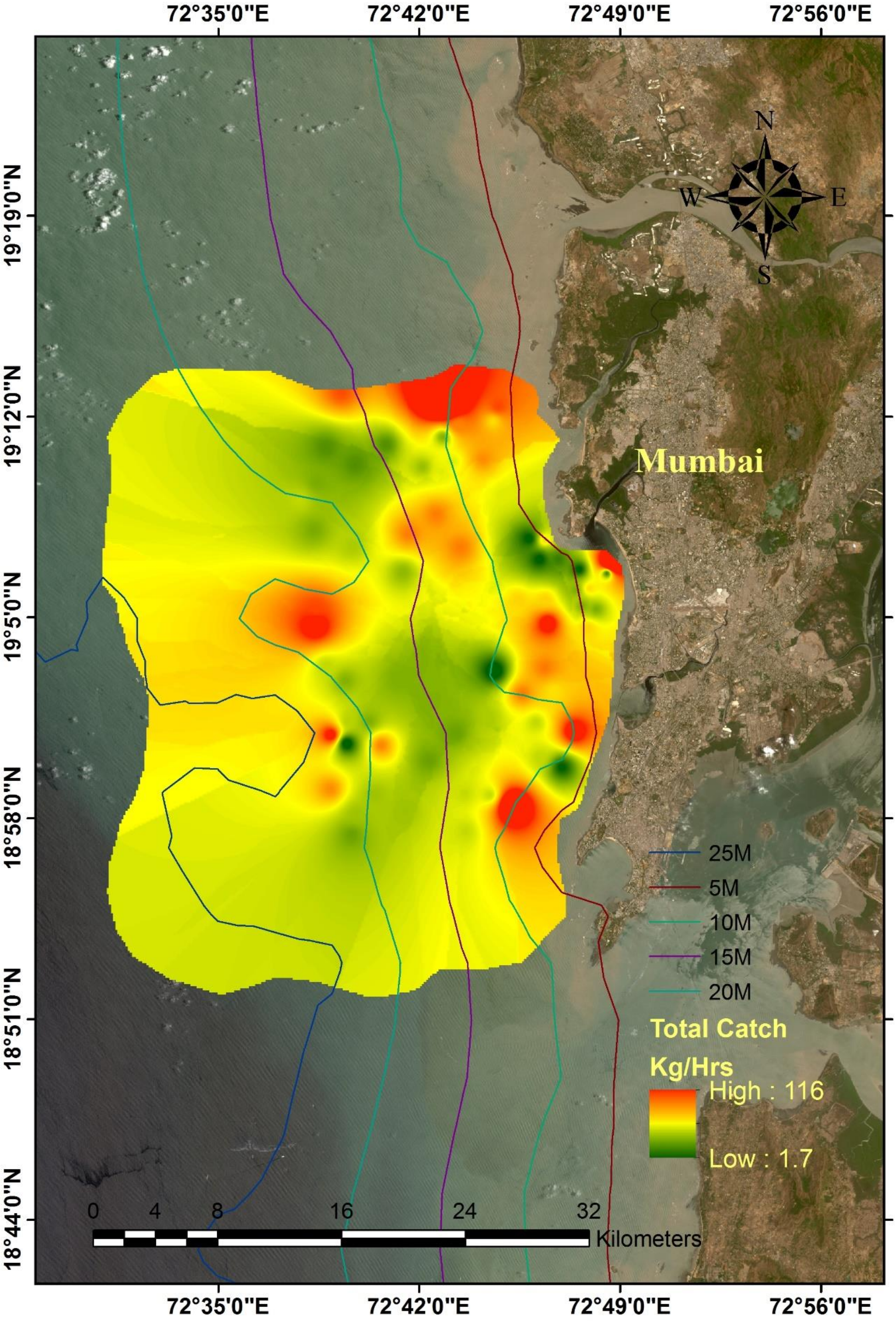
4.2.2.12. Miscellaneous

These consisted of non-edible species: small crabs, puffer fishes, toad fishes, sea snakes, etc. They were observed throughout the sampling and formed a significant percentage contribution to the catch.

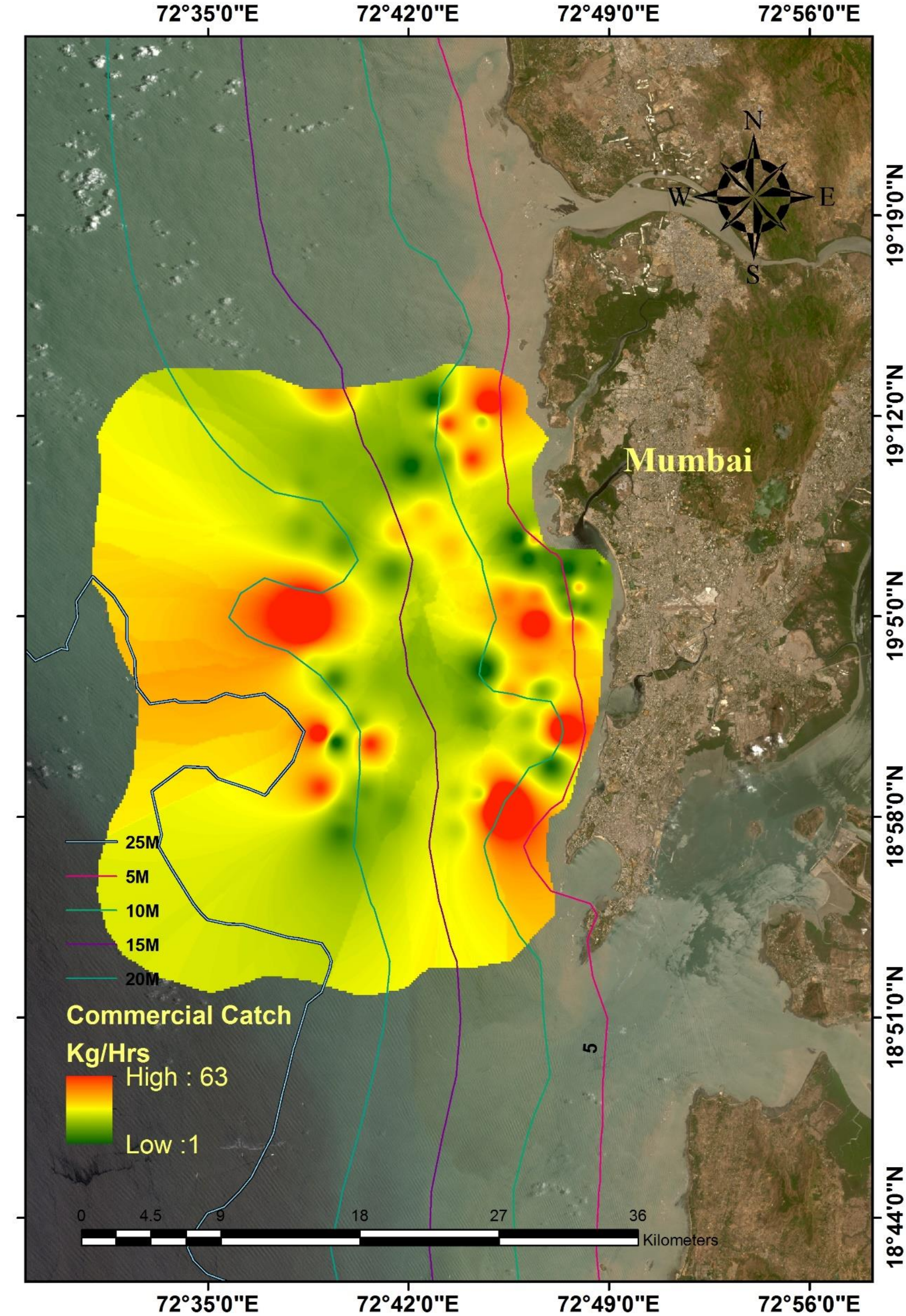
Table. 4.2.4: Temporal variations in composition of major resources

Group	Pre monsoon	Post monsoon	P value
Total Catch	32.53±4.98	21.51±1.97	0.001
Metapenaeus affinis	0.5±0.1	0.17±0.08	0.001
Metapenaeus brevicornis	0.4±0.2	0.38±0.19	0.001
Parapenaeopsis hardwickii	3.1±0.6	2.97±0.64	0.001
Parapenaeopsis sculptilis	0.3±0.1	0.03±0.03	0.001
Parapenaeopsis stylifera	0.8±0.2	1.04±0.34	0.001
Penaeus merguiensis	0.1±0.03	0.35±0.08	0.001
Penaeus monodon	0.03±0.02	0.26±0.13	0.001
Penaeus semisulcatus	0.0±0.04	0.25±0.11	0.001
Johnius belangerii	1.6±0.4	2.93±0.89	0.001
Johnius elongatus	0.1±0.0	0.24±0.15	0.001
Johnius glaucus	0.6±0.2	1.94±0.50	0.001
Johnius macrorhynnus	0.4±0.2	0.72±0.21	0.001
Johnius sina	0.03±0.03	0.44±0.15	0.001
Johnius vogleri	0.5±0.1	0.55±0.24	0.001
Otolithes cuvieri	0.6±0.2	0.74±0.45	0.001
Otolithoides biauritus	0.1±0.1	0.88±0.42	0.001
Exhippolysmata ensirostris	0.1±0.03	0.06±0.02	0.001
Nematopalaemon tenuipes	1.1±0.6	0.30±0.14	0.001
Acetes indicus	1.3±0.4	0.26±0.18	0.001
Scoliodon laticaudus	0.10±0.05	0.27±0.11	0.001
Chiloscyllium arabicum	0.03±0.02	0.02±0.01	0.001
Himantura imbricata	0.16±0.09	0.67±0.21	0.001
Uroteuthis duvaucelli	0.97±0.27	0.22±0.13	0.001
Octopus vulgaris	0.0012±0.0012	0.05±0.03	0.001
Sepiella inermis	0.18±0.07	0.06±0.03	0.001
Coilia dussumieri	3.45±0.48	3.08±0.96	0.001
Cyanoglossus arel	0.14±0.04	0.20±0.06	0.001
Charybdis cruciata	0.23±0.07	0.10±0.06	0.001
Portunus pelagicus	0.20±0.10	0.35±0.14	0.001
portunus sanguinolentus	0.18±0.09	0.02±0.01	0.001
Hermit crab	1.18±0.44	0.27±0.14	0.001
Harpiosquilla raphidea	0.12±0.07	0.14±0.04	0.001
Miyakea nepa	1.61±0.49	1.34±0.41	0.001
Oratosquillina perpensa	0.03±0.01	0.49±0.23	0.001
Harpodon nehereus	0.07±0.04	1.89±0.85	0.001
Lepturacanthus savala	0.74±0.17	0.46±0.15	0.001

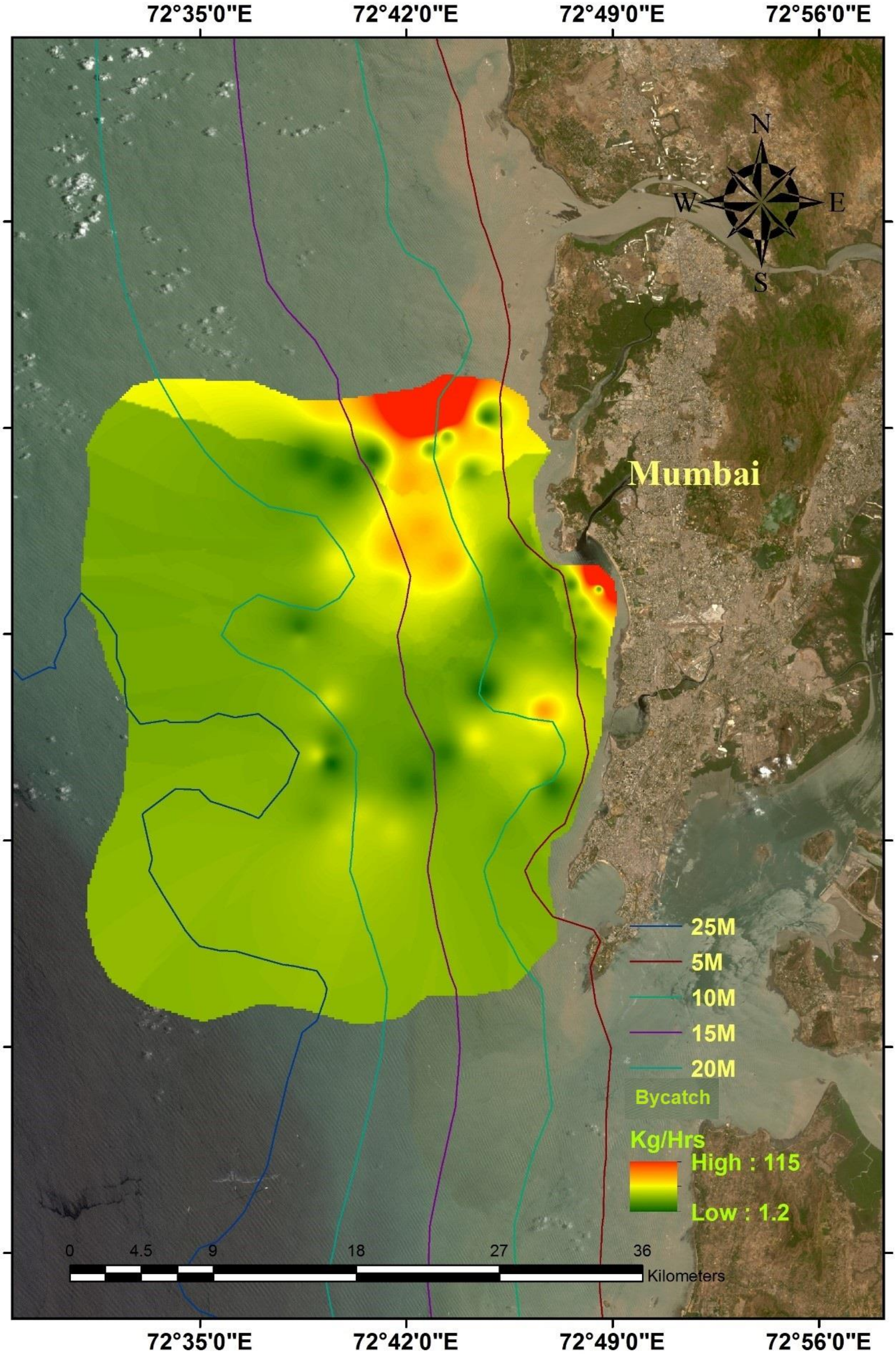
Data are expressed as the Mean ± SE. (Post hoc grouping by Tukey's HSD, P<0.05)



