



# **IMPACT OF CLIMATE CHANGE ON SMALL PELAGIC FISHERY RESOURCES OFF SOUTH-WEST COAST OF INDIA**

Thesis submitted in partial fulfillment  
of the requirements  
for the degree of

**Ph.D. (Aquatic Environmental Management)**

By

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***DEDICATED***  
***TO***  
***MY PARENTS***

## **DECLARATION**

I hereby declare that the thesis entitled “**IMPACT OF CLIMATE CHANGE ON SMALL PELAGIC FISHERY RESOURCES OFF SOUTH-WEST COAST OF INDIA**” is an authentic record of the work done by me and that no part thereof has been presented for the award of any degree, diploma, associateship, fellowship or any other similar title.

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## CERTIFICATE

Certified that the thesis entitled “**IMPACT OF CLIMATE CHANGE ON SMALL PELAGIC FISHERY RESOURCES OFF SOUTH-WEST COAST OF INDIA**” is a record of independent bonafide research work carried out by **Mr. Vivekanand Bharti** during the period of study from September 2013 to July 2019 under our supervision and guidance for the degree of **Doctorate of Philosophy (Aquatic Environmental 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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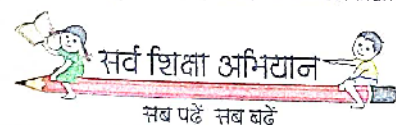
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## सारांश

समुद्री मात्स्यिकी पर जलवायु परिवर्तन के दृष्टिकोण को ध्यान में रखते हुए, भारत के दक्षिण-पश्चिमी तट पर वर्तमान अध्ययन किया गया ताकि यह पता लगाया जा सके कि जलवायु परिवर्तन का विभिन्न जलवायु-महासागरीय कारक और छोटे-छोटे वेलापवर्ती संसाधनों पर कितना प्रभाव है। भारत के दक्षिण-पश्चिमी तट का कुल 8 पर्यावरणीय मापदंडों पर मासिक आँकड़ों का एकत्रन विभिन्न स्रोतों से कर जलवायु-महासागरीय मानकों का निरीक्षण किया गया। इसके अलावा, भारत के दक्षिण-पश्चिमी तट के चयनित मछलियों जैसे तारली, भारतीय बाँगड़ा, स्टॉलीफोरस एसपीपी और थ्रिस्सा एसपीपी का कुल उत्पाद और इसके मत्स्यन प्रयास का आँकड़ा माहवार तरीका से कोच्चि के केंद्रीय समुद्री मत्स्य अनुसंधान संस्थान से एकत्र किया गया। प्रत्येक मछली के लिए भारत के पूरे दक्षिण-पश्चिमी तट के लिए प्रति यूनिट प्रयास (कैच प्रति घंटा, सीपीएच) का मानकीकृत कैच निकला गया। इसके अलावा, सभी पर्यावरणीय मानकों और सीपीएच आँकड़ों को दक्षिणी क्षेत्र (सतह\_1), मध्य क्षेत्र (सतह\_2) और उत्तरी क्षेत्र (सतह\_3) के रूप में तीन क्षेत्रों में अलग किया गया, और पूर्ववर्ती-मानसून, मानसून और मनसूनोत्तर जैसे तीन मौसमों में बाँटकर स्थानिक और कालिक रूप से निरीक्षण किया गया। इसके अलावा, सभी चयनित मछलियों के लिए संभार द्वारा इसके पकड़ की प्रवृत्ति का अध्ययन किया गया। समय श्रृंखला विश्लेषण के लिए तीन मरूपता परीक्षणों (पेटिट के परीक्षण, बुशंड विस्तार परीक्षण और मानक सामान्य समरूपता परीक्षण) और परिवर्तन विश्लेषण किया गया ताकि यह पता लगाया जा सके कि पर्यावरणीय मापदंडों और मछली के सीपीएच के समय श्रृंखला आँकड़ा में किसी प्रकार का परिवर्तन हुआ है कि नहीं। जलवायु-महासागरीय कारक और और छोटे-छोटे वेलापवर्ती संसाधनों के बीच गतिशीलता में संबंध स्थापित करने के लिए वृद्धिघात समाश्रयण और पदशः समाश्रयण का उपयोग किया गया। इस अध्ययन से पता चला है कि समुद्र का तापमान (एस एस टी) भारत के दक्षिण-पश्चिमी तट पर लगातार बढ़ रहा है। एस एस टी के कारण भारत के दक्षिण-पश्चिमी तट के समुद्री पर्णहरित, वायु और समुद्री प्रवाह, उत्प्रवाह सूचकांक, समुद्र तल विसंगति और वर्षा दर में बदलाव आया है। भारत के दक्षिण-पश्चिम तट पर पर्णहरित में स्थानांतरण 2011-13 की अवधि के दौरान हुआ है। जलवायु परिवर्तन ने तारली, भारतीय बाँगड़ा, स्टॉलीफोरस एसपीपी और थ्रिस्सा एसपीपी के क्षैतिज और ऊर्ध्वाधर विस्तार का किया है। थ्रिस्सा एसपीपी के लिए 63% सीपीएच तक की भविष्यवाणी पर्णहरित-ए एकाग्रता, दाक्षिणात्य समुद्री प्रवाह, समुद्र तल विसंगति और वर्षा दर का उपयोग करके पदशः समाश्रयण की मदद से की जा सकती है।

# Abstract

Keeping the view of climate change on marine fisheries, the present study was conducted along the south west coast of India to ascertain the extent of the impact of the change in climato-oceanographic features and biological aspect of the small pelagic resources. The monthly data on total 8 environmental parameters were collected from various open access sources to observe the climate-oceanographic features along the south west coast of India. Further, the monthly data on catch and effort data for selected fishes such as Indian oil sardine, Indian mackerel, *Stolephorus* spp. and *Thryssa* spp. along the south west coast of India were collected from Central Marine Fisheries Research Institute, Kochi. Standardized catch per unit effort (catch per hour, CPH) for the entire south west coast of India in relation to selected fish was estimated. Further, data on all environmental parameters and CPH was segregated into three regions as southern region (Stratum\_1), middle region (Stratum\_2) and northern region (Stratum\_3), and three seasons like pre-monsoon, monsoon and post-monsoon to observe the trend both spatially and seasonally. Also, the trend for gear-wise catch for all selected fishes was conducted in the present study. Time series analysis with the help of three homogeneity tests (Pettitt's test, Buishand range test and Standard normal homogeneity test) and changepoint analysis was performed to detect the change in the time series data of both environmental parameters and CPH of fish. Logistic regression and stepwise regression model were applied to establish the relationship in dynamics between climato-oceanographic features and small pelagic resources. This study revealed that the sea surface temperature (SST) is continuously rising over the south west coast of India. The rising SST led to a change in the trend of chlorophyll-a, wind and current speed, upwelling index, sea level anomaly and precipitation rate along the south west coast of India. Shifting in chlorophyll-a at the south west coast of India have been taken place during the period 2011-13. Climate change led both horizontal and vertical expansion of Indian oil sardine, Indian mackerel, *Stolephorus* spp. and *Thryssa* spp. The CPH of *Thryssa* spp. might be predicted up to 63% with the help of the stepwise regression model by using chlorophyll-a concentration, meridional current speed, sea level anomaly and precipitation rate.

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# 1.INTRODUCTION

In recent epochs, climate change has emerged as an important area of both international as well as domestic research, policy making and development planning. Climate change refers to significant and long-term changes in the global climate. It is a large-scale, long-term shift in the planet's weather patterns or average weather condition (Nwankwoala, 2015). Understanding the energy flows through the climate system is imperative for interpreting climate variability and change in the context of the observational record (Trenberth *et al.*, 2009). Changes in these flows can have profound effects on global surface temperature and perceptions of climate change. Climate change refers to the gradual change in the Earth's climate and physical geography that accompany an increase in the Earth's temperature. It is one of the greatest challenges facing life on the earth (Chan, 2018).

Climate is the most important part of nature, the basis for human survival and development, a crucial resource, and the basic condition for sustainable economic and social development (Chao and Feng, 2018). A systematic observation, recording and processing of the climatic elements such as temperature, rainfall, atmosphere, pressure, humidity, wind, sunshine and clouds are essential steps to ascertain the climatic condition of a place (IPCC, 2007b; Nwankwoala, 2015). The earth's climate has demonstrably changed on global and regional scales since the pre-industrial era, with some of these changes attributable to human activities (Seneviratne *et al.*, 2016). Also, the changes in the regional climate affect the physical and biological properties of ecosystems, which disturbs the social and economic condition of the ecosystems (IPCC, 2007b).

Earth's temperature depends on the heat balance mechanism between energy entering and leaving the planet's system. When incoming energy from the sun is absorbed by the Earth surface, Earth warms. On the other hand, if the sun's energy is reflected back into space, Earth avoids warming (Fig.1). In a broad sense, changes in Earth's energy balance are the aftermath of so many human activities and some natural occurrences. As natural level, variations in the Earth's

orbital characteristics, volcanic eruptions, variation in solar output, plate tectonics and thermohaline circulation are considered the important factors for climate change (Nwankwoala, 2015). Increasingly, the international and national studies have pointed towards damage to the climate due to anthropogenic causes including emissions of greenhouse gases, the various appearance being increased in global average earth surface temperature, increases in global average sea level, and decrease in the northern hemisphere snow cover. Greenhouse gases absorb thermal radiation emitted from the Earth's surface, thereby acting as a 'blanket' to keep the planet warm (Houghton, 2004). The main greenhouse gases are water vapour and carbon dioxide, which exist naturally in the atmosphere. However, while the natural greenhouse effect is necessary for supporting life on the Earth, the enhanced greenhouse effect (also referred to as human-induced climate change or global warming) has been identified as a potentially damaging outcome of the increased amount of carbon dioxide in the atmosphere since the industrial revolution.

The industrialization of human society from 1750, has coupled with the marked increase in human activities causes for accelerating in rising in global temperature, influences significantly the climate of the Earth and, finally significantly affecting natural ecosystems and the economic society at the global level (Chao and Feng, 2018). The continued increase in the atmospheric concentration of carbon dioxide due to anthropogenic emissions is predicted for significant changes in the global climate. About half of the current greenhouse gases emissions are being absorbed by the ocean and land ecosystems, but this absorption is sensitive to climate as well as to atmospheric carbon dioxide concentrations, creating a feedback loop (Cox *et al.*, 2000). The main reason for global warming is the emission of Green House Gases (GHG) like carbon dioxide, methane and other gases from different sources and these emitted gases are responsible for increasing the temperature of the earth's surface (Ahmad and Hossain, 2015).

Human activities are the main reasons for GHG emission, which includes the burning of fossil fuels, cutting and burning the trees in the forest.

Adverse of climate change including seasonal change affecting the ecosystem by abructing many unfavourable weather events like storms, flood and a rise in the sea level due to ice melt in the polar areas (Bebbington and Larrinaga-Gonzalez, 2008). The Intergovernmental Panel on Climate Change (IPCC) reports that recent decades have witnessed a continued increase in the emissions of carbon dioxide (IPCC, 2013). The global mean atmospheric carbon dioxide concentration increased by 40% from a pre-industrial value of 278 ppm to 390.5 ppm in 2011. There is convincing evidence that increases in global atmospheric carbon dioxide and other GHG concentration levels have resulted in rising global average surface air temperature. Water temperature and dissolved oxygen (DO) are two pivotal environmental factors for marine lives. The solubility of DO decreases with increased temperature, thus heat stress is commonly accompanied by hypoxia stress (Parthasarathy *et al.*, 1992).