Map 3. Contribution of total catch along the Mumbai coast



Map 4. Contribution of commercial catch along the Mumbai coast



Map 5. Contribution of bycatch along the Mumbai coast

4.2.3. Species-Wise Monthly Catch Composition

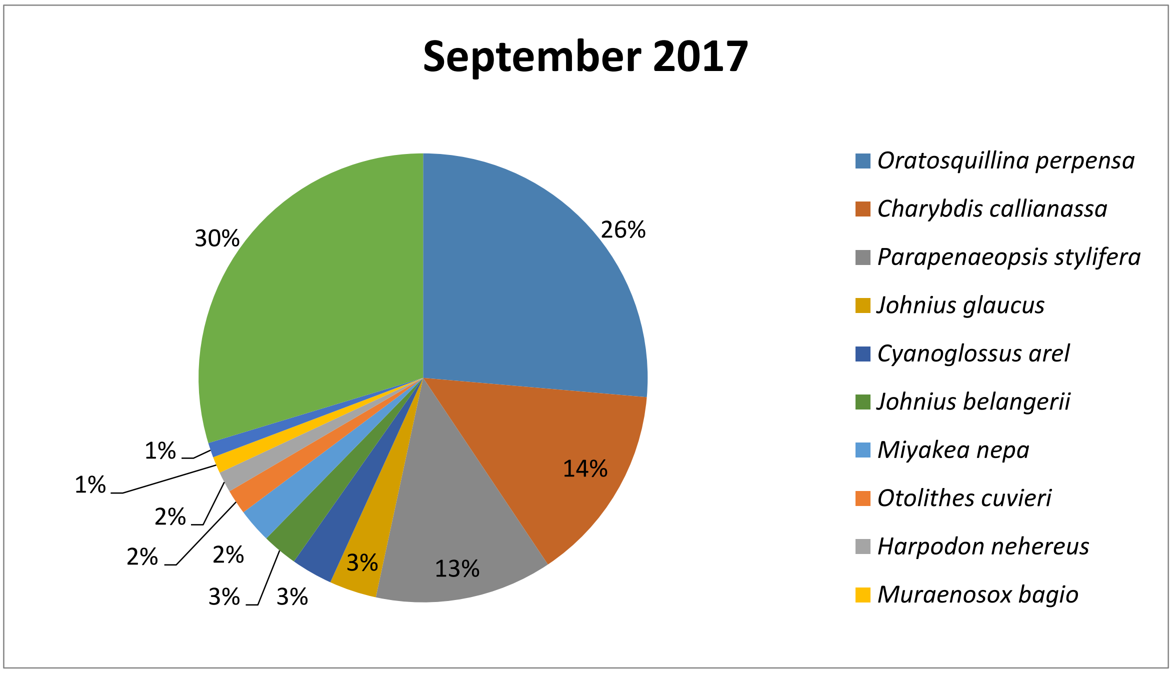


Figure. 4.2.3: Percentage of major species (bycatch) during September 2017

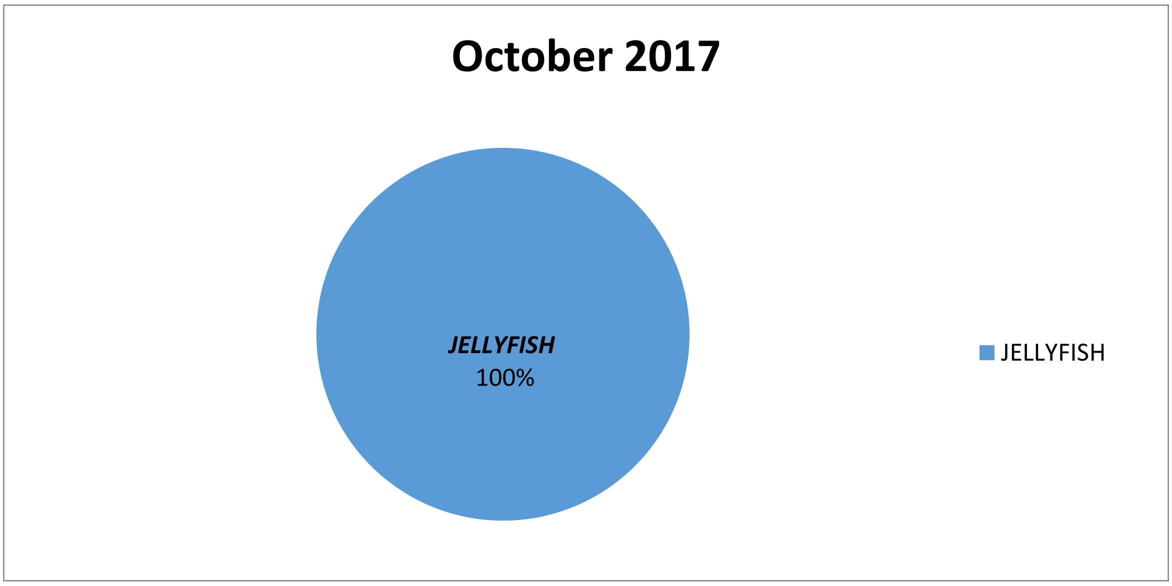


Figure. 4.2.4: Percentage of major species (bycatch) during October 2017

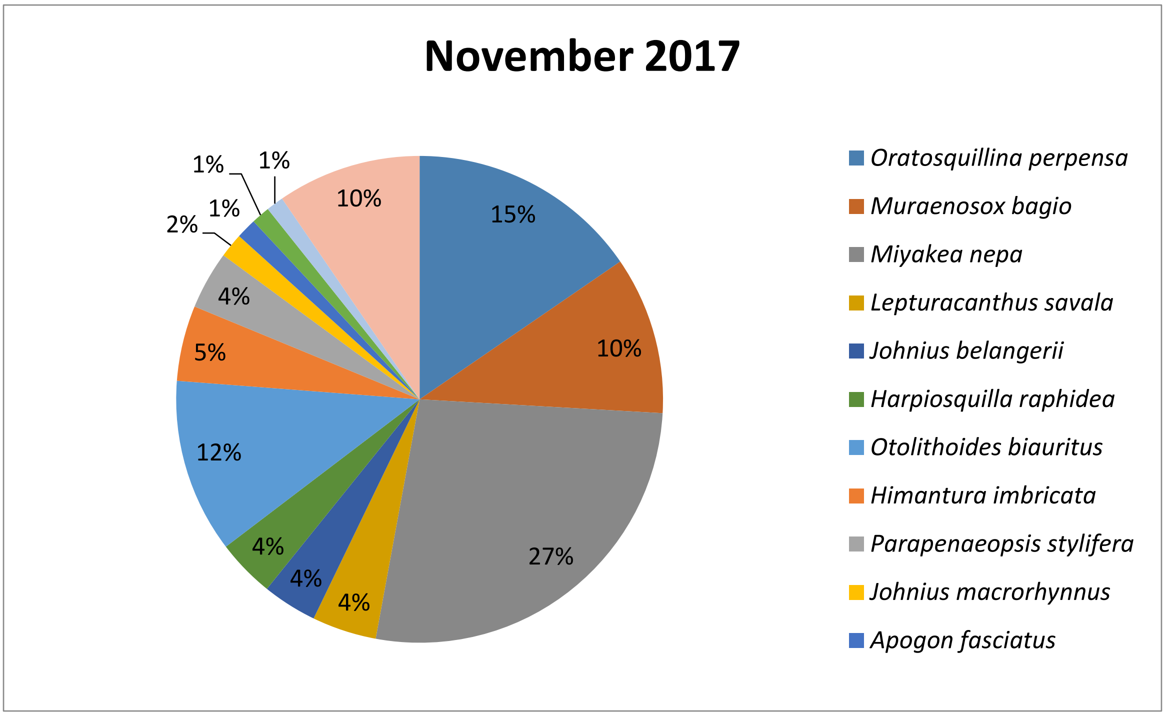


Figure. 4.2.5: Percentage of major species (bycatch) during November 2017

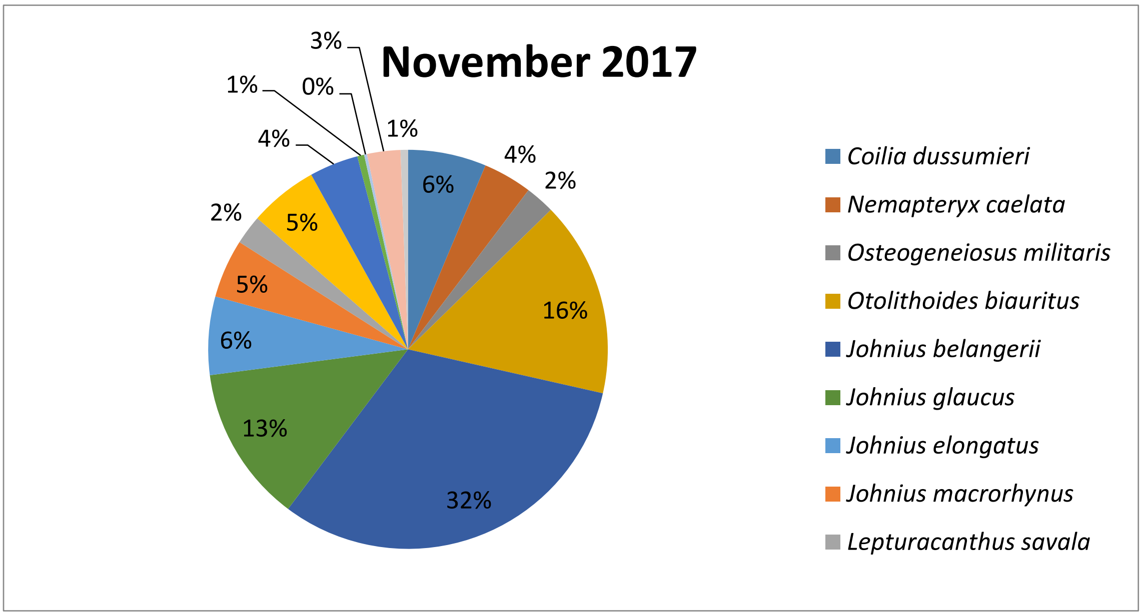


Figure. 4.2.6: Percentage of major species (Commercial) during November 2017

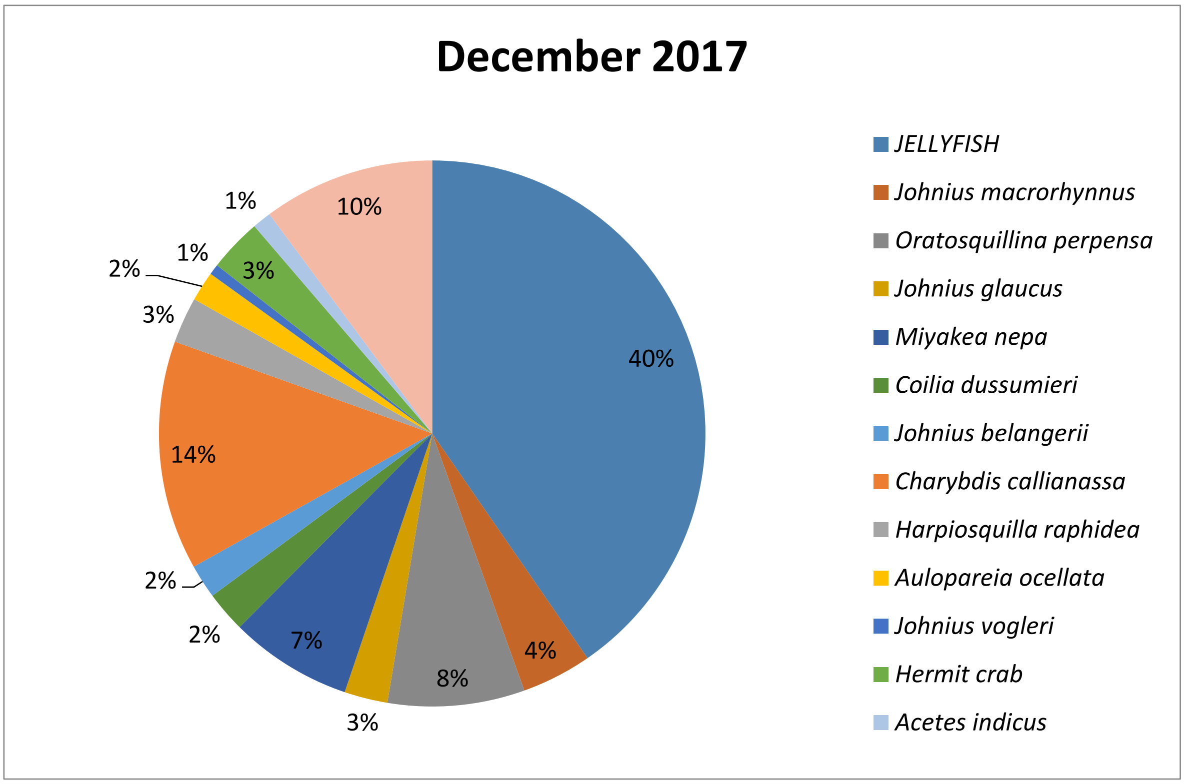


Figure. 4.2.7: Percentage of major species (bycatch) during December 2017

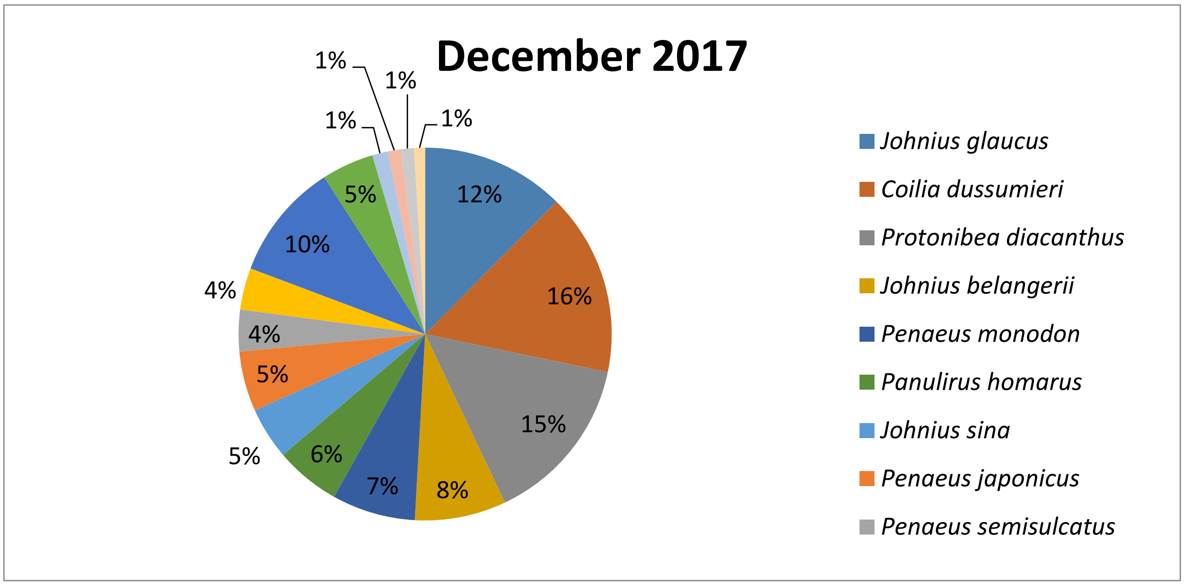


Figure. 4.2.8: Percentage of major species (Commercial) during December 2017

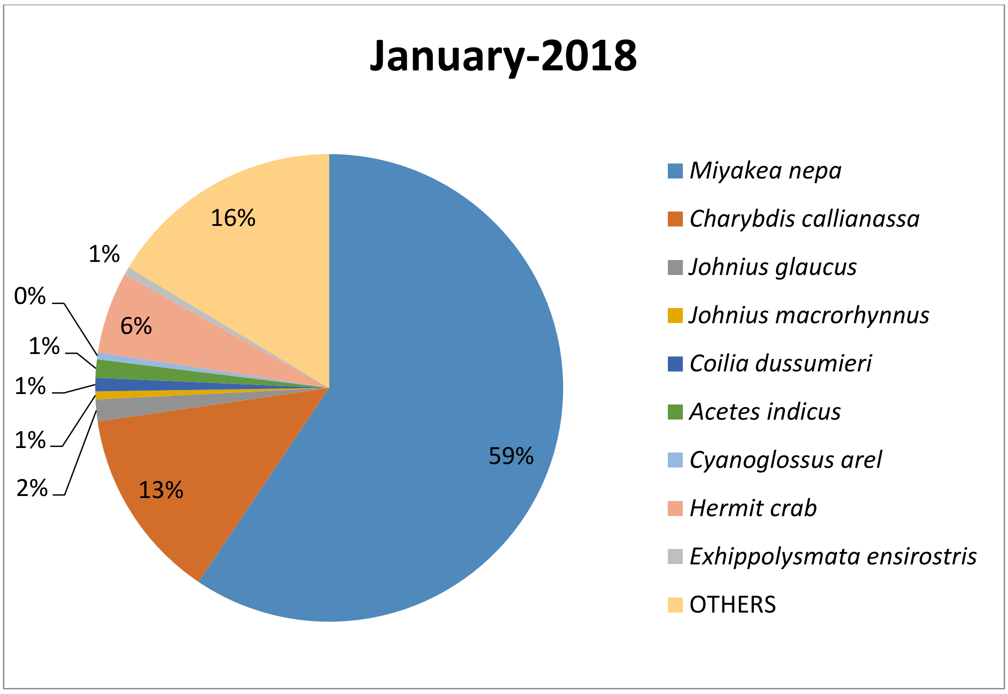


Figure. 4.2.9: Percentage of major species (bycatch) during January-2018

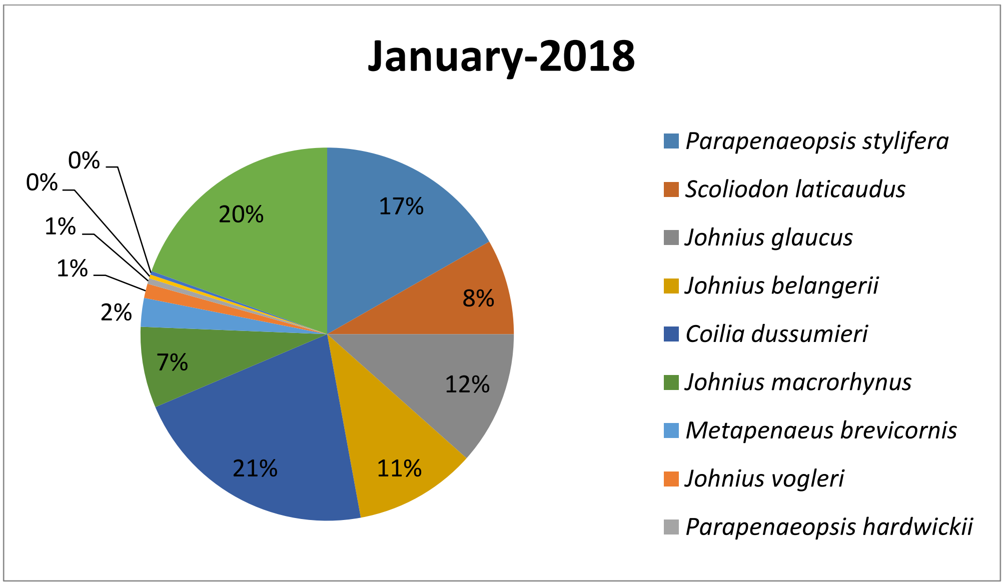


Figure. 4.2.10: Percentage of major species (Commercial) during January 2018

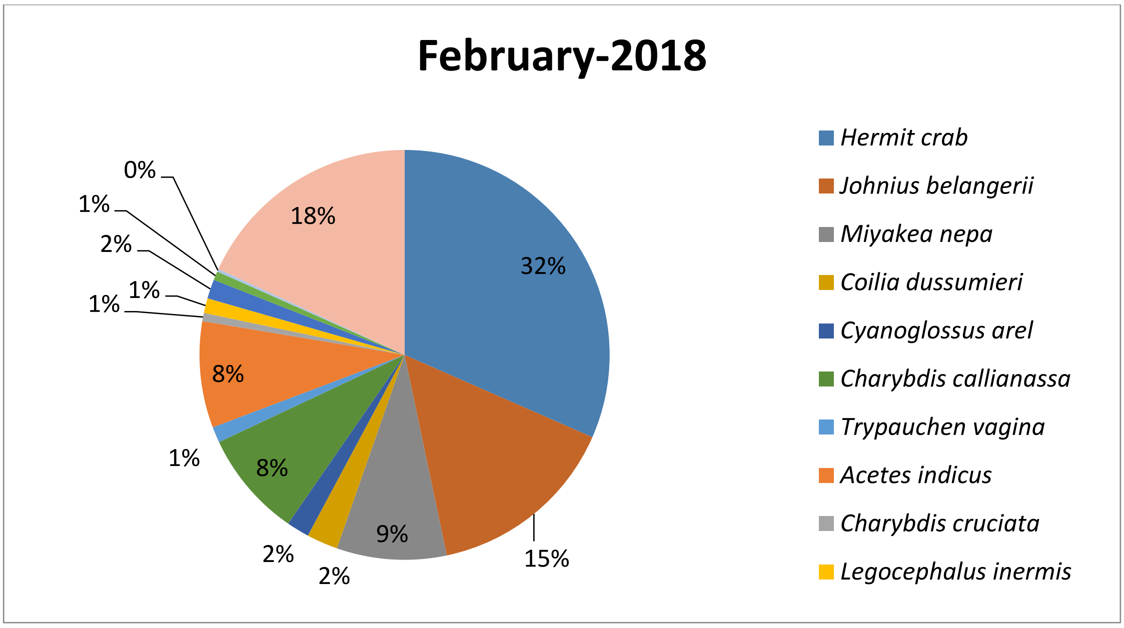


Figure. 4.2.11: Percentage of major species (bycatch) during February-2018

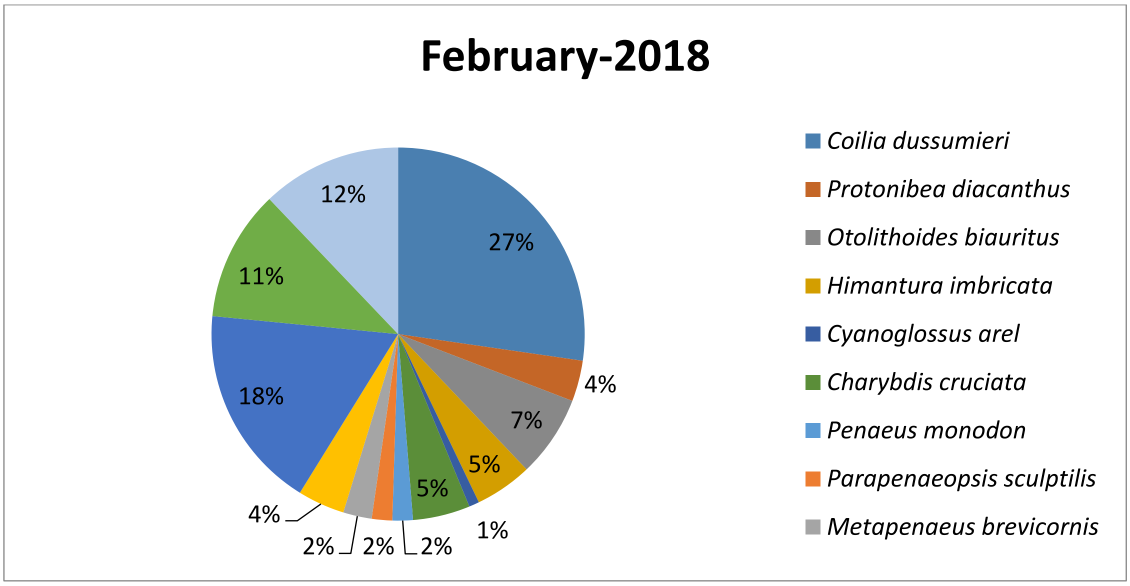


Figure. 4.2.12: Percentage of major species (Commercial) during February-2018

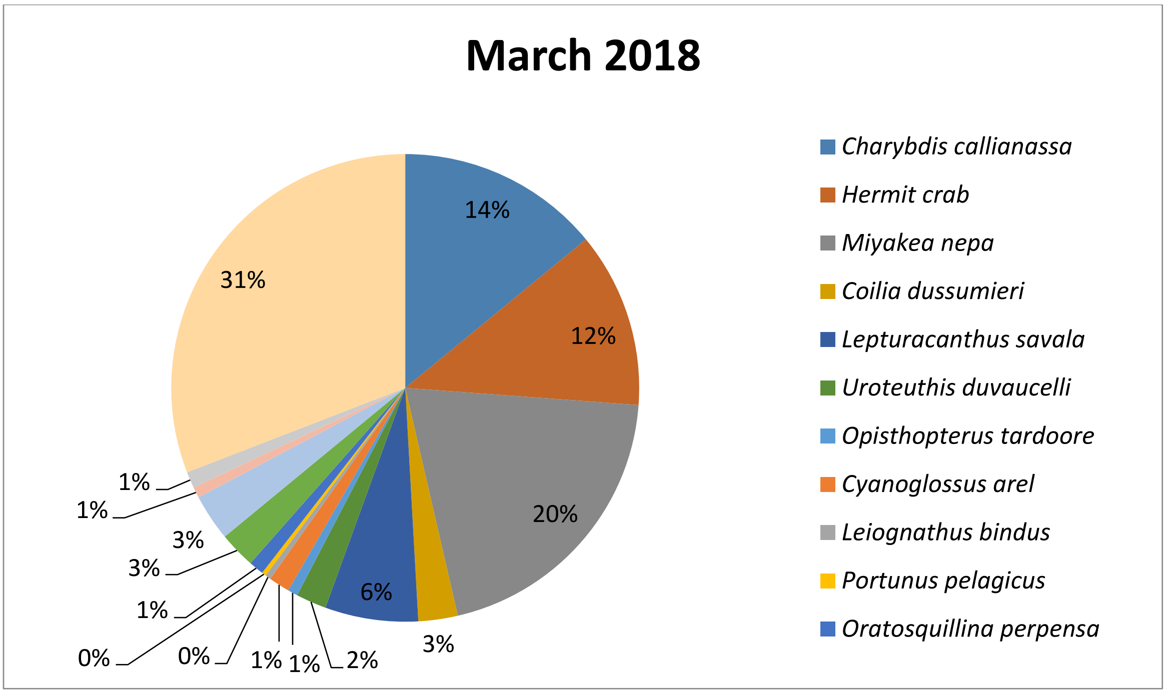


Figure. 4.2.13: Percentage of major species (bycatch) during March 2018

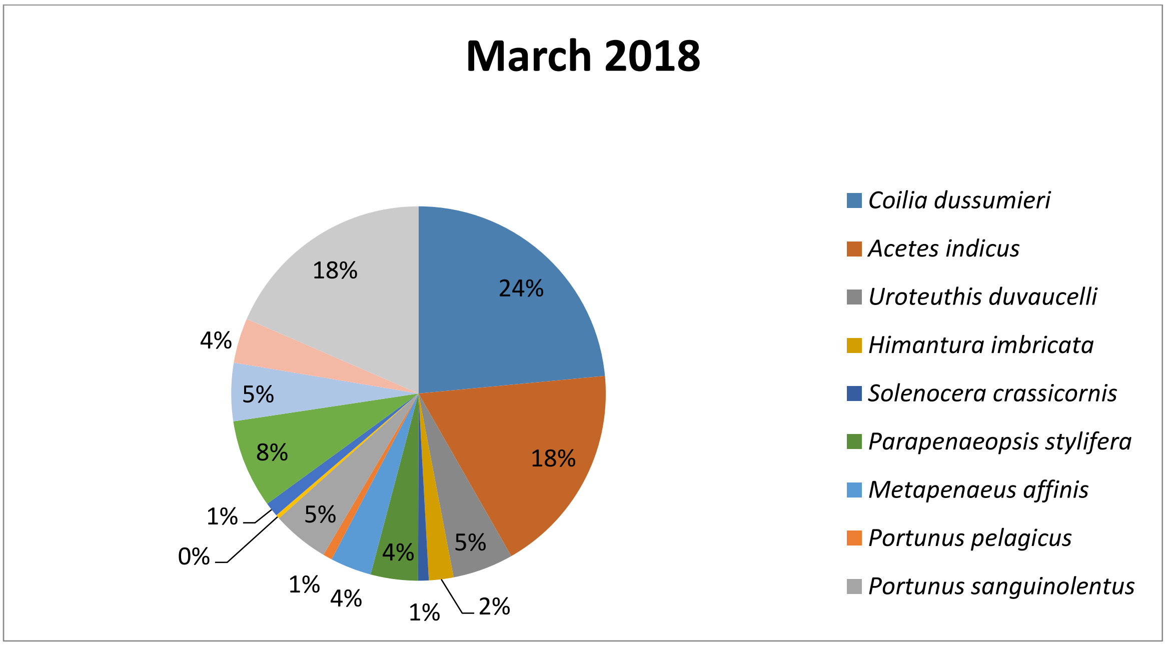


Figure. 4.2.14: Percentage of major species (Commercial) during March 2018

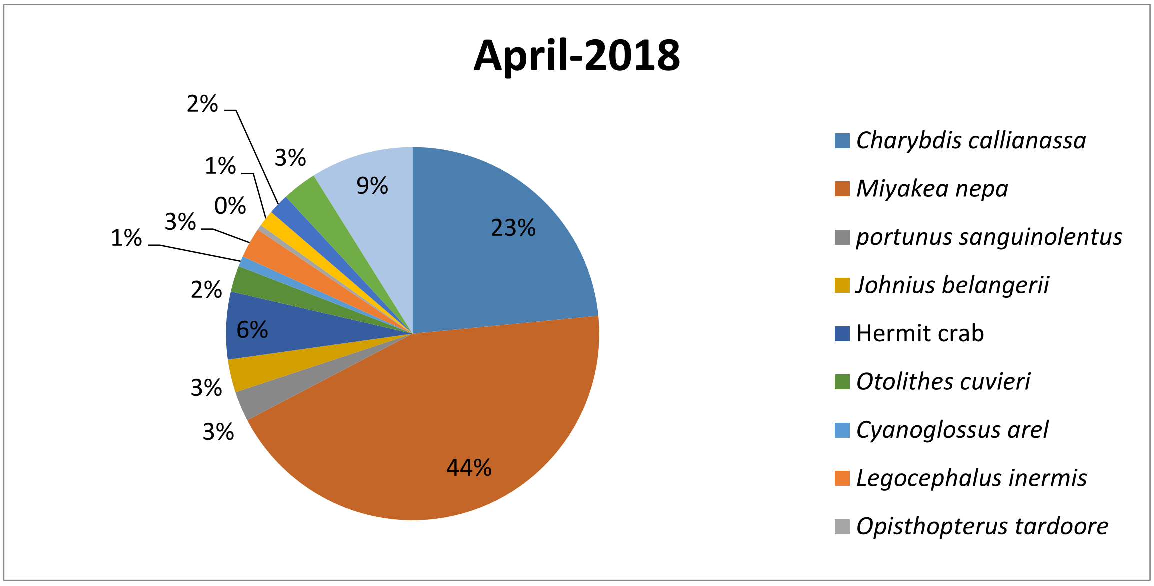


Figure. 4.2.15: Percentage of major species (bycatch) during April-2018

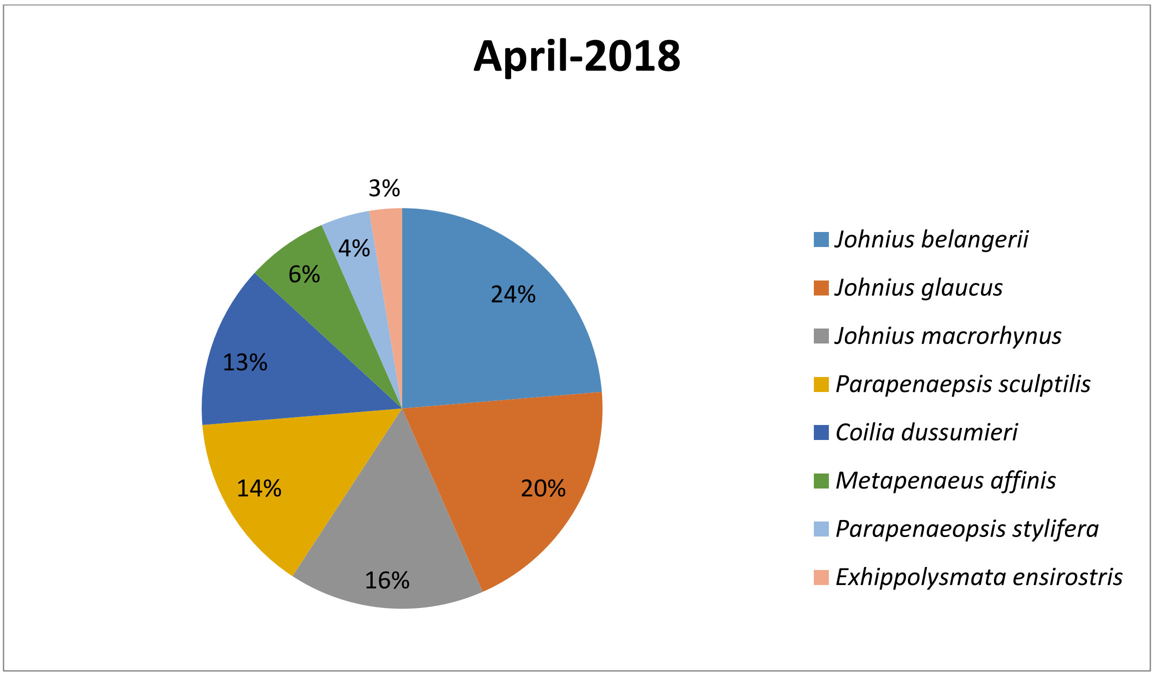


Figure. 4.2.16: Percentage of major species (Commercial) during April-2018

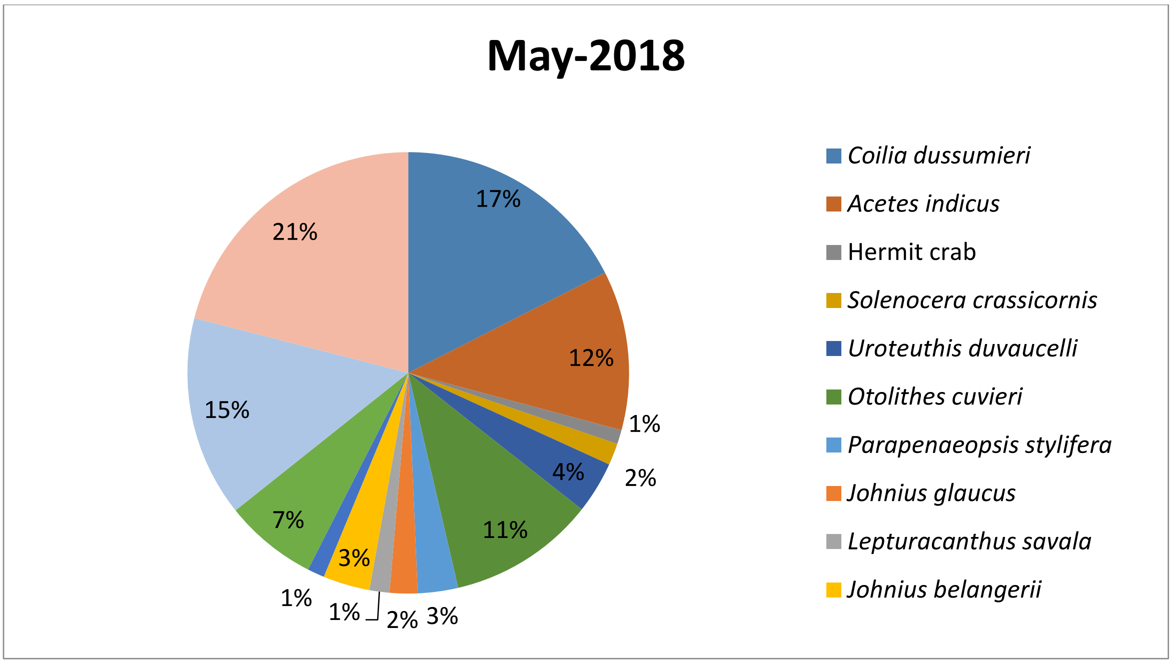


Figure. 4.2.17: Percentage of major species (bycatch) during May-2018

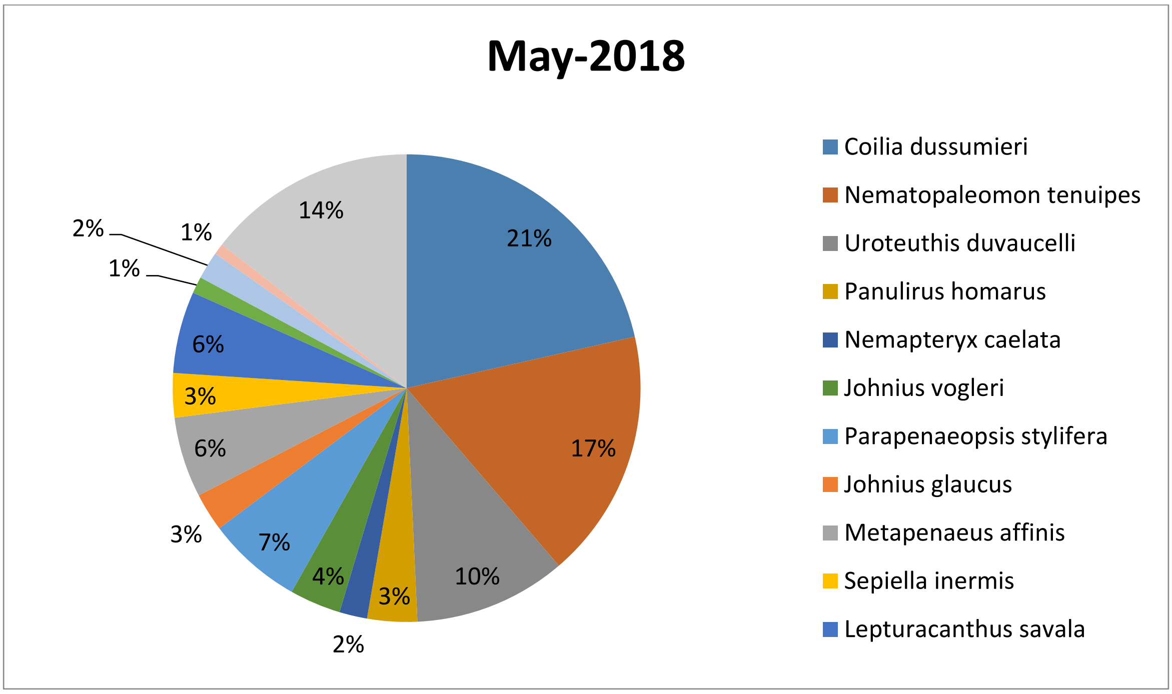


Figure. 4.2.18: Percentage of major species (Commercial) during May-2018

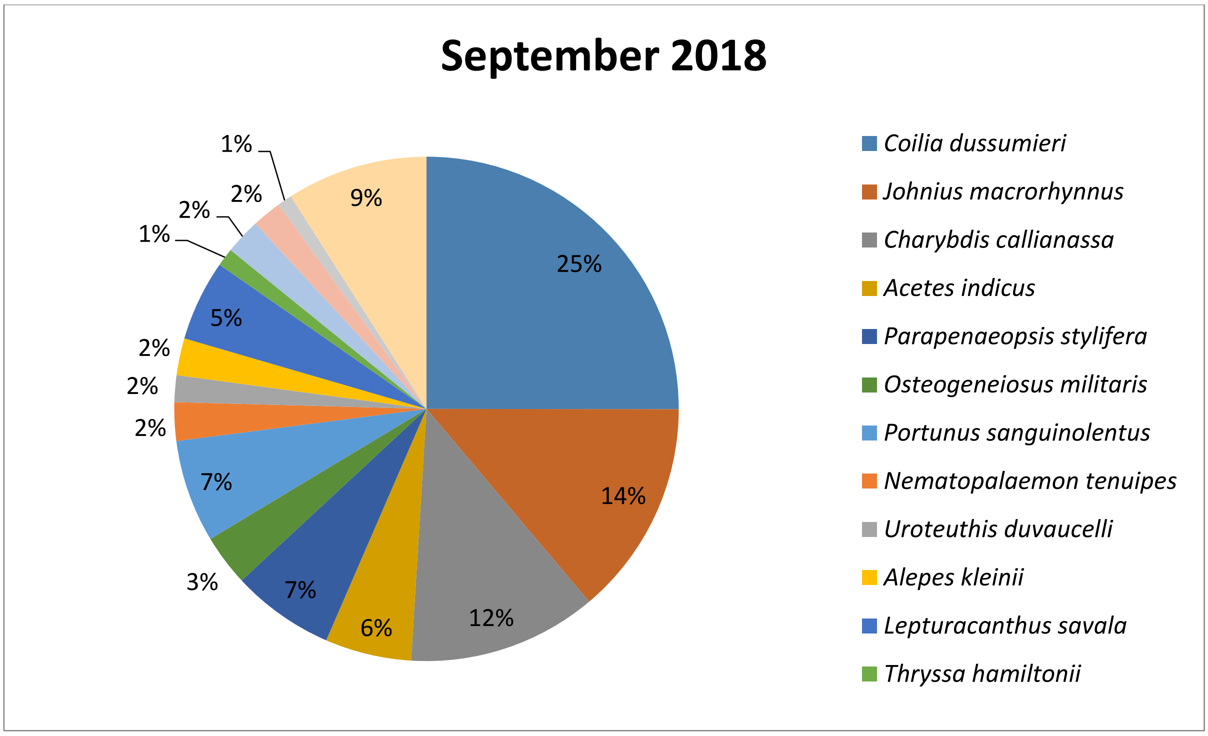


Figure. 4.2.19: Percentage of major species (bycatch) during September 2018

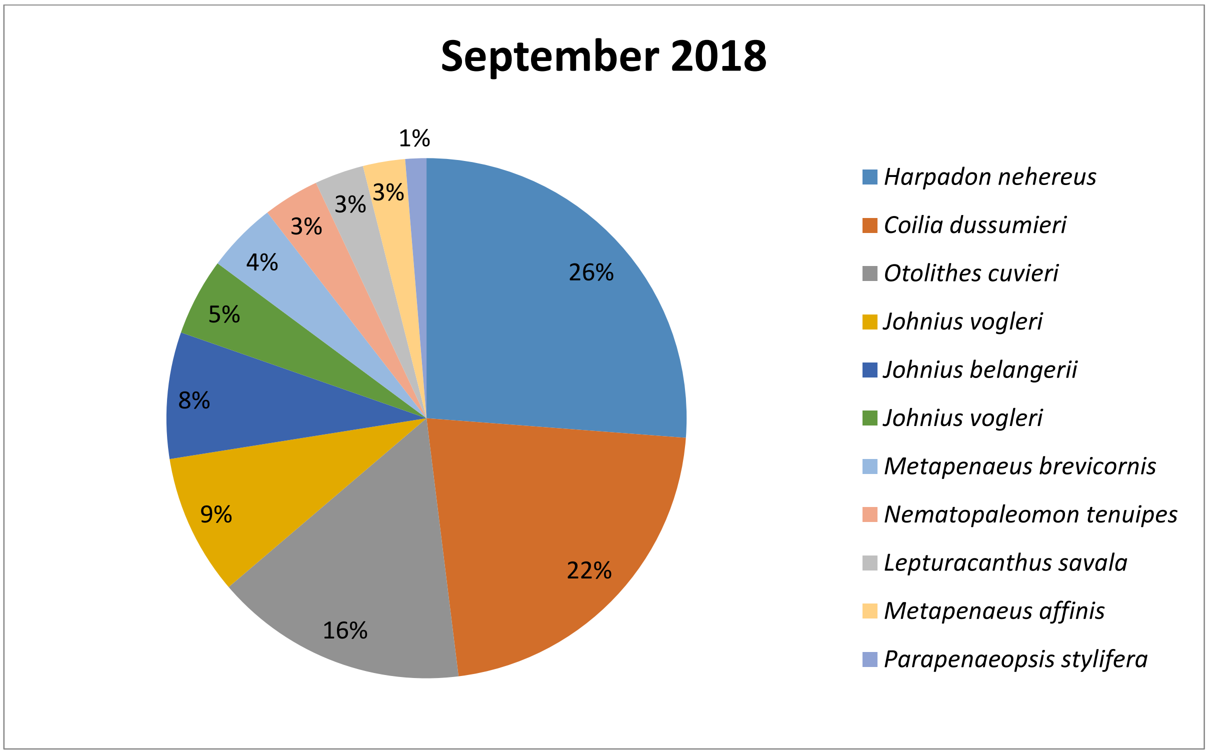


Figure. 4.2.20: Percentage of major species (Commercial) during September 2018

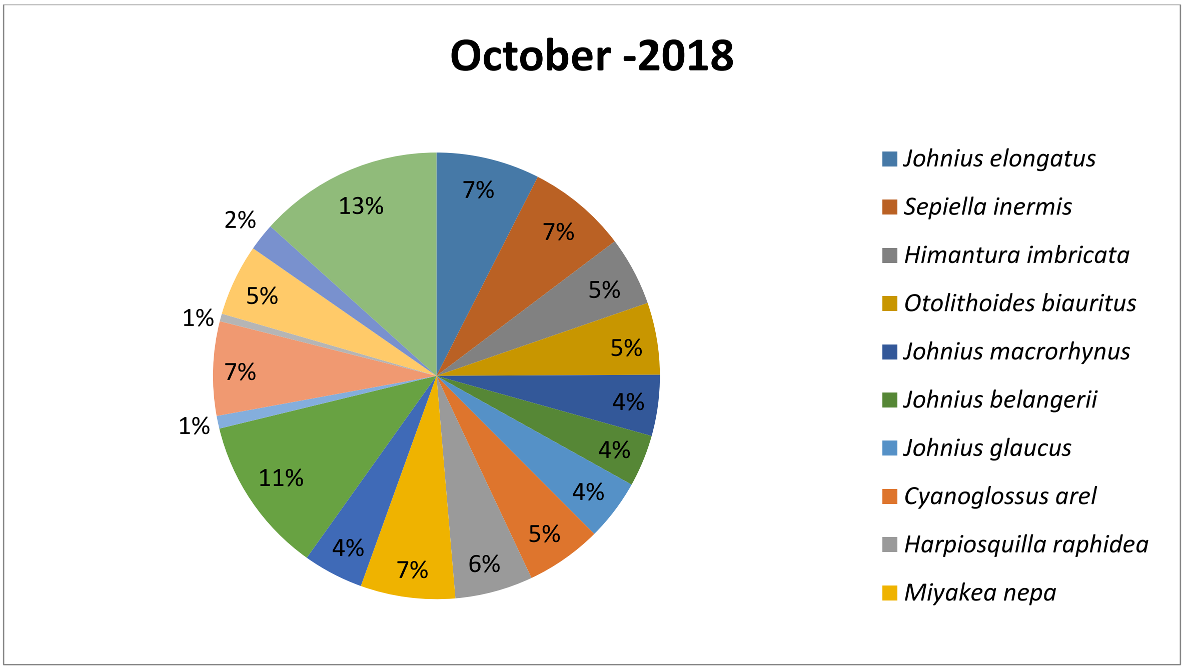


Figure. 4.2.21: Percentage of major species (bycatch) during October -2018

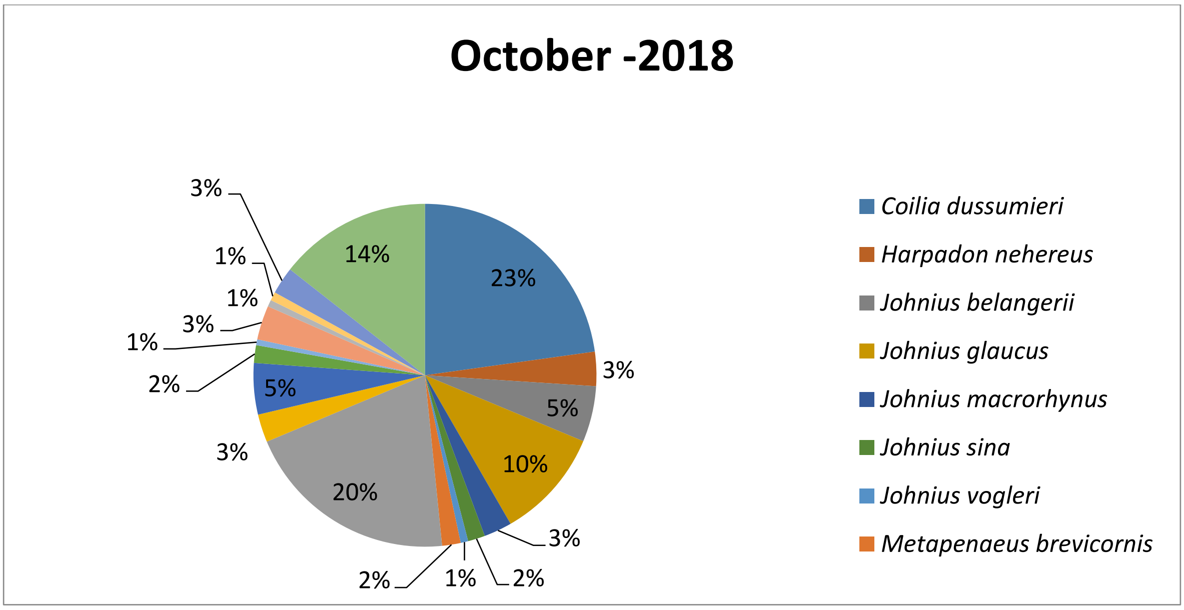


Figure. 4.2.22: Percentage of major species (Commercial) during October -2018

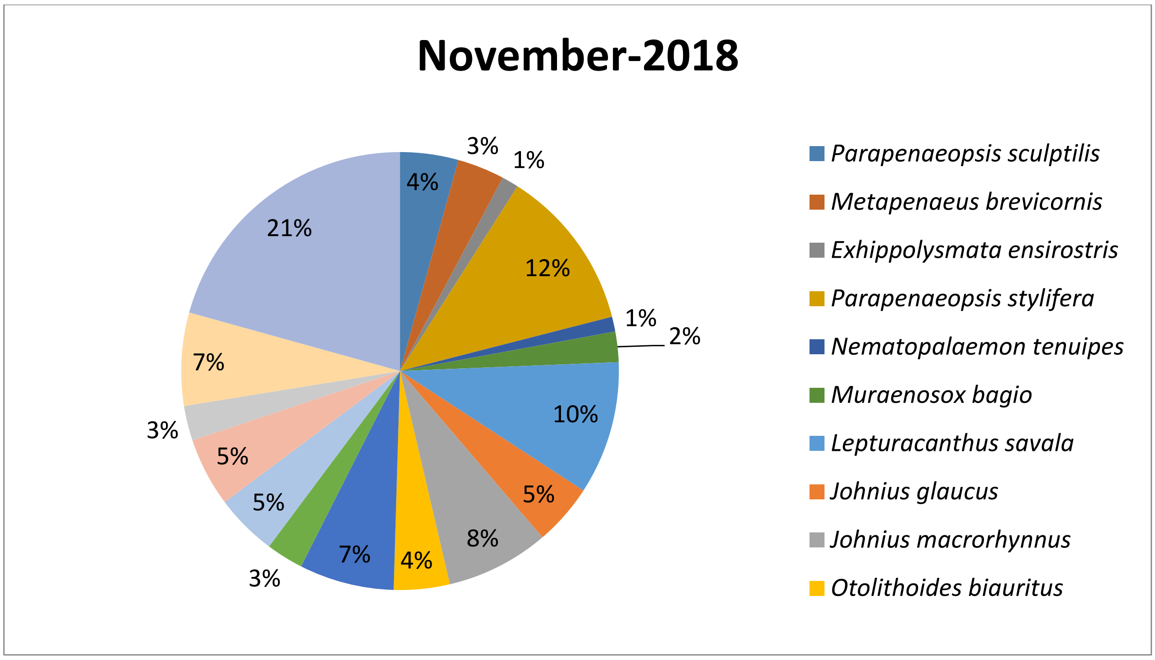


Figure. 4.2.23: Percentage of major species (bycatch) during November-2018

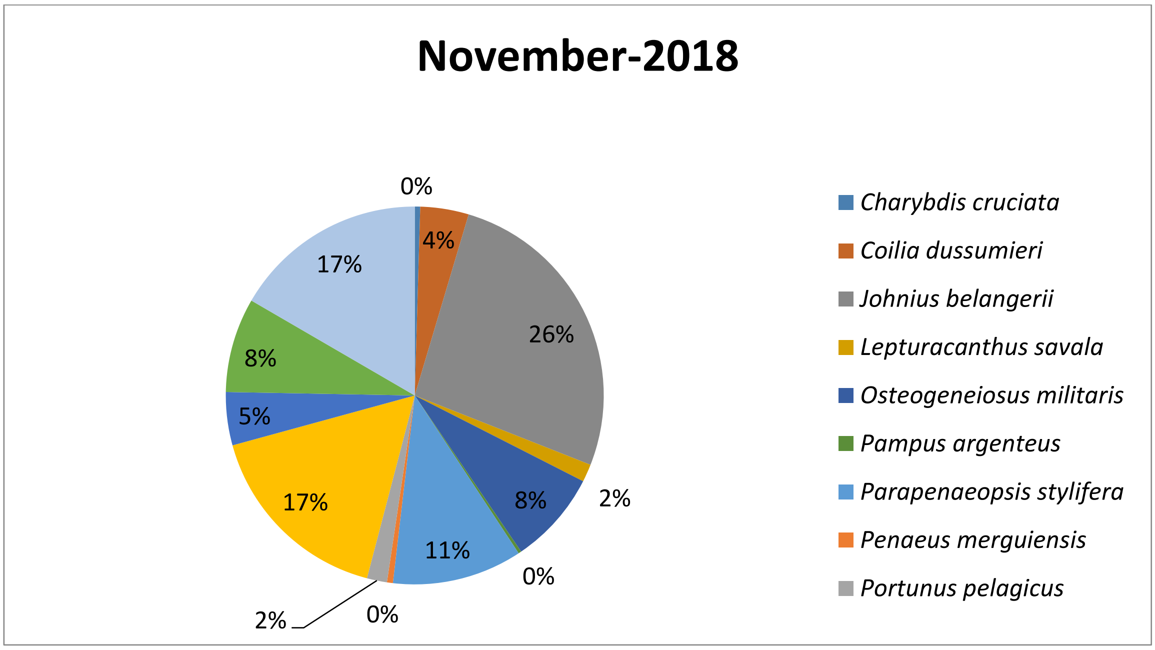


Figure. 4.2.24: Percentage of major species (Commercial) during November-2018

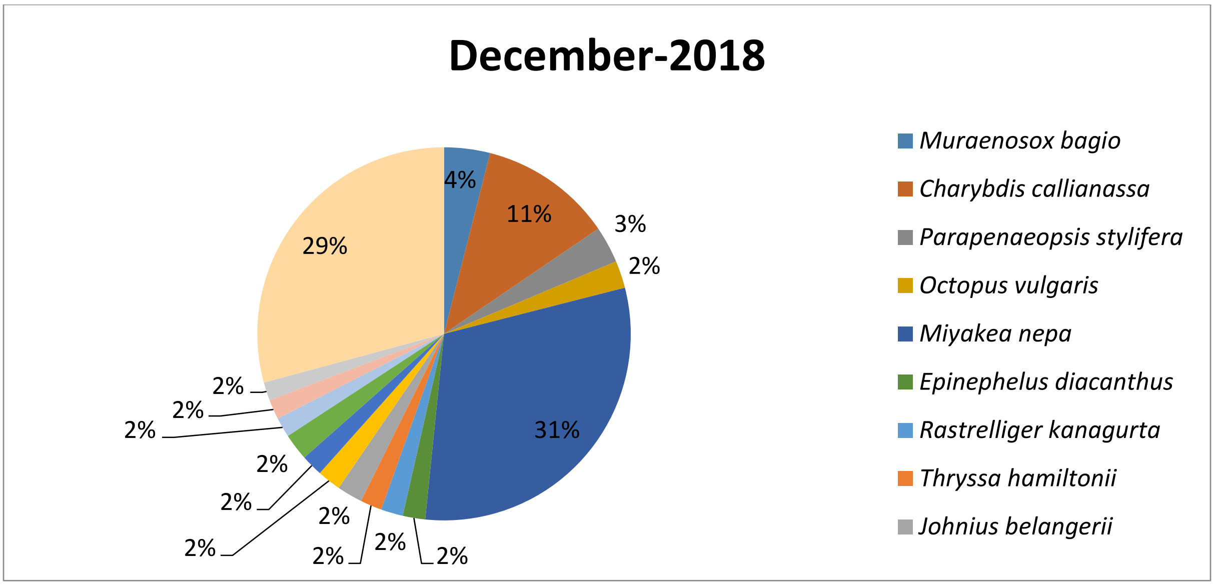


Figure. 4.2.25: Percentage of major species (bycatch) during December-2018

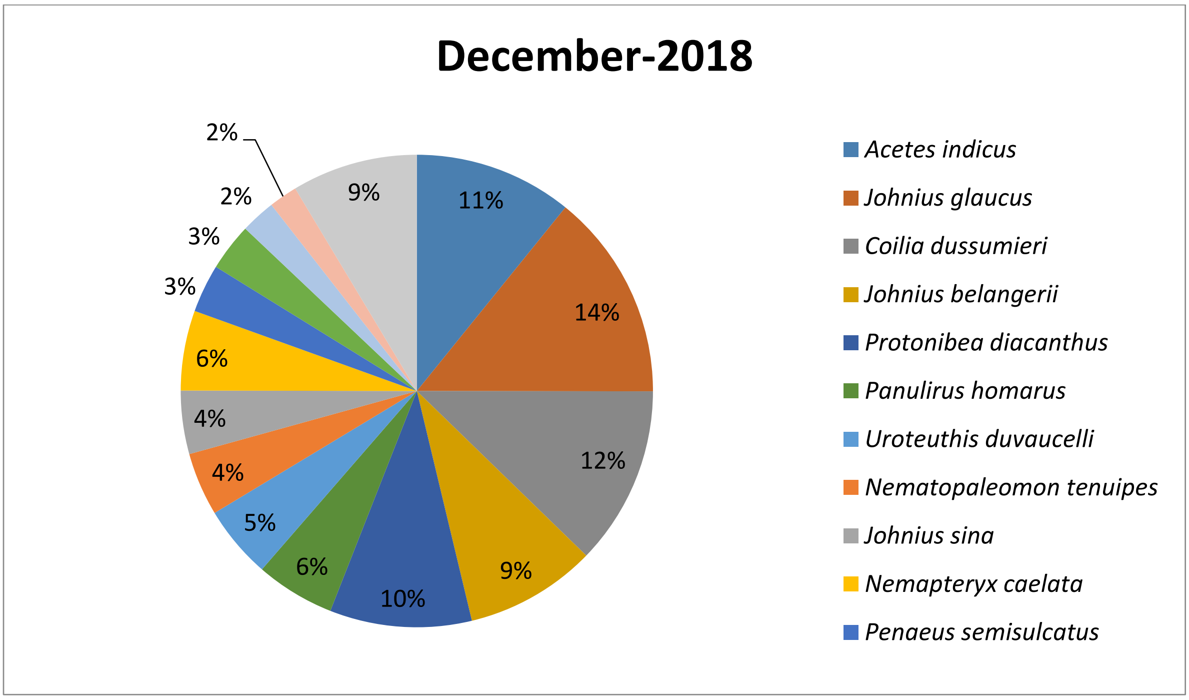


Figure. 4.2.26: Percentage of major species (Commercial) during December-2018

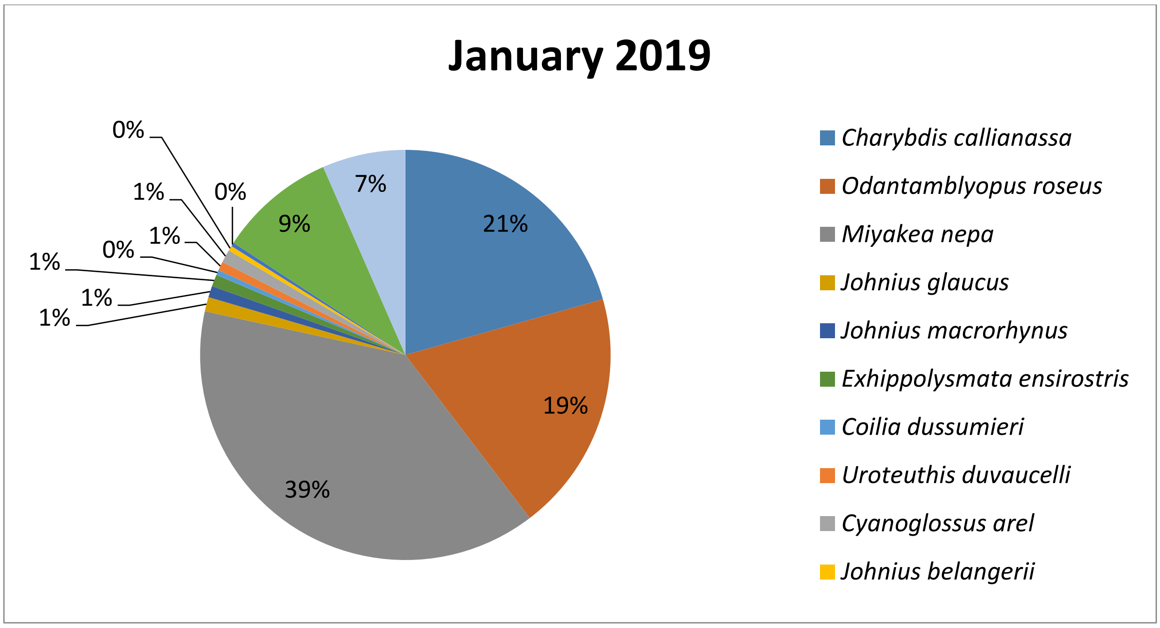


Figure. 4.2.27: Percentage of major species (bycatch) during January 2019

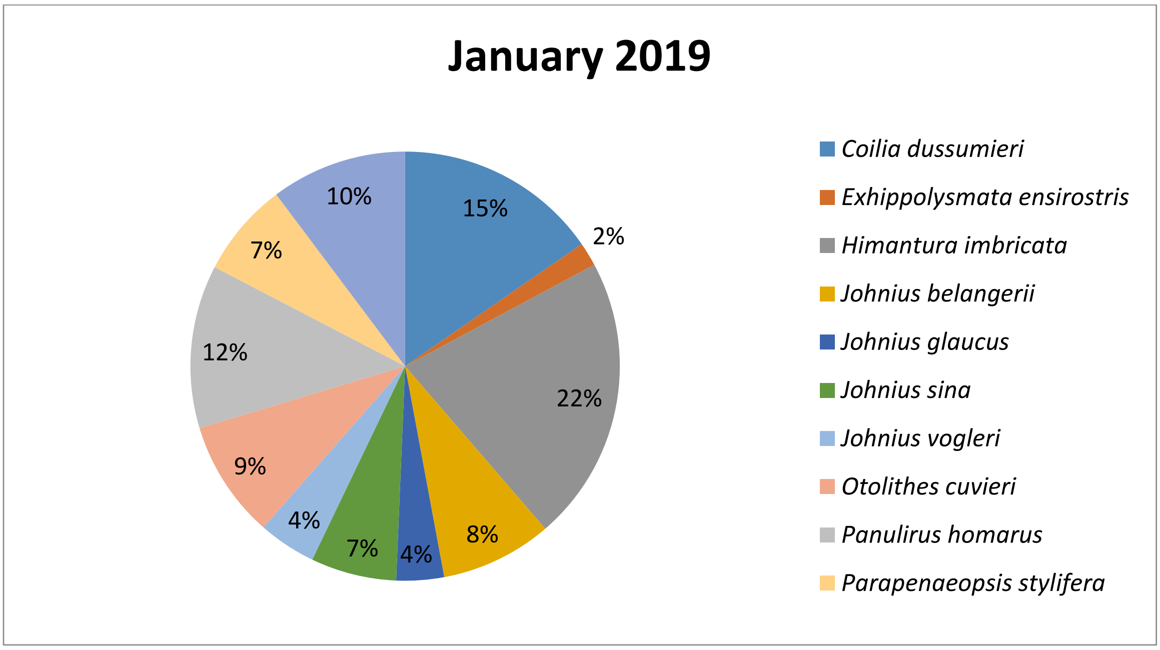


Figure. 4.2.28: Percentage of major species (Commercial) during January 2019

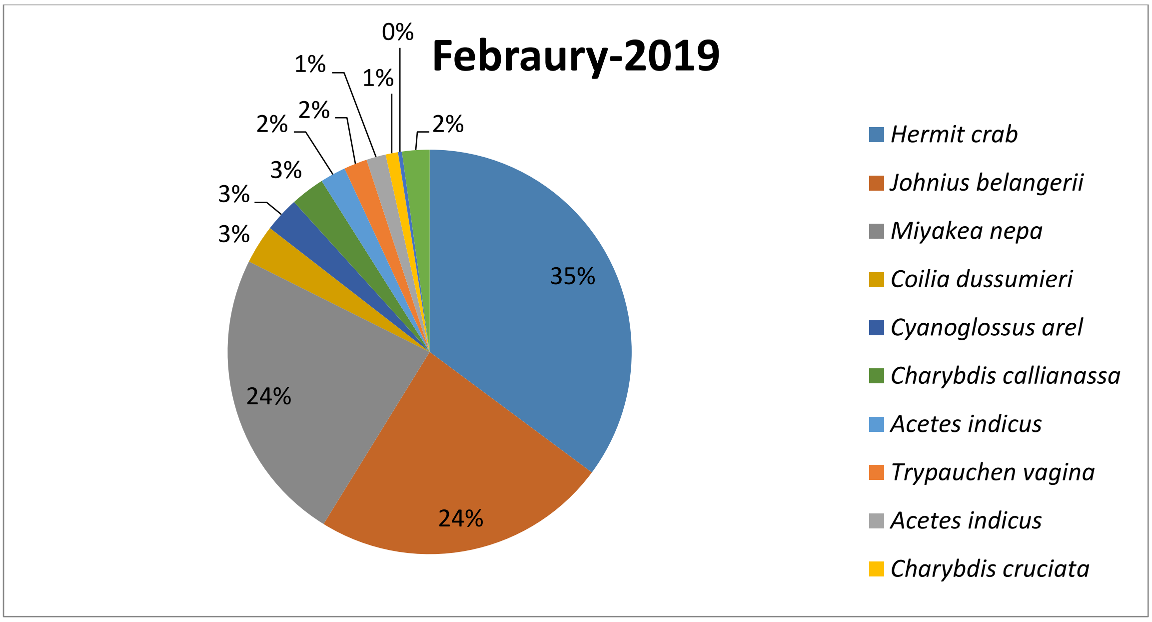


Figure. 4.2.29: Percentage of major species (bycatch) during Febraury-2019

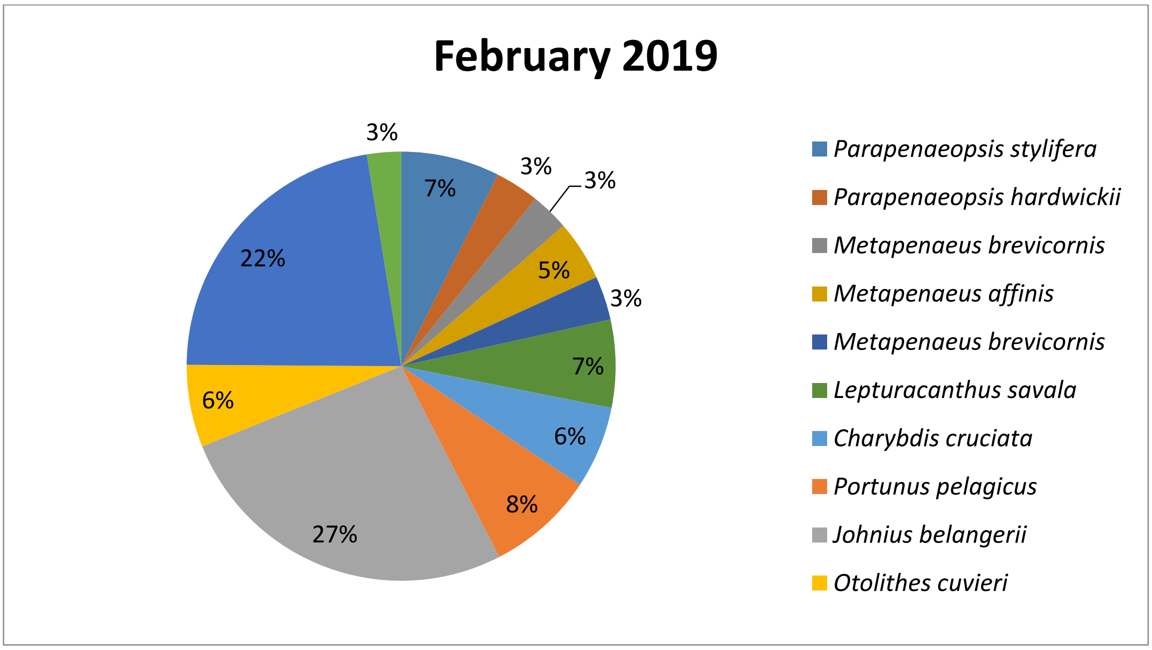


Figure. 4.2.30: Percentage of major species (Commercial) during Febraury-2019

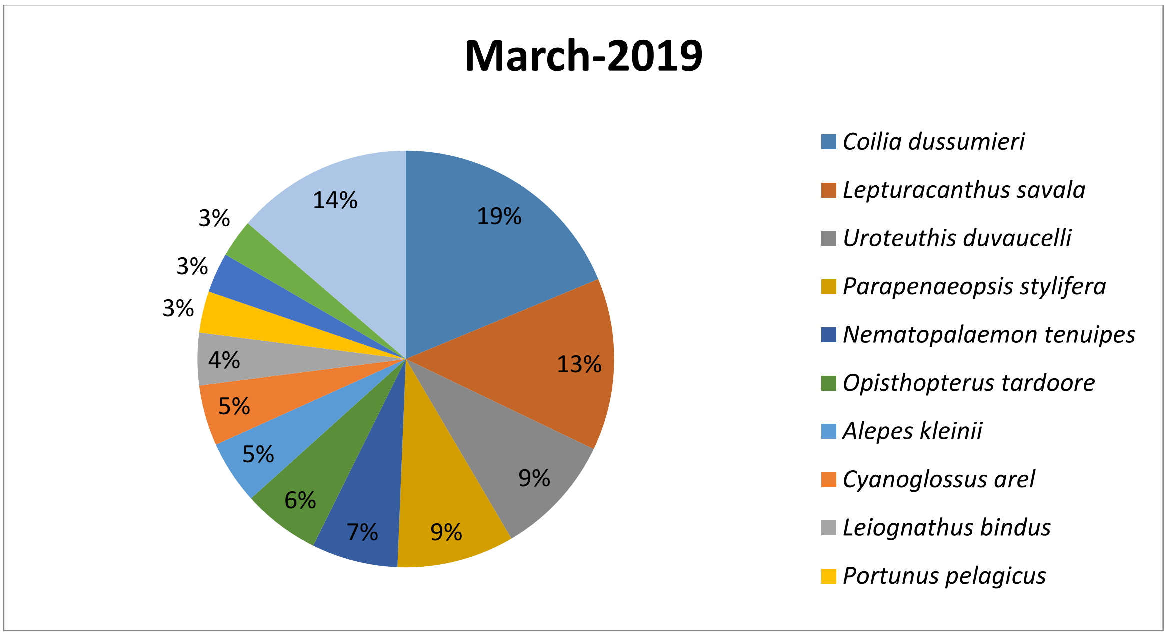


Figure. 4.2.31: Percentage of major species (bycatch) during March-2019

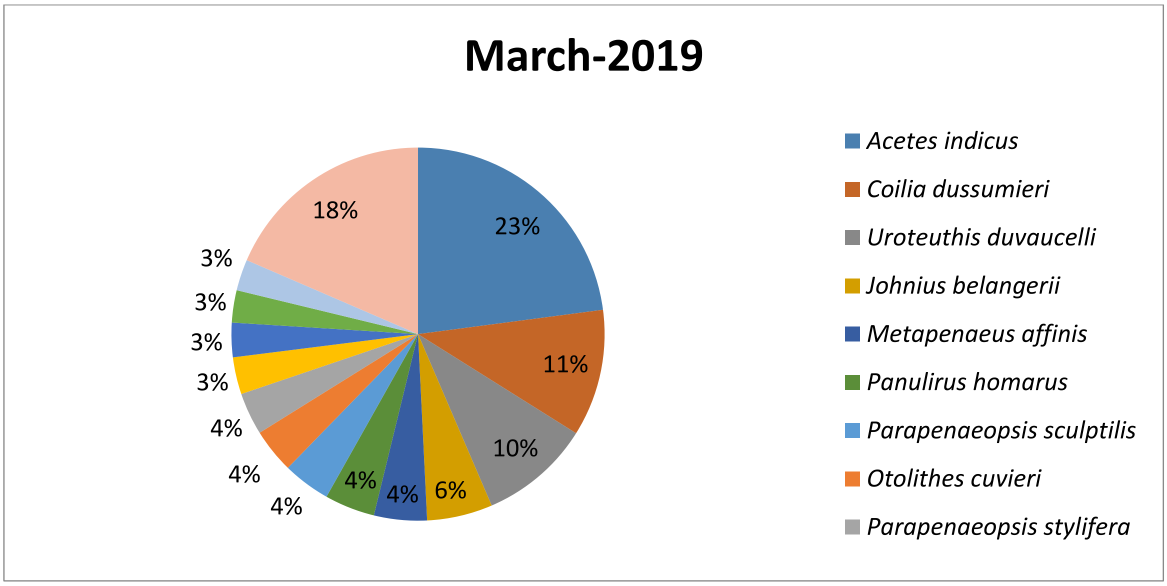


Figure. 4.2.32: Percentage of major species (Commercial) during March-2019

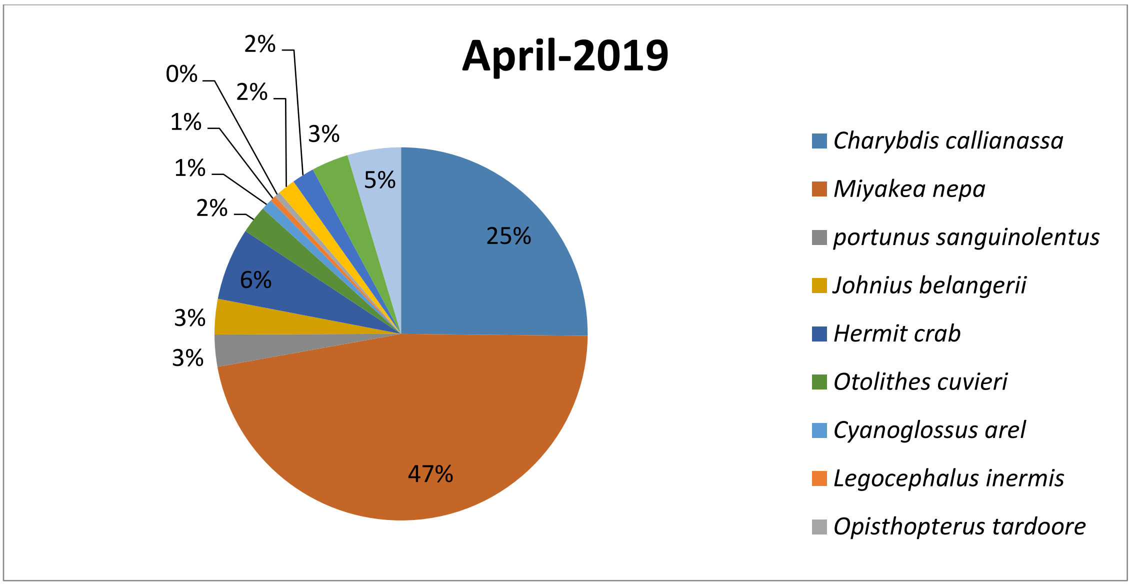


Figure. 4.2.33: Percentage of major species (bycatch) during April-2019

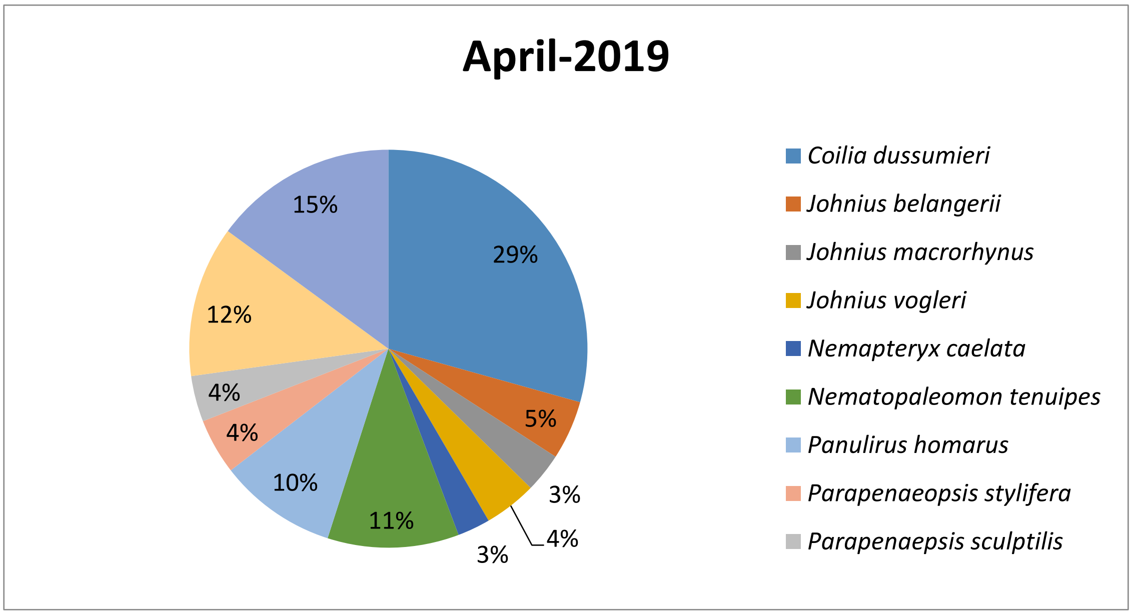


Figure. 4.2.34: Percentage of major species (Commercial) during April-2019

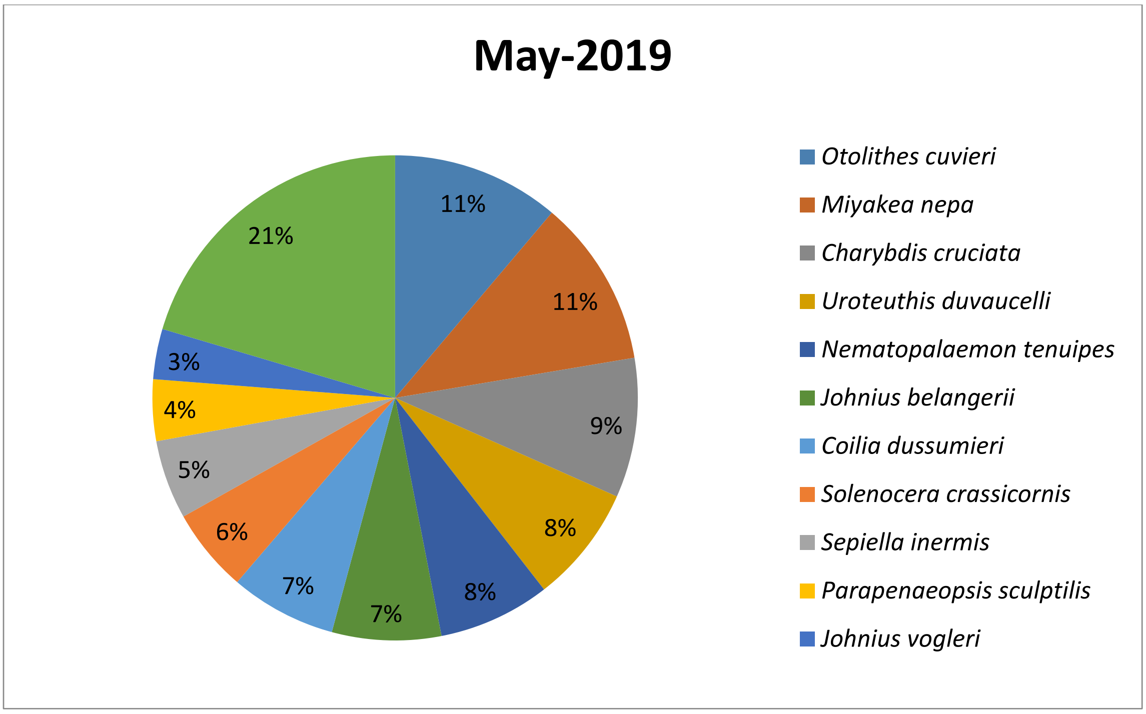


Figure. 4.2.35: Percentage of major species (bycatch) during May-2019

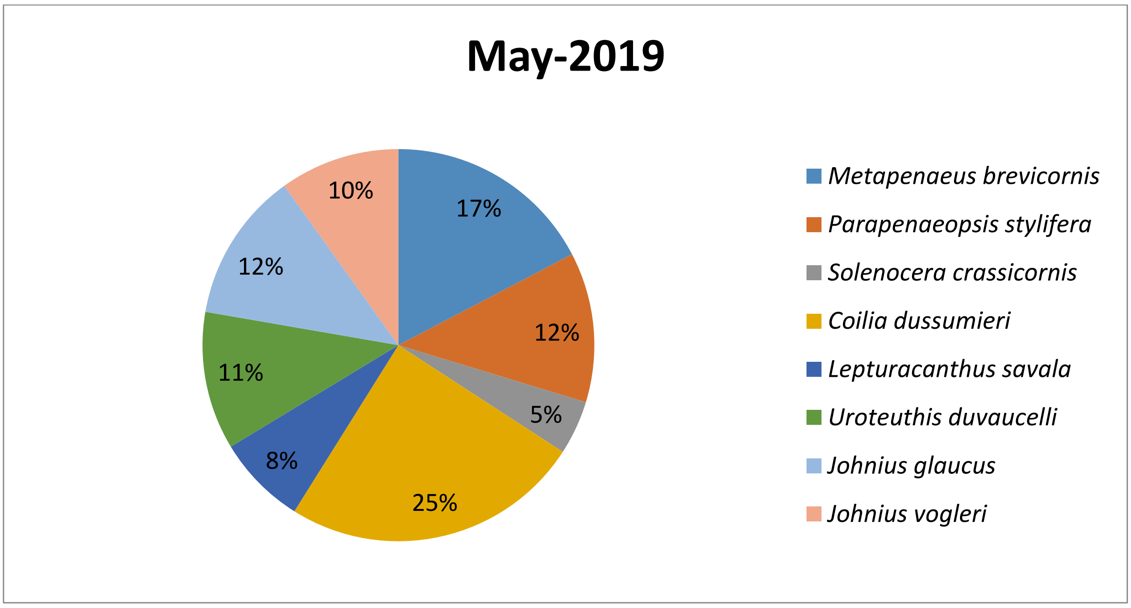


Figure. 4.2.36: Percentage of major species (Commercial) during May-2019

4.3. Composition of targeted catch and bycatch

Shrimp trawl was used for conducting experimental fishing. To study the contribution of shrimps to the total catch, the entire catch was split into three categories: target catch which included only shrimps; non-target catch which included portion of the catch with good market value and demand other than shrimps; and bycatch which included all miscellaneous fishes and juveniles. The target catch was very low compared to the non-target and bycatch in all the months. Considering the overall contribution to catch composition, bycatch contributed maximum followed by non-target catch and the target catch. Shrimp: bycatch ratio calculated for different months during the study period ranged from 1:3.08 to 1:60.98. The mean monthly bycatch from shrimp trawl along Mumbai coast during the present study was estimated as 13.3 kg h^{-1}.

4.4. Similarity percentage analysis

Using the abundance data, the similarity/dissimilarity in fish assemblages between the seasons was compared employing similarity percentage analysis. By applying this method, the species that contributed significantly to fish assemblages were measured and ranked. SIMPER analysis could identify the discriminating species responsible for spatio-temporal variation based on their contribution to average dissimilarity. Based on SIMPER analysis, about 41.42% overall average dissimilarity was found among the seasons. The species contributing maximum with average percentage dissimilarity among the seasons and stations are shown in Table. 4.4.1.

Table. 4.4.1. Discriminating contribution of major groups through SIMPER analysis

Taxon	Av. dissim	Contrib. %	Cumulative %	Pre-monsoon	Post-monsoon
Johnius belangerii	5.081	12.27	12.27	28.7	82.1
Harpodon nehereus	4.94	11.92	24.19	1.2	53
Johnius glaucus	4.16	10.03	34.22	10.7	54.4
Parapenaeopsis hardwickii	2.64	6.37	40.59	55.4	83.1
Coilia dussumieri	2.29	5.53	46.12	62	86.1
Otolithoides biauritus	2.15	5.18	51.3	2.13	24.7
Acetes indicus	1.55	3.74	55.04	23.6	7.33
Himantura imbricata	1.51	3.64	58.68	2.83	18.7
Hermit crab	1.41	3.41	62.1	20.1	5.21
Parapenaeopsis stylifera	1.36	3.28	65.38	15	29.3
Oratosquillina perpensa	1.25	3.01	68.39	0.613	13.7
Johnius macrorhynnus	1.16	2.79	71.18	8.02	20.2
Johnius sina	1.12	2.71	73.89	0.686	12.5
Nematopalaemon tenuipes	1.10	2.66	76.55	20	8.43
Uroteuthis duvaucelli	1.06	2.57	79.11	17.4	6.26
Otolithes cuvieri	1.02	2.47	81.59	10	20.8
Penaeus merguiensis	0.83	2.01	83.6	0.93	9.68
Miyakea nepa	0.81	1.95	85.55	29.1	37.5
Penaeus semisulcatus	0.67	1.63	87.18	0	7.07
Penaeus monodon	0.64	1.55	88.72	0.56	7.3
Johnius vogleri	0.61	1.48	90.21	9.01	15.5
Portunus pelagicus	0.58	1.41	91.61	3.56	9.69
Johnius elongatus	0.53	1.29	92.9	1.23	6.84
Parapenaeopsis sculptilis	0.49	1.19	94.09	6.12	0.94
Scoliodon laticaudus	0.47	1.14	95.23	1.74	6.69
Metapenaeus affinis	0.39	0.93	96.17	8.81	4.75
Metapenaeus brevicornis	0.31	0.76	96.92	7.23	10.5
Cyanoglossus arel	0.30	0.73	97.65	2.53	5.69
portunus sanguinolentus	0.25	0.61	98.26	3.16	0.5
Harpiosquilla raphidea	0.18	0.44	98.7	2.13	4.05
Sepiella inermis	0.15	0.36	99.06	3.17	1.6
Octopus vulgaris	0.14	0.33	99.39	0.023	1.46
Charybdis cruciata	0.13	0.32	99.71	4.11	2.69
Lepturacanthus savala	0.05	0.11	99.83	13.4	12.9
Chiloscyllium arabicum	0.04	0.09	99.92	0.405	0
Exhippolysmata ensirostris	0.03	0.08	100	2.12	1.76

4.5 Distribution of fishes

During the period of study, around 93 species were encountered in the experimental trawling carried out along Mumbai coast. These species were identified to get an overall picture of the distribution of species along the coast. Numbers of species in each category were as follows: finfishes (53), shrimps (13), gastropods (11), crabs (4), cephalopods (4), stomatopods (3), elasmobranch (3), lobster (1) and hermit crab (1). Major species landed by trawl are enclosed in the plates 2a to 2e.