According to NASA, the Earth average temperature has increased by about 1° Fahrenheit during the 20<sup>th</sup> century. However, it sounds like not a great change, but its effects on our environment have proven as the impacts of this small change in the temperature leads longer drought seasons and more aggressive hurricanes (IPCC, 2007a; Kaddo, 2016). Global warming is the slow process, where the average temperature of the earth's atmosphere is increased because a high amount of the energy (heat) striking the earth from the sun is being trapped in the atmosphere, instead of radiation out into space. Global warming may be defined as the phenomenon of increasing average surface temperatures of the Earth over the past one to two centuries. Over the past century (1906-2005), global average surface temperatures have increased by  $0.74 \pm 0.18^{\circ}\text{C}$  (IPCC, 2007a). Temperature projections for the end of the 21<sup>st</sup> century range from 1.1 to 6.4°C, compared to end of the 20<sup>th</sup> century, based on the 'Special Report on Emission Scenarios' for GHG emissions (IPCC, 2000 & 2007a). Global climate change is the best estimates of ocean warming in the top 100 m are about 0.6°C (RCP 2.6) to 2.0°C (RCP 8.5) by the end of the 21<sup>st</sup> century (IPCC, 2013). This exceptional rise in temperature is expected to have severe impacts on the global hydrological system, ecosystems, sea level, crop production and related processes. The

impacts are severe in tropical region, where mainly developing countries, including India are existing. However, global warming generally considers the anthropogenic component of climate change alone, where surface warming associated with it (Barton, 2017). Besides the changes in mean climate, the extreme climate is also of great importance to society, which is more sensitive to global warming (Knutti *et al.*, 2016).

A warmer atmosphere makes melting of glaciers and mountain snow packs, the polar ice cap, and the great ice shield of Antarctica leads raising sea levels. Changes in atmospheric temperature alter the great patterns of wind affect monsoon precipitation in Asia, making drought and frequent unpredictable weather. The consequences of climate change for ecological communities accelerated in the mid-1990's, when "climate change" was colloquially referred to as "global warming", but it is not surprising that initial ecological studies emphasized the effects of temperature. However, the phrase is misleading, as some areas are cooling or not changing at all (Barton, 2017). This is why researchers have stopped focusing just on global warming and now focus on the larger topic of climate change.

The impacts of climate change are being differed at the regional and seasonal level since regional climate affects regional environmental (PBL, 2009). In many cases, the impacts are detrimental, although some regions welcome slight changes, e.g. in cold-limited regions limited warming are useful for agriculture or access to mineral reserves. The impacts are, however, associated with large uncertainties. Climate change is driven by elevated concentrations of GHG, in particular, carbon dioxide. The changes in the global average temperature have a wide variety of effects on global, regional and local levels, such as changes (average and extremes) in temperature, sea levels, precipitation rate, drought, wind patterns, food production, ecosystem health, species distributions and phenology, and human health (IPCC, 2007b).

Marine fisheries supports to nutritional security, livelihood and income generation to a large population in India. But the sustainability of marine fisheries is under critical condition due to the growth of the human population, over-fishing,

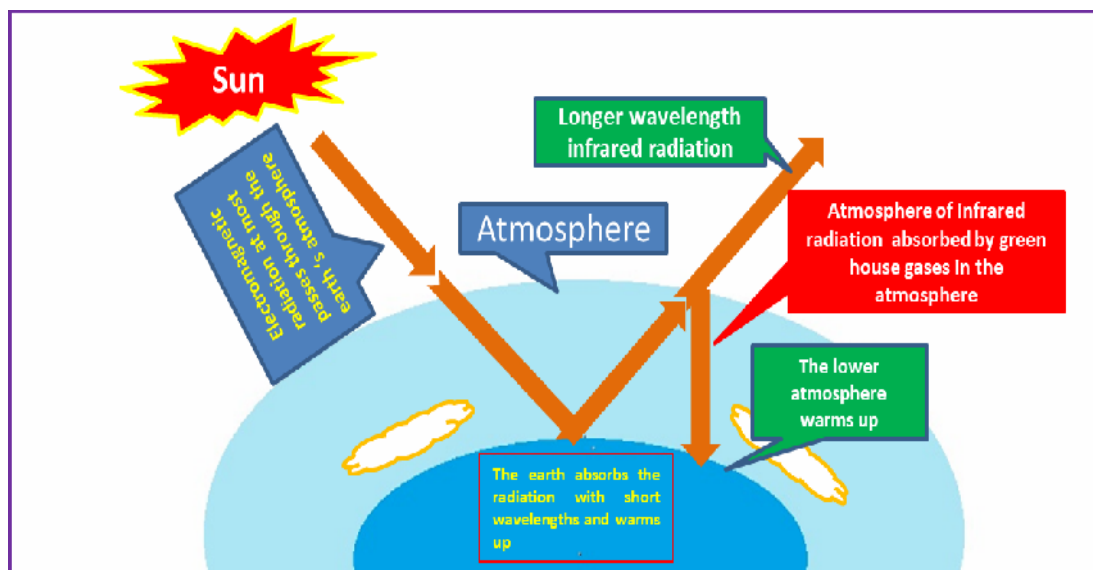
global climate change, pollution and habitat degradation (Klemas, 2013). Recently, environmental issues particularly climate change has been recognized as one of the critical issues in fisheries (Vivekanandan, 2011). The biological characteristics of the marine organism depend on climate-oceanographic features and these features vary regionally and seasonally in the ocean (Martino *et al.*, 2019). The hydrographic features represent a dynamic equilibrium between the sea and the atmospheric conditions. The conditions in the aquatic environment and their short and long-term variations exert a profound influence on the periodic and seasonal migrations, the spawning, recruitment, survival, feeding, growth, abundance and distributional pattern of marine fish (Jayaprakash, 2002).

An early or late onset of southwest monsoon or its failure affects the abundance of various fishery resources. Thus, the long period trends in climate and hydrography affect the distribution, changes in abundance and composition fishery resources as influenced by the physical, chemical and biological characteristics of the given area (Jayaprakash, 2002). Recently, species have changed the timing of their life cycles during the year and shifted their geographic distributions toward higher latitudes and elevations (Chen *et al.*, 2011). The systematic changes in plankton abundance and community structure over recent decades have been observed worldwide (Hays *et al.*, 2005). However, besides climate change, fishing pressure also influences the age, size, and geographic diversity of populations fish and the biodiversity of marine ecosystems (Brander, 2007). Since the last two decades, mackerel landing has increased along the southeast coast due to effect of changing climatic conditions (Vivekanandan, 2011).

The total marine fish landings from the mainland of India during the year 2015 were estimated at 3.40 million tonnes registering a 5.3% decline compared to 3.59 million tonnes in 2014. Indian oil sardine (*Sardinella longiceps*), the major single species fishery along the Indian coast witnessed a drastic decline in its landings. A drastic reduction (17%) in marine landing in the southwest coast comprising Kerala, Karnataka and Goa was recorded in 2015 compared to 2014 (CMFRI, 2016). Considering the parameters such as temperatures, salinity, wind,

current, water mass movement, upwelling and sunspot have the vital role in the spawning, recruitment and abundance of small pelagic (Vivekanandan and Krishnakumar, 2010). It is important to understand the mechanism of interactions between global change events and localized distribution, which is the driver of change the distribution of marine organisms, to the sustainable management of marine fisheries (Vivekanandan, 2010). So far, little is known about how species respond physiologically to climate variation in the southwest coast of India. Catches of Indian oil sardine (*Sardinella longiceps*) and Indian mackerel (*Rastrelliger kanagurta*) are not only caught at the south west coast in last two decades but also their recognizable catches come from the northwest coast and east coast of India due to the effect of climate change (Vivekanandan, 2010). Therefore, this study has been proposed with the following objectives:

- To ascertain the extent of the impact of the change in climato-oceanographic features between epochs
- To study the impact of climate change on the biological aspect of the small pelagic resources
- To establish the relation in dynamics between climato-oceanographic features and small pelagic resources



**Fig.1.** Heat balance in the Earth surface

## 2. REVIEW OF LITERATURE

### 2.1. Marine ecosystem

Marine communities are biological networks, where a large number of species is linked directly or indirectly through various biological interactions such as predator-prey relationships, competition and mutualism. The aggregate effect of these interactions constitutes a functional ecosystem by nutrient cycling, primary and secondary productivity, and this ecosystem provides the natural benefits to society depends upon, such as fisheries and aquaculture production (Doney *et al.*, 2012). Marine biodiversity, ecosystem health and fisheries are currently threatened not only by overfishing but also by pollution and other anthropogenic impacts (Pitcher and Cheung, 2013).

Climate impacts on the ocean biota have widespread economic implications since the biota of the oceans has huge socio-economic value, estimated at US\$21 trillion  $y^{-1}$  globally, through food production, recreation, nutrient recycling and gas regulation (Costanza *et al.*, 1997). Climate change and ocean warming resulting from GHG emissions are directly altering species distributions and disrupting ecosystem functions (Loarie *et al.*, 2009; Genner *et al.*, 2010; Cheung *et al.*, 2013). Marine fishes and invertebrates change their distribution range (Perry *et al.*, 2005; Dulvy *et al.*, 2008) and phenology (Genner *et al.*, 2010) to cope with changing temperature.

### 2.2. Global warming and climate change

Climate change denotes longer-term shifts in the mean values of temperature, wind fields, hydrological cycles and biogeochemical cycles (Brander, 2010; Wang *et al.*, 2014). The CO<sub>2</sub> concentration fluctuated from a pre-industrial level of 280 ppm to 370 ppm in the year 2000 (Fortunato, 2015). Predictions indicate a further rise up to 560 ppm (*i.e.* the double the pre-industrial level) by 2070 (Caldwell *et al.*, 2015). Heat-trapping GHG (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, tropospheric ozone, and chlorofluorocarbons) warm the planet's surface globally (Doney *et al.*, 2012). The best

estimates of projected global mean surface temperature increase over the twenty-first-century range from approximately 1.8°C to 4.0°C, depending on the emission scenario (IPCC, 2007a). The average temperature on Earth has risen by 0.7°C since the beginning of industrial revolution (from the second half of the 18<sup>th</sup> century), and “a large proportion of the warming observed in the last 50 years, attributable to human activities” (IPCC, 2013). Sathaye *et al.* (2006) observed a rapid rise in global greenhouse gas sharing of India by booming developmental and industrialization activities after 1990 onwards.

Upper-ocean heat content has been growing substantially since the 1950s decade, in the tune with mean global sea surface temperature (SST) is increasing (Levitus *et al.*, 2009). The world oceans act as CO<sub>2</sub> sink and absorbed over 48% of anthropogenically derived CO<sub>2</sub>, thus reduces the pace of global warming with serious consequences for ocean chemistry (Le Quéré *et al.*, 2009). Surface ocean pH has already decreased by 0.1 units since 1800, and current estimates predict an additional drop of 0.2-0.4 pH units by the year 2100 (Doney *et al.*, 2009; Feely *et al.*, 2009). Under the conditions of global warming, climatic changes in different parts of the world reveal different characters, and the nature of regional climate changes is determined by the features of physical-geographical and landscape-climatic conditions (Elizbarashvili *et al.*, 2017). Climbing temperatures create additional changes, such as rising sea level, increased ocean stratification, decreased sea-ice extent, and altered patterns of ocean circulation, precipitation and freshwater input (Hoegh-Guldberg and Bruno, 2010). Both warmings as well as altered ocean circulation reduce subsurface oxygen (O<sub>2</sub>) concentrations (Keeling *et al.*, 2010).

Warming is not spatially uniform due to ocean circulation, spatial changes in winds pattern and interaction with natural modes of climate variability such as El Niño Southern Oscillation (ENSO) (Ishii *et al.*, 2005). Climate warming affects regional wind patterns and thus ocean circulation in multiple dimensions (Roemmich *et al.*, 2007). The change in oceanographic phenomena especially the impact of sea level rise is considered as the indication of climate change has gained momentum in

recent years (Mimura, 2013). Besides its global effects, climate change is manifested in many regionally pronounced features, resulting from changes in the atmospheric and oceanic circulation (Hand *et al.*, 2018). Important climate variables linked to ocean circulation and productivity are sea-level pressure, surface winds, SST, surface air temperature, and cloudiness and also these physical factors have been combined into a Multivariate ENSO Index (MEI) for evaluating the strength of El Niño Southern Oscillation cycles (Behrenfeld *et al.*, 2006). Strong El Niño/Southern Oscillation events have major impacts on phytoplankton, fisheries, marine birds and mammals (Behrenfeld *et al.*, 2006).

Phenology (the study of the annually recurring life cycle) of a living being can provide a sensitive indicator of climate change. The marine pelagic community responds to climate changes, where the level of response differs throughout the community and the seasonal cycle, leading to a mismatch between trophic levels and functional groups (Edwards and Richardson, 2004). The impacts of GHG induced climate change in the marine ecosystem included decrease in ocean productivity, alteration in food web dynamics, reduction in abundance of species and diversity, shifting species distributions and a greater incidence of disease are observed worldwide (Hoegh-Guldberg and Bruno, 2010; Poloczanska *et al.*, 2013; Wabnitz *et al.*, 2018).

In the open ocean, rising atmospheric CO<sub>2</sub> and the resulting increased oceanic CO<sub>2</sub> uptake are the predominant driving factors for ocean acidification. Also, in the marine environment, nutritional status, thermal tolerance, oxygen availability, environmental chemistry, food availability, or other factors may limit growth and production, or other biological processes, regardless of metabolic rate (Doney *et al.*, 2012), which leads to alter the patterns of species richness, changes in community structure and ecosystem functions, and consequential changes in marine goods and services (Wabnitz *et al.*, 2018). Climate change has been linked to parallel changes in pelagic fish populations and production (Zhang *et al.*, 2000; Gattuso *et al.*, 2015). The phytoplankton biomass changes along the Kerala coast under the changing strength

of physical parameters such as sea surface temperature, alongshore wind stress, Ekman mass transport, sea level anomaly and rainfall (Menon *et al.*, 2019).

## **2.3. Climate-oceanic parameters**

Effects of climate change on the ocean include increasing ocean temperatures, ocean acidification, changing patterns of ocean currents and productivity, sea level rise, and decreasing dissolved oxygen have been observed (IPCC, 2013).

### **2.3.1. Sea surface temperature**

Though the mean global sea surface temperature has increased of 0.67°C over the past century, it is predicted to increase between 1.0 and 3.3°C over the next century (Pachauri *et al.*, 2014). Sea surface environmental conditions are used for the study of pelagic fish distribution (Wabnitz *et al.*, 2018; Menon *et al.*, 2019). Sea surface temperature is one of the oceanographic characteristics with the strongest link to biotic impacts of climate change, as temperature influences the physiologies, phenologies, and distributions of species (Hansen *et al.*, 2006; Cheung *et al.*, 2010). Rising atmospheric CO<sub>2</sub> is one of the most critical problems because its effects are globally pervasive and irreversible in ecological transformation due to increasing ocean temperatures (Hoegh-Guldberg and Bruno, 2010). Lima and Wethey (2012) analyzed changes in SST worldwide at a scale of 0.25°C over the last three decades (1982 - 2010) and rates of change have been highly heterogeneous in both spatial and seasonal.

The changes in physico-chemical properties of the ocean alter the physiological functioning, behaviour, and demographic traits (e.g., productivity) of organisms, leading to shifts in the size structure, spatial range, and seasonal abundance of populations (Hoegh-Guldberg and Bruno, 2010). Over the next 50 years, the temperature in the Indian seas is expected to rise by 1 to 3°C and also it is predicted that ocean will acidify, become more saline, the sea level will rise, and currents pattern will change (Vivekanandan, 2010). The Arabian Sea is experiencing

a regional climate-shift after 1995, resulted in five-fold increase in the occurrence of intense cyclones, progressively warmer winters and decreased decadal monsoon rainfall (Prasanna Kumar *et al.*, 2009). Warming signal in terms of rise in sea surface temperature (0.1°C/decade) as well as rise in surface air temperature (0.05°C/decade) are observed over Arabian Sea and central India, respectively (Shah and Srivastava, 2019).

### **2.3.2. Productivity**

Plankton is considered as an indicator of climate change in the marine environment for three reasons. First, unlike other marine species, such as fish and many intertidal organisms, few species of plankton are commercially exploited, and hence, any long-term changes can be attributed to climate change. Second, most species are short-lived and so population size is less influenced by the persistence of individuals from previous years. Third, plankton shows dramatic changes in its distribution due to free-floating behavior, and also responds easily to changes in temperature and oceanic current systems by expanding and contracting its distributional ranges (Hays *et al.*, 2005). Chlorophyll-a concentration has a close direct relationship with primary production (Gopinathan *et al.*, 1994). Sometimes rising in SST enhances the proliferation of phytoplankton via increasing metabolic rates of phytoplankton (Lewandowska *et. al.*, 2014).

The Humboldt Current is hugely impacted by the El Niño Southern Oscillation (ENSO), with phases of warm water leading to reduced plankton production due to restricted nutrient upwelling (Alheit and Niquen, 2004). Climate change influencing phytoplankton growth and bottom-up processes (*i.e.* the role of members of one trophic level as food items for higher trophic levels) throughout the pelagic food chain (Richardson and Schoeman, 2004). Physiological performance is the determinant factor of a specie tolerance to environmental variability and change. As climate or other conditions shift, organisms initially respond based on physiological and behavioral adaptations molded through their evolutionary history (Somero, 2012).

Many species of the genus *Ceratium*, important primary producers in tropical and temperate waters, have expanded their distributional range (Hays *et al.*, 2005).

Growth-limiting factors for phytoplankton are regulated by physical processes of ocean circulation, mixed-layer dynamics, upwelling, atmospheric dust deposition and the solar cycle (Behrenfeld *et al.*, 2006). Chlorophyll concentration at upper-ocean is be used to estimate phytoplankton standing stocks and productivity throughout the photic zone (Behrenfeld *et al.*, 2006). Behrenfeld *et al.* (2006) have reported a strong correspondence between MEI variability and chlorophyll, where an increase in the MEI (warmer conditions) results in a decrease in Chlorophyll, and vice versa. The variation in chlorophyll-a concentration caused by environmental fluctuations has impact the India oil sardine catch along south west coast of India (Menon *et al.*, 2019).

### **2.3.3. El Niño Southern Oscillation (ENSO)**

The El Niño Southern Oscillation (ENSO) is now recognized as a climatic event of global significance and this periodic variation in oceanic and climatic conditions influences the abundance and distribution of pelagic marine fishes (Bakun and Broad, 2003). The strongest El Niño of the 20<sup>th</sup> century occurred in 1997 - 98 due to significant positive correlation between the ENSO events and sea surface temperature (Yu and Lau, 2005). The Indian Ocean response to ENSO is well known to surface warming/cooling with a lag of about a season, whereas the subsurface response appears to be simultaneous, forced by ENSO-related wind anomalies (Yu and Lau, 2005). The intense El Niño is associated with high sea surface temperature, resulting in weaken of coastal upwelling along the coastal region (Krishnakumar and Bhat, 2008).

The sudden fluctuations in SST, sea-level pressure and scalar wind associated with these extreme climate transitions resulted in a regime shift in the Malabar upwelling system during 1997-98 (Krishnakumar *et al.*, 2006). Scombroid fishes like mackerel are very sensitive to temperature, as they maintain higher body temperature than the ambient temperature (Yohannan and Abdulrahiman, 1998).

Hence, the extreme oceanographic events as El Niño of 1997-98 adversely affected the spawning and recruitment of most of the mackerel, resulted in the failure of pelagic fishery along the southwest coast of India (Krishnakumar and Bhat, 2008). During 1990's decade, sardine catch had downward sliding trend in the effect of intense El Niño (Srinath *et al.*, 2003).

The Southern Oscillation is considered as the single most prominent signal in year-to-year climate variability in the marine ecosystem, which is associated with fluctuations in atmospheric pressure at sea level in the tropics, monsoon rainfall, and winter time circulation over North America and other parts of the extratropics (Rasmusson and Wallace, 1983). The influence El Niño /La Niña on local weather also very high, it significantly modifies the local weather/monsoon system. During this period Indian landmass has to experience droughts/floods. ENSO manifests in the anomalies of the zonal distribution of convection which are triggered by El Niño, La Niña and SST anomalies in the central and eastern Pacific. However, the SST anomalies typically peak during a particular season, but prolonged events may last for months or years (Yan *et al.*, 2018). A positive DMI ends up with severe droughts over eastern Indian Ocean (Clark *et al.*, 2003). The positive DMI cause delay in summer monsoon over Kerala region (Bala and Singh, 2008). The DMI index implied abrupt changes in its dynamics in the year 2000 (Piontkovski and Al-Jufaili, 2013).

#### **2.3.4. Precipitation rate**

Precipitation pattern varies from year to year and over decades, where changes in its amount, intensity, frequency and type (e.g. snow vs. rain) affect the coastal environment (Trenberth, 2011). The precipitable water and SST over the oceans in both the overall patterns and their variations over time have been observed by Trenberth *et al.* (2005). The largest decrease in precipitation trend is characteristic for the Greater Caucasus and amounts to 9 mm per year, and with the rate of 6 mm per year rainfall increased in the coastal zone, in the Colchis Lowlands and Adjara mountains (Elizbarashvili *et al.*, 2017). In the 20<sup>th</sup> century, droughts and floods are more common compared to the previous period (Karl *et al.*, 1995).

Along Kerala coast, the seasonal variation in precipitation has been observed due to the impact of climate change, where to increasing probability of water scarcity in the pre-monsoon time and a delaying monsoon onset (Pal and Al-Tabbaa, 2009). During pre-monsoon, a significantly decreasing trend in rainfall affects the nutrient in flow from land to coastal water (Bera, 2017). Arabian Sea shows coherent variation with precipitation extremes with rising sea surface temperature over India, where significant changes in it are sensed from cold to warm years, with increases in heavy precipitation and decreases in light and/or moderate precipitation (Mishra *et al.*, 2018).