List of identified species

SHARKS & RAYS

Order: CARCHARINIFORMES

Family: Carcharinidae

1. *Scoliodon laticaudus* Muller & Henle, 1838

Order: ORECTOLOBIFORMES

Family: Hemiscylliidae

2. *Chiloscyllium arabicum* Gubanov,1980

Order: MYLIOBATIFORMES

Family: Dasyatidae

3. *Himantura imbricata* (Bloch & Schneider, 1801)

FINFISHES

Order : Anguilliformes

Family: Muraenosocidae

4. *Muraenesox bagio* (Hamilton-Buchanan, 1822)
5. *Muraenesox cinereus* (*Forsskål*, 1775)

Order : Aulopiformes

Family: Harpadontidae

6. *Harpadon nehereus* (Hamilton, 1822)

Order: Clupeiiformes

Family: Clupeidae

7. *Anodontostoma chacunda* (Hamilton, 1822)
8. *Escualosa thoracata* (Valenciennes, 1847)

Family: Pristigasteridae

9. *Opisthopterus tardoore* (Cuvier, 1829)

Family: Engraulidae

10. *Coilia dussumieri* Valenciennes, 1848
11. *Thryssa hamiltonii* Gray,1835

Order : Gadiformes

Family: Bregmacerotidae

12. *Bregmaceros macclellandi* Thompson, 1840

Order : Lophiiformes

Family: Antennariidae

13. *Antennarius indicus* Schultz, 1964

Order : Pleuronectiformes

Family: Cynoglossidae

14. *Cynoglossus arel* (Schneider, 1801)

Family: Bothidae

15. *Bothus myriaster* (Temminck & Schlegel, 1846)

Order : Perciformes

Family: Apogonidae

16. *Ostorhinchus fasciatus* (White, 1790)

Family: Carangidae

17. *Alepes kleinii* (Bloch, 1793)
18. *Parastromateus niger* (Bloch, 1795)
19. *Decapterus russelli* (Ruppell, 1830)
20. *Megalaspis cordyla* (Linnaeus, 1758)
21. *Scomberoides tala* (Cuvier, 1832)
22. *Scomberoides tol* (Cuvier, 1832)
23. *Elagatis bipinnulata* (Quoy&Gaimard, 1824)

Family: Gobiidae

24. .*Aulopareia ocellata* (Day, 1873)
25. *Odontamblyopsus roseus* (Valenciennes, 1837)
26. *Trypauchen vagina* (Bloch & Schneider, 1801)

Family : Leiognathidae

27. *Leiognathus bindus* (Valenciennes, 1835)

Family : Mullidae

28. *Upeneus guttatus* (Day, 1868)
29. *Upeneus vittatus* (Forsskål, 1775)
30. *Upeneus moluccensis* (Bleeker, 1855)

Family : Polynemidae

31. *Eleutheronema tetradactylum* (Shaw, 1804)
32. *Filimanus heptadactyla* (Cuvier, 1829)

Family : Sciaenidae

33. *Johnius borneensis* (Bleeker, 1851)
34. *Johnius belangerii* (Cuvier, 1830)
35. *Johnius dussumieri* (Cuvier, 1830)
36. *Johnius elongates* Lal Mohan, 1976
37. *Johnius glaucus* (Day, 1876)
38. *Johnius macrorhynus* (Lal Mohan, 1976)
39. *Otolithes cuvieri* Trewavas, 1974
40. *Otolithoides biauritus* (Cantor, 1849)
41. *Protonibea diacanthus* (Lacepede, 1802)
42. *Otolithes ruber* (Bloch & Schneider, 1801)
43. *Nibea maculata*(Bloch & Schneider, 1801)

Family : Scombridae

44. *Rastrelliger kanagurta* (Cuvier, 1816)

Family : Serranidae

45. *Epinephelus diacanthus* (Valenciennes, 1828)

Family : Sillaginidae

46. *Sillago sihama* (*Forsskål, 1775)*

Family : Stromateidae

47. *Pampus argenteus* (Euphrasen, 1788)

Family : Tetradontidae

48. *Lagocephalus inermis* (Temminck & Schlegel, 1850)
49. *Lagocephalus lunaris* (Bloch & Schneider, 1801)

Family : Teraponidae

50. *Terapon jarbua* (*Forsskål, 1775)*
51. *Terapon therops Cuvier, 1829*

Family : Trichiuridae

52. *Lepturacanthus savala* (*Cuvier, 1829)*

Order : Scorpaeniformes

Family : Synanceiidae

53. *Minous inermis* Alcock, 1889

Order : Siluriformes

Family : Ariidae

54. *Nemapteryx caelata* (Valenciennes, 1840)
55. *Osteogeneiosus militaris* (Linnaeus, 1758)

Family : Plotosidae

56. *Plotosus lineatus* (Thunberg, 1787)

SHRIMPS, LOBSTERS AND CRABS

Order: DECAPODA

Family: Hippolytidae

57. *Exhippolysmata ensisrostris* (Kemp,1914)

Family: Palaemonidae

58. *Nematopaleomon tenuipes* (Henderson,1893)

Family: Penaeidae

59. *Metapenaeus affinis* (H. Milne Edwards, 1837)
60. *Metapenaeus brevicornis* (H. Milne Edwards, 1837)
61. *Penaeus japonicus* (Spence Bate, 1888)
62. *Penaeus monodon* (Fabricius, 1798)
63. *Penaeus merguiensis* (De Man, 1888)
64. *Penaeus semisulcatus* (De Hann, 1844)
65. *Parapenaeopsis hardwickii* (Miers, 1878)
66. *Parapenaeopsis sculptilis* (Heller, 1862)
67. *Parapenaeopsis stylifera* (H. Milne Edwards, 1837)

Family: Sergestidae

68. *Acetes indicus* (H. Milne Edwards, 1830)

Family: Solenoceridae

69. *Solenocera crassicornis* (H. Milne Edwards, 1837)

Family: Palinuridae

70. *Panulirus polyphagus* (Herbst, 1793)

Family: Portunidae

71. *Charybdis callianassa* (Herbst, 1789)
72. *Charybdis feriatus* (Linnaeus, 1758)
73. *Portunus pelagicus* (Linnaeus, 1766)
74. *Portunus sanguinolentus* (Herbst, 1783)

Family : Diogenidae

75. *Diogenes alias* McLaughlin & Holthuis, 2001

STOMATOPODS

Order: STOMATOPODA

Family: Squillidae

76. *Harpiosquilla raphidea* (Fabricius, 1798)
77. *Miyakella nepa* (Latreille in Latreille, Le Peletier, Serville & Guérin, 1828)
78. *Oratosquillina perpensa* (Kemp, 1911)

MOLLUSCS

Class: CEPHALOPODA

Order: OCTOPODA

Family: Octopodidae

79. *Octopus vulgaris* (Cuvier, 1797)

Order: TEUTHIDA

Family: Loliginidae

80. *Uroteuthis duvaucelii* (d’Orbigny, 1835)
81. *Loliolus (Loliolus) hardwickei* (Gray, 1849)

Order: SEPIIDA

Family: Sepiidae

82. *Sepiella inermis* (Van Hasselt, 1835)

CLASS : Gastropoda

Order: Neogastropoda

Family: Babyloniidae

83. *Babylonia spirata* (Linnaeus, 1758)

Family: Muricidae

84. *Rapana rapiformis* (Born, 1778)

Family: Pisaniidae

85. *Cantharus spiralis* Gray, 1839

Family: Clavatulidae

86. *Turricula javana* (Linnaeus, 1767)

Family: Muricidae

87. *Indothais lacera* (Born, 1778)

Order: Littorinimorpha

Family: Rostellariidae

88. *Tibia curta* (G. B. Sowerby II, 1842)
89. *Gyrineum natator* (Röding, 1798)

Family: Ranellidae

90. *Gyrineum natator* (Röding, 1798)

Family: Bursidae

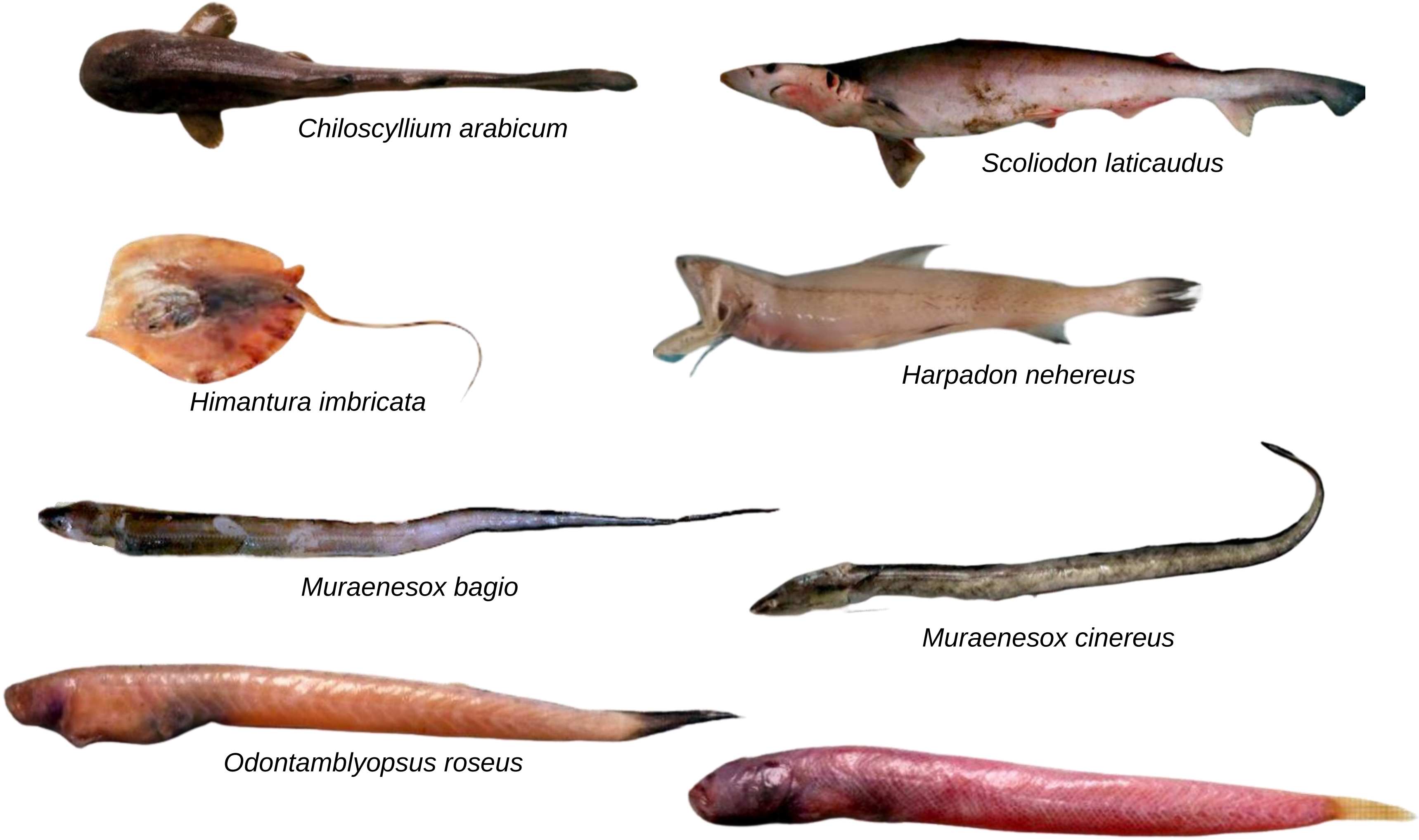
91. Bufonaria echinata (Link, 1807)

Family: Naticidae

92. *Tanea lineata (Röding, 1798)*

Family: Tonnidae

93. Tonna cumingii (Reeve, 1849)



Chiloscyllium arabicum

Scoliodon laticaudus

Himantura imbricata

Harpadon nehereus

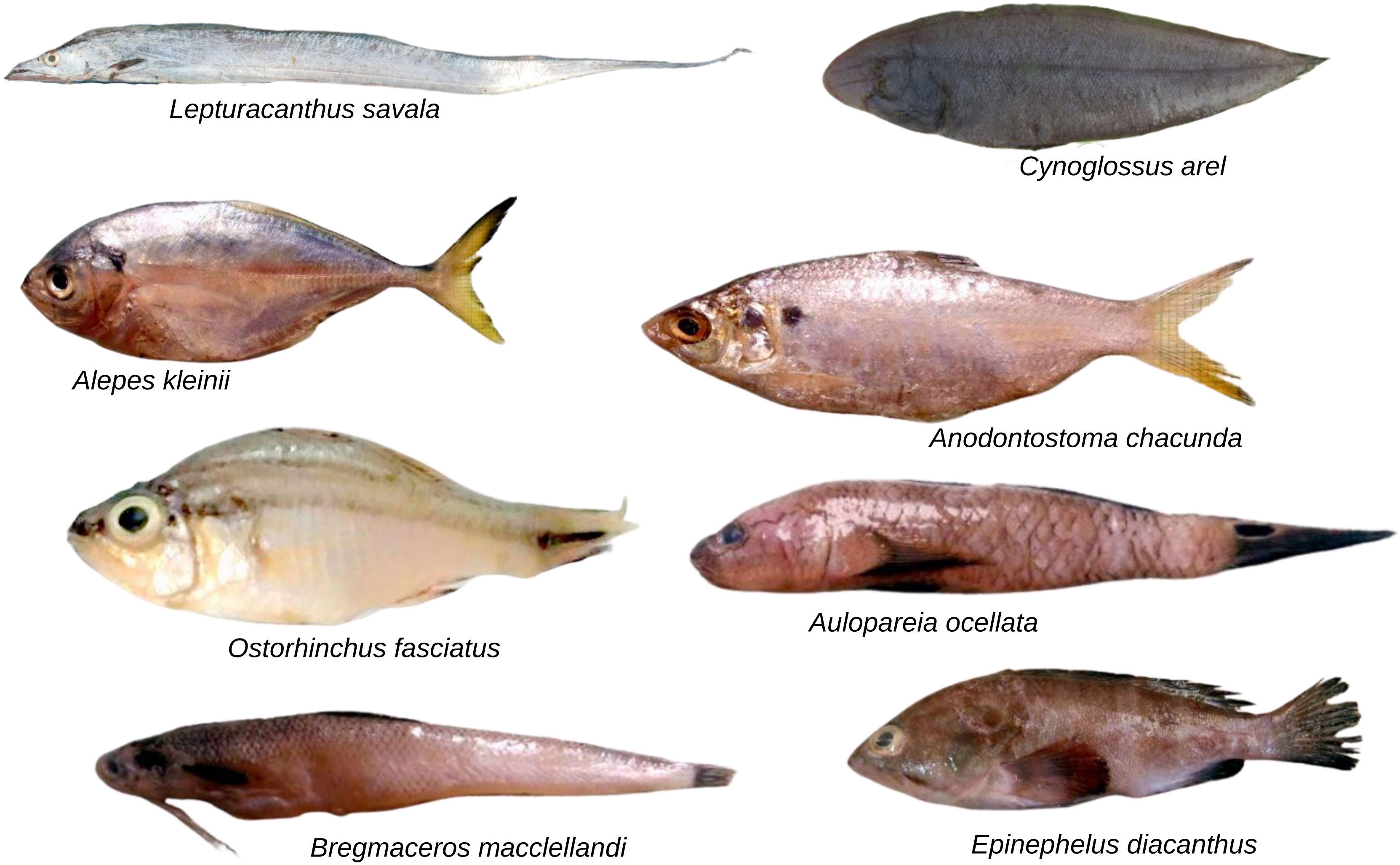
Muraenesox bagio

Muraenesox cinereus

Odontamblyopsus roseus

Trypauchen vagina

Plate 2a. Species landed by trawl along Mumbai coast



Lepturacanthus savala

Cynoglossus arel

Alepes kleinii

Anodontostoma chacunda

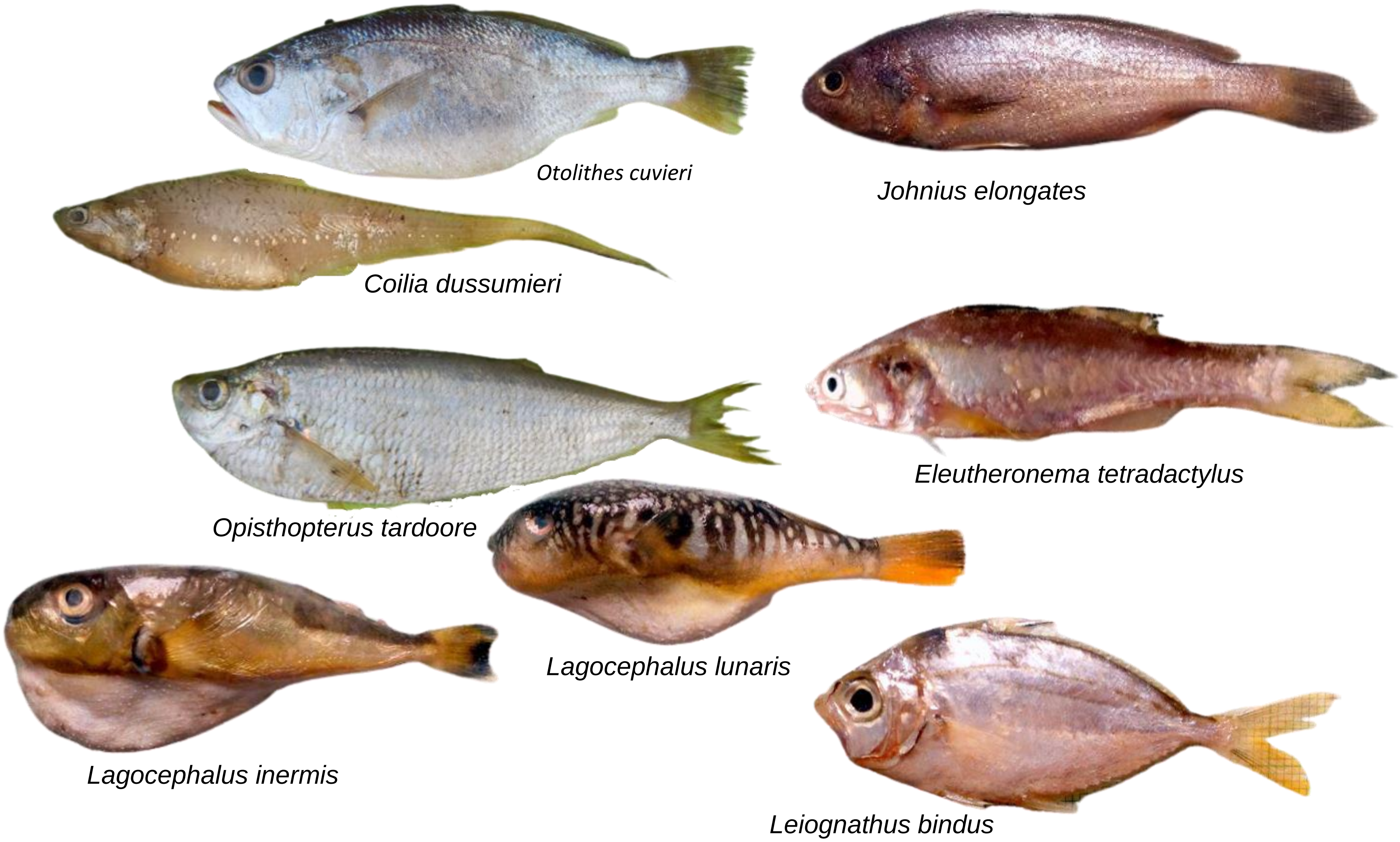
Ostorhinchus fasciatus

Aulopareia ocellata

Bregmaceros macclellandi

Epinephelus diacanthus

Plate 2b. Species landed by trawl along Mumbai coast



Otolithes cuvieri

Johnius elongates

Coilia dussumieri

Eleutheronema tetradactylus

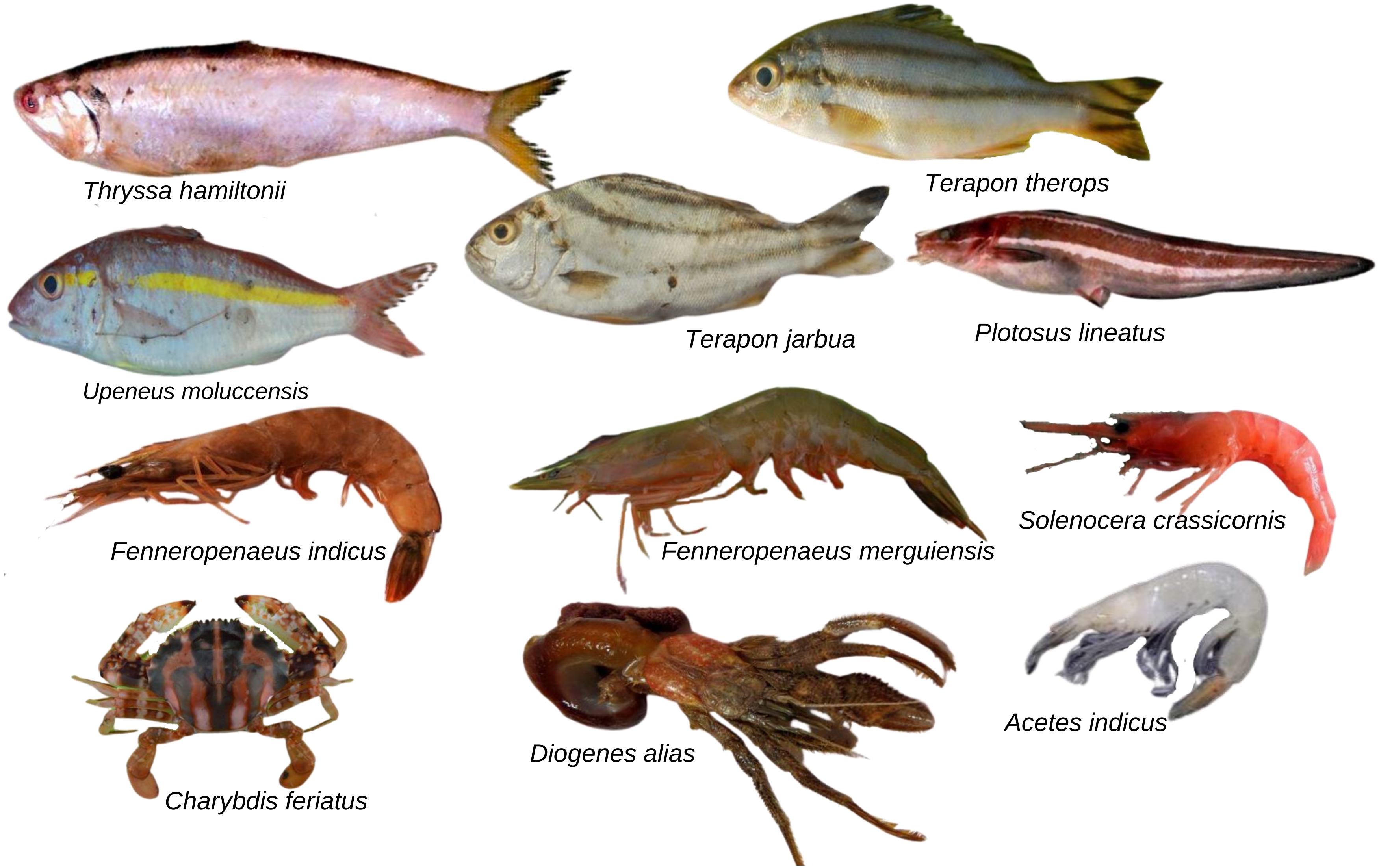
Opisthopterus tardoore

Lagocephalus lunaris

Lagocephalus inermis

Leiognathus bindus

Plate 2c. Species landed by trawl along Mumbai coast



Thryssa hamiltonii

Terapon therops

Terapon jarbua

Plotosus lineatus

Upeneus moluccensis

Fenneropenaeus indicus

Fenneropenaeus merguiensis

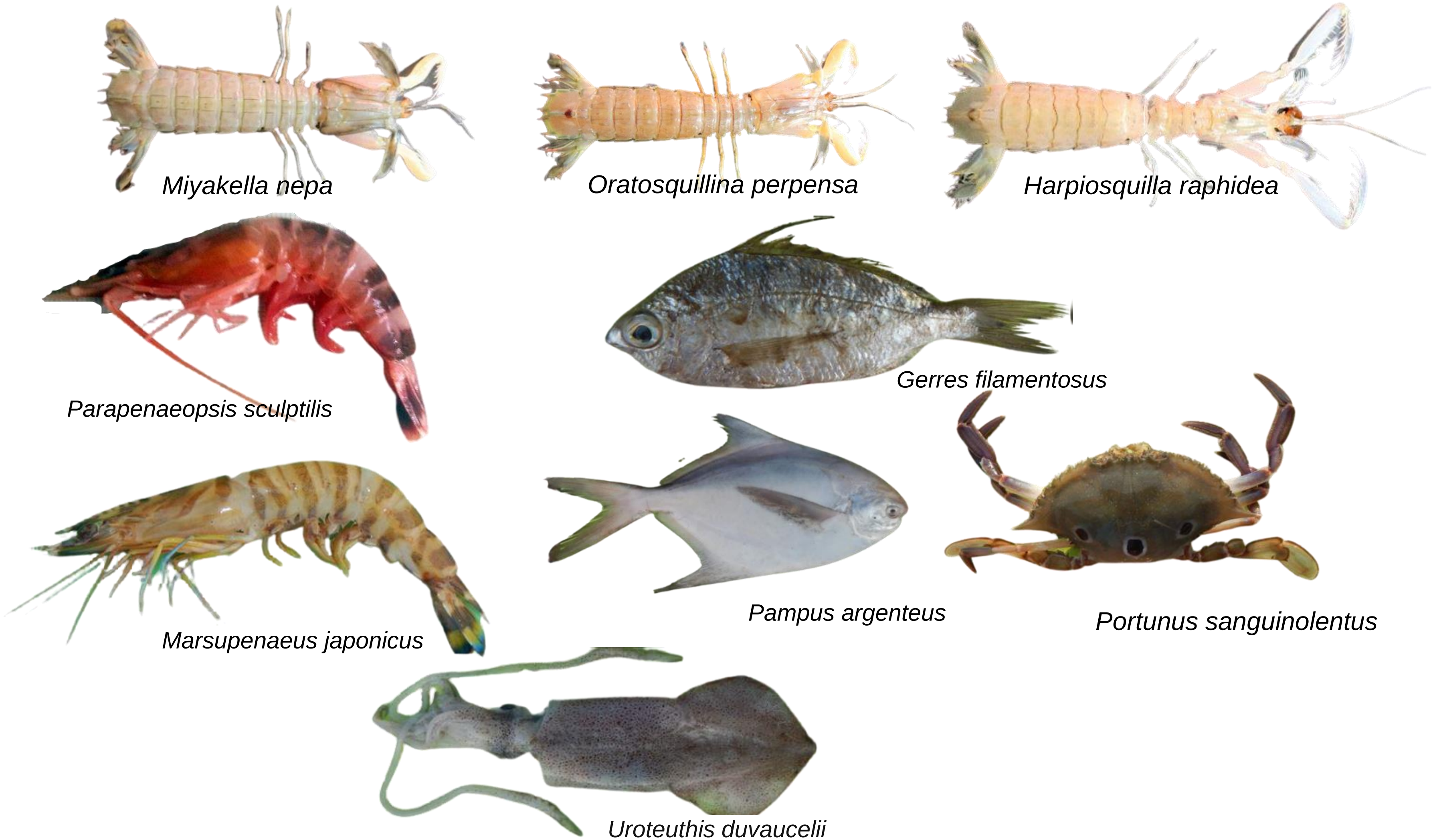
Solenocera crassicornis

Acetes indicus

Charybdis feriatus

Diogenes alias

Plate 2d. Species landed by trawl along Mumbai coast



Miyakella nepa

Oratosquillina perpensa

Harpiosquilla raphidea

Parapenaeopsis sculptilis

Gerres filamentosus

Marsupenaeus japonicus

Pampus argenteus

Portunus sanguinolentus

Uroteuthis duvaucelii

Plate 2e. Species landed by trawl along Mumbai coast

4.6. Spatio-temporal distribution of fisheries resources from trawl

4.6.1 Temporal Distribution

Jellyfish catch was recorded only in October 2017. Species which were represented in all the months except October 2017 month were *Cynoglossus arel, Johnius belangerii, Trypauchen vagina, Parapenaeopsis stylifera, Miyakella nepa and Sepiella inermis*. The species which were abundant next to these six species includes *Coilia dussumieri, Johnius macrorhynus, Charybdis callianassa, Harpiosquilla raphidea, Oratosquillina perpensa, Johnius borneensis, Johnius glaucus, Lagocephalus inermis, Otolithes cuvieri, Hermit crab* and *Uroteuthis duvaucelii.* Maximum species in terms of numbers (51) were recorded in May 2018 (Table. 4.6.1; Figure. 4.6.1).

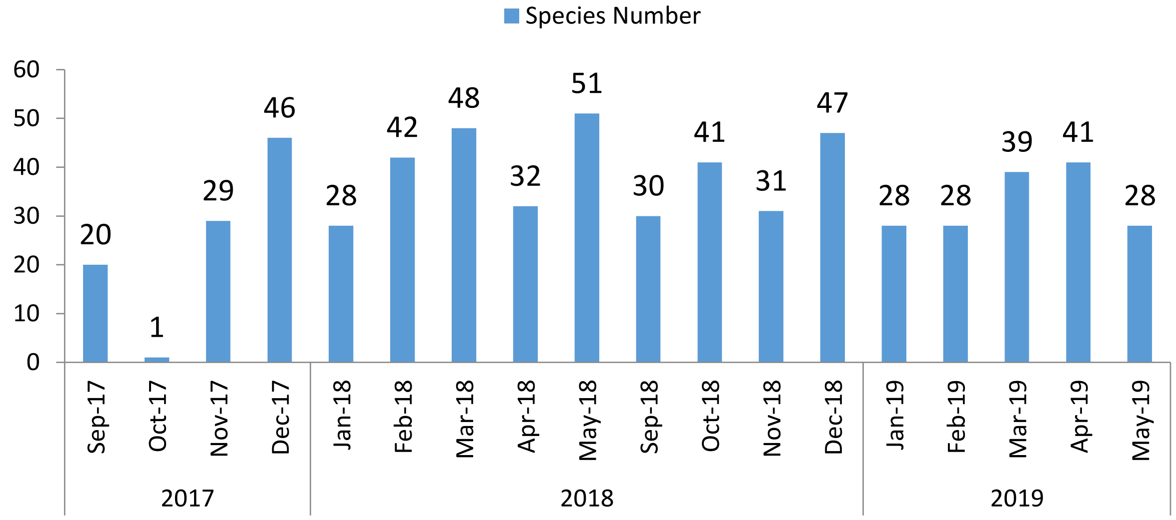


Figure. 4.6.1: Temporal Distribution of fish Resources from Trawl along Mumbai Coast

Table. 4.6.1. Temporal Distribution of fisheries Resources from trawl along Mumbai Coast

SPECIES	SEP-17	OCT	NOV	DEC	JAN-18	FEB	MAR	APR	MAY	SEP	OCT	NOV	DEC	JAN-19	FEB	MAR	APR	MAY-19
FINFISHES																		
Alepes kleinii	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	+	+	+
Anodontostoma chacunda	-	-	-	-	-	+	-	-	+	-	-	-	-	-	+	-	-	+
Antennarius indicus	-	-	+	+	-	-	-	-	-	-	-	+	+	-	-	-	-	-
Aulopareia ocellata	+	-	-	+	-	-	+	-	+	+	-	-	+	-	-	+	-	+
Bothus myriaster	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Bregmaceros macclellandi	-	-	-	-	+	+	+	+	+	-	-	-	-	+	+	+	+	+
Coilia dussumieri	-	-	+	+	+	+	+	+	+	-	-	+	+	+	+	+	+	+

Cynoglossus arel	+	-	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
Eleutheronema tetradactylum	-	-	-	-	+	+	-	-	-	-	-	-	-	+	+	-	-	-
Epinephelus diacanthus	-	-	-	+	-	-	-	+	+	-	-	-	+	-	-	-	+	+
Escualosa thoracata	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	+	+	+
Filimanus heptadactyla	-	-	-	+	+	+	-	-	-	-	-	-	+	+	+	-	-	-
Harpadon nehereus	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Johnius belangerii	+	-	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
Johnius vogleri/Johnius borneensis	-	-	+	+	+	+	+	-	+	-	-	+	+	+	+	+	-	+
Johnius sina/Johnius dussumieri	-	-	-	+	+	-	-	-	+	-	-	-	+	+	-	-	-	+

Johnius elongates	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Johnius glaucus	+	-	+	+	+	-	+	-	+	+	-	+	+	+	-	+	-	+
Johnius macrorhynus	-	-	+	+	+	+	+	+	+	-	-	+	+	+	+	+	+	+
Otolithes ruber	-	-	-	+	+	-	-	-	+	-	-	-	+	+	-	-	-	+
Nibea maculata	+	-	+	+	+	-	+	-	+	+	-	+	+	+	-	+	-	+
Lagocephalus inermis	-	-	-	+	+	+	+	+	+	-	-	-	+	+	+	+	+	+
Lagocephalus lunaris	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+
Leiognathus bindus	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-
Lepturacanthus savala	-	-	+	-	-	+	+	+	+	-	-	+	-	-	+	+	+	+

Minous inermis	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Muraenesox bagio	+	-	+	+	-	-	+	+	-	+	-	+	+	-	-	+	+	-
Muraenesox cinereus	+	-	-	-	-	+	+	+	-	+	-	-	-	-	+	+	+	-
Nemapteryx caelata	-	-	-	+	-	+	-	-	+	-	-	-	+	-	+	-	-	+
Odontamblyopsus roseus	+	-	-	-	+	-	-	-	+	+	-	-	-	+	-	-	-	+
Opisthopterus tardoore	-	-	-	-	-	+	+	+	+	-	-	-	-	-	+	+	+	+
Osteogeneiosus militaris	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+
Ostorhinchus fasciatus	+	-	+	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-
Otolithoides biauritus	+	-	+	-	-	-	+	-	-	+	-	+	-	-	-	+	-	-

Otolithes cuvieri	+	-	-	-	+	+	+	+	+	+	-	-	-	+	+	+	+	+
Pampus argenteus	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	+	-	+
Parastromateus niger	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Decapterus russelli	+	-	+	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-
Megalaspis cordyla	-	+	-	+	-	-	+	-	-	-	-	-	-	+	-	+	-	-
Elagatis bipinnulata	-	-	-	+	+	-	-	-	-	-	-	-	-	+	-	-	-	-
Scomberoides tol	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Scomberoides tala	-	-	+	-	-	-	-	-	+	-	-	+	-	-	-	-	-	+
Plotosus lineatus	-	-	-	-	-	+	+	-	-	-	-	-	-	-	+	+	-	-

Protonibea diacanthus	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+
Rastrelliger kanagurta	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Sillago sihama	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Soleidae	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-
Terapon jarbua	-	-	+	-	-	-	-	-	+	-	-	+	-	-	-	-	-	+
Terapon therops	-	-	-	+	-	-	-	-	+	-	-	-	+	-	-	-	-	+
Thryssa hamiltonii	-	-	-	+	-	+	+	-	+	-	-	-	+	-	+	+	-	+
Trypauchen vagina	+	-	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
Upeneus guttatus	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-

Upeneus vittatus	-	-	-	-	+	+	-	-	-	-	-	-	-	-	+	-	-	-
Upeneus moluccensis	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-
Chiloscyllium arabicum	-	-	-	-	-	+	+	-	+	-	-	-	-	-	+	+	-	+
Himantura imbricata	-	-	+	-	-	+	-	-	-	-	-	+	-	-	+	-	-	-
SHRIMPS																		
Acetes indicus	-	-	-	+	+	+	+	-	+	-	-	-	+	+	+	+	-	+
Exhippolysmata ensisrostris	-	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	+	+
Metapenaeus affinis	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-
Metapenaeus brevicornis	-	-	-	+	+	-	+	-	+	-	-	-	+	+	-	+	-	+

Nematopaleomon tenuipes	-	-	-	-	-	+	+	+	+	-	-	-	-	-	+	+	+	+
Parapenaeopsis hardwickii	-	-	-	+	+	-	+	-	-	-	-	-	+	+	-	+	-	-
Parapenaeopsis sculptilis	-	-	-	-	-	+	+	-	+	-	-	-	-	-	+	+	-	+
Parapenaeopsis stylifera	+	-	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
Penaeus merguiensis	-	-	-	+	+	-	+	-	-	-	-	-	+	+	-	+	-	-
Penaeus monodon	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-
Solenocera crassicornis	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+
CRABS																		
Calappa spp.	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-

Charybdis feriatus	-	-	-	+	-	+	+	+	+	-	-	-	+	-	+	+	+	+
Charybdis callianassa	+	-	-	+	+	+	+	+	+	+	-	-	+	+	+	+	+	+
Portunus pelagicus	-	-	+	+	+	-	+	+	-	-	-	+	+	+	-	+	+	-
Portunus sanguinolentus	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	+	+
Hermit crab	-	-	-	+	+	+	+	+	+	-	-	-	+	+	+	+	+	+
STOMATOPDS																		
Harpiosquilla raphidea	+	-	+	+	-	+	+	+	+	+	-	+	+	-	+	+	+	+
Miyakella nepa	+	-	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
Oratosquillina perpensa	+	-	+	+	-	+	+	+	+	+	-	+	+	-	+	+	+	+

CEPHALOPODS																		
Octopus vulgaris	+	-	+	+	-	-	-	-	+	+	-	+	+	-	-	-	-	+
Sepiella inermis	+	-	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
Uroteuthis duvaucelii	-	-	-	+	+	+	+	+	+	-	-	-	+	+	+	+	+	+
OTHERS																		
Jellyfish	-	+	-	+	-	-	-	-	+	-	+	-	+	-	-	-	-	+
Sea anemone	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-
Shells	-	-	-	-	-	+	+	-	+	-	-	-	-	-	+	+	-	+

(+ : Found, - :Not found)

4.6.2 Spatial distribution

All the experimental fishing operations were carried out in the depth range of 6-21 m. Five different depth strata viz. 6-9m, 9-12 m, 12-15 m, 15-18 m,18-21 m was selected with a view to studying the variation in the spatial distribution of fish resources from the trawl. The maximum number of species was 69 recorded in the depth strata of 12-15 m followed by 67 species in the depth strata of 6-9 m. About twenty species were represented in all the five strata (Table. 4.6.2; Figure. 4.6.2).

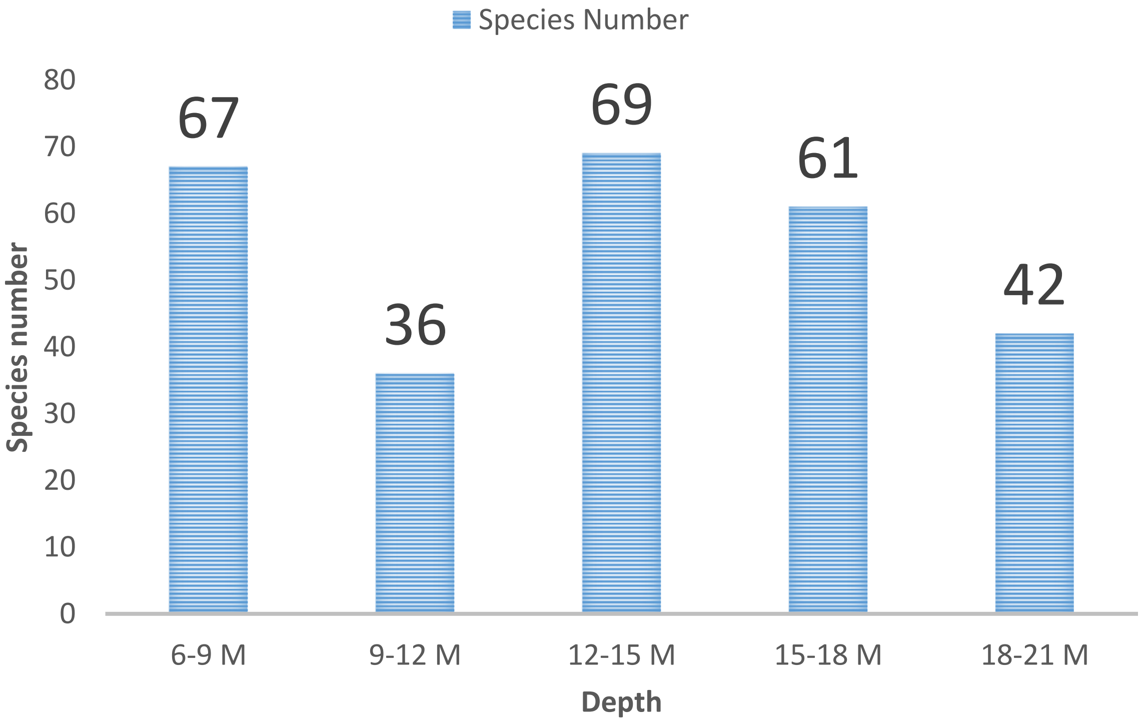


Figure. 4.6.2: Spatial Distribution of fish Resources from trawl along Mumbai coast

Table. 4.6.2. Spatial Distribution of fish Resources from trawl along Mumbai Coast

SPECIES	DEPTH RANGE (m)				
	6-9	9-12	12-15	15 - 18	18 - 21
FINFISHES					
Alepes kleinii	+	+	+	+	+
Anodontostoma chacunda	-	+	+	-	-
Antennarius indicus	+	+	-	+	-
Aulopareia ocellata	+	+	-	+	-
Bothus myriaster	-	+	-	+	-
Bregmaceros macclellandi	+	-	+	+	+
Coilia dussumieri	+	+	+	+	+
Cynoglossus arel	+	+	+	+	+
Eleutheronema tetradactylum	-	-	+	-	+
Epinephelus diacanthus	-	-	-	+	+
Escualosa thoracata	+	+	-	-	-
Harpadon nehereus	-	+	-	-	-
Filimanus heptadactyla	-	+	-	+	+
Johnius belangerii	+	+	+	+	+
Johnius vogleri/Johnius borneensis	+	-	+	+	+

Johnius sina/Johnius dussumieri	-	-	-	+	+
Johnius elongates	-	-	+	-	-
Johnius glaucus	-	+	+	+	+
Johnius macrorhynus	+	+	+	+	+
Lagocephalus inermis	+	+	+	+	+
Lagocephalus lunaris	-	+	-	-	-
Leiognathus bindus	+	-	-	-	+
Lepturacanthus savala	+	+	+	+	+
Minous inermis	-	+	-	-	-
Muraenesox bagio	+	+	+	+	+
Muraenesox cinereus	-	+	+	-	+
Nemapteryx caelata	-	+	+	+	-
Odontamblyopsus roseus	-	+	+	-	+
Opisthopterus tardoore	+	+	+	-	+
Osteogeneiosus militaris	-	+	+	+	-
Ostorhinchus fasciatus	+	+	-	-	-
Otolithoides biauritus	-	+	+	-	+
Otolithes cuvieri	+	+	+	+	+

Pampus argenteus	+	+	-	-	-
Parastromateus niger	-	-	-	+	-
Plotosus lineatus	+	-	-	-	+
Protonibea diacanthus	-	+	+	-	-
Rastrelliger kanagurta	-	-	-	+	-
Sillago sihama	-	-	+	-	-
Soleidae	-	+	-	-	-
Terapon jarbua	-	+	+	-	-
Terapon therops	-	+	-	-	-
Thryssa hamiltonii	-	+	+	+	+
Trypauchen vagina	+	+	+	+	+
Upeneus guttatus	-	-	-	-	+
Upeneus moluccensis	-	+	-	-	-
Upeneus vittatus	-	+	+	+	+
Decapterus russelli	-	-	-	+	+
Megalaspis cordyla	-	+	+	-	+
Elagatis bipinnulata	-	+	-	-	+
Scomberoides tol	-	+	+	+	+

Scomberoides tala	-	-	+	-	-
Otolithes ruber	+	+	-	-	+
Nibea maculate	+	+	-	-	+
ELASMOBRANCH					
Himantura imbricata	-	-	+	-	-
Chiloscyllium arabicum	+	+	-	-	+
SHRIMPS					
Acetes indicus	-	+	+	+	+
Exhippolysmata ensisrostris	+	+	+	+	+
Metapenaeus affinis	-	-	-	-	+
Metapenaeus brevicornis	+	+	+	+	-
Nematopaleomon tenuipes	+	+	+	+	+
Parapenaeopsis hardwickii	+	-	-	+	+
Parapenaeopsis sculptilis	+	-	+	+	-
Parapenaeopsis stylifera	+	+	+	+	+
Penaeus merguiensis	+	+	-	+	-
Penaeus monodon	-	-	+	-	-
Solenocera crassicornis	-	+	-	+	+
CRABS					
Calappa spp.	-	-	-	-	+

Charybdis feriatus	+	+	+	+	+
Charybdis callianassa	+	+	+	+	+
Portunus pelagicus	+	+	-	+	-
Portunus sanguinolentus	-	+	+	-	-
Hermit crab	+	+	+	+	+
STOMATOPODS					
Harpiosquilla raphidea	+	+	+	+	+
Miyakella nepa	+	+	+	+	+
Oratosquillina perpensa	+	+	+	+	+
CEPHALOPODS					
Octopus vulgaris	+	+	+	+	-
Sepiella inermis	-	+	+	+	+
Uroteuthis duvaucelii	+	+	+	+	+
Loliolus (Loliolus) hardwickei	-	+	-	+	-
Jellyfish	-	+	+	+	-
Sea anemone	+	-	-	-	+
Shells	+	+	+	-	+

(+: Found, - : Not found)

4.7. Quality Assessment of Satellite-Derived parameters

4.7.1 Sea Surface Chlorophyll

The significant monthly variations in Sea Surface Chlorophyll are depicted in Figure 2, illustrating the maximum during the September 2018 (2.96±0.48 mg m^{-3}) and minimum during the November 2018 month (0.50 mg m^{-3}). The representation of Chl-*a* data as a histogram plot depicts the present study region (Figure. 4.7.3). The median of Chl-*a* value was highest for the MODIS product at 4.7 mg m^{-3} (ranged from 3.16-21.24mg m^{-3}), followed by SNPP-VIIRS as 3.86 mg/m^3 (ranged from 2.81-13.93 mg/m^3), OCM2 as 1.34 mg m^{-3} (ranged from 0.81-2.66 mg m^{-3}) and *in-situ* as 1.12 mg m^{-3} (ranged from 0.2-5.04 mg m^{-3}) (Table. 4.7.1; Figure. 4.7.1 and Figure. 4.7.3). The mean ratio of $C_a^{OCM2}/C_a^{In\text{-}situ}$ is closer to 1 with narrow deviation (i.e., 0.90±0.24 mg m^{-3}), in contrast to the higher ratio for $C_a^{VIIRS}/C_a^{In\text{-}situ}$ (3.35±0.38 mg m^{-3}) and $C_a^{MODIS}/C_a^{In\text{-}situ}$ (4.00 ±0.36mg m^{-3}), which depicts the overestimation of Chl-*a* for the satellite products. The correlation analysis between the in-situ and satellite Chl-a data set (Table. 4.7.2; Figure. 4.7.2) revealed a correlation between *in-situ* vs MODIS (0.56, p<0.001), *in-situ* vs SNPP-VIIRS (0.41, p<0.001*), in-situ* vs OCM2 (0.61, p<0.001). The OCM2 satellite product is having less uncertainty in comparison with the other products in the study region. Analysis of mean absolute percentage differences (MPD) between the products of three different algorithms and *in-situ* measurements are shown in the Table. 4.7.3. The lower MPD value was noticed for the OCM2 (31.21 %), which is having better accuracy with the in-situ data than the other products, i.e., VISSR (68.72%) and MODIS (74.44%).

The bias percentage is lower in case of C_a^{OCM2} product at 4.55%, followed C_a^{VIIRS} (38.4%) and C_a^{MODIS} (46.8%). The RMS error was observed lower for the OCM2 (0.58), followed VISSR (3.29) and MODIS (4.03). In conclusion, the bias errors are significantly lower for the OCM2 than other products (MODIS and SNPP-VIIRS). The scatter plots of three different satellite products versus *in-situ* values of Chl-*a* were produced (Figure. 4.7.2), for which the slope, coefficient of determination (r^2), and root mean square of the regression (RMSE) are listed in Table 13.

The SIQR is an indication of uncertainty of the satellite and *in-situ* Chl-*a* value, the lower uncertainty was observed in C_a^{OCM2} vs. $C_a^{In\text{-}situ}$ (0.24 mg m^{-3}), followed by C_a^{VIIRS} vs. $C_a^{In\text{-}situ}$ (0.38 mg m^{-3}) and C_a^{MODIS} vs. $C_a^{In\text{-}situ}$ (0.36 mg m^{-3}). The C_a^{OCM2} is nearly scattering around the base of regression line, suggesting that the bias errors in $C_a^{OCM2}/C_a^{In\text{-}situ}$ is significantly lower than those in $C_a^{VIIRS}/C_a^{In\text{-}situ}$ and $C_a^{MODIS}/C_a^{In\text{-}situ}$. The validation results indicate that the C_a^{OCM2} is much improved over C_a^{VIIRS} and C_a^{MODIS}. The high r^2 and slopes close to unity suggest that the validation comparisons are agreed over the measured dynamic range. The slopes of the regression plots for three algorithms are deviating from the unity, i.e., MODIS (0.19), SNPP-VIIRS (0.52) and OCM2 (0.69).

The r^2 values for the three regression equations are not so strong, but shown significant variability ($p<0.001$), out of which the highest value was observed for OCM2 ($r^2 = 0.35$), next to MODIS ($r^2 = 0.29$) and VISSR ($r^2 = 0.16$). Out of three algorithms observed, the OCM2 can explain highest of 35.0% of variability of *in-situ* Chl-*a*, followed by MODIS (29.0%) and VISSR (16.0%). The expression of RMSE for the log transformed data of three different algorithms with respect to *in-situ* values depicts the overall uncertainty and observed highest for MODIS (0.7), SNPP-VIIRS (0.62) and smaller for OCM2 (0.21) (Table. 4.7.3).

Table. 4.7.1. Descriptive statistics of Sea Surface Chlorophyll *in-situ* and satellite derived data used in the study (mg m^{-3})

Algorithm	Range	Q1	Q3	Mean ± SE	Median	SD	IQR	CV (%)
In-situ	0.2-5.04	0.76	1.55	1.24±0.05	1.12	0.68	0.79	55.55
MODIS	3.16-21.24	4.16	4.8	4.96±0.13	4.7	1.82	0.64	36.72
OCM2	0.81-2.66	1.19	1.58	1.40±0.02	1.34	0.3	0.39	21.72
SNPP-VIIRS	2.81-13.93	3.45	4.1	4.16±0.12	3.86	1.66	0.65	39.35

Table. 4.7.2. Correlation matrix between *in-situ* and satellite derived datasets of Sea Surface Chlorophyll (mg m^{-3})

Algorithm	In-situ	OCM	MODIS
OCM	0.61 (0.000*)		
MODIS	0.56 (0.000*)	0.07 (0.000*)	
VIIRS	0.41 (0.000*)	-0.19 (0.0072)	0.44 (0.000*)

* $p<0.05$, which indicates significant correlation between the variables

Table. 4.7.3. Validation statistics of the matchups of Sea Surface Chlorophyll (mg m^{-3})

Parameter	C_a^{MODIS} vs. $C_a^{In-situ}$	C_a^{OCM2} vs. $C_a^{In-situ}$	C_a^{VIIRS} vs. $C_a^{In-situ}$
Ratio (±SIQR)	4.00 (±0.36)	0.90 (±0.24)	3.35 (±0.38)
MPD (%)	74.44	31.21	68.72
Bias	1622.4	33.79	1084.2
RMSE	4.03	0.58	3.29
Log_Bias	46.8	4.55	38.4
Log_RMSE	0.7	0.21	0.62
a	0.21	1.37	0.17
b	0.19	-0.69	0.52
R^2	0.29	0.35	0.16

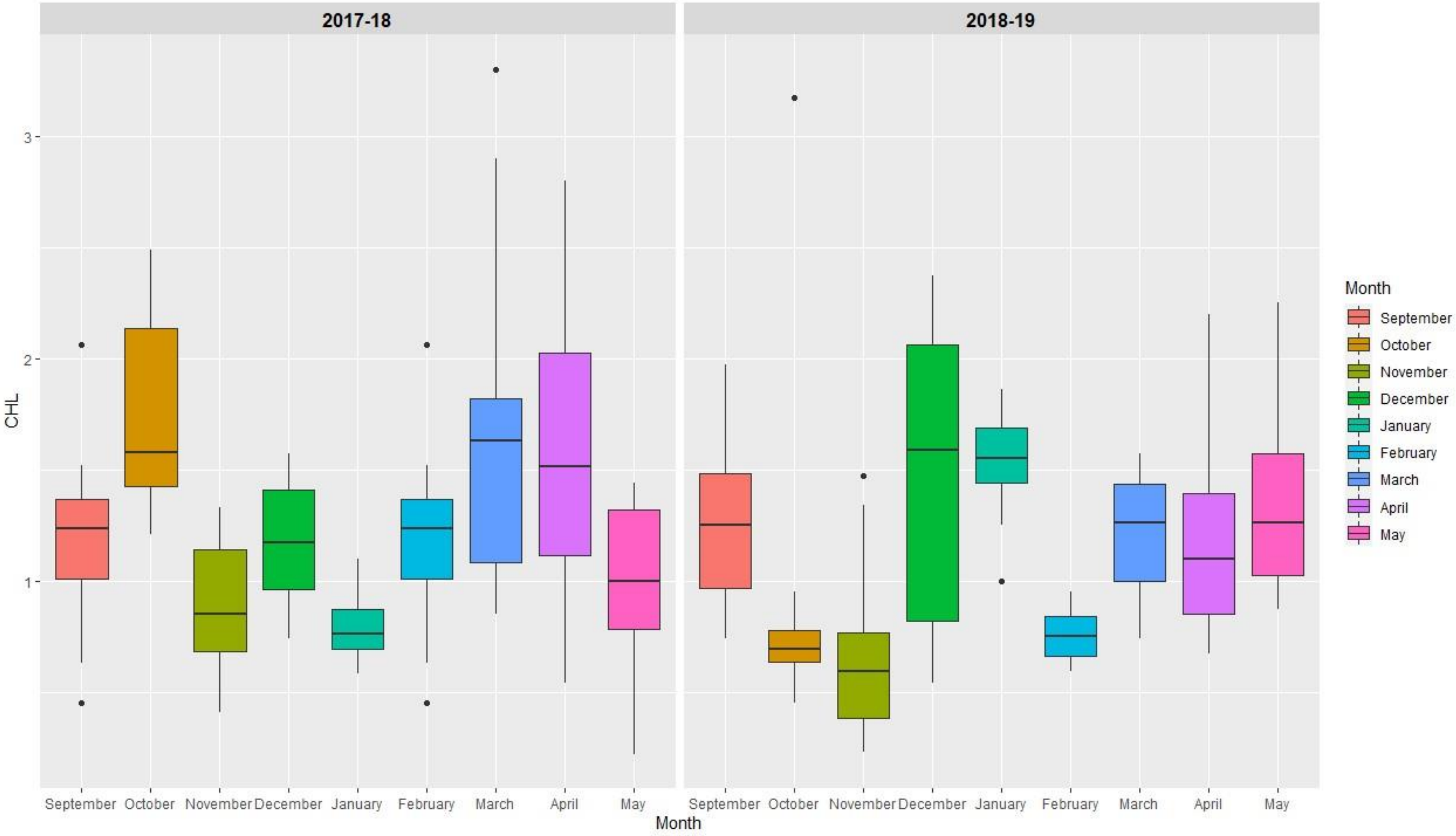


Figure. 4.7.1. Temporal variations in in-situ Chl-a (mg m^{-3}) in the study region

Figure. 4.7.2: Scatter plot between satellite estimated algorithms (MODIS, OCM2 & VIIRS) and in-situ Chlorophyll-a (mg m^{-3})

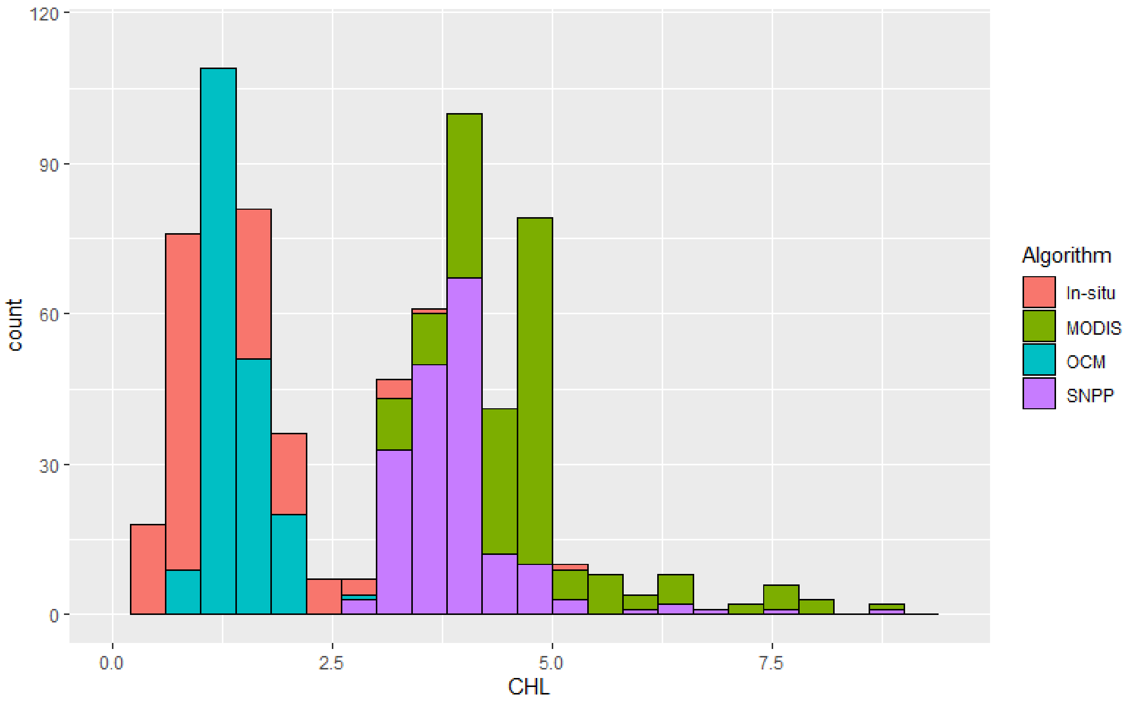


Figure. 4.7.3: Chlorophyll-a distribution histogram for the various datasets.

4.7.2 Sea Surface Temperature (SST)

The significant monthly variations in in-situ sea-truth measured Sea Surface Temperatures are depicted in Figure. 4.7.4, observed in the range of 23.9-32^{0}C. The median of SST value was highest for the SNPP-VIIRS product at 28.5^{0}C (ranged from 24.5-30.8^{0}C), followed by MODIS as 28.2^{0}C (ranged from 24.5-31.2^{0}C) and *in-situ* as 28.3^{0}C (Table. 4.7.4; Figure. 4.7.4 and Figure. 4.7.6). The mean ratio of both satellite parameter is closer to 1 with narrow deviation (i.e., 0.99±0.502 for MODIS and 0.99±0.501 for SNPP-VIIRS respectively, which depicts the accurate estimation in the study region. Both SNPP-VIIRS and MODIS derived parameters showed less uncertainty in terms of quality concern. The correlation analysis between the in-situ sea truth and satellite SST value revealed a strong correlation between both satellite derived SST products, i.e., 0.87, $p<0.001$ (Table. 4.7.5). The study of mean absolute percentage differences (MAPD) between these algorithms and *in-situ* sea-truth measurement showed better accuracy in terms of mean absolute percentage differences. Both algorithms had almost the same level of variation in mean values, i.e., 2.27% for MODIS and 2.14% for SNPP-VIIRS (Table. 4.7.6). The bias percentage observed in the case of MODIS derived SST product at 110.9% the bias errors are significantly lower for the SNPP-VIIRS (100.7%). The RMS error was observed lower for the MODIS (1.05) and SNPP-VIIRS (1.0).

The SIQR has observed the same in both satellite products in the case of MODIS. It was 0.502^{0}C and for SNPP-VIIRS is 0.501^{0}C. The same kind of trend is found in the scatter plot and regression line. The high r^2 around 0.75-0.76 for both datasets and slopes close to unity suggest that the validation comparisons are agreed over the measured in-situ sea truth measurements. The r^2 values for the both regression equations in comparison with in-situ sea truth observation are strong (0.77 for MODIS and 0.78 for SNPP-VIIRS), it has shown significant variability ($p<0.001$) (Table. 4.7.6 and Figure. 4.7.5). The slopes of the regression plots for these algorithms are significantly deviating from the unity, i.e., MODIS (4.55) and SNPP-VIIRS (3.60). The expression of RMSE for the data of two algorithms with respect to *in-situ* sea-truth values depicts the overall uncertainty and observed highest for MODIS (1.05) and 1 for SNPP-VIIRS (Table. 4.7.6).

Table. 4.7.4. Descriptive statistics of Sea Surface Temperature *in-situ* and satellite derived data used in the study (^{0}C)

Algorithm	**Range**	**Q1**	**Q3**	**Mean ± SE**	**Median**	**SD**	**IQR**	**CV (%)**
In-situ	23.9-32	26	29.9	27.97±0.15	28.3	2.00	3.80	7.15
MODIS	24.5-31.2	25.9	29.9	27.82±0.15	28.2	2.07	4.01	7.43
SNPP-VIIRS	24.5-30.8	26.12	30	27.93±0.15	28.5	2.01	3.96	7.19

Table. 4.7.5. Correlation matrix between *in-situ* and satellite derived datasets of Sea Surface Temperature (^{0}C)

Algorithm	**In-situ**	**VIIRS**
In-Situ		
VIIRS	0.87 (0.000*)	
MODIS	0.87 (0.000*)	0.98 (0.000*)

* $p<0.05$, which indicates significant correlation between the variables

Table. 4.7.6. Validation statistics of the matchups of Sea Surface Temperature (^{0}C)

Parameter	**SST_a^{MODIS} vs. $SST_a^{In\text{-}situ}$**	**SST_a^{VIIRS} vs. $SST_a^{In\text{-}situ}$**
Ratio (±SIQR)	0.99(±0.502)	0.99(±0.501)
MPD (%)	2.27	2.14
Bias	110.9	100.7
RMSE	1.05	1.0
Log_Bias	0.027	0.025
Log_RMSE	0.016	0.016
A	0.84	0.87
B	4.55	3.60
R^2	0.77	0.78

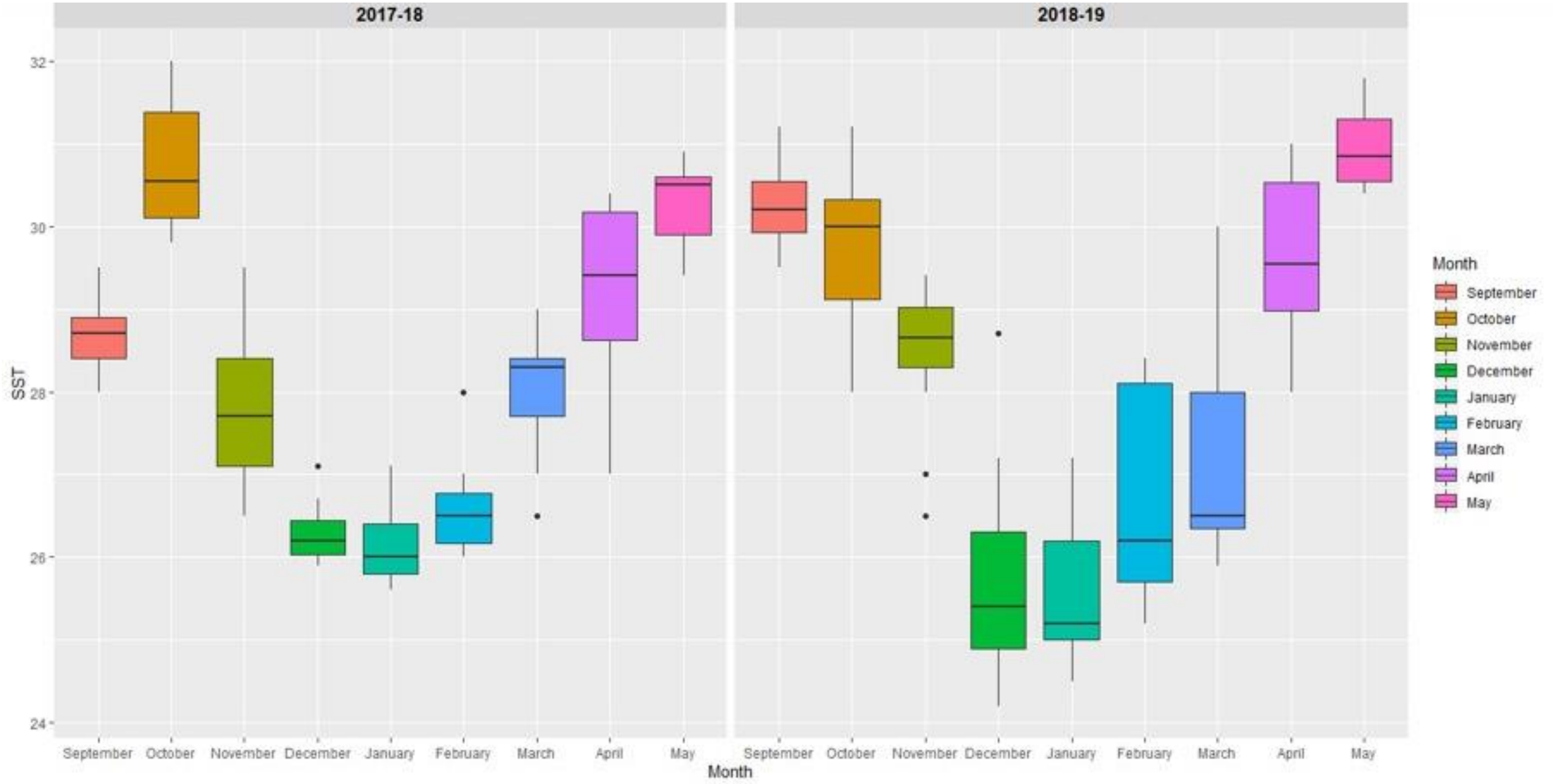


Figure. 4.7.4. Temporal variations in in-situ Sea Surface Temperature (^{0}C) in the study region