There is a seasonal shift in the precipitation rate over Indian atmosphere as the precipitation rate has been decreased in the summer monsoon, but it shows an increasing trend in the precipitation rate during pre-monsoon and post-monsoon season (Dash *et al.*, 2007). Shah and Srivastava (2019) has found an increasing (0.5  $\mu\text{m}/\text{decade}$ ) trend in the precipitation rate over Arabian Sea, whereas it decreases (0.1  $\mu\text{m}/\text{decade}$ ) over central India due to climate change. Palghat gap in Western Ghat range is responsible for heavy rain fall at the immediate northern southwest coast of 10° N (Dahanukar *et al.*, 2004).

### **2.3.5. Sea surface wind speed**

Sea surface wind speed is observed from satellite sensors, starting with a US Defense Meteorological Satellite Program satellite F08 in July 1987, which is marked the beginning of the modern period of remote sensing over the global oceans. Winds at the ocean surface are a key element in the Earth system and critically important to oceanographic and atmospheric applications because ocean surface winds are crucial to determining fluxes of momentum, energy, and mass between the atmosphere and ocean (Atlas *et al.*, 2011). Time-resolved ocean surface wind datasets are needed to better understand, assess, and predict ocean circulation and wave generation, as well as to document any changes that occur because of long-term fluctuations in El Niño-Southern Oscillation (ENSO) as the climate changes (Atlas *et al.*, 2011).

Two atmospheric wind conditions *i. e.* alongshore wind stress and wind-stress curl induce different types of upwelling in the coastal ecosystems, resulting in rapid and slow upwelling (Rykaczewski and Checkley, 2008). A decreasing trend in both zonal and meridional wind speed during monsoon period at arabian along the coast of India was found by Rashmi *et al.* (2016). A reduction in speed of zonal wind with respect to greenhouse gas-induced SST warming has been investigated by Palipane *et al.* (2017). The changes in the surface wind affect the sea surface currents, which cause the occurrence of coastal upwelling (Haryanto, 2018). The warming is negatively correlated with wind speed change over the tropics (Xie, 2004; Xie *et al.*, 2010). The SST-induced modification of the surface wind stress depends on the orientation of the wind stress relative to perturbations of the SST gradient vector (Chelton *et al.*, 2001). The Study on the interannual scale fluctuations of SLA showed a diminishing SLA from 1993 to 2000, and a switch in tendency later on, with a subsequent rising trend from 2000 to 2008 (Piontkovski and Al-Jufaili, 2013).

### **2.3.6. Upwelling**

Winds supply surface waters with the nutrients required for biological production, “coastal upwelling” and the importance of coastal upwelling to major fisheries production has long been recognized, therefore it is used to investigate the relationship between climate and fish catch in the coastal water (Ryther, 1969). The coastal upwelling is induced by winds force water away from the coastal boundary, a process known as Ekman transport, where nutrient-rich waters are drawn up into the euphotic zone to replace the surface waters (Rykaczewski and Checkley, 2008). Coastal upwelling is defined by the characteristic wind patterns that push surface waters offshore and thus pump (*i.e.*, ‘upwell’) nutrient-rich deeper waters into the illuminated surface layers, where they are available to support photosynthesis.

Coastal upwelling ecosystems generally represents the most productive large marine ecosystems of the world’s oceans, in terms of both primary production rates and massive populations of small pelagic fishes such as sardines and anchovies (Bakun *et al.*, 2010). Global greenhouse warning intensifies the alongshore wind stress on the ocean surface, which accelerates coastal upwelling (Bacun, 1990).

But, Varela *et al.* (2016) found that that a decrease in upwelling index along the South Coast of Java due to even small coastal warming over the last three decades (1982 - 2015).

In the Indian Ocean, phytoplankton distribution is influenced by the seasonally reversing monsoon winds, which are southwesterly with strong during the summer monsoon and northeasterly with weak during the winter monsoon (George *et al.*, 2013). Smitha *et al.* (2008) found the strong northerly winds, which are responsible for highest upwelling during monsoon season along the south west coast of India. Coastal upwelling index is presumably governed by the direction of the upwelling-favorable winds and the local configuration of the coast (Dabuleviciene *et al.*, 2018). The dynamic medium of the ocean produces sea surface height anomaly, hence sea surface height can be used as a proxy for detection of many of the phenomena such as upwelling or eddy (Lumban-Gaol *et al.*, 2015). Low sea surface height (SSH) along the coastal ecosystem is indicative of the occurrence of upwelling (Xu *et al.*, 1982; Ho *et al.*, 2000).

Smitha *et al.* (2008) found three different patterns of upwelling along south west coast of India *viz.* moderate upwelling occurs between 9° N to 13° N due to the combined action of the alongshore wind stress, the coastally trapped Kelvin waves, and the offshore propagating Rossby waves. The northern part of the south west coast of India between 13° N to 15° N, upwelling is weak due to weak wind stress and also closely confined to the coastal belt.

### **2.3.7. Ocean Currents**

Wind change leads to variations of the oceanic circulation with some regions experiencing a complete reversal of the circulation (Kämpf and Kavi, 2018). Currents are part of the major wind-driven circulations of the oceans, and they play an important role in the global thermohaline circulation. In addition, currents mediate the fluxes of biogeochemical properties and planktonic organism in the oceanic biomes, in so doing, the intensity, duration and timing of Indian Ocean currents influence the nutrient inputs and productivity responses, resulting, these currents have impacts on

both lower (e.g., copepods, decapods) and higher (e.g., fishes) trophic level recruitment, production and behavior (Hood *et al.*, 2017). Changes in the meridional ocean current are most pronounced via changes in sea surface temperature (Stouffer *et al.*, 2006).

During the northeast monsoon, there is a north equatorial current, while during the south west monsoon the circulation in the northern Indian Ocean largely reverses and the westward north equatorial current is replaced by an eastward south west monsoon current, flowing with the equatorial counter-current (Vivekanandan *et al.*, 2003). Seasonal changes in winds and currents induce an annual cycle of hydrographic events along the south west coast of India. During the monsoon, the southerly current spreads over the entire continental shelf force to upwell the water along the south west coast, resulting in dense and cool water with low dissolved oxygen occupy the surface near the coast (Vivekanandan *et al.*, 2003). Dispersal of fish eggs and larvae that cannot yet swim of pelagic fishes is supported by ocean currents (Ramesh *et al.*, 2019).

### **2.3.8. Sea surface height**

The rise in sea level shows changes in patterns in ocean circulation (Wilson, 2001; Li and Clarke, 2007). Local sea surface height (SSH) maxima indicate convergent flow (downwelling) and minima indicate divergence (upwelling), and upwelling area are known as a nutrient-rich region (Grantham *et al.*, 2004; Ban *et al.*, 2016). Climate change also associated with complex and variable effects on upwelling and downwelling patterns (Doney *et al.*, 2012; Ban *et al.*, 2016). Schneider *et al.* (2005) have suggested that random eddies and winds were the primary forcings for California Current System salinity variations. Broad-scale temperature fluctuations in the California Current System (CCS) act strongly in controlling upwelling in the northern CCS and salinity variations in the CCS and controlled upwelling in the southern part of the CCS (Miller *et al.*, 2015).

Long-term sea level trends are induced by steric contributions global warming (Suzuki and Ishii, 2011). The wind anomalies also have strongly impact on

sea level anomaly (Rao *et al.*, 2002). Long time scales both wind stress and salinity variability, in addition to ocean heat content variability, are important in causing sea level anomaly variability at many locations across the global oceans (Fasullo and Gent, 2017). Over the equatorial Indian Ocean, SLA is consistent with ocean wave response to easterly wind change, with an upwelling Kelvin wave wedge in the east and downwelling Rossby waves with an off-equatorial peak on either side of the equator (Xie *et al.*, 2010). Intensification of upwelling from 8° N to 16° N along the south-west coast of India during July and August is observed with more dominant along the southern latitudes (Shah *et al.*, 2019).

## **2.4. Climate change and marine fisheries**

Marine organisms have been repeatedly exposed to considerable environmental changes, including dramatic changes in ocean chemistry (Martin, 1995; Zeebe, 2012). Long-term natural variability in climate, oceanography and marine ecosystems leads to fluctuations on the periodic and seasonal migration of marine fishes (Francis and Hare, 1994; Lehodey *et al.*, 2006; Brander, 2007; Krishnakumar and Bhat, 2008; Hare *et al.*, 2010; Doney *et al.*, 2012; menon *et al.*, 2019). The variation on pelagic fish catch to environmental parameters such as SST, salinity, rainfall, upwelling, chlorophyll distribution are well studied in Indian coast (Banse, 1959; Johannessen *et al.*, 1981; Longhurst and Wooster, 1990; Madhuprathap *et al.*, 1994; Yohannan and Abdulrahiman, 1998; Jayaprakash, 2002; Mukhopadhyay *et al.*, 2019).

In the absence of adaptation or acclimatize ability in pace to changing climatic conditions in Indian oil sardine lead to a reduction in its distribution and abundance along the Kerala coast (Sajna *et al.*, 2019). An increase in temperature results in a decrease in the length and age at first maturation, thus affecting the growth of adults as surplus energy is channeled into reproduction at an earlier age and smaller size (Pörtner and Peck, 2010). Anchovy show changes associated with environmental variability, indicators such as abundance,

trophodynamics are also affected by predators, competitors, and parasites (Yáñez *et al.*, 2017).

Ocean warming initially prompts physiological or behavioural responses of fishes (Caldwell *et al.*, 2015), which are likely to be species-specific (Sunday *et al.*, 2015). Warming waters increase metabolic activity and locomotory performance in the ectothermic marine organisms (Ober *et al.*, 2016). Physiological responses to climate change are species-specific, changes in the timing of life-history events (phenology) induced by climate change often differ between interacting species at different trophic levels, leading to mismatches in trophic synchrony and effects on prey-predator relationships (Sims *et al.*, 2004; Brander, 2010). The change in climato-oceanographic features negatively effects on physiological (growth, reproduction, respiration, larval development and tissue damage) and ecological (larval settlement, competition and predation) aspects of aquatic organisms and their populations (Riebesell *et al.*, 2000; Gazeau *et al.*, 2007; Kuffner *et al.*, 2008; de Moel *et al.*, 2009; Widdicombe *et al.*, 2010, Sajna *et al.*, 2019). Eggs are one of the most thermally sensitive life stages in fishes, and small increases in temperature dramatically increases egg mortality, especially in tropical species (Pankhurst and Munday, 2011).

If the appearance of new conditions due to climate change are physiologically tolerable, allowing acclimatization (an adjustment of physiology within individuals) or adaptation (increased abundance and reproduction of tolerant genotypes over generations), or else intolerable environment promotes migration (by individuals or populations), change in phenology, or death and local extinction (Parmesan, 2006; Pörtner and Farrell, 2008). Global climate change is the driving force for rapid distributional and seasonal shifts in the marine ecosystem (Parmesan, 2006; Chen *et al.*, 2011), which are well established for the marine animal at lower trophic levels, where many species currently shifting their range poleward (Parmesan and Yohe, 2003; Jump *et al.*, 2009; Sumaila *et al.*, 2011).