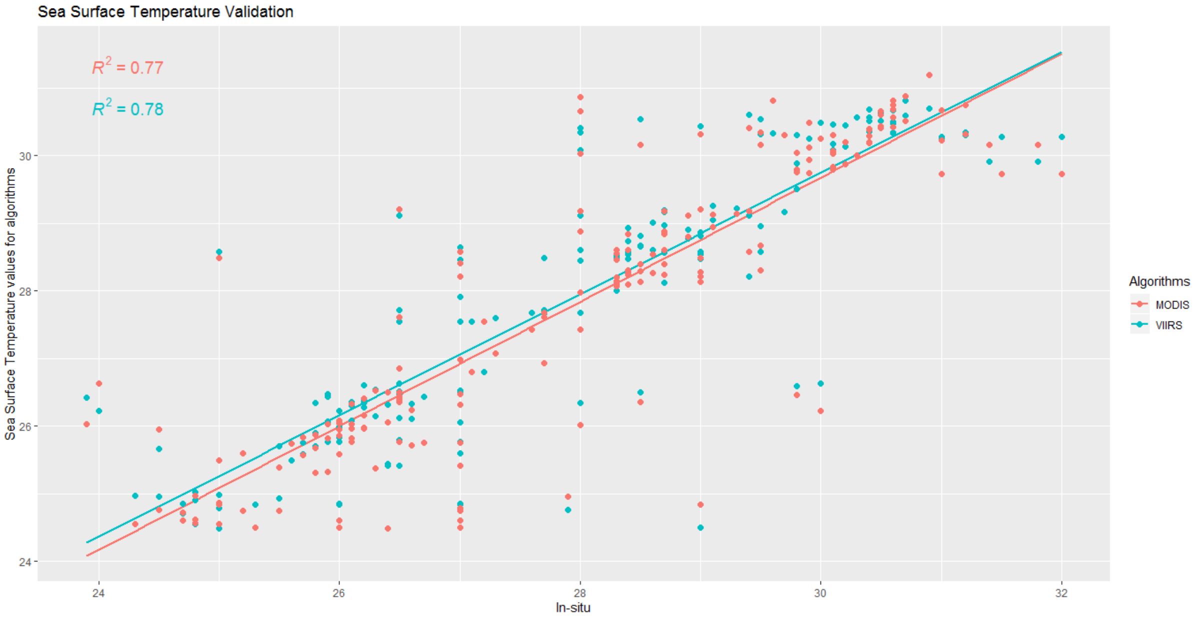


Figure. 4.7.5: Scatter plot between satellite estimated algorithms (MODIS & VIIRS) and in-situ Sea Surface Temperature (^{0}C)

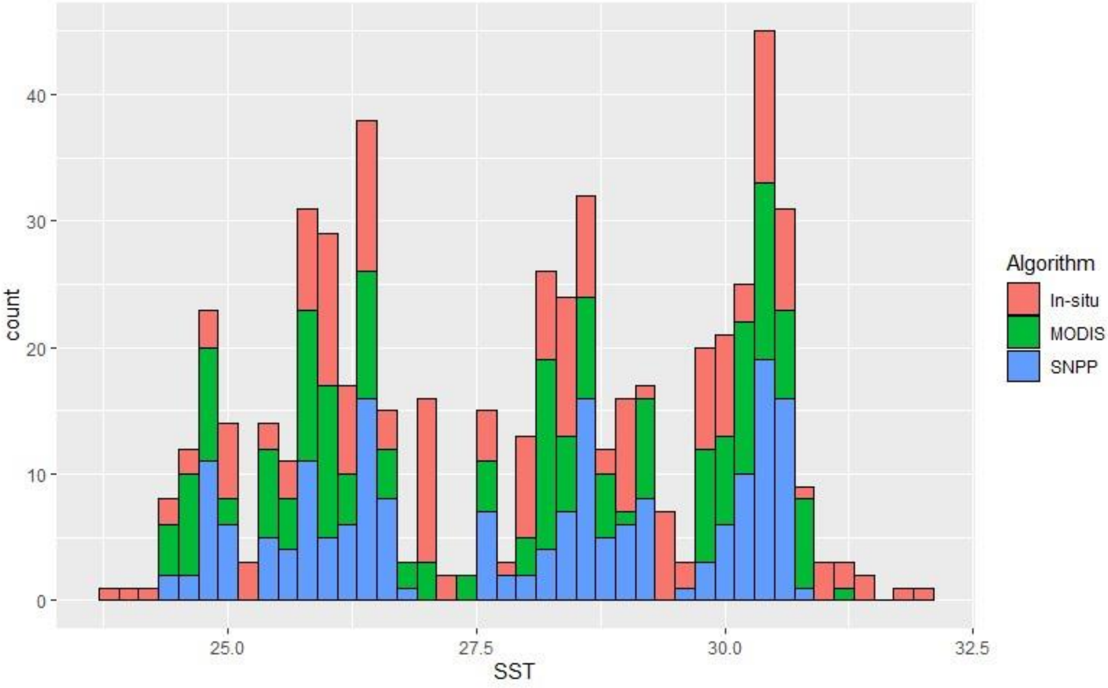


Figure. 4.7.6: Sea Surface Temperature distribution histogram for the various datasets

4.7.3 Sea Surface Salinity (SSS)

The significant monthly variations in Sea Surface Salinity are depicted in Figure. 4.7.7, illustrating the range of values observed (31.60-34.10 $^{0}/_{00}$). The representation of SSS data as a histogram plot represents the distribution in the present study region (Figure. 4.7.7). The median of SSS value recorded for the SMAP satellite derived product at 34.86 $^{0}/_{00}$ (ranged from 34.03-35.46 $^{0}/_{00}$), followed by *in-situ* as 32.80 $^{0}/_{00}$ (ranged from 31.60-34.10$^{0}/_{00}$) (Table. 4.7.7; Figure. 4.7.7 and Figure. 4.7.9). The mean ratio of SSS_a^{SMAP} vs $SSS_a^{\text{In-situ}}$ observed around 1.06±0.528 (closer to 1 with narrow deviation) which depicts the overestimation of SSS for the satellite-derived products. The correlation analysis between the in-situ and satellite SSS data set revealed a better correlation between *in-situ* vs Satellite-derived parameter (0.64, $p<0.001$) (Table. 4.7.8).

Mean absolute percentage difference (MAPD) between satellite derived environmental parameter and *in-situ* sea truth measurements are shown in Table. 4.7.9. The MAPD value 5.73%, and 416% bias was observed. The scatter plot of satellite products versus *in-situ* values of SSS were produced (Figure. 4.7.8), for which the slope, coefficient of determination (r^2) and root mean square of the regression (RMSE) are listed in Table. 4.7.8. The expression of RMSE for the data of algorithms to *in-situ* values depicts the overall uncertainty and observed (2.04). The r^2 values for the regression equations are not so strong, but shown significant variability ($r^2 = 0.40$, $p<0.001$) and the slopes of the regression significantly deviating from the unity, which was around b=3.44 (Figure. 4.7.9).

Table. 4.7.7. Descriptive statistics of Sea Surface Salinity and satellite derived data used in the study

Algorithm	Range	Q1	Q3	Mean ± SE	Median	SD	IQR	CV (%)
In-situ	31.60-34.10	32.40	33.20	32.82±0.04	32.80	0.55	0.80	1.66
SMAP	34.03-35.46	34.45	35.20	34.82±0.03	34.86	0.41	0.75	1.18

Table. 4.7.8. Correlation matrix between *in-situ* and satellite derived datasets of Sea Surface Salinity

Algorithm	In-situ	SMAP
In-Situ	1	0.64 (0.000*)
SMAP	0.64 (0.000*)	1

* $p<0.05$, which indicates significant correlation between the variables

Table. 4.7.9. Validation statistics of the matchups of Sea Surface Salinity

Parameter	SSS_a^{SMAP} vs. $SSS_a^{In\text{-}situ}$
Ratio (±SIQR)	1.06(±0.528)
MPD (%)	5.73
Bias	416
RMSE	2.04
Log_Bias	0.069
Log_RMSE	0.016
a	0.84
b	3.44
R^2	0.4

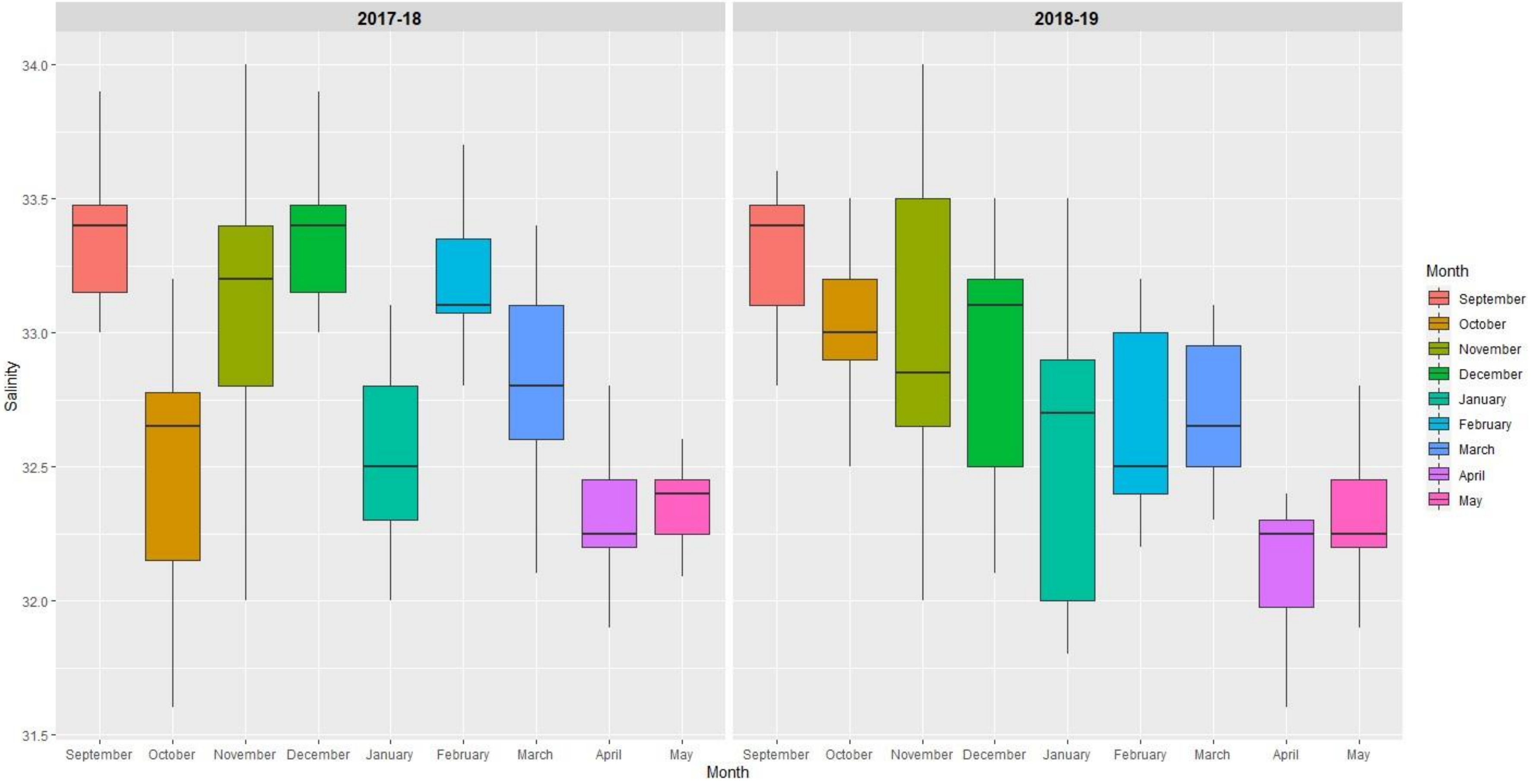


Figure. 4.7.7: Temporal variations in in-situ Sea Surface Salinity in the study region

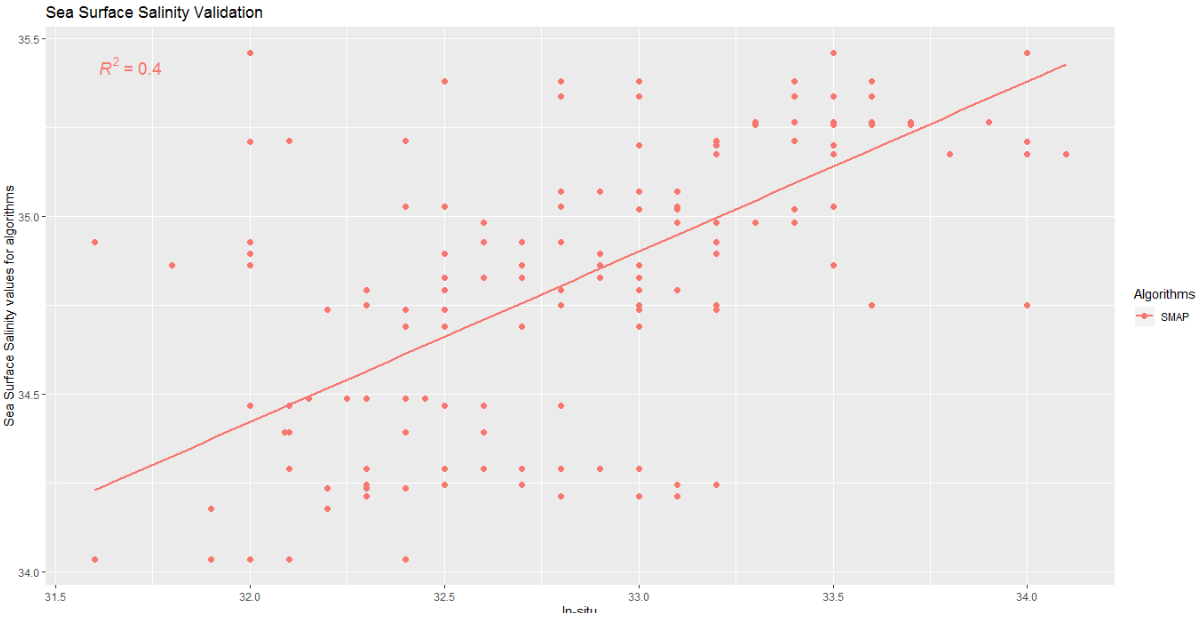


Figure. 4.7.8: Scatter plot between satellite estimated algorithms (SMAP) and in-situ Sea Surface Salinity

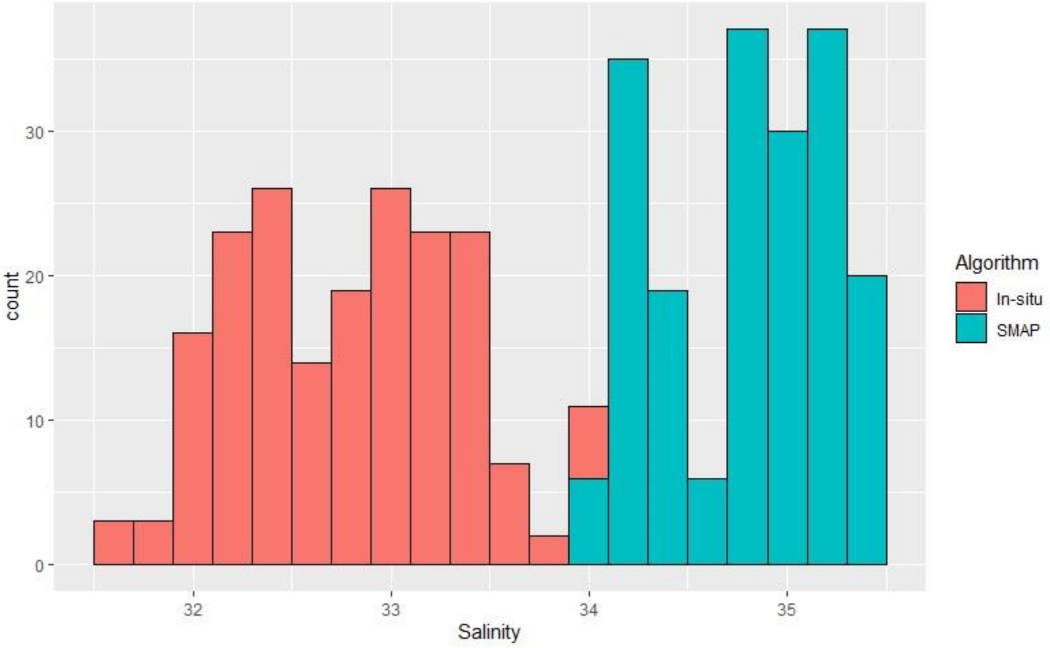


Figure. 4.7.9: Sea Surface Salinity distribution histogram for the various datasets

4.8. Influence of Satellite derived environmental data on in-situ trawl fish catch

4.8.1. Canonical correspondence analysis

CCA was carried out to demonstrate the spatio-temporal variability in major fish species in correspondence with the Satellite derived environmental parameters. A total of ten environmental covariates and thirteen major resource group in the catch were included in the CCA. Four axes were identified, of which, axes 1 and 2 were found to be significant, and together contributed 59.53% (Axis 1: 38.80% and Axis 2: 20.73%) of the total variability (Table. 4.8.1). The canonical correlation between environmental variables and major resources are presented in Figure. 4.8.1, and the canonical coefficients with the first two axes are given in Table. 4.8.1. The first canonical axis was significantly loaded with the environmental parameters like Sea Bottom Temperature (BT), Sea Surface Height (SSH) and Current Speed (CS) while the second canonical axis was significantly loaded with Sea Surface Temperature (SST), Salinity (SAL), Sea Water Potential Temperature (SWPT), Ocean Mixed Layer (OMXL) and Bottom Chlorophyll (BCHL).

The analysis of correlation between environmental covariates and fish assemblages revealed that the major species in catch were distributed within two groups with respect to the environmental characteristics. First group consisted of Cephalopod (Cepha), Non-penaeid (Nonpen), Crabs, Penaeid, Flatfish, Commercial catch (Comm), Elasmobranch (Elasm) and Sciaenid which synchronously fluctuated with environmental parameters such as Sea Surface Salinity (SAL), Bottom Chlorophyll (BCHL), Ocean Mixed Layer (OMXL) and Dissolved Oxygen (DO). Similarly, Sea Surface Temperature (SST), Sea Bottom Temperature (BT), Sea Surface Height (SSH), Current Speed (CS) and Sea Surface Chlorophyll (Mchla) were associated with the density of second group with four major resource group of trawl catch *Harpadon nehereus* (Harpo), Squilla (Squi), Bycatch (TD) and *Coilia dussumierii* (Coili)

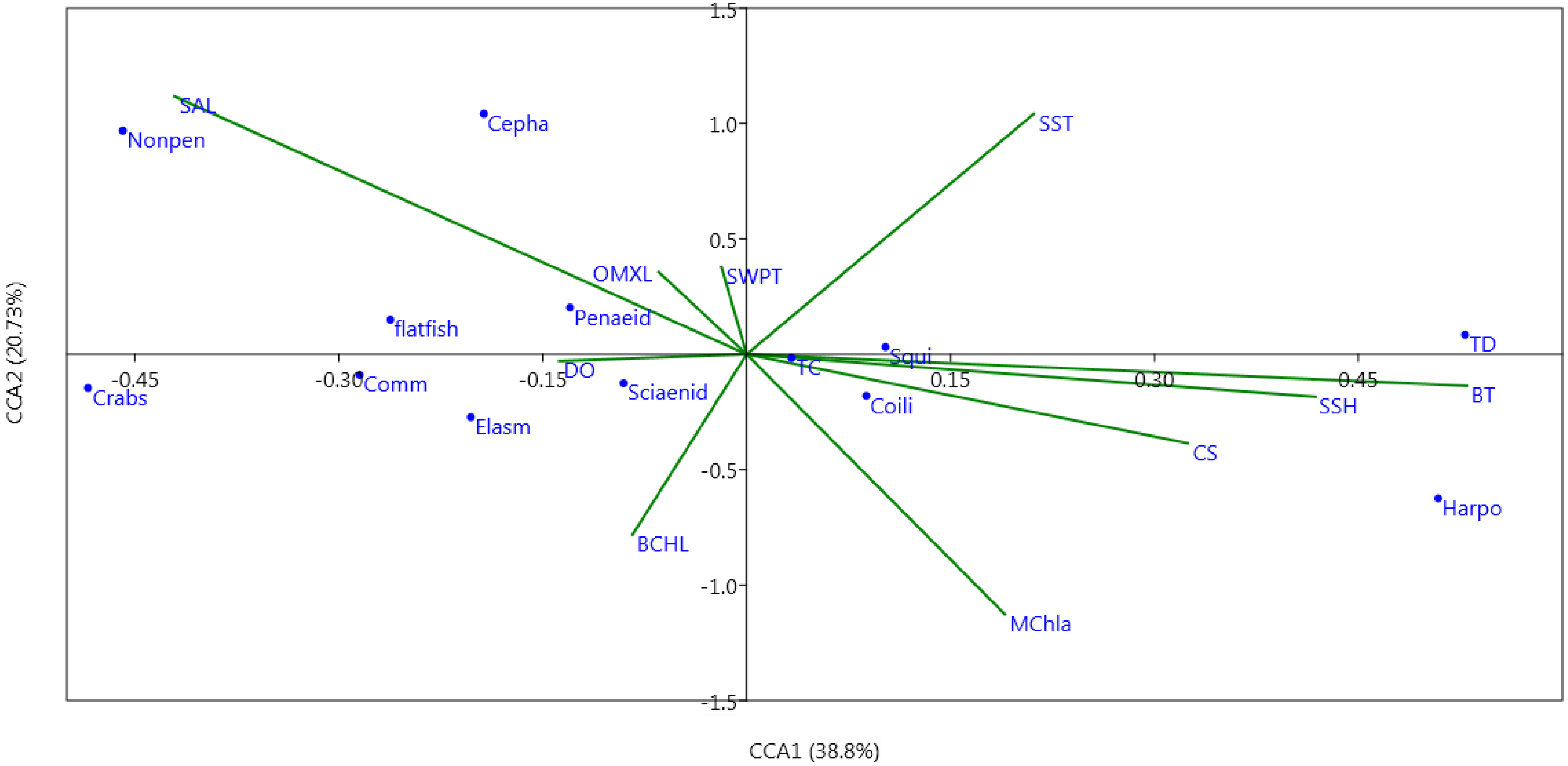


Figure. 4.8.1: CCA biplot for major fish species and environmental parameters (Abbreviations are given in Table. 4.8.1)

Table. 4.8.1: Canonical coefficients of environmental variables and major fish species

CCA (Major species/Parameter)	**Axis1** **(38.8%)**	**Axis2 (20.73%)**	**CCA (Major species/Parameters)**	**Axis1** **(38.8%)**	**Axis2 (20.73%)**
Total Catch (TC)	0.033	-0.016	Sciaenid	-0.09	-0.13
Commercial catch (Comm)	-0.28	-0.09	Sea Surface Chlorophyll (Mchla)	0.09	**-0.56**
Bycatch (TD)	**0.53**	0.08	Sea Surface Temperature (SST)	0.11	**0.52**
Squilla (Squi)	0.10	0.03	Sea Surface Salinity (SAL)	-0.21	**0.56**
Elasmobranch (Elasm)	-0.20	-0.27	Bottom Temperature (BT)	0.27	-0.07
Bombay Duck (Harpo)	**0.51**	**-0.62**	Sea Water Potential Temperature (SWPT)	-0.01	0.19
Cephalopod (Cepha)	-0.19	1.04	Ocean Mixed Layer (OMXL)	-0.03	0.18
Coilia dussumierii (Coili)	0.09	-0.18	Sea Surface Height (SSH)	0.21	-0.09
Crabs	**-0.48**	-0.15	Dissolved Oxygen (DO)	-0.07	-0.01
Flatfish	-0.26	0.15	Bottom Chlorophyll(BCHL)	-0.04	-0.39
Non-penaeid (Nonpen)	-0.46	**0.97**	Current Speed (CS)	0.16	-0.19
Penaeid	-0.13	0.20			

4.8.2. Pearson correlation analysis

Pearson correlation analysis was performed to understand the major environmental factors influencing in-situ trawl fish catch data. Correlation matrix between major fish groups and satellite derived environmental data is shown in Table. 4.8.2. The total fish catch was found to be significantly positively correlated at the significant level ($p<0.05$) with Sea Surface Chlorophyll (Mchla), Sea Surface Temperature (SST), Sea Surface Salinity (SAL), Bottom Temperature (BT) and Current Speed (CS) and negatively correlated with Ocean Mixed Layer (OMXL). Significant positive correlations of total catch were also found with Sciaenid, *Coilia* and Penaeid. The abundance of Squilla groups in the catch was positively correlated with Sea Surface Chlorophyll. *Coilia* abundance was positively correlated with current speed. Sciaenids positively correlated with Sea Surface Temperature (SST) and Sea Surface Salinity (SAL). Non-penaeids showed a positive correlation with salinity. The abundance of Bombay duck was in positive correlation with current speed. Non-penaeid (Nonpen) were observed to have a positive correlation was significantly negatively correlated with current speed. TC (Total catch) and Bycatch (TD) both were positively correlated ($r=0.62$) with each other and the Bycatch (TD) also supported by the catch of Squilla (Squi). Moreover, reported total catch (TC) was also positively correlated with the concentration of Sea surface chlorophyll (Mchla) and significant catch of Bombay Duck (Harpo), *Coilia dussumierii* (Coili) and Sciaenid group of fishes.

Table. 4.8.2. Correlation matrix of major environmental parameters with fish groups

	TC	Comm	TD	Squi	Elasm	Harpo	Cepha	Coili	Crabs	Cyano	Nonpen	Penaeid	Sciaenid	MChla	SST	SAL	BT	SWPT	OMXL	SSH	DO	BCHL
TC																						
Comm	0.61																					
TD	0.62	-0.23																				
Squi	-0.08	-0.32	0.22																			
Elasm	0.09	0.27	-0.16	0.02																		
Harpo	0.41	0.61	-0.10	-0.20	-0.15																	
Cepha	0.08	0.15	-0.05	-0.16	-0.11	-0.12																
Coili	0.43	0.72	-0.18	-0.22	0.00	**0.48**	0.16															
Crabs	0.05	0.10	-0.05	0.02	0.14	-0.14	-0.08	0.09														
Cyano	-0.11	-0.10	-0.04	0.18	0.19	-0.13	0.00	-0.18	0.26													
Nonpen	0.11	0.19	-0.05	-0.21	-0.12	**-0.56**	0.61	0.26	-0.06	-0.08												
Penaeid	0.34	0.56	-0.14	-0.17	-0.16	**0.55**	0.23	0.41	-0.08	-0.08	0.11											
Sciaenid	0.49	0.78	-0.16	-0.20	0.42	0.38	0.00	0.30	0.10	-0.02	-0.02	0.31										
MChla	**0.44**	-0.07	-0.10	**0.37**	0.20	0.00	-0.41	-0.18	0.00	0.01	-0.41	-0.11	-0.03									
SST	**0.56**	-0.21	0.11	-0.07	-0.28	**-0.56**	0.43	-0.09	-0.13	-0.13	**0.46**	0.21	**0.50**	**0.34**								
SAL	**0.41**	-0.24	-0.27	0.02	-0.18	**-0.35**	0.43	0.00	0.21	0.02	**0.45**	0.04	**0.63**	**-0.23**	**0.44**							
BT	**0.32**	0.10	0.06	-0.25	-0.25	0.19	0.22	0.21	-0.33	-0.36	0.12	0.23	0.09	-0.47	**0.64**	-0.05						
SWPT	0.08	0.04	0.06	-0.17	-0.23	0.11	0.26	0.19	0.05	-0.24	0.08	0.29	0.07	-0.39	**0.67**	0.11	0.75					
OMXL	-0.29	-0.15	-0.20	0.03	0.13	-0.22	-0.07	-0.05	-0.04	-0.07	0.12	-0.12	-0.14	-0.09	-0.22	0.28	-0.18	-0.27				
SSH	-0.22	-0.30	0.03	0.19	0.14	-0.41	-0.18	-0.41	-0.07	-0.01	-0.30	-0.36	-0.13	0.27	-0.37	0.09	-0.37	-0.46	0.40			
DO	0.06	0.02	0.05	**0.40**	-0.01	-0.04	0.01	-0.03	0.31	0.22	0.06	-0.11	0.01	-0.38	**-0.20**	**-0.23**	-0.17	-0.07	-0.12	-0.02		
BCHL	-0.21	-0.15	-0.11	0.18	0.12	-0.07	-0.40	-0.18	0.11	-0.06	-0.28	-0.14	-0.19	0.56	-0.73	-0.15	-0.56	-0.57	0.37	0.50	-0.06	
CS	**0.54**	0.42	0.24	-0.16	-0.07	**0.61**	0.15	**0.32**	0.08	-0.03	0.12	**0.39**	0.38	-0.18	0.21	-0.22	0.26	0.35	**0.51**	-0.52	0.02	-0.50

Figures in red show significant correlations (P<0.05); Total Catch (TC), Commercial catch (Comm), Bycatch (TD), Squilla (Squi), Elasmobranch (Elasm), Bombay Duck (Harpo), Cephalopod (Cepha), *Coilia dussumierii* (Coili), Crabs, Flatfish(Cyano), Non-penaeid (Nonpen),Penaeid, Sciaenid, Sea Surface Chlorophyll (Mchla), Sea Surface Temperature (SST), Sea Surface Salinity (SAL), Bottom Temperature (BT), Sea Water Potential Temperature (SWPT), Ocean Mixed Layer (OMXL), Sea Surface Height (SSH), Dissolved Oxygen (DO), Bottom Chlorophyll (BCHL), Current Speed (CS)

4.8.3. Generalized additive models

GAMs with a Gaussian distribution and identity link function were used to investigate the influence of satellite derived environmental parameters studied on the catch abundance of major resource groups. A manual backward stepwise procedure based on minimum AIC was used to select the environmental variables influencing the abundance of targeted resources and non-significant environmental variables were not selected for the model. The final GAM model for each targeted resource and total catch is shown in Table. 4.8.3. The results revealed the influence of environmental factors on the catch of major resources and total catch. Deviance explained in the final model varied from 28.6% (Elasmobranch) to 75.4% (Total catch).

The analysis showed that environmental parameters like Sea Surface Chlorophyll (SCHL), Sea Surface Temperature (SST), Sea Surface Salinity (SAL), Sea Bottom Temperature (BT) and Current Speed (CS) Ocean Mixed Layer (OMXL) exhibited more influence and affected the species distribution and catch of major resources with high F value, which is depicted in Table. 4.8.4. Based on the F value obtained from GAM analysis, the most influential environmental variables for Total catch, Non- penaeid and Bombay duck were Sea Surface Temperature, Sea Water Potential Temperature, and Sea Surface Height respectively.

The plot of the best smoothing showed higher probability of catch of penaeid shrimp at Sea Bottom Temperature (BT) >27 °C, Sea Surface Temperature (SST) >28 °C, salinity 34-35.5 ‰ and Sea Surface Height (SSH) >0.35m, respectively (Figure. 4.8.5). Whereas for Non- penaeid, the plot showed a higher probability of catch at Sea Surface Height (SSH) <0.34 m, Sea Surface Temperature (SST) 26-28 °C, Sea Surface Salinity > 34.5 ‰ and current speed >0.05 ms $^{-1}$(Figure. 4.8.11). For Sciaenid group, the best smoothing plot revealed a high probability of catch at Sea Bottom Temperature (BT) >27 °C, current speed >0.05 ms $^{-1}$, Sea Surface Chlorophyll (SCHL) <1.0 mgm^{-3} and Sea Surface Temperature (SST) >28 °C (Figure. 4.8.10). For *Coilia*, the higher probability of catch was observed at Sea Surface Salinity > 34.5 ‰, current speed > 0.05 ms^{-1}, Sea Surface Temperature (SST) 27-29°C and Sea Surface Height (SSH) >0.35 m (Figure. 4.8.3).

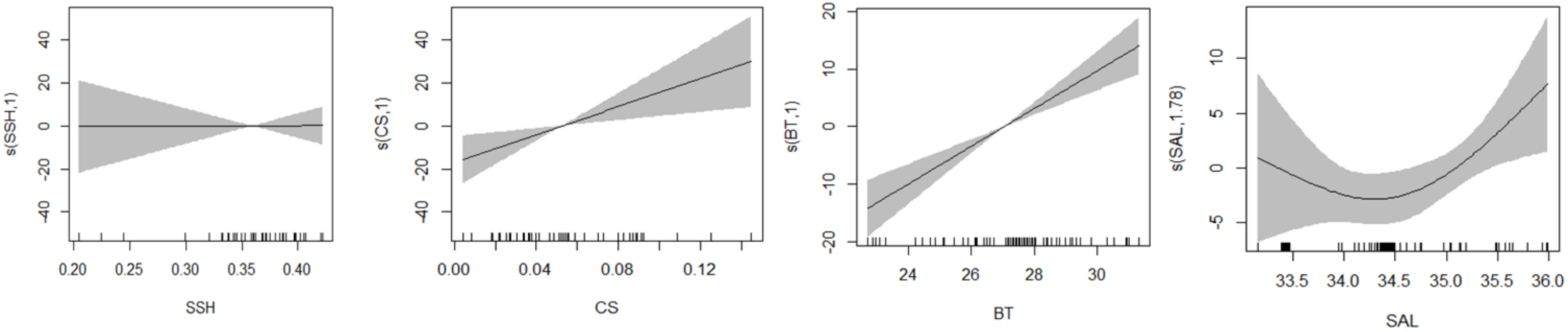
High probability of Cephalopod catch was observed at Sea Surface Temperature (SST) >28 °C, Sea Surface Height (SSH) 0.26-0.34 m and Dissolved Oxygen 180-200 cms^{-1} (Figure. 4.8.4). For Bombay duck, the plot of best smoothing showed a high probability of catch at Sea Surface temperature >28°C, Sea Surface Height (SSH) < 0.34 m, Sea Bottom Temperature (BT) <26°C and current speed 0.03-0.07 ms^{-1}(Figure. 4.8.9). The plot of the best smoothing for the Elasmobranch group, at current speed < 0.07 ms^{-1}, Sea Surface Height (SSH) 0.25-0.35 m, Dissolved Oxygen > 200 mmol/m^{3}, Bottom chlorophyll <1.0 mgm^{-3}(Figure. 4.8.8). The plot of the best smoothing showed higher probability of catch for crabs at Sea Surface Salinity 33-35.5 ‰, Dissolved Oxygen 200-220 mmol/m^{3}, Bottom chlorophyll >1.0 mgm^{-3} and current speed 0.04-0.08 ms^{-1}(Figure. 4.8.6). whereas for Squilla plot showed a higher probability of catch at Sea Surface Salinity >35 ‰, Sea Bottom Temperature (BT) >27°C and Dissolved Oxygen <200 mmol/m^{3}. As per GAM plot probability of getting good catch for flatfishes observed at Sea Surface Height (SSH) > 0.35 m, Sea Bottom Temperature (BT) <28°C and Bottom chlorophyll 0.5-1.5 mgm^{-3} (Figure. 4.8.7). The probability of getting maximum total catch, according to GAM plot was at current speed >0.07 ms^{-1}, Sea Surface Salinity >34 ‰, Sea Surface temperature >28°C and optimum Sea Surface Height (SSH) of 0.35-0.40 m (Figure. 4.8.2)

Table. 4.8.3. Final GAM model for targeted resource of Experimental fishing.