However, the influence of human activities such as commercial fishing also observes on life-history traits of commercially harvested fish, but it has been determined to be as low as 0.1 - 0.6% per year on life-history parameters such as

size at maturation, consumption, and gonad investment (Andersen and Brander, 2009). Global warming leads to a widespread reduction in the maximal size of natural fish (van Rijn *et al.*, 2017). Raybaud *et al.* (2017) has observed the substantial poleward shifts in *Stolephorus* occurrence of the warming scenario, resulting in an increase in the catch in more northern areas.

In the northeast Atlantic, rising SST is thought to be the major control behind northwards distribution shift at a variety of trophic levels, from phytoplankton (Reid *et al.*, 1998; Beaugrand and Reid, 2003; Richardson and Schoeman, 2004) through to zooplankton (Beaugrand *et al.*, 2002; Beaugrand and Reid, 2003) and fish (Genner *et al.*, 2004; Beare *et al.*, 2004; Perry *et al.*, 2005). The growth and reproduction of marine fishes decrease with increasing of ocean temperatures, ultimately reducing their abundance (Pörtner and Knust, 2007). On the other hand, some fishes colonize and flourish in areas previously unsuitable for their survival due to shifting their distribution toward higher-latitudes (Perry *et al.*, 2005), which is expected to affect the availability of exploited populations (Cheung *et al.*, 2013). Liang *et al.* (2018) suggest that ocean warming is already having an impact on China's marine fisheries, where required to curtail GHG emissions are urgently needed to minimize the increase of these impacts on fisheries.

A number of anthropogenic perturbations have been suggested as potential causes of abnormal jellyfish mass occurrence, including global warming, eutrophication, overfishing and the increase of artificial hard substrates (Purcell *et al.*, 2007; Richardson *et al.*, 2009; Purcell, 2012). The enhance jellyfish populations and blooms have the likelihood of negative jellyfish impacts on human activities (Purcell *et al.*, 2007). Jellyfish populations also compete with fish for resource utilization and prey upon fish eggs and juveniles, which lead to reduced fish stocks (Purcell and Arai, 2001). Chlorophyll is both a direct and indirect measure of biological productivity, although its biological mechanisms are influenced by climate change (Henson *et al.*, 2009). The sardine and anchovy fluctuations are associated with large-scale changes in ocean temperatures (Chavez *et al.*, 2003).

## 2.5. Influences of climate change on Indian marine fisheries

The SST has increased by 0.2°C along the northwest, southwest and northeast coasts, and by 0.3°C along the southeast coast of India during 45 years' period from 1961 to 2005 (Vivekanandan, 2010). Since last two decades, Indian oil sardine and Indian mackerel are not only caught by the southwest coast of India but also their recognizable catches come from the northwest coast and east coast of India due to the effect of climate change (Vivekanandan, 2010; Rao, 2011). Being poikilothermic, most fish species have a fairly narrow range of optimum temperatures, *i.e.* even a difference of 1°C in SST or 0.1 unit pH in seawater affects their distribution and life processes. Therefore, to nullify change in optimum physico-chemical properties of water, Indian marine fishes are showing the extension of the distributional boundary, shift in latitudinal distribution, shifting in depth of occurrence and phenological changes (Rao, 2011). Rao (2011) also found that the catches from the Malabar upwelling zone have not decreased indicating the distributional "extension" and not distributional "shift".

In the case of catfishes, the region between 8° N - 14° N latitude was considered as the major zone during 1970 - 2007, but at the present scenario, distributional shift in catfish resulted to increase the catches from the northwest and northeast coasts (latitude 15° N - 22° N), which showed the positive correlation with SST. The Indian mackerel, in addition to the extension of its northern boundary, is also found to descend to deeper waters in the last two decades (Rao, 2011). Due to climate changes leads the extension of Indian oil sardine fishery even along the Saurashtra coast from October to March (Fotedar and Savaria, 1988; Gopal and Savaria, 1991).

The early stages of larval history are considered to be the critical stages with respect to mortality rate, since larval survival rate is mediated through environmental changes (Antony Raja, 1973). A study of marine fish landing trends during the period 1980-84 and 1990-95 had revealed the remarkable changes in resource composition in catch, because during in the 1980's small pelagic fishes such

as Indian oil sardine, Indian mackerel and anchovies made up 50% in total marine catch, but in the 1990's their sharing in catch drastically reduced due to dynamics in oceanic features such as sunspot activity, rainfall, ENSO effects, sea level pressure, upwelling and currents (Nair, 1953; Murty and Edelman, 1970; Antony Raja, 1973; Madhupratap *et al.*, 1994; Srinath, 1998; Ganga, 2000). A positive correlation between plankton and the abundance of pelagic fisheries composed of clupeids and the mackerel is demonstrated by Panikkar (1949). Manjusha *et al.* (2013) have been reported that the climatic and oceanographic factors play an important role in the catch marine fish in off Kerala coast.

The distribution of the Indian oil sardine has responded markedly to increase in sea temperature because able to establish itself in the new territories and support to the fisheries along the northwest and northeast coasts of India. Indian mackerel shows a shift in the depth of distribution and are now caught by bottom trawlers. Threadfin bream (*Nemipterus japonicus*) shows shifting in the month of peak spawning toward colder months. Copepod abundance is shifting toward colder months off Mangalore. These findings indicate that the adaptable species able to adjust to the immediate challenge of the rise in temperature for a shorter or longer duration (Vivekanandan, 2006).

Indian oil sardine fishery along Kerala coast has shown a phenomenal increase in landings after the year 2000 and has reached a record high during 2012, due to major changes observed in different oceanographic parameters caused by the global warming process resulting in comparatively higher sea water temperature and subsequent increase in primary productivity leading to the availability of preferred food for Indian oil sardine (Kripa *et al.*, 2015). Therefore, the problems of immediate concern regarding the small pelagic fishery over climate variations can be easily understood by studies through analysis of the distributional and spawning behaviour patterns of the fish in relation to the environment. Under both climate change of Representative Concentration Pathway (RCP) scenarios 4.5 and 6.0, both catch and catch per unit effort decrease even with increasing of fishing effort along Kerala Coast (Sajna *et al.*, 2019).

## 6. South west coast of India

The south west coast of India (Malabar Coast) is one of the important upwelling systems of the world (Bakun *et al.*, 1998; Krishnakumar and Bhat, 2008), which supports Indian marine fisheries at that region (Rajagopalan *et al.*, 1992). The south west coast of India having only 16% of the Indian coastline, contributing 32.2% of total Indian marine fish landings during 2017 (CMFRI, 2018). This region extends from about 8° N to 16° N with a total coastline of 994 km, comprising three maritime states namely, Kerala, Karnataka and Goa (Vivekanandan *et al.*, 2003), where pelagic fishes were the most abundant and accounted about 8 lakh tonnes in 2017 (CMFRI, 2018). The total continental shelf area off the south west coast is 75400 km<sup>2</sup>, and 31% of the area is situated within less than 50 m depth (Vivekanandan *et al.*, 2003). In this region, about 2.79 lakh fisher populations are directly or indirectly involved in the marine fisheries sector (Kuriakose *et al.*, 2012). Upwelling is appeared from 8° N to 15° N along south west of India during the onset of the south west monsoon, by the large scale, wind-driven, clockwise circulation, causing a south-flowing current along the west coast of India (Banse, 1959; Ramamirtham and Rao, 1973; Johannessen *et al.*, 1981).

The strong coastal upwelling along the southwest coast of India occurs during July-September with a peak in August (Ramamirtham and Patil, 1964; Krishnakumar and Bhat, 2008). Upwelling along the southwest coast of India during July-September is mainly caused by strong southerly current, which is supported by local wind (Krishnakumar and Bhat, 2008). The onset of south west monsoon generates the Somali current resulting in a general clockwise circulation in the Arabian Sea, which in turn develops into a relatively strong southerly current at the surface levels along the west coast of India (Johannessen *et al.*, 1981).

Coinciding with upwelling, chlorophyll-a concentration increases during August-October from the inshore south west coast of India (Banse, 1959; Ramamirtham and Rao, 1973; Johannessen *et al.*, 1981; Smith and Madhupratap, 2005; Marra and Barber, 2005; Krishnakumar and Bhat, 2008). Relatively higher

zooplankton biomass is observed in during October immediately after the upwelling period (Smith and Madhupratap, 2005; Krishnakumar and Bhat, 2008). The SST in the south west coast of India has been reported as low (21-27°C) and high (29 -31°C) during monsoon and pre-monsoon period, respectively (Devaraj *et al.*, 1997; Vivekanandan *et al.*, 2003).

## **2.7. Small pelagic fisheries**

The marine fisheries of India can be broadly grouped under two major categories, namely pelagic fisheries and demersal fisheries. Pelagic species are found near the surface or in the water column but not on or near the seafloor; they undertake both horizontal and vertical migrations and are mostly aggregating species (Cochrane and Japp, 2015). Small pelagic fishes is defined as the group of pelagic fishes having shorter life span with shoaling behaviour, swim on the surface water, performing limited migratory journeys and small size limit of less than a foot in length, which provide the bulk of the catches within short period of their growth (Panikkar, 1949; Cury *et al.*, 2000).

The small pelagic resources are the shoal forming resources like anchovies, Indian oil sardine and Indian mackerel, and these species are commonly caught by coastal fishers. In most cases, they are a staple food source and may also be used for animal feed (Cochrane and Japp, 2015). These small pelagic fish are mainly planktivorous, which is an important source of food for predators and typically dominated by only one, or at most a few, species (Bakun, 1996; Cury *et al.*, 2000), thus their populations are crucial to the transfer of energy and biomass from lower to higher trophic levels (Cury *et al.*, 2000). Small pelagic fish populations have exhibited a substantial degree of global synchrony that is believed to be driven by global climatic teleconnections (Klyashtorin, 1997).

The catch of small pelagic fishes by the mechanized sector showed an upward trend along the south west coast of India, which accounted about three-fourth of the total landings during 2010. At the same time, the proportion of its landings in the motorized sector was decreased from 28% in 2009 to 25% in 2010 (Kuriakose *et*

*et al.*, 2012). Among the mechanized sector, the bulk of the landings are by trawlers, purse seiners and ring seiners (powered by the inboard engine), whereas ring seiners (powered by outboard motors) and gillnetters are the major contributors in the motorized sector. Therefore, major gears are trawl nets, seine nets and gillnet for the landings of small pelagic along the south west coast of India (Kuriakose *et al.*, 2012). Small pelagic fishes like Indian oil sardine, Indian mackerel and anchovies are distributed with high biomass between 8° N and 14° N latitudinal and 75° E and 77° E longitudinal along Malabar upwelling zone of India, where annual SST range from 27 to 29°C (Panikkar, 1949; Vivekanandan *et al.*, 2005; Rao 2011). Historically, small pelagic fishery in the south west coast of India has shown wide fluctuations during the last 100 years of the time period (Krishnakumar and Bhat, 2008; Manjusha *et al.*, 2013).

Although the pelagic fish landings in the south west region comprised 100 different species, more than half of the landings are constituted by Indian oil sardine, Indian mackerel and anchovies (Kuriakose *et al.*, 2012). The major portions of landings for these small pelagic fishes are accounted from Cochin, Munambum, Sakthikulangara and Neendakara Fishing Harbours in Kerala. Similarly, Mangalore and Malpe are the major fish harbours that play a vital role in their landings of Karnataka (Kuriakose *et al.*, 2012). Fluctuations in landings of the small pelagic fisheries are caused by physical factors like temperature, salinity, rainfall, ocean currents, availability of nutrients and biological factors like availability of food items (Sahadevan, 2017). Wind speed and SST are known to influence the nutrient levels and productivity in the coastal waters (Krishnakumar and Bhat, 2008). Higher productivity results in an abundant supply of food leading to a higher probability of larval survival and recruitment, ultimately leading to an increase in fish abundance and catch (Cury *et al.*, 2000; Ghosh *et al.*, 2016). The changes in the abundance of small pelagic fishes in coastal ecosystem during the past century have been taken place due to natural environmental variability (Hsieh *et al.*, 2006). The length at first maturity of fishes depends upon changes in the climatic conditions, food availability, fishing removals and growth rates (Hood and Johnson, 2000; Potts and Manooch, 2001).

## 2.8. Indian oil sardine

Indian oil sardine, *Sardinella longiceps* (Valenciennes, 1847) ranks top position in Indian marine fisheries and one of the best known commercially exploited fish of India, which is extensively used as food in the fresh and cured conditions. It is known to restrict its distribution in India to Malabar coasts (Panikkar, 1949; Rao, 2011). The annual fluctuation of the Indian oil sardine fishery is very well known, and Day (1889) observed that fishery of Indian oil sardine is cyclic in nature under the influence of environmental variation. Indian oil sardine (hereafter as sardine) distinguished easily from other Indian sardine by its relatively long head and grows to a maximum size of 22-23 cm (Nair and Chidambaram, 1951).

Diverse factors are responsible for reduction of survival and recruitment to the stock such as unsuitable hydrological conditions, low survival rate of the larvae and lack of the necessary food for the fry and juvenile, periodical migration into offshore waters, heavy natural mortality and overfishing (Nair and Chidambaram, 1951; Panikkar, 1952; Nair 1953; Nair and Subrahmanyam, 1955). Being a plankton feeder with a population doubling time of fewer than 15 months, its role in the marine ecosystem as forage fish for larger predators is significant (Krishnakumar *et al.*, 2008; Froese and Pauly, 2011). Thara (2011) found an inverse relationship of mackerel to sardine fisheries. However, Sahadevan (2017) did not observe negative relationship between the landings of sardine and mackerel in India.

### 2.8.1. Fishery

The fishery of sardine has a regular pattern which starts with the appearance of the spawners and juveniles every year in the coastal waters, which are mainly influenced by the changes in the hydrological conditions brought about by the south west monsoon (Nair, 1959). The fishery starts immediately after the commencement of the south west monsoon, and lasts from August to March; the September - December portion being the best period for the fishery also its fisheries are restricted to a narrow belt within 50 m depth (Deshmukh *et al.*, 2010). Normally its landings decline considerably after March, with the rise of salinity and temperature to

high values (Sekharan and Dhulkhed, 1963). The nets used in the sardine fishery are the seines, including the large shore seines, and the gillnets (Panikkar, 1949). Occasionally, sardine in small quantity was landed by trawl nets and a bottom gillnets during the period of 1957-63 (Sekharan and Dhulkhed, 1963).

During monsoon months the catches are composed mainly of mature fish, which are more than two years old. On the other hand, from October to March, when salinity and temperature have intermediate values, one-year-olds comprise the bulk of the catches (Sekharan and Dhulkhed, 1963). The commercial fishery of sardine belongs to O-year class, those born during June to August manifest themselves strongly in the fishery, while those result from September or October spawning fail to establish a fishery by them (Antony Raja, 1970). According to Antony Raja (1970), the success of any season's fishery for sardine is largely dependent on the successful spawning and the survival rate in that year. During the months of October 2012 to February 2013, a high catch is recorded even in the Raigad coast of Maharashtra (Rao, 2013). Kamble *et al.* (2017) revealed that sardine shared 28.58% in the total fish landings of purse seine operated from Mirkarwada fish landing center at Ratnagiri coast.

### **2.8.2. Growth and maturity**

Hornell and Nayudu (1924) found a very rapid rate of growth of sardine in the early stages resulting in a length of about 15 to 17 cm at the end of first year, 19 cm at the end of second year and 19.5 cm at the end of 2.5 years, which they considered as the normal life span of the fish, while Chidambaram (1950) and Nair (1960) suggested that the average life span of sardine is about 3 to 4 years. Chidambaram (1950), on the other hand, estimated an average length of 10.0, 14.5, 18.3 and 20.5 cm at the end of the first to the fourth year, respectively. Balan (1964) concluded that the average lengths of 1, 2 and 3-year-old fish are 13, 16 and 17.5 cm, respectively. Although in rare instances the fish lives up to 3 years, the normal life span is found to be about 2.5 years (Nair and Chidambaram, 1951; Antony Raja, 1970; Antony Raja 1973). The  $L_{\infty}$  (19.8 cm) and  $K$  ( $1.14 \text{ yr}^{-1}$ ) obtained in the Nair *et*

*al.* (2016) are lower than the values of 20.8 cm and 0.6 yr<sup>-1</sup> reported by Antony Raja (1972). The growth rates of sardine was obtained by Nair *et al.* (2016) were higher than the values reported by Nair (1958), who reported a length of 10,15 and 19 cm in the first, second and third years, respectively.

The length at first maturity has been reported by various researchers as 16 - 17 cm (Dhulkhed, 1964), 15.6 - 15.8 cm (Kumar and Balasubramanian, 1987) and 15.2 - 15.7 cm (Nair *et al.*, 2016). The size of juvenile size ranges from 95 - 135 mm with the maturity stages of I and II from October to February. Also, immature size of sardine is considered as 16 - 18 cm from September to December (Radhakrishnan, 1965).

Factors like external appearance, extent of gonads in relation to body cavity length, length and weight of gonads, gonad and body weight ratio, maximum and modal size of ova and their general appearance under a microscope are taken into consideration to describe the sexual stages (Antony Raja, 1967). Antony Raja (1966) described about seven stages of sexual maturity with two subdivisions under Stage II to distinguish the virgin developing and spent-resting conditions and two other subdivisions for Stage VII to differentiate between the partially spent and completely spent nature, both for male and female of sardine. The study on the developmental stage of sardine has been conducted by Nair (1959) and found during September, the ovaries of almost all the females show the development stages V and VI, while the maturity stage I, II, III (maturing stage) and IV & V (mature) are dominated during September to December, November to February, March to April and in May to July, respectively. During July - September period, fish in various degrees of spent condition (Sekharan and Dhulkhed, 1963; Dhulkhed, 1964).

A high gonado somatic index (GSI) during August - September indicates the maturity period of sardine (Deshmukh *et al.*, 2010). Majority of the females are immature (stage II) during October - November, while they were in maturing stage (stage III, 60%; stage IV, 31%) in December - January and most of them were in stage IV (66.6%) during February - March (Ahirwal *et al.*, 2017). On the basis GSI,

Deshmukh *et al.* (2016) suggested that sardine gonad matures from June to September, when the spawning takes place once in a year. Gonadal maturity stage IV, V, VI, VII, VIII and spent stages are found during June to October along the the south west coast of India, thus spawning season is June to September (Deshmukh *et al.*, 2016).

### **2.8.3. Spawning season**

Hornell and Nayudu (1924) have found that a considerable percentage of males and females with gonads varying from half to three-quarters the mature size during September and October. Sardine spawns during June - August (Kumaran *et al.*, 1988), June - October (Antony Raja, 1967), June - September (Dhulkhed, 1964), June - December (Prabhu and Dhulkhed, 1970) and June - August with peak in July (Rohit and Bhat, 2003). Antony Raja (1964) reported that sardine normally spawns twice in their lifetime. Sekharan (1965) and Antony Raja (1967) made one significant remark as the possibility of being two broods in a year. The study by Nair *et al.* (2016) shows two peak recruitment periods, one in February or March and the other from in May-August. The spawning of sardine in the Sohar region occurred during two seasons, the first one during February - March and the second season being September - October (Al-Jufaily, 2011; Zaki *et al.*, 2012). However, sardine spawns only once a year along the Maharashtra coast (Deshmukh *et al.*, 2010).

Sardines are serial batch spawners (as are anchovies, sprats, tunas, etc.) and they spawn for many days during extended spawning seasons (George *et al.*, 2012). Sardines spawn in shallow water mainly in the nearshore areas during the peak of southwest monsoon along the southwest coast of India (Pillai, 1991). The earliest spawned surviving individuals are recruited to the fishery by the end of the spawning period, which in turn determines the yearly landings. Thus, larval ecology decides the recruitment, abundance and fishery of sardine (Hornell, 1910; Hornell and Nayudu, 1924; John and Menon, 1942; Devanesan, 1943).

#### **2.8.4. Feeding habit**

Observation on the food of sardine shows that the diet consists mostly of phytoplankton, especially diatoms. The important forms were *Fragilaria oceanica* and species of *Coscinodiscus*, *Biddulphia*, *Pleurosigma*, *Nitzschia* and *Rhizosolinia* (Nair, 1959; Kuthalingam, 1960; Sekharan and Dhulkhed, 1963). Sardine depends mainly on pelagic organisms for its food and therefore, is a surface and column feeder (Devavesan, 1943; Nair, 1959; Kuthalingam, 1960). In the case of sardine larvae, the phytoplankton bloom that decides its biology is an upwelling-induced bloom, the variations in initiation time and intensity of the bloom account for changes in the food supply to sardine larvae (George *et al.*, 2012). Larval development is rapid in sardines, with yolk sac absorption taking place within 3 days (Nair, 1960). These larvae undergoes in their critical stage at first feeding period almost immediately after yolk absorption (Lasker, 1975; Lasker, 1981; Hunter, 1981). The high K-value was in April with high feeding activity and lower K-value from August due to spawning stress and decrease in feeding activity (Ahirwal *et al.*, 2017).

#### **2.8.5. Migration**

Deshmukh *et al.* (2010) has reported that the average values of total length of sardine in the north west coast is similar to that of the south west coast of India, but north west coast shows larger fish compare to south west coast of India as major spawning grounds are available along the south west coast of India and the fishes then migrate towards the north west coast of India due to which larger size fish ranging from 17 - 20 cm are found along Ratnagiri coast. Sardine remains in offshore water prior to spawning period, while spawners move to inshore water in August and September to feed their young ones on the abundant plankton biomass during the post-monsoon season (Nair and Chidambaram, 1951). The shoreward migration of spawners during monsoon months and their outward migration to deeper waters during post-monsoon months are reported for feeding on the luxuriant growth of phytoplankton that blooms up during the onset of monsoon (Hornell, 1910; Hornell and Nayudu, 1924; Chidambaram, 1950; Nair, 1953; Nair, 1959).

Sardines perform a normal migration from offshore to coastal waters and vice versa coinciding with the customary wind conditions (Hornell, 1910). A gradual increase in temperature within the range of 26 to 28°C is favourable for the inshore migration of sardine, and with increasing temperatures (above 29°C) during March to May they disappear to deeper waters (Chidambaram, 1950). The longitudinal migration is an excursion from offshore to inshore waters and vice versa due to the availability of food and favourable hydrographic conditions (Devanesan, 1943). From April to September, the shoals of spawners and juveniles migrate from offshore to inshore all along the west coast of India following the onset of bloom (Antony Raja, 1972), where low salinity and temperature are perhaps favourable for spawners (Sekharan and Dhulkhed, 1963).