Resource	**Final Model**	**DE**	**R^2**	**AIC**
Total catch	s(SST, k = 3)+s(SAL, k = 3)+s(BT, k = 3)+s(SSH, k = 3)+s(SCHL, k = 3) +s(CS, k = 3) +s(DO, k = 3)	75.4%	0.74	1007.0
Penaeid	s(SST, k = 3)+s(SAL, k = 3)+s(BT, k = 3)+s(SWPT, k = 3)+s(OMXL, k = 3)+s(SSH, k = 3)+s(SCHL, k = 3)+s(DO, k = 3)+s(CS, k = 3)	59.8%	0.56	1416.3
Non- penaeid	s(SST, k = 3)+s(SAL, k = 3)+s(BT, k = 3)+s(SWPT, k = 3) +s(SCHL, k = 3)+s(CS, k = 3)	31.7%	0.28	737.0
Sciaenid	s(SST, k = 3)+s(SAL, k = 3)+s(BT, k = 3)+s(SSH, k = 3)+s(SCHL, k = 3)+ s(CS, k = 3)	44.6%	0.41	493.6
Harpadon nehereus	s(SST, k = 3)+s(BT, k = 3)+s(SWPT, k = 3)+s(SSH, k = 3)+s(SCHL, k = 3)+s(CS, k = 3)	64.9%	0.62	823.0
Elasmobranch	s(SAL, k = 3)+s(BT, k = 3)+s(OMXL, k = 3)+s(SSH, k = 3)+s(SCHL, k = 3) +s(BCHL, k = 3)	28.6%	0.24	441.2
Flatfishes	s(BT, k = 3)+s(OMXL, k = 3)+s(SCHL, k = 3)	36.9%	0.34	923.5
Crabs	s(SST, k = 3)+s(SAL, k = 3)+s(BT, k = 3)+s(SWPT, k = 3)+s(OMXL, k = 3)+s(SSH, k = 3)	44.6%	0.42	611.9
Squilla	s(SAL, k = 3)+s(BT, k = 3)+s(SSH, k = 3)+s(DO, k = 3)	40.9%	0.38	37.1
Cephalopod	s(SST, k = 3)+s(BT, k = 3)+s(SWPT, k = 3)+s(SSH, k = 3)+ s(DO, k = 3)+s(DO, k = 3)	50%	0.47	817.3
Coilia dussumieri	s(SST, k = 3)+s(SAL, k = 3)+s(BT, k = 3)+s(SSH, k = 3)+s(BCHL, k = 3)+s(CS, k = 3)	52.6%	0.50	1196.6

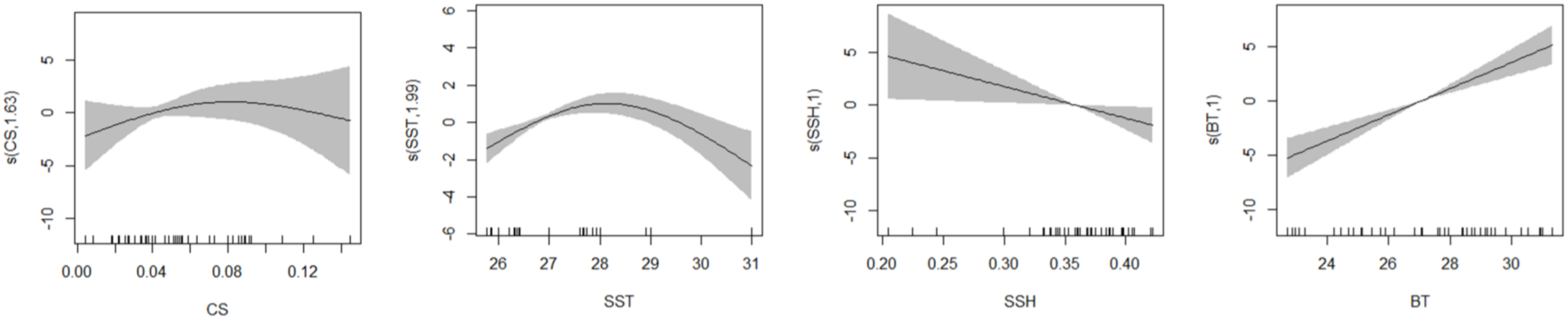
Table. 4.8.4. The F value from GAM analysis

Resource /Species	F Value									
	SST	SAL	BT	SWPT	OMXL	SSH	SCHL	DO	BCHL	CS
Total catch	164	11.2	12.7	-	-	26.8	5.37	-	-	1
Penaeid	12.6	1.9	1.9	2	1.8	2	1.92	1.1	-	1.86
Non- penaeid	7.7	16	2.7	8.3	-	-	7.4	-	-	4.7
Sciaenid	10.8	8.19	7	-	-	-	6.4	-	-	27.5
Harpadon nehereus	19	2.93	-	5.59	-	78	25.73	-	-	19.4
Elasmobranch	18	-	1.9	-	1	2	1.3	-	1	-
Flatfishes	-	-	26.8	-	7.9	-	7.8	-	-	-
Crabs	9.5	14.6	12.8	31.42	-	6.12	-	-	-	-
Squilla	-	9.5	5.2	-	-	5.05		34.3	-	-
Cephalopod	37.18	-	6.8	5.05	-	-	-	3.6	-	-
Coilia dussumieri	83.2	33.01	50.8	-	-	45.6	-	-	10.12	4.9



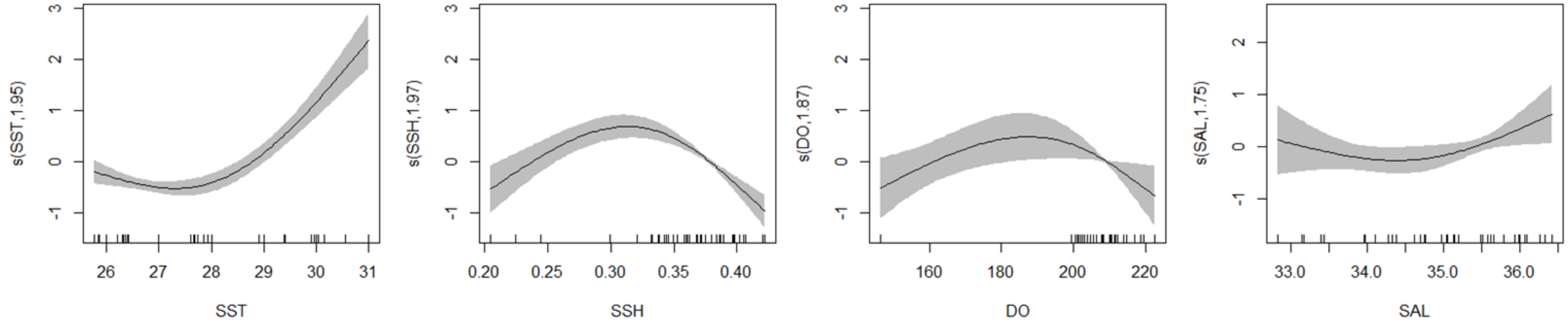
Sea Surface Height (SSH), Current Speed (CS), Bottom Temperature (BT) and Sea Surface Salinity (SAL)

Figure. 4.8.2: Plot for best smoothing in GAM analysis for total catch



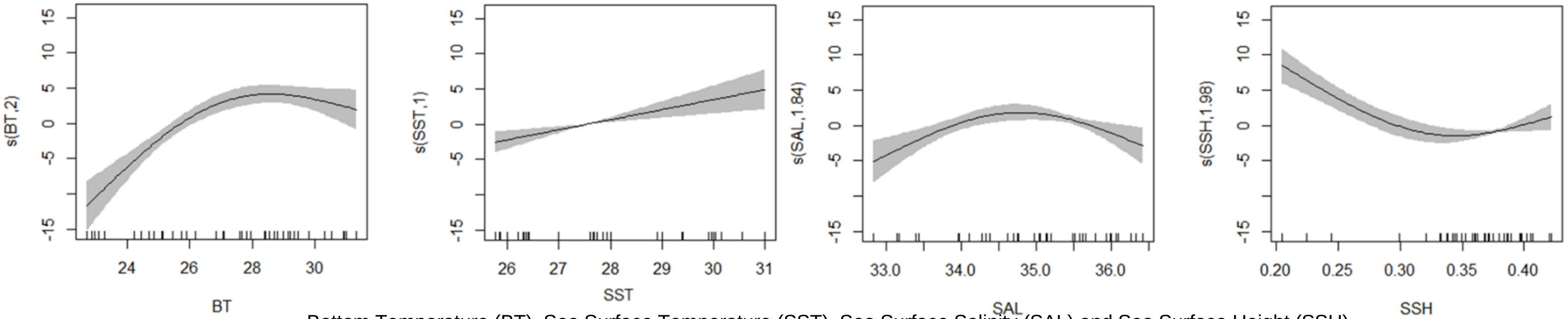
Current Speed (CS), Sea Surface Temperature (SST), Sea Surface Height (SSH) and Bottom Temperature (BT)

Figure. 4.8.3: Plot for best smoothing in GAM analysis for *Coilia dussumierii*



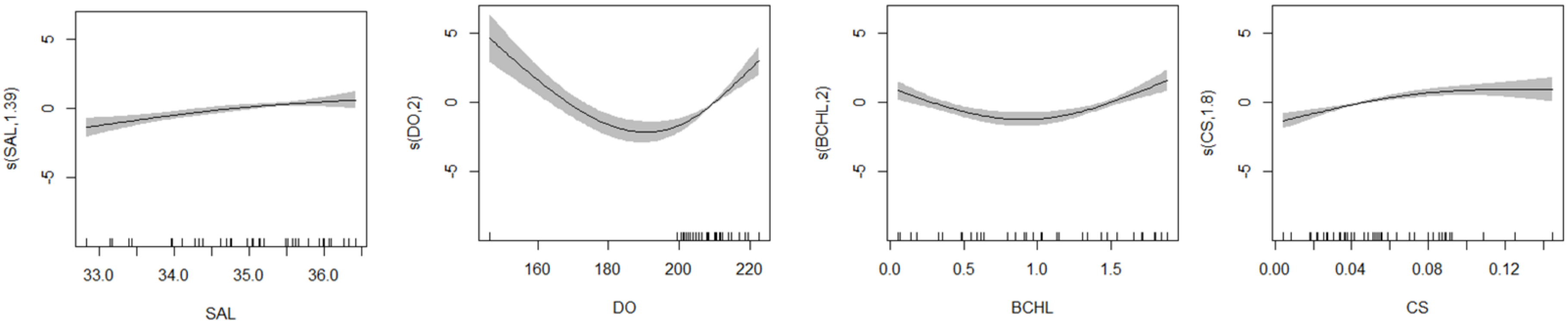
Sea Surface Temperature (SST), Sea Surface Height (SSH), Dissolved Oxygen (DO) and Sea Surface Salinity (SAL)

Figure. 4.8.4: Plot for best smoothing in GAM analysis for Cephalopods



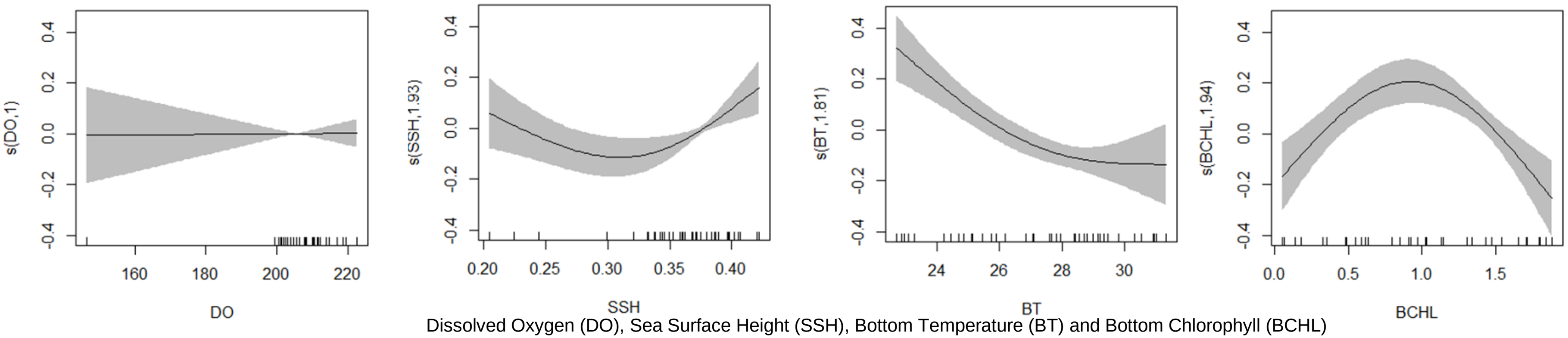
Bottom Temperature (BT), Sea Surface Temperature (SST), Sea Surface Salinity (SAL) and Sea Surface Height (SSH)

Figure. 4.8.5: Plot for best smoothing in GAM analysis for Penaeids



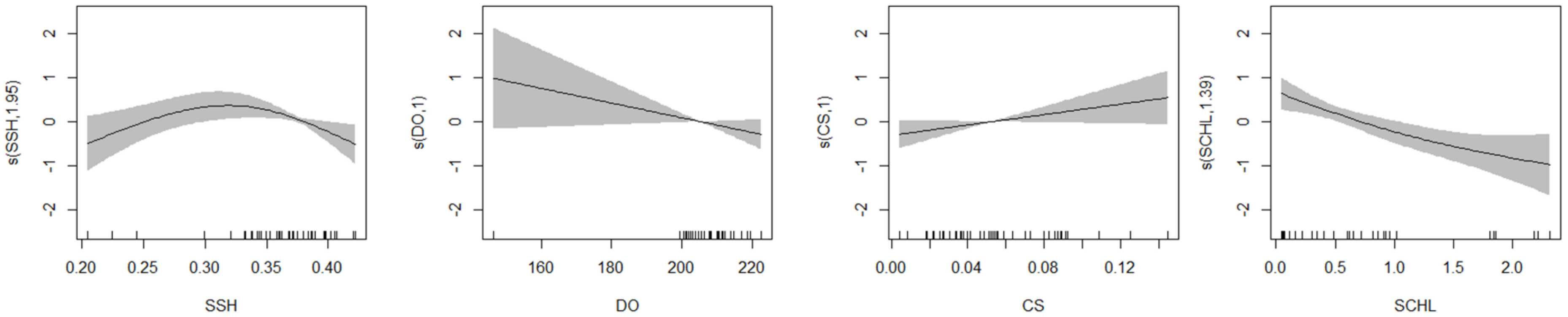
Sea Surface Salinity (SAL), Dissolved Oxygen (DO), Bottom Chlorophyll (BCHL) and Current Speed (CS)

Figure. 4.8.6: Plot for best smoothing in GAM analysis for Crabs



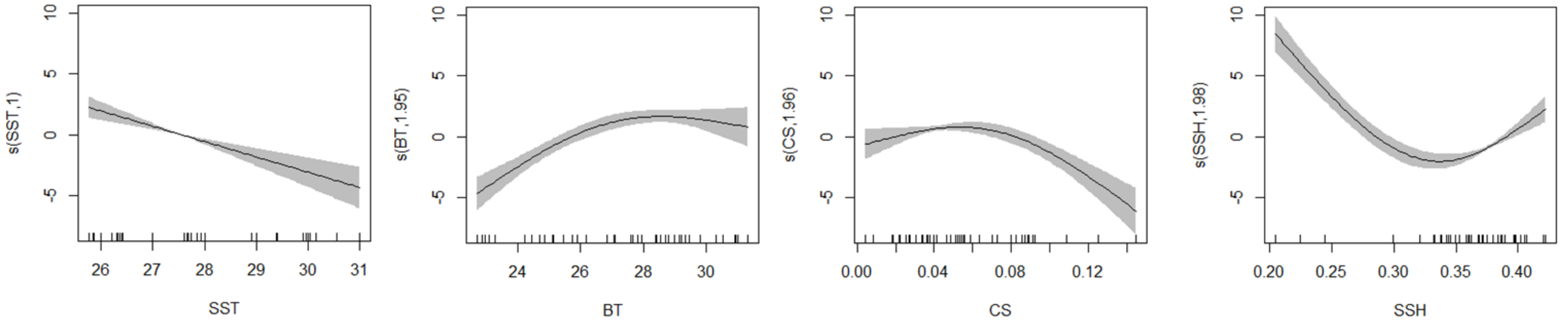
Dissolved Oxygen (DO), Sea Surface Height (SSH), Bottom Temperature (BT) and Bottom Chlorophyll (BCHL)

Figure. 4.8.7: Plot for best smoothing in GAM analysis for Flatfishes



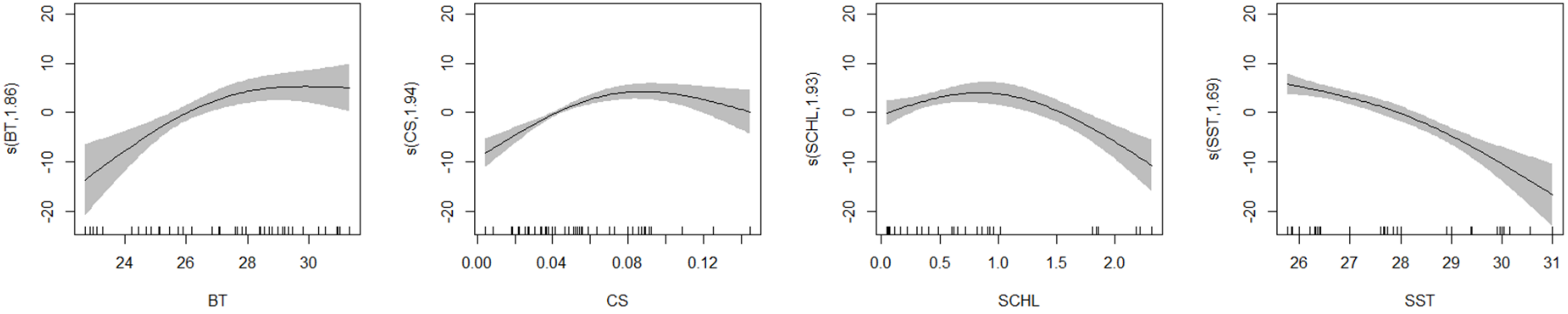
Sea Surface Height (SSH), Dissolved Oxygen (DO), Current Speed (CS) and Sea Surface Chlorophyll (SCHL)

Figure. 4.8.8: Plot for best smoothing in GAM analysis for Elasmobranchs



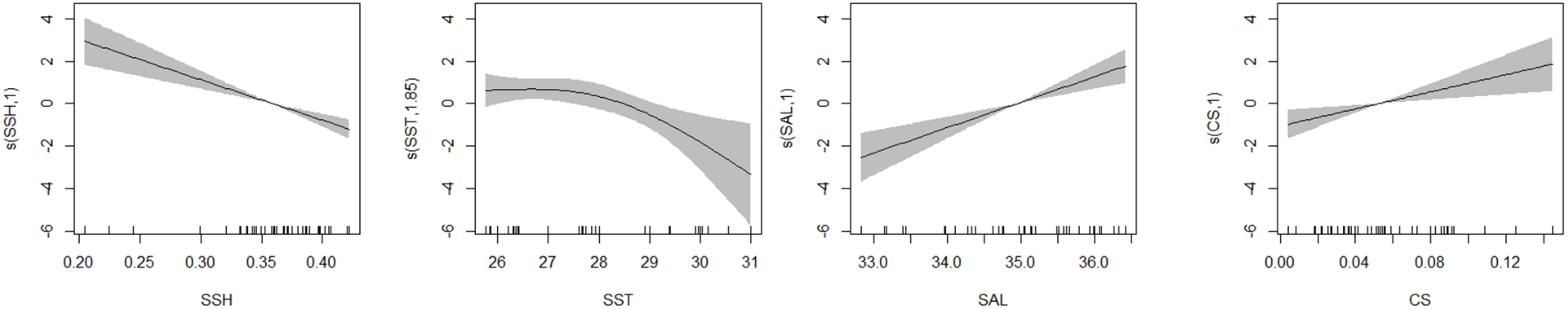
Sea Surface Temperature (SST), Bottom Temperature (BT) and Current Speed (CS) and Sea Surface Height (SSH)

Figure. 4.8.9: Plot for best smoothing in GAM analysis for *Harpadon nehereus*



Bottom Temperature (BT), Current Speed (CS), Sea Surface Chlorophyll (SCHL) and Sea Surface Temperature (SST)

Figure. 4.8.10: Plot for best smoothing in GAM analysis for Sciaenids



Sea Surface Height (SSH), Sea Surface Temperature (SST), Sea Surface Salinity (SAL) and Current Speed (CS)

Figure. 4.8.11: Plot for best smoothing in GAM analysis for Non- penaeids

1 INTRODUCTION

2 REVIEW OF LITERATURE

3 MATERIAL AND METHODS

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5. DISCUSSION

The perusal of literature revealed that the present study was the first to adopt an integrated approach to trawl fisheries using sea-truth and remotely-sensed data through experimental trawl fishing while assessing the quality of satellite-derived environmental variables and their influence on the in-situ trawl catch. The data generated though with limited sampling can help in improving an ecosystem-based fishery implementation plan in the region.

5.1 Trawl Catch

5.1.1 Composition of catch

Increase in profits from trawling operations resulted in unfair competition for exploitation of marine resources which generated huge quantities of bycatch. Bycatch is a major concern in global fisheries and bycatch level are significantly higher in trawling than other fishing. India is a tropical country which is well known for its multi-species and multi-gear fishery that makes bycatch is a more complex issue to solve. Several studies were conducted along the Indian coast to address the issue of trawl bycatch (Boopendranath 2007, 2012; Meenakumari *et al.,* 2009; Pravin *et al.,* 2011; Dineshbabu *et al.,* 2016; Madhu, 2018). Though regional studies have been addressed certain issues but still lack of comprehensive study on this issue especially in Indian scenario. Bycatch includes non-targeted catch which is retained as they have market value and also some portion which may get discarded due to no or poor demand in the market. The perspective regarding bycatch is the greatest challenge, as yesterday's bycatch becomes today's target catch (Boyce, 1996).

The present study estimated bycatch between 3.44-61.34 kg/hour with the abundance of jellyfish and *Trypauchen* spp. in the month October 2017 and November 2018 respectively. Contribution of commercial catch ranged from 3.80kg/h in April 2018 to 57.25kg /h in September 2018. The first study on fishing by-catches along Indian waters was carried out in 1979. The study conducted during 2016-18 on trawl fishery of coastal Mumbai showed that for every hour, multi-day trawlers discarded catch ranging from 5.33 to 16.00 kg and single-day trawlers from 3.00 to 7.67 kg/hour (Kharatmol *et al*., 2018).

Available Studies reported state-wise landings of by-catches by smaller trawlers. George *et al.* (1981) reported discards accounting for 1.5 % (5 mt) of trawl catch. Report on Mangalore and Malpe trawl fish landings in 1980-82 showed that only 13% of the total annual trawl catch was shrimp and 85% of by-catch was recorded (Sukumaran *et al*., 1982).

Trawl fishing along the Karnataka coast recorded bycatch as 56.04 mt in 2001 and 52.38 mt in 2002, with discards estimated at 34.96 mt in 2001 and 38.32 mt in 2002 (Zacharia *et al.,* 2006). Research studies conducted from 1985-90 along the states of Kerala, Karnataka and Tamil Nadu revealed that target groups like shrimp (16%) and cephalopods (4%) and together constituted just 20% while others such as finfish (65%) and benthic species (15%) constituted the remaining trawl landings (Menon, 1996).

Current study on trawl catch composition along the Mumbai coast shows that bycatch contributed a maximum of 1202.30 kg (79.43%) while the share of commercial catch was limited to 304.6 kg (20.12%) and marine debris 6.8 kg (0.45%) in the total catch (1513.7 kg). The findings are consistent with similar work conducted along the Indian coast, with a higher percentage of bycatch than commercial catches Pillai (1998); Pravin and Manohardoss (1996); Dixitulu (2003); Prabhu (2013); Jagadis *et al*. (2003); Zynudheen *et al*. (2004); Zacharia *et al*. (2006).

Assessment of Indian coastal trawl fisheries from 2008-11 revealed that low-value bycatch landing grew from 14% in 2008 to 25% in 2011 and recorded around 237 species as bycatch. (Dineshbabu *et al*., 2013). During the years of 2015-16, the research study on trawl fishery along Maharashtra's Ratnagiri coast recorded catch and discard percentage of multi-day trawlers as 61% to 96% and 70% to 97% in the case of single-day trawlers (Singh *et al.,* 2017). Study on Participatory GIS in trawl fishery along Mumbai coast from 2013-14 reported 7-33% discards by multi-day trawlers and 4-30% by single-day trawlers (Bhendekar *et al*., 2016).

Analysis of composition of shrimp and bycatch from present study revealed that shrimp: bycatch ratio ranged from 1:3.08 to 1:60.98. The present study reports that target catch (shrimps) contributed 12.8%, non-target 47.3% and 39.9% bycatch. The mean monthly by-catch of shrimp trawling along the Mumbai coast was estimated at 10.26-91.47 kg h^{-1}. The earlier reported monthly bycatch in shrimp trawling along the Mumbai coast varied from 11.82 to 20.65 kg h^{-1}, with a mean of 16.82 ± 0.97 (SE, n=8) kg h^{-1} (Samantha *et al*., 2018). Shrimp bycatch ratio ranged from 1:0.6 to 1:69 as calculated from experimental shrimp trawling in the conventional trawling grounds of Kochi from 2004 - 2006 (Gibinkumar *et al.,* 2012). The catch composition in this study indicated that non-conventional fish, juveniles and sub-adults of commercially important species contributed to discards.

A systemic, long-term targeted exploitation of shrimps using small cod end-mesh trawl resulted in the overall decline and overfishing of shrimps from coastal fishing ground (Ansari *et al*., 2006). This discard composition analysis illustrates growth overfishing along the Mumbai coast. Trawling is primarily targeted towards shrimp and non-target species make a significant contribution to the total catch in terms of their number, and biomass as elucidated in the present investigation. Similar trends have been reported from various parts of the country (George *et al.,* 1981; Sukumaran *et al*., 1982; Boopendranath 2007; Pravin *et al.,* 2011; Zacharia *et al.,* 2006; Bijukumar and Deepthi, 2006; Menon, 1996; Dineshbabu *et al*., 2013; Bhendekar *et al*., 2014; Pillai *et al*., 2014; Singh *et al.,* 2017; Kharatmol *et al*., 2018; Samanta *et al*., 2018). The present study clearly indicated that the continuous harvesting of commercially important juveniles and targeted species will have long-term implications affecting the fish recruitment pattern.

5.1.2 Species composition

Present study on commercial catch from the experimental fishing along the Mumbai coast comprised of major resources: sciaenid (37%), shrimp (21%), coilia (17%), Bombay duck (7%), ribbonfish (3%), elasmobranch (3%), crab (2%), cephalopods (3%) and catfish (4%), lobsters (2%), pomfrets (0.4%) and remaining comprise around 4% . In case of bycatch, the major groups were Squilla (28.4 %), sciaenids (13%), shrimp (11.4%), hermit crab (9.1%) and miscellaneous (8%), crab(15.5 %), cephalopods (2.2%),flatfishes (1.8%), lobsters (2%), eel (1.6%), elasmobranch (0.5%) and ribbon fish (1.8%).

A related study on the diversity of trawl catches along the Mumbai coast recorded abundance of *Otolithes cuvieri* (24%), followed by *Arius maculatus* (16%), *Lepturacanthus savala* (15%), Penaeid prawns (10%), *Uroteuthis duvaucelli* (8%), *Cynoglossus macrostomus* (6%), *Megalaspis cordyla* (6%), *Harpodon nehereus* (5%), *Thryssa dussumieri* (5%), and *Pampus argenteus*(5%) (Kharatmol *et al*., 2018). Bhendekar *et al*., (2016) estimated that the major contributors to catch trawl along the coast of Mumbai were *Coilia dussumieri, Apogon quadrifasciatus, Johnieops vogleri, Harpadon nehereus, Lepturacanthus savala, Parapenaeopsis stylifera, Metapenaeus affinis, Johnius glaucus, Harpiosquilla hapex* and *Sepiella inermis.*

Studies on Tamil Nadu coastal trawl fisheries documented abundance of silver bellies (23.2%) among others such as clupeids (4.2%), penaeid prawns (10.5%), croakers (4.8%), carangids (4.3%), rays (3.9%), threadfin breams (3.9%), perches (3.3%), goatfish (3.1%) and crabs (2.8%) (Mini and Srinath, 2003). Research studies based on experimental fishing in Mumbai's trawling grounds using shrimp trawl recorded 143 species in 2015 to 2016. Among all the species, Sciaenids (35%) were the most dominant, accompanied by sharks and rays (10%), anchovies (10%), prawns (8%), Bombay duck (6%) and other demersal classes (Samantha *et al*., 2018)

The present study reported a wide range of fish and shellfish species are available along the Mumbai coast. However, occurrence for most of the major resource group was limited with few species dominating in the total catch. High diversity and low species abundance are a common phenomenon in tropical ecosystems (Ansari *et al*., 1995; Whitfield, 1999; Rojo-Vazquez *et al.*, 2008). This is confirmed by the fact that, given the high diversity of fish stocks in tropical environments, a few species dominate fishing (Blaber *et al.,* 1995; Sreekanth *et al.,* 2017; Ratheesh Kumar, 2019). The present study observed continuous occurrence of three squilla species in trawl bycatch which suggested intermittent recruitment and reduced level of predation (Antony and Madhsoodana, 2010; Antony *et al*., 2010). Squilla known to feed at different trophic levels (Antony *et al.,* 2010) which probably favours enhanced abundance and continuous occurrence.

Global trawl bycatch estimates shown a rise from the 1970s (46.84%) to the 1990s (89.30%). This is primarily due to increased use of bottom trawlers (Watson *et al*., 2006). Sciaenids represent an important component of the present study and also forms around 11% of the total demersal fish catches of India (CMFRI, 2020). The biological traits of these fishes especially the feeding behavior along with higher reproductive potential might have supported their abundance. The feeding diversity and prolonged spawning activity in the study area might be responsible for their higher abundance and sustainability along this region (James and Badrudeen, 1986; Abraham *et al*., 2011; Borah *et al.,* 2016; Zacharia and Jayabalan, 2007; Ghosh *et al.,* 2014).

Present study shows abundance of crustaceans with consistent patterns due to multiple breeding cycles of various crustacean species (Achuthankutty and Parulekar, 1986). Crabs comprised both juveniles as well as gravid females throughout the study period indicating that these are coastal resident species (Wagle and Kunte, 1999). Increased contribution of groups such as finfish, crustacean, squilla, molluscs, and other fauna during the study underlines the non-selective nature of the fishing gear (Bijukumar and Deepthi, 2006). Significant amount of gastropods forms part of trawl catch due to lack of potential predators such as predatory finfishes and crabs (Palmer, 1979). This might be responsible for their higher abundance along the present study area as these are removed by continuous fishing activities.

Two-way ANOVA and post-hoc comparison of species from major resource using Tukey's HSD revealed significant differences. Among the different groups, catch rates of penaeid, non-penaeid shrimp, ribbon fish, crabs, cephalopods, catfishes were comparatively higher during the pre-monsoon whereas Sciaenids, Bombay duck, Elasmobranch and flatfishes were higher during the post-monsoon (September-January). Seasonal variations may be correlated to the coastal environmental water parameters those might regulate the physiological processes of the coastal residents and migrant species. Similar variations in demersal fish catches were reported from previous studies (Bapat *et al.,* 1972; Prabhu and Dhawan, 1974; Radhakrishnan, 1974; Ansari *et al*., 1995; Dineshbabu *et al*., 2012; Pillai *et al*.,2014; Bhendekar *et al.,*2016; Mahesh *et al*., 2017; Kharatmol *et al.,* 2018; Samantha *et al*., 2018; Jenishma *et al.,*2019) from the west coast of India.

Present study observed major species responsible for the variation in catch composition among the seasons through SIMPER analysis were *Johnius belangerii, Harpodon nehereus, Johnius glaucus, Parapenaeopsis hardwickii, Coilia dussumieri, Otolithoides biauritus, Acetes indicus, Himantura imbricata, Parapenaeopsis stylifera, Oratosquillina perpensa, Johnius macrorhynnus, Johnius* *sina, Nematopalaemon tenuipes, Uroteuthis duvaucelli* and *Otolithes cuvieri*. As Shirodkar *et al.* (2012) reported, catches in different seasons are associated with environmental parameter fluctuations. Seasonal patterns of fish may also be attributed to seasonal migrations for feeding and breeding (Gaughan and Potter, 1997; Ansari *et al.,* 1995). Crustacean catch analysis showed that few shrimps generally dominated the catches of trawl. Such shrimps are residents of nearby waters, juveniles of which are known to migrate into the nearby estuaries (Achuthankutty and Parulekar, 1986).