A northward migration of sardines during the south west monsoon period and retrogression from north to south in the northeast monsoon phase has been recorded (George *et al.*, 2012). Therefore, the fact that sardines employ a combination of migrating capabilities, ability to feed on very small particles and serial spawning habits (Pillai, 1991). During April - June, the warmest part of the year, the higher temperature and salinity values coincide with the absence of the fish in the coastal water, and the fish make their appearance in the inshore areas soon after the commencement of the rains in July - August when temperature and salinity values are lowered with the appearance of adults first (Bensam, 1970).

Factors such as feeding and spawning impulses seem to play a role, if any, secondary to temperature and salinity in influencing the movements of the sardine. Landings of sardine trend are increasing along the Karwar coast, which indicates its shifting from southern to northern region along the southwest coast of India (Deshmukh *et al.*, 2016). The spwaners with a modal size of 19 cm enter the coastal waters in July and remained up to September, but disappeared from the inshore waters by the end of September (Nair, 1959). It shows a typical schooling species, which occurred within 40 km offshore and Its schooling is associated with upwelling on the shelf (Pillai, 1991). Hornell and Nayudu (1924) have stated that the shoreward migration of the spawners is to feed upon the immense quantities of

unicellular plants and animals which develop and concentrate in the sheltered coastal waters towards the close of the southwest monsoon. Nair (1959) and Bensam (1970) noted the empty stomachs of the spawners, believed that their shoreward migration is for "spawning only".

#### **2.8.6. Oceano-climatic parameters**

Both short term and long term abundance of sardine are influenced by oceanographic and meteorological conditions (Longhurst and Wooster, 1990; Madhupratap *et al.*, 1992; Jayaprakash and Pillai, 2000; Menon *et al.*, 2019). The role of temperature and salinity on sardine biology and fishery appears to be very significant, and the fishing mortality does not influence the future stock so much as the variations in the hydrographical conditions (Bensam, 1970). The south west monsoon is an important factor influencing the entry of spawners into the coastal waters (Nair, 1959; Deshmukh *et al.*, 2010).

The shorter fishing duration of south west monsoon is observed by rising in salinity and temperature more than 35‰ and 30°C, respectively in very early during the season *i.e.* by November, while such high values are normally expected only after March (Sekharan and Dhulkhed, 1963). The optimal conditions of temperature (27 - 28°C) and salinity (34 - 35‰) influence the appearance of stronger shoals into the fishery (Nair, 1953; Bensam, 1970). Temperature and salinity during July - September period, when catches of sardine are smaller, are generally lower and range within the values of 25.5 - 26.9°C and 22.8 - 33.5‰ (Bensam, 1970). Therefore, temperature and salinity values towards the end of the season, during March-May period, show increasing trends from the optimum conditions, sardine landings are decreasing or totally absence during May - June period due to high temperature and salinity during this period range between 29.1 - 30.8°C and 34.3 - 36.3‰.

The amount of rainfall during the spawning period influences the spawning pattern on sardine (Antony Raja, 1970). The daily rainfall along the southwest coast during monsoon has been considered useful for good recruitment to

the fishery (Antony Raja, 1972 & 1970; Kumaran *et al.*, 1992; Pillai, 2011). Delays in the onset of monsoons on Indian coasts are often followed by delays in the fishing seasons for sardines, Indian mackerel and anchovies (Panikkar, 1949). A weak or erratic monsoon is suspected to bring fluctuation in sardine fisheries, which are not conducive to successful reproduction and survival of the young fish (Antony Raja, 1973). Dhulkhed (1964) found that the spawning period of sardine is from June to September coinciding with the southwest monsoon period when the hydrological conditions *viz.*, temperature and salinity of the inshore waters are low due to the influx of flood waters. Temperature, salinity and availability of food as factors are controlling sardine abundance (Chacko and Mathew, 1955; Jadhav *et al.*, 1989).

Murty (1974) has established the relation of sardine landings to wind drift. Since, El Niño phenomenon directly or indirectly influences solar activity and manifested with an abnormal increase in sea temperature and related changes in hydrographic parameters are also responsible for fluctuations in its abundance (Jayaprakash and Pillai, 2000). The unusual occurrence of young sardine in large proportions in the inshore waters of Bombay was observed during 1971, which was explained due to variations in water temperature and salinity (Devadoss, 1973). Wind patterns and water circulation in the Arabian Sea differ drastically from patterns in similar latitudes, where there is a seasonal change in the winds north of the equator (Wyrki, 1973). Winds blow over the equatorial ocean between November and March causing the northeast monsoon. From May to September, the system reverses and the southeast trade winds extend across the equator and blow across the northern Indian Ocean as the southwest monsoon (Tomczak and Godfrey, 1994).

## 2.8.7. Summary of biological characteristics

The summary of biological characteristics for sardine has been depicted in table1.

**Table 1. Summary of biological characteristics for Indian oil sardine**

Biological parameters	Characteristics	References
Maximum size	22-23 cm (22.5 cm)	Nair and Chidambaram, 1951
	20.8 cm	Antony Raja, 1972
	19.8 cm	Nair <i>et al.</i> , 2016
Sexual maturity size	16 -17 cm (16.5 cm)	Dhulkhed, 1964
	15.6 cm for male and 15.8 cm for female (15.7 cm)	Kumar and Balasubramanian, 1987
	15.2 cm	Nair <i>et al.</i> , 2016
Sexual maturity season	During September, almost all ovaries show the development stages V and VI	Nair, 1959
	July - September period fish in various degrees of the spent condition is caught in large numbers	Dhulkhed, 1964
	Juvenile (95 - 135 mm) is found during October - February and immature stage (16 - 18 cm) is from September to December	Radhakrishnan, 1965
	August - September indicates the maturity period of sardine; Immature (stage II) during October-November, while maturing stage (stage III) in December-January	Deshmukh <i>et al.</i> , 2010
Spawning season	September - October	Hornell and Nayudu, 1924
	August - November	Panikkar, 1949
	August - September	Nair, 1959
	July - September	Antony Raja, 1964
	June - October	Antony Raja, 1967

	June - September	Dhulkhed, 1964
	June - December	Prabhu and Dhulkhed, 1970
	June - August with a peak in July	Rohit and Bhat, 2003
	August - September along Maharashtra coast	Deshmukh <i>et al.</i> , 2010
	May - August	Nair <i>et al.</i> , 2016
Fishery	Commencement of the south west monsoon lasts from August to March; the September-December portion being the best period for the fishery	Panikkar, 1949
	Short term and long term abundance of sardine in relation to the oceanographic and meteorological conditions	Longhurst and Wooster, 1990; Madhupratap <i>et al.</i> , 1992
Ovaries stage	V and VI during September	Nair, 1959
	Stage I - September to December Stage II - November to February Stage III - March and April for maturing Stage IV & V - May to July period for mature and July - September period for Spent	Dhulkhed, 1964
Environmental factors	Sunspot activity, rainfall, ENSO effects, sea level pressure, upwelling and currents	Nair, 1953; Murty and Edelman, 1970; Antony Raja, 1972; Madhupratap <i>et al.</i> , 1994; Srinath, 1998; Ganga, 2000
Migration	Sardine remains in offshore water prior to spawning period, while spawners move to inshore water in August - September to feed their young ones on the abundant plankton biomass during post-monsoon season	Nair and Chidambaram, 1951
	The shoreward migration of spawners during monsoon months and their outward	Nair, 1959

	<p>migration to deeper waters during post-monsoon months is for feeding. The spwaners with a modal size of 19 cm enter the coastal waters in July and remained up to September, but disappeared from the inshore waters by the end of September</p>	
	<p>The shoreward migration of sardine is for spawning only</p>	Nair, 1959; Bensam,1970
	<p>From April - September, the shoals of spawners and juveniles migrate from offshore to inshore all along the west coast following the onset of bloom</p>	Antony Raja, 1972
	<p>During April - June, the warmest part of the year, the higher temperature and salinity values coincide with the absence of the fish in the coastal water, and the fish make their appearance in the inshore areas rather suddenly, soon after the commencement of the rains in July - August when temperature and salinity values are lowered with the appearance of adults first</p>	Bensam, 1970
	<p>Fishes then migrate towards the northwest coast of India</p>	Deshmukh <i>et al.</i> ,2010
	<p>The increasing temperature and salinity are felt by the juveniles rather immediately, while the adults appear to have a higher range of tolerance, leave the coastal waters a little later</p>	Deshmukh <i>et al.</i> , 2016
Larval feeding habit	<p>Predominantly surface and column feeders, with phytoplankton forming a major group, dominated by diatoms like <i>Fragillaria oceanica</i>, <i>Pleurosignia</i> sp. and <i>Coscinodiscus</i> sp.</p>	Nair, 1959; Kuthalingam, 1960

	The phytoplankton bloom that decides larval biology is an upwelling-induced bloom, the bloom initiation time and intensity is the only variation that could account for changes in the food supply to sardine larvae	Grinson <i>et al.</i> , 2012
Adult feeding habit	Sardine depends mainly on pelagic organisms for its food	Devanesan, 1943
	Diet consists mostly of phytoplankton, especially diatoms ( <i>Fragilaria oceanica</i> ), <i>Coscinodiscus</i> , <i>Biddulphia</i> , <i>pleurosigma</i> , <i>Nitzschia</i> and <i>Rhizosolinia</i>	Sekharan and Dhulkhed, 1963
	Feeding activity decreases in August due to spawning stress	Ahirwal <i>et al.</i> , 2017
Water quality	Southwest monsoon influencing the entry of spawners into the coastal waters	Nair, 1959; Deshmukh <i>et al.</i> , 2010
	Low salinity and temperature are favourable for spawners	Sekharan and Dhulkhed, 1963
	Optimum temperature is 25.9 - 29.6°C and salinity within the range 29 -35‰	Nair, 1953; Sekharan and Dhulkhed, 1963
	Rainfall during the spawning fortnights influences the spawning pattern	Antony Raja, 1970; Kumaran <i>et al.</i> , 1992
	Spawning period of sardine is from June to September coinciding with the south west monsoon period when the hydrological conditions viz., temperature and salinity of the inshore waters are low due to the influx of flood waters	Dhulkhed, 1964

## 2.9. Indian mackerel

The general features for Indian mackerel, *Rastrelliger kanagurta* (Cuvier, 1817) are well separated dorsal fins, the first dorsal with 8 to 11 spines; the second dorsal and anal fins with 12 rays, followed by five finlets; pectoral fins very

short with 19 to 20 rays; gill rakers very long, visible when mouth is open, 30 to 46 on lower limb of first arch; front and hind margins of eye covered by adipose eyelid; scales behind head and around pectoral fins larger and more conspicuous than those covering rest of body, generally silver; usually a double longitudinal row of small dusky spots on upper back; a prominent black spot on body under lower margin of pectoral fin; dorsal fins yellowish with black tips; caudal and pectoral fin often yellowish. The Indian mackerel (thereafter as mackerel) is considered as pelagic shoaling fish that forms commercial fisheries along the coasts of the countries bordering the Red Sea, Oman Sea, Arabian Gulf, Pakistan, India, Sri Lanka, Bangladesh, Myanmar, Thailand and Malaysia (Collette and Nauen, 1983).