5.2 Spatio-temporal distribution of species

Previously, fish landing data from landing centers formed the base data used in marine fisheries management. Sustainable fishing management requires information on spatio-temporal changes in fisheries and fish habitat preferences is required (González *et al.,* 1995). One of the key lacunae for fishery managers when designing marine fisheries management policies is the lack of reliable data on the distribution of species in the fishing grounds. In the past, the fishery managers believed that the fish must be equally distributed in the fishing area. While formulating management strategies, this range of distribution of fishes needs to be fully understood.

Through this analysis an attempt was made in the present to investigate the spatial and temporal distribution of species. Of all 93 species observed during the present study from September 2017 to May 2019, number of species in the trawl catch observed were as follows: Finfishes (53), Shrimps (13), Gastropods (11), Crabs (4), Cephalopods (4), Stomatopods (3), Elasmobranch (3), Lobster (1) and Hermit crab (1).

During present study Jellyfish catch was encountered only during October, 2017. The varieties of species were represented at all times except some like *Cynoglossus arel, Trypauchen vagina, Parapenaeopsis stylifera, Miyakella nepa and Sepiella inermis, Johnius belangerii observed* in Septemer and October, 2017. The maximum species in terms of number of species (51) were recorded in May, 2018. This indicated that the maximum exploitation of biodiversity in terms of the number of fish species was in May, followed by March, 2018 (48). Maximum exploitation of biomass in terms of quantity was during October (jellyfish catch) followed by

November, 2017. Month-wise analysis of single-day trawl net fishery on the Mumbai coast revealed that the highest sciaenid catch was in the months October and March. (Samanta *et al*., 2018).

Five different depth strata viz. 6-9m, 9-12 m, 12-15 m, 15-18 m, 18-21 m were selected with a view to studying variation in the spatial distribution of non-conventional and low-value fish resources from the trawl. The maximum number of species were 69 recorded in the depth strata of 12-15 m followed by 67 species in the depth strata of 6-9 m. About twenty species were represented in all the five strata. Data on spatial and temporal distribution of these resources generated through this study can be utilized to develop fishery management policies along the coast. Several reports have shown that variation in faunal abundance in relation to depth of fishing (Prabhu and Dhawan, 1974; Gibinkumar *et al*., 2012; Samantha *et al*., 2018; Jenishma *et al.,*2018). Earlier studies also reported on the spatio-temporal variations in fish catch and number of species from trawl fishing grounds (Rao and Dorairaj, 1968; Prabhu and Dhawan, 1974; Gibinkumar *et al*., 2012; Kurup *et al*., 2003,2004; Dineshbabu *et al*., 2009,2010,2012; Pillai *et al*.,2014; Bhendekar *et al.,*2016; Mahesh *et al*., 2017; Kharatmol *et al.,* 2018; Samantha *et al*., 2018; Jenishma *et al.,*2018).

A study on bycatch using shrimp trawl in traditional trawling grounds off Cochin reported 281 species. It consisted of 191 species of fish, 11 species of shrimp, 3 species of lobsters, 13 species of crabs, 11 species of cephalopods, 44 species of molluscan shells, 2 species of echinoderms, 2 species of jellyfish, 2 species of stomatopods, one species of each for sea snake and sea turtle (Gibinkumar *et al*., 2012). Discards from trawlers along coastal waters of Kerala was quantified, it comprised of 13 species of finfishes, 23 species of gastropods, 14 species of crabs, 4 species of shrimp, 2 species of stomatopods and 3 species of echinoderms (Kurup *et al*., 2004). Research study on bycatch along the coast of Mangalore recorded 116 species of finfish, 31 species of gastropods, 4 species of bivalves, 7 species of cephalopods, 13 species of shrimps, 3 species of stomatopods, 21 species of crabs, 3 species of lobsters, 2 specimens of unidentified sharks and rays (Dineshbabu *et al*., 2012)

Kurup *et al.* (2003) estimated discards along the Kerala coast amounting to approximately 0.225 mt. Species-wise bycatch included 103 finfishes, 65 gastropods, 12 bivalves, 8 shrimps, 2 stomatopods, 12 crabs, 5 cephalopods, 3 echinoderms and four species of jellyfishes. Mangalore and Malpe coast trawl bycatch consisted of finfishes 35, crustaceans 6 in number, cephalopods 3, squilla one, echinoderms 2, bivalves 8 species and gastropods 6 species (Zacharia *et al.,* 2006). During the year 2007-2008 evaluation of quantitative and seasonal variations of Mangalore and Malpe bycatch, 25 finfishes were reported and a maximum of five shellfish contributed to the bycatch of juveniles (Dineshbabu *et al*., 2009).

The spatio-temporal analysis from the fishing ground off Mangalore recorded that 45 species were of commercial significance out of 202 and bycatch was contributed by 35 species of finfish, 20 crustaceans and gastropods, 3 cephalopods, 2 species of squilla, 3 echinoderms, 2 coelenterates and 1 sea snake. (Dineshbabu *et al*., 2010). Pillai *et al*. (2014) studied the diversity of bycatch from trawl fishing along North Tamil Nadu consisting of 64 species for crustacean bycatch: 37 species of brachyuran crabs, 1 species of anomuran crabs, 16 species of shrimps, 2 species of lobsters and 8 species of stomatopods. The total number of crustacean species were 9 in April, 2006 to 44 in July, 2008. When measured on an annual basis, post-monsoon showed maximum diversity (Pillai *et al*., 2014). Research study was conducted at Mangalore fisheries harbor to evaluate the low-value bycatch (LVB) of 121 finfish species where, LVB was estimated at 38.2% and 20.4% for single-day and multi-day trawlers respectively (Mahesh *et al*., 2017).

Kharatmol *et al.* (2018) observed about 112 species from single-day and multi-day trawl landings along Mumbai coast. Samantha *et al*., (2018) reported 143 species based on experimental fishing in the Mumbai trawling grounds that included finfish (82), molluscs (24), shrimps (17), crabs(8), elasmobranch(7), mantis shrimp (4) and lobster(1). Bhendekar *et al.* (2016) recorded 121 species including finfishes (72), shrimps (13), elasmobranch (5), crabs (9), lobsters (1), cephalopods (5) and stomatopods (4) from trawlers along Mumbai coast. The Ichthyofauna from present study showed a pattern of variation for abundance in terms of species recorded. The variation in teleostean abundance may be attributed to variation in abundance of primary food for most of the juveniles.

5.3. Quality Assessment of Satellite-Derived parameters

5.3.1. Sea Surface Chlorophyll

The satellite-derived maps provide a unique temporal and a spatial picture of the chl-*a* at the global scale (McClain *et al*., 1998). It is mentioned that validating several historical and operational ocean color missions and the datasets can be used for global climate studies, where a high-quality data set covering consistently a multi-year time span is essential (Bailey and Werdell, 2006).

The global accuracy goals in clear, natural waters for modern sensors for the parameter spectral reflectance and Sea Surface Chlorophyll are defined as 5% and 35%, respectively (Hooker *et al*., 1992). Marina *et al.* (2006) has reported the Sea Surface Chlorophyll concentration (C_a, mg m^{-3}) from satellite data in the Southern Ocean was significantly lower than the *in-situ* water samples and also revealed the percentage overestimation of *in-situ* data will increase with the decrease in chl-*a* concentrations. However, satellite observations are limited to the ocean surface and the error was calculated by matchup analysis of concurrent satellite and *in-situ* measurements, evaluated to vary around ±35 % in the open ocean (Moore *et al*., 2009).

Range of chl-*a* concentration recorded were for in-*situ* (0.2-5.04 mg m^{-3}), MODIS (3.16-21.24mg m^{-3}), VIIRS (2.81-13.93mg m^{-3}) and OCM2 (0.81-2.66mg m^{-3}). Chl-*a* data were acquired from encompassing globe which ranged from 0.012 to 72.12 mg m^{-3} (Werdell and Bailey, 2005). The OC2(v2) algorithm was used in the west marginal sea of the Antarctic Peninsula and applied to CZSC and SeaWiFS imagery, underestimated Chlorophyll-*a* (0.7–43 mg m^{-3}) concentrations by 60% (Dierssen and Smith, 2000). An underestimation of 87% was also found in the Chl-*a* concentration range of 0–1.0 mg m^{-3} and by 30% in concentration values of >5 mg m^{-3} in the South Georgia area (Kwok, and Comiso, 2002). Along South George region the SeaWFiS satellite chl-*a* value was only 87% of Fluorescence chl-*a* in case of lower concentrations (<1 mg m^{-3}) and only 30% for higher concentrations (>5 mg m^{-3}) (Korb *et al.,* 2004). The Sea Surface Chlorophyll concentration varies from 0.5 to 7.1 mg m^{-3} with an average value of 2 mg m^{-3} in the Godavari estuarine waters of India (Latha, *et al.,* 2013).

The permissible errors in the log-transformed Sea Surface Chlorophyll data products during the algorithm development were about 0.2 or less and nearly 60% root mean square (RMS) relative error (O'Reilly *et al.,* 2000). In the global validation of Sea Surface Chlorophyll, the error for most of the ocean basins are about 0.3 (Gregg and Casey, 2004), but in case of the Southern Ocean, the reported errors are significantly larger. According to Raman (2013), RMSE for the log-transformed data of satellite derived versus *in-situ* chl-*a* value was higher for OC2 (23.50%), OC4 (20.90%) and OC-OCM (16.10%).

The present study results, i.e., log bias and log RMSE percentage are coherent with the previous studies for different algorithms like MODIS (log bias 46.8 & log RMSE 0.7); VIIRS (log bias 38.4 & log RMSE 0.62) and OCM2 (log bias 4.55 & log RMSE 0.21).The OCM2 sensor performed better for estimation of Chl-*a* in the region with lower log RMSE and log bias values than the other two sensors i.e., MODIS and VIIRS. The satellite-based analysis of Chl-*a* along the Ardley Cove showed good agreement at high latitude, high Chlorophyll-*a* region with correlation at 59.46% (Zeng *et al.,* 2017). Chlorophyll-*a* product from MODIS and VIIRS show poor correlation with in-situ chl-*a*.

Uncertainty in Sea Surface Chlorophyll estimation also depends on band ratio of satellite sensor used. Sensitivity test declares little difference in band ratio selection for both MODIS and VIIRS (Zeng *et al.,* 2016). The RMSE percentage measures the similarity/dissimilarity between the in-situ and satellite-derived Chl-*a* value, the OCM2 had lower RMSE (0.58) than the other algorithms i.e., VIIRS (3.29) and MODIS (4.03). Many contemporary empirical algorithms have been developed successfully using regional data by considering the local range of geophysical conditions (Darecki and Stramski, 2004; Garcia *et al*., 2005; Gohin *et al.,* 2002).

The r^2 values for the three regression equations showed significant variability in comparison with *in-situ* data, i.e., OCM2 (r^2 = 0.35 and slope = -0.69), followed by MODIS (r^2 = 0.29 and slope = 0.19) and VISSR (r^2 = 0.16 and slope =0.52). Werdell, (2003) attempted the validation for the SeaWiFS global data set with *in-situ* measurements and recorded error and regression parameters as a percentage difference (27.3%), RMSE (0.567), slope ±standard error (1.034±0.025) and r^2 (0.849). In the present study, the variability between satellite sensor and *in-situ* data sets are meliorate explicated, while the OCM2 data set explains highest of 35.0% of variability of *in-situ* Chl-*a*, followed MODIS (29.0%) and VISSR (16.0%).

The validation attempted between Chlorophyll-*a* measured from HPLC and retrieved from OCM-2 (OC2 and OC4V4 algorithms) along the estuarine waters of the Bay of Bengal showed a significant regression relationship with r^2 as 0.60 and difference in Chl-*a* concentration with in-situ sea-truth data (Latha., 2013). The mean absolute percentage differences for OC2, OC4 and OC-OCM products were observed at 47.17%, 30.87% and 22.34% with *in-situ* Chl-*a* concentration. The coefficient of determination r^2 of satellite estimated versus in-situ dataset was highest for OC-OCM (r^2=0.76; slope=0.89), followed by OC4 (r^2=0.59; slope=0.56) and OC2 (r^2=0.45; slope=0.43) (Raman, 2013). The OCM2 showed the lowest RMSE error as 0.58 which is comparatively lower than the other satellite data. However, OCM2 algorithm has a lower log bias (4.55) than the other two algorithms, i.e., VISSR (38.4) and MODIS (46.8). The OCM2 product has lower bias and good performance than the other two products, i.e., VISSR and MODIS. The most widely used global algorithms for the estimation of Chlorophyll-*a* provide acceptable results when developed using a cohesive global data set (Maritorena *et al.*, 2002).

The global algorithms (MODIS and VIIRS) overestimate *in-situ* Chl-a concentration (mg m^{-3}), while the OCM2 algorithm is in tune with the *in-situ*. Overall the satellite sensors (MODIS and VIIRS) overestimate Chl-*a* concentration in comparison with *in-situ* data mainly due to the significant influence of sediments, CDOM and land discharges. The satellite measurements from space still have large errors in estimating global Sea Surface Chlorophyll (Marrari *et. al.,*2006; Gregg and Casey, 2004; Friedrichs, *et al.,* 2009). Blondeau-Patissier *et al.,* (2004) stated that in order to gain more accurate result in detecting Chl-*a*, effort should be focused on improving the atmospheric correction due to sediments and CDOM rather than more complicated Chl-*a* algorithms. The validation exercise in the region suggests requirement of better accuracy indicators for the OCM2 algorithm and more suitable to the regional bio-optical characteristics.

5.3.2. Sea Surface Temperature

Sea surface temperature distribution has a major impact on marine environments and SST data widely used in many environmental applications such as fish habitat modeling and fish physiology (Solanki *et al.*, 2003; Park, *et al.*, 2007). In the present study, the range of SST values observed were i.e., *in-situ* (23.9-32˚C), MODIS (24.5-31.2˚C) and VIIRS (24.5-30.8˚C) which are in similar range with the previous studies (Li *et al*., 2013; Kusuma *et al*.,2017; Pinker *et al*., 2018; Cronin *et al*., 2019; Kilpatrick *et al*., 2019). Gentemann (2014) found that the global MODIS Aqua satellite derived SST bias ± SD for an average of 25 km was -0.09 ± 0.58°C, which is around 0.1°C higher than earlier values -0.09 ± 0.58°C reported by Minnett *et al.*(2004).

The present study results for log bias and log RMSE percentage of present study are coherent with the previous reports for different algorithms: MODIS (log bias is 0.027 & log RMSE is 0.016); VIIRS (log bias is 0.025 & log RMSE is 0.016). Both satellite sensors performed well for the estimation of SST in the region with lower log RMSE and log bias. The SST product from MODIS and VIIRS showed good correlation with *in-situ* sea-truth dataset.

Using a regional algorithm, Hosoda *et al*. (2007) showed that root mean square errors (RMSEs) were 0.70 for SST. Lee *et al.* (2010) assessed cloud-free match-up data for accuracy assessment of SSTs and recorded a 0.03°C bias and 0.75°C RMSE around Taiwan coast. Ghanea *et al.* (2016) showed that biases were 0.07 ± 0.53°C and RMSE 0.44 for MODIS SST in the northern Persian Gulf.

The RMSE measures the similarity/dissimilarity between the in-situ and satellite-derived parameters, VIIRS and MODIS SST dataset in relation to in-situ sea-truth dataset shows almost same level of error (1.0-1.05). Satellite product has lower bias and good performance with in-situ data. The r^2 values for the regression equations showed significant variability in comparison with *in-situ* data, i.e., MODIS (r^2 = 0.76 and slope = 4.55) and VISSR (r^2 = 0.76 and slope =3.60). In the present study, the variability between satellite sensor and *in-situ* data sets are meliorate explicated, while the MODIS and VISSR data set explains variability of 76.0% with *in-situ*.

Owing to the high quantities of cloud penetration, aerosol, and water vapor, the quality and accuracy of MODIS derived SST alter for different areas (Kim *et al.,* 2010; Kilpatrick *et al.,* 2015). The SST derived from satellites is stated to have a higher spatial and temporal variation as in coastal regions. (Castro *et al.,* 2012). It is an area associated with the production of aerosols that are known to influence infra-red SSTs (Guan and Kawamura, 2003; Chan and Gao, 2005; Nalli and Stowe; 2002).

It has been observed that the highest quality that was recorded over the ocean waters for satellite observations, as reported by earlier studies was not achieved in this study (Karagali *et al*., 2012; Ding *et al.,* 2015; Alavipanah *et al*., 2016; Luo *et al*., 2019). It is also very well recognized that regional validation errors can surpass these numbers in the ocean surface (Chan and Gao, 2005; Høyer *et al*., 2012; Minnett *et al*., 2019; Fiedler *et al*., 2019). The explanation for this may be that the SST default algorithm was designed not for coastal water bodies but for open ocean. Coastal areas have relatively limited spatial dimensions and high volatility, as opposed to those in the open ocean (Woo and Park, 2020). The SST variability in coastal waters is slightly quicker than open oceans, and the amount of available sample points were limited, which may also have an effect on the quality evaluation.

5.3.3. Sea Surface Salinity (SSS)

In the present study, the range of sea surface salinity were i.e., *in-situ* (31.60-34.10 ˚/◦◦), and SMAP satellite-derived product (34.03-35.46 ˚/◦◦). SMAP (Soil Moisture Active Passive) and SMOS (Soil Moisture Ocean Salinity) dataset validation in the Bay of Bengal and Gulf of Mexico reported standard deviation variations recorded below 0.3 (Boutin *et al.*, 2016; Boutin *et al.*,2018; Vazquez-Cuervo *et al.*,2018). Salinity variation based on standard deviation was observed to be more common in the Bay of Bengal where SMAP is closer to in-situ (0.89-0.96) than the Arabian Sea (0.71-0.94) (Vazquez-Cuervo *et al.*,2018; Vazquez-Cuervo *et al.*, 2019). The global variation between satellite and in-situ SSS observations is about 0.2 (Menezes.,2020). Tang *et al.* (2017) reported that SMAP Sea salinity Root Mean Square Error (RMSD) was nearly 0.2 psu. It met target essential accuracy reported by Lee (2016) for global ocean observation of 0.2 psu in Aquarius SSS. Boutin *et al.* (2016) also reveals that monthly SMOS SSS values are 0.2 psu worldwide.

The results of the present study, i.e., log bias and log RMSE percentage are coherent with the previous studies (Font *et al.* 2010; Prakash and Gairola,2013; Ratheesh *et al.* 2013; Subrahmanyam *et al.,*2013; Menezes *et al*., 2014; Köhler *et al*., 2015; Fournier *et al*., 2017; Garcia-Eidell *et al*., 2017; Vazquez-Cuervo *et al.*, 2018; Vazquez-Cuervo *et al.*, 2019, Menezes.,2020) for different algorithms (log bias is

0.069 and log RMSE is 0.016). The RMSE measures between the in-situ and satellite-derived Sea Surface Salinity observed 2.04. The r^2 values for the regression equations showed significant variability in comparison with *in-situ* data, i.e., SMAP ($r^2 = 0.4$ and slope = 3.44). In the present study, the variability between satellite sensor and *in-situ* data sets are explained clearly, while the SMAP data set explains 40.0% of variability.

It becomes difficult for satellite's inherent measurement technique to retrieve salinity in the presence of potential contamination by larger footprint of radio frequency interference (RFI) linked to artificial sources like radars that emit in the frequency band of the instruments (Reul *et al*., 2012; Subrahmanyam *et al.,* 2013). Coastal areas are prone to land contamination, river generated sediment in inter-annual time scales and radio frequency interference from the unauthorized use of the protected L-band that may be intense in some coastal areas (Meissner *et al.,* 2018; Le Vine *et al.,* 2016; Dinnat *et al*., 2019; Meissner *et al.,* 2019). Zhang *et al*. (2013) on a SSS analysis of the global accuracy wide RMSE range observed near ice edges, the mouth of the Amazon River and along the coasts of East Asia, India and West Africa. Assessment of the SSS near to land is critical and challenging for quantifying the role of sediment on seasonal to inter-annual time scales. The present study could not achieve the accuracy reported by other studies as the location was near the coast.

5.4. Influence of Satellite-derived environmental data on in-situ trawl fish catch

Variations in fish abundance attributed mainly to environmental conditions. Environmental variables are crucial factors in assessing the structure and abundance of fish species in an aquatic environment (Whitfield and Elliot 2002; Mansor *et al.*, 2012). Environmental fluctuations have impact on the variations in the structure of the fish community and processes like food availability, predation and competition for space (Ramos *et al*., 2011; Gjosaeter 1988).

The Canonical Correspondence Analysis (CCA), Pearson's correlation analysis and Generalized additive models (GAMs) were used to assess the effect of satellite-derived environmental data on in-situ fish catch. Analysis showed that the environmental variables Sea Surface Chlorophyll (Mchla), Sea Surface Temperature (SST), Sea Surface Salinity (SAL), Bottom Chlorophyll (BCHL), Sea Surface Height (SSH) and Current Speed (CS) played a significant role in structuring the catch abundance. The multiplicative influence of a region's physical and chemical characteristics is known to regulate the patterns of distribution and the abundance of various components of the species diversity complex.

This research is complimented by results from Mukundan (1967), Naomi (1986), Suseelan *et al*. (1985), Pörtner (2010) and Das *et al.* (2017) indicated that the abundance of fish in a region is regulated by sea surface temperature, sea surface chlorophyll and sea surface salinity. The temporal trends and abundance of fish targeted by trawlers are largely influenced by environmental variables, extending across the continental shelf (Martinez Arroyo *et al*., 2011). Several experiments in Indian waters have been performed to understand the relationship between sea surface temperatures and trawl catches (Chidambaram and Menon, 1945; Jayaraman *et al*., 1960; Banse, 1959; Kizhakudan *et al.,* 2014). Sudarsan (1964). Azmi *et al., (*2015) associated trawl catches off the coast of Mumbai with sea surface chlorophyll-induced productivity, as most of the semi-demersal fish in nature depend on planktivorous fishes. Therefore, it could be also concluded that high catches in the present study due to high standing plankton crop during the post-monsoon.

Pannikar (1951) reported that food and environmental parameters such as sea surface temperature, salinity and chlorophyll influenced growth and increase in the rate of metabolism. The present study showed that Sea Surface Temperature, Sea Surface Chlorophyll, and Sea Surface Salinity played an important role in the availability of the main resource category, which correlates with the positive correlation of these parameters with the in-situ catch. The current speed increases the movement of slow-moving fish into the trawl net (Perry *et al.,* 2000; Wieland *et al.,* 2011; Weinberg *et al.,* 2002; Somerton and Weinberg, 2001).

Canonical correspondence analysis (CCA) is a restricted ordination method, in which linear combination of explanatory variables are restricted to the sample scores. (Van den Brink and Ter Braak, 1999). This technique is one of the most widely used for gradient analysis of environmental studies, given its ability to manage highly distorted distributions of organisms, its high noise-level, its complex sampling nature and its ability to avoid artificial arch effects (Palmer, 1993).

Diagnosis of CCA has been identified and indicated that Sea Surface Height (SSH) and Current Speed (CS) are highly influential for *H. nehereus*. Speed and direction of current is known for its role in integrating warm and cold water to form nutrient-rich fronts and eddies (Banse and McClain 1986; Madhupratap *et al.,* 1996). Fishes such as *H. nehereus* and *Coilia* spp, are weak swimmers which show a positive correlation with current speed. Bapat (1970) addressed Bombay duck's low temperature preference, which agrees with the negative association between Bombay duck and Sea Surface temperature found in the present work. Sciaenids are reported to prefer warm coastal waters (Bhat *et al.,* 2014; Kizhakudan *et al*., 2014). This explains the positive association between sciaenids and sea surface temperature. Sciaenids are also marine migrants that do not prefer low salinities (Elliott *et al*., 2007). This could be the reason for the positive correlation of sciaenids with Sea Surface salinity. The catch of cephalopod is positively correlated with Sea Surface and Sea Surface salinity which is concurrent with the reports of Solanki *et al,.* (2017), Mohamed *et al.,* (2018) and Akter (2018).

Using GAM analysis, catch data of major resources and the environmental parameters were integrated to understand the influence of satellite-derived environmental data on catch. The results showed that each fish species has different sets of preferred environmental parameters with varying weightages. The Sea Surface Chlorophyll (Mchla), Sea Surface Temperature (SST), Sea Surface Salinity (SAL), Sea Surface Height (SSH) and Current Speed (CS) have more influence on the catch of major resources with significant F values. Ocean Mixed Layer (OMXL) and Bottom Chlorophyll (BCHL) could have affected the distribution of fishes, and current speed might have influenced the total catch.

GAM analysis identified the most important environmental parameter for the abundance of major resource of in-situ catch: *H. nehereus* and *Coilia* spp. are influenced most by current speed; non-penaeid, penaeids and sciaenids by Sea Surface Temperature. The best smoothing plot showed the set of most important environmental parameters where the probability of resource abundance likelihood is maximum. Although the results of the present study with a limited sampling period may not be adequate to predict comprehensively the environmental effects on fish catch, the indications obtained from the analysis will provide guidance for future research. Taken together, these results can be utilized as a baseline information for further improvements and experiments. After further validations, the findings may be used to identify suitable fishing grounds for the targeted species.

1 INTRODUCTION

2 REVIEW OF LITERATURE

3 MATERIAL AND METHODS

4 RESULT

5 DISCUSSION

6 SUMMARY

7 REFERENCES

6. SUMMARY

Millions of people across the globe depend upon ocean or marine fisheries sector for their livelihood. Fishing pressure among others influences spatio-temporal changes in the composition of fish catch mainly due to increased direct and indirect mortality of target as well as non-target fish. Coastal trawling areas are of particularly greater concern as they are subjected to indiscriminate removal of non-target species. Environmental influence plays a major role in structuring species composition and niche overlap. Spatial and temporal analysis of relative abundance and distribution of species is helpful in visualizing and further understanding the complex changes taking place in the ocean ecosystem.

Though many studies are available on food and feeding, reproductive biology, growth and mortality aspects of marine fishes, change in their spatiotemporal distribution in relation to environmental factors has not been very clearly examined. In a situation where increasing fishing pressure due to capital intensive fishing shows declining pattern in rate of fish catch from known fishing ground, prediction based on environmental variables becomes important because of its accuracy and reliability. Environmental variables control the spatio-temporal distribution of fish population and therefore it is crucial to find out relationship between the environment and catch rate. Due to paucity of such information, investigations were carried out by adopting an integrated approach through experimental trawl fishing off Mumbai coast in synchronization with satellite pass during Sep 2017- May 2019 to fulfil the following objectives: (1) to study the pattern of catch composition and their spatio-temporal distribution (2) to assess the quality of satellite-derived environmental parameters using in-situ data and (3) to correlate satellite-derived environmental data with in-situ trawl fish catch data. Experimental fishing was carried out fortnightly between 18°57'N to 19°12'N latitude and 72°40' E to 72°43' E longitude using *M.F.V NARMADA* of ICAR-CIFE, Mumbai.

During experimental trawl fishing, 46 hauls of 1-hour duration were carried out in the depth range of 6-21 m. Three environmental parameters viz., Sea surface temperature (SST); Chlorophyll-*a* concentration (Chl-*a*); and Sea surface salinity (SSS) were used to assess the quality of satellite-derived environmental data with in-situ sea-truth information. In all, 190 sea-truth data points were collected in near synchronization with remote-sensing satellite pass and mapped. Matchup between the sea-truth and various remote-sensing parameters were compared with assorted available global algorithms to understand the correlation, variability in data, accuracy and error.

Composition of trawl catch revealed that 93 species comprised the fish community off Mumbai coast. The species recorded are categorized into finfishes (53), shrimps (13), gastropods (11), crabs (4), cephalopods (4), stomatopods (3), elasmobranch (3), lobster (1), and hermit crab (1). Quantitative analysis of trawl catch composition revealed dominance of bycatch (79.43%) over commercial catch (20.12%) with marine debris forming 0.45%. Catch consisted of mainly Sciaenids (37%), shrimps (21%) and coilia (17%). Squilla (28 %), sciaenid (13 %), shrimp (11 %) comprised majority of bycatch (low value catch, juveniles of commercially important fishes and non-edible fishes). The estimated bycatch ranged from 3.44-61.34 kg/h and commercial catch from 3.80kg/h - 57.25kg /h. Detailed analysis of major groups revealed significant increase in the contribution of non-target species to the total catch in terms of their number and biomass. This clearly indicates continuous indiscriminate harvesting of juveniles of commercially important and target species which will have long-term implications affecting the recruitment pattern. Analysis of season-wise contribution revealed that highest commercial catch was observed in pre-monsoon while post-monsoon recorded highest bycatch.

Analysis of variations in spatial distribution of non-conventional and low-value fish resources from the trawl revealed that the maximum number of species (69) was recorded in the 12-15m depth strata. Temporal distribution of trawl fish resources showed that maximum species in terms of numbers (51) were recorded in May 2018. Using the abundance data, the similarity/dissimilarity in fish assemblages between the seasons was compared employing similarity percentage (SIMPER)analysis. SIMPER analysis identified the discriminating species responsible for spatio-temporal variation based on their contribution to average dissimilarity and about 41.42% overall average dissimilarity was found between the seasons.

Observations on the satellite-derived environmental parameters revealed the range of Chl-*a* concentration as follows: *in-situ* (0.20-5.04 mgm^{-3}), MODIS (3.16-21.24 mgm^{-3}), VIIRS (2.81-13.93mgm^{-3} and OCM (0.81-2.66 mgm^{-3}). Performance of OCM2 sensor was found better or more suitable for the estimation of Chl-a in the region. With regard to the range of SST values, *in-situ* (23.9-32.0°C), MODIS (24.5-31.2°C) and VIIRS (24.5-30.8°C), performance of both satellite products was in sync with in-situ data. Range of SSS concentration was *in-situ* (31.60-34.10 ˚/◦◦), and SMAP satellite-derived product (34.03-35.46 PSU). Comparison of SMAP satellite-retrieved salinity products with in-situ data showed r^2 value of 0.4; $p<0.001$ and a root-mean-square error (RMSE) of 2.04. Inter-satellite and inter-sensor comparison showed good results, but accuracy reported by earlier studies for global scale was not achieved in the present analysis. The comparative study highlighted the need for further development of algorithm for Chlorophyll-a and Salinity measurement from satellite observations.

Catch composition and satellite-derived environmental parameters were subjected to different statistical analyses. The results of CCA, Pearson’s correlation analysis and GAM showed that the environmental variables like current speed, temperature, salinity, pH, DO, turbidity and chlorophyll-a were found to influence the catch occurrence and abundance. The seasonal migration of different species mediated by environmental variables seems to be an important factor which determines the temporal variation in catch composition. The most suitable range of environmental variables for target species were identified using GAM, based on which predictive models were developed. After further validations using more time-series data as well as datapoints, the GAMs developed through the study can be used to map the potential fishing grounds.

Even though the results from the present study of limited sampling stations and sampling period may not be adequate for comprehensive prediction of environmental influence on the fishery, It would provide guidance for future research on these lines. Findings of this study would help in understanding essential habitat conditions to achieve fishing with less effort, time and fuel consumption and in suggesting management measures like seasonal and spatial restrictions on resource utilization to conserve and maintain the sustainability of these resources. This study generated baseline data to work out an ecosystem-based fishery management framework in the region.

Recommendations

Based on the findings of the present study, following recommendations are made for the effective management of fishery resources in the region:

1. The generation of high proportion of bycatch, comprising mostly juveniles. Mitigation of this problem requires strict enforcement of fisheries laws (The Maharashtra Marine Fisheries Regulation Act, 1981) relating to bycatch reduction including the use of recommended mesh size, by-catch reduction devices and duration of harvest.
2. Study recommended the use of OCM-2 dataset for regional environmental assessment.
3. The study highlighted the need for further development of algorithm for measurement from satellite observations more suitable for the region
4. Since the spatial variations in the catches were not significant, it is possible to evolve uniform conservation strategies along the Mumbai coast.
5. After further validations the results from GAM analysis can be used to map potential fishing grounds for the targeted group of species

7 REFERENCES

7. REFERENCES

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APPENDICES

Abbreviations and Acronyms

CDOM- Colored Dissolved Organic Matter
NIR- Near Infrared
CZCS- Coastal Zone Color Scanner
SeaWiFS- Sea Viewing Wide Field-of View Sensor
MODIS- Moderate Resolution Imaging Spectroradiometer
VIIRS- Visible Infrared Imaging Radiometer Suite
SNPP- Suomi-National Polar-orbiting Partnership
OLCI- Ocean Land Color Instrument
IOCCG- International Ocean-Colour Coordinating Group
OCM- Ocean Colour Monitor
Rrs- remote sensing reflectance
SPM- Suspended Particulate Matter
SST- Sea Surface Temperature
NOAA- National Oceanic and Atmospheric Administration
AVHRRs- Advanced Very High-Resolution Radiometers
EMR- Electromagnetic Radiation
PSU- Practical Unit of Salinity
PSS- Practical Scale of Salinity
SSS- Sea Surface Salinity
ESA- European Space Agency
SMOS- Soil Moisture and Ocean Salinity
SMAP- Soil Moisture Active Passive
RMSE- Root mean square error

Data collection for operational performance

Details of fishing:

Date:

S. No.	**Particulars**	**Information**
1	Distance from the shore	
2	Depth of Experimental Fishing	
3	Latitude	
4	Longitude	
5	Shooting details	
6	Hauling details	
7	Speed of fishing vessel	
8	Speed of fishing vessel during fishing	
9	Direction of fishing ground	
10	Bycatch (in Kgs)	
11	Bycatch species composition	
12	Commercial catch (in Kgs)	
13	Commercial catch species composition	