India shares 90% of the world Indian mackerel production, out of which 77% is from the west coast and 23% is from the east coast of India (Das *et al.*, 2016). Its fishery plays a pivotal role in Indian marine catch after the fishery of sardine. To facilitate the formulation of such appropriate exploitation and management strategies on local/ regional scales a holistic knowledge-base on biology, life history and behaviour of major commercial fish species in the region is crucial (Adams, 1980; Begg and Waldman, 1999). With regard to studies on food and feeding habits, maturity and spawning on mackerel, have carried out along the Malabar Coast by various researchers (Kutty, 1962; Rao, 1967; Noble, 1974; Gopakumar *et al.*, 1991; Noble and Geetha, 1992). According to FSI (2014), there is evidence that mackerel moves away from inshore waters and become demersal especially when there is a paucity of food in the surface waters, resulted in presence of mackerel in significant quantities beyond conventional zone along the west coast of India.

### **2.9.1. Fishery**

Dense shoals occur in the coastal waters up to 50 m depths forming a major fishery along the west coast of India, while along the east coast, distribution and maximum abundance recorded at about 70 - 100 m depths (Ganga, 2011). Maximum exploitation of the resource has been recorded from the south west coast of India using seines, gillnets and trawl nets (Ganga, 2011; Nair, 2015). By the late

90s decade a sizeable portion of mackerel caught by ring seines along the Malabar Coast was executed during the monsoon period (Yohannan and Nair, 2002). The post-monsoon period is considered as the peak fishing season along the south west coast of India (Sekharan, 1958). However, the variations in the marine environment such as SST have impacted the mackerel and sardine stocks leading to the northward extension of their distribution ranges resulting in the development of new fisheries targeting mackerel especially along the north west coast of India (Asokan *et al.*, 2009). Mackerel exhibited seasonal and annual fluctuation at the south west coast of India with peak production by all gears together during September-October (Rohit and Gupta, 2004).

In recent years, mackerel fishery has undergone various changes in regards to fishing grounds. The landing of mackerel has recorded in multi-day fishing by trawlers operated 50 - 70 km away from the shore at a depth up to 120 m, indicates both horizontal and vertical extension of the fishing beyond the conventional fishing ground (Sivadas and Bhaskaran, 2009). Among the various gears, the seines (purse seine and boat seine) are the most efficient in mackerel fishery, which accounted 85% landing in the total catch of that species (Rohit and Gupta, 2004). Around 27% of marine fish was caught by multi-day trawlers and 51% by ring seiner along the south west coast of India (Sivadas and Bhaskaran, 2009). Sudarsan *et al.* (1988) have observed that mackerel form only 1 to 10% of the demersal catches along the west coast especially between 8° and 18° N. Again, Sudarsan *et al.* (1988) reported an abundance of mackerel in deeper waters with abundance increasing from 20 - 150 m depths. Therefore, mackerel exhibit its expansion of fishing ground to the distant and deeper area compared to earlier periods (Nath *et al.*, 2015).

In West Bengal, mackerel are showing an increasing catch trend over the last decade, resulting the catch has increased 130% during 2011-2014 compared to that of during 2001-2010 (Das *et al.*, 2016). The intrusion of an immature generation in the fishery has an adverse effect on the fishery of subsequent years (Devanesan and Chidambaram, 1948). Large scale exploitation of spawners during

the peak spawning period is bound to have a deleterious impact on recruitment and fishery in the subsequent years (Rohit and Gupta, 2004).

Although the fishery occurred throughout the year, peak catches were recorded during the monsoon period followed by the post-monsoon period (Qasim, 1973). The ring seine is a surface gear dominated by its fishery during July - October with peak catches in August - September catch of mackerel, but its catches start by bottom trawls from October and the catches gradually increase and reach a peak in May and end by June (Yohannan and Abdurahiman, 1998). The fishing season extends from August to May with peak landings during September - November and April - May by purse seiners, trawlers, gillnetters, ring seiners and indigenous non-mechanized crafts (Yohannan and Abdurahiman, 1998; Supraba *et al.*, 2013). Recruitment of young ones 120 - 150 mm to the fishery are seen during most of the years in August - September (Radhakrishnan, 1962). The juveniles measuring 3.0 - 6.0 cm occurred in the inshore waters during the October to February (Rao, 1962). Since the commercial fishery mainly depends on fish ranging in size from 18 to 22 cm *i.e.* fish are in the 0-year completing its 1<sup>st</sup> year of life (George and Banarji, 1964).

### **2.9.2. Growth and maturity**

The life span of mackerel is believed to be about two years and growth is very fast especially in the juvenile stages, thus fishes reaching a length of about 190 mm by the end of the first year (Devaraj *et al.*, 1997). The larva of mackerel prefers the above 30 m of the coastal water column with the temperature, salinity and dissolved oxygen range 28.60 - 29.89°C, 35.08 - 35.13‰ and 4.50 - 5.55 ml/l, respectively (Kramer, 1960). Larvae and juveniles were most frequently observed between 09° and 13° N at depths of about 13 m (Pillai, 1991).

Among the tropical marine fishes, maturation of mackerel is a continuous process resulting in the occurrence of mature fishes throughout the year (Longhurst and Pauly, 1987). However, oceano-climatic factors such as rainfall, water temperature and wind act independently or in combination as a kind of stimulus for

gonad development, maturation and spawning to create peak spawning in certain months of the years (Radhakrishnan, 1965; Rao, 1967; Weber, 1974; Sundararaj, 1981; Lam, 1983; Peter and Yu, 1997; Nath *et al.*, 2007; Ganga, 2010). The weight of mature gonads of mackerel decreases from February to March by lowering of plankton abundance along the south west coast of India but by May as the plankton availability increases the gonads also increases (Yohannan and Abdurahiman, 1998). Kutty (1962) found immature gonad of mackerel during in November and December along west coast of India, he also stated that the gonadal maturity of female during August and September showed the stages I, II, III, IV, V, VI (a) and VI (b) with most prominent stage of V and VI (a), while predominant stages I and II in October to February.

According to Hulkoti *et al.* (2013), III stage was dominant in June and stage V and VI (a) were dominant in July. Advanced stages of maturity (stage IV and above) are observed from February to October with a maximum in period May - October, and stage V is observed in fairly good numbers during October. Spent and spent-recovering stages along with stage IV are found during the January - March period (Rao, 1967). During August to September, all mackerel mature with gonad in stage VII a & b (Supraba *et al.*, 2013). For the sake of convenience, the different stages of maturity observed are grouped into the following five categories, *i.e.*, immature (I-II), maturing (III), Mature (IV-V), Spawning (VI-VI b) and spent (VII) by Rao (1962). Sekharan (1958) found that the gonads with immature stage I and II in November and December and with the maturing stage III and above in February, but a very advance state of maturity in March. The fishery of the mackerel is during October - March when the catch is composed of mainly immature specimens (Radhakrishnan, 1962).

Devanesan and John (1940) have remarked that mackerel attain maturity at about a length of 190 mm. The minimum size at first maturity, as determined by Pradhan (1956), is 224 mm. Radhakrishnan (1964) stated that Indian mackerel mature for the first time when it was measured 210 - 220 mm in total length. Fish matures at a size of around 21 cm (Yohannan and Abdurahiman, 1998). Later,

the study reported that size at sexual maturity (170 - 180 mm) is lower along the west coast of India (Sivadas *et al.*, 2006 and Rohit and Gupta, 2004).

Mackerel during November, December and January comprised mostly of mature and spawning fish with some individuals in spent condition having maturity size of 22 - 24 cm along the southwest coast of India (Rao, 1962). The individual is found with 140 to 170 mm in September, 165 to 180 mm in October and 180 to 195 mm in November, 190 to 225 mm in March and 210 to 220 mm in April and 120 to 160 mm in the month of July - August (Rao, 1962). Mackerel is dominated in the inshore water of size 40 - 70 mm during May and June (Balakrishnan, 1957). During February, April and May, a large-sized fish with ranging from 30 - 35 mm has been recorded by Sivadas and Bhaskaran (2009). The post larvae and juvenile size are 5 - 6 mm and 25 mm, respectively (Kuthalingam, 1956). According to Sekharan (1958), mackerel of 120 to 140 mm length is seen in July, supports the fishery of the same year for the months of October to March.

### **2.9.3. Feeding habit**

The diet of fishes changes with a number of factors which are extrinsic (biotope, region) or intrinsic such as species, size, behavior (Nath *et al.*, 2015). Therefore, the study on feeding habit of fish provides true information on distribution pattern and the feeding ground of both local and regional. In the inshore waters, the food of mackerel consists of phytoplankton and zooplankton elements strained from the surrounding waters by the well developed and feathery gill rakers. The phytoplankton elements comprising the food are the diatoms represented chiefly by *Coscinodiscus*, *Pleurosigma*, *Chaetoceros*, *Fragilaria*, *Thalassionema*, *Nitzschia*, *Rizosolenia*, *Skeletonema*, *Thalassiothrix*, *Biddulphia*, and *Asterionella* and the Dinophyceae by *Ceratium*, *Peridinium* and *Dinophysis*. The preferred zooplankton items are made of varied groups of organisms as the crustaceans form the major portion with copepods and the other organisms in smaller proportions constituted by tintinids, foraminiferans, polychaete larvae, molluscan larvae, chaetognaths,

appendicularians, fish eggs and fish larvae (Bhimachar and George, 1952; Vivekanandan *et al.*, 2009; Ganga, 2010; Sahdevan, 2017).

Mackerel is a plankton feeder and feeds chiefly on diatoms, dinoflagellates, copepods, rotifers, fish eggs, dead and decaying state at the bottom, etc, therefore, higher density of these constituents provides better health condition and gonadal maturity of the fish (Devanesan and Chidambaram, 1948; Bhimachar and George, 1952; Pradhan, 1956; Venketaraman, 1961; Kutty, 1962; Rao, 1965; Noble, 1962; Sivadas and Bhaskaran, 2009; Das *et al.*, 2016). The occurrence of macroscopic organisms such as fish larvae and juveniles occasionally found in the stomach of mackerel (Venkataraman and Mukundan, 1971; James and Santha, 1976; Sivdas and Bhaskaran, 2009). Mackerel along south west coast India is not carnivorous, but is exclusively plankton feeder as fish larvae and vertebrate materials are totally absent in the guts and normally feed at the surface (Hardenberg, 1956).

However, mackerel is basically planktivorous, feeding mostly on zooplankton especially copepods, but copepods in the stomach content decreased due to rise in SST. Therefore, with the impact of global warming, mackerel substitutes from small-sized phytoplankton to macroplankton and juveniles of fish by resorting to bottom feeding (Supraba *et al.*, 2016; Sahdevan, 2017). Young mackerel feeds on the fish *Stolephorus* (Chidambaram, 1944; Devanesan and Chidambaram, 1948; Venketaraman and Mukundan, 1971), which indicates the carnivorous habit of the young fish (Chidambaram, 1944; Devanesan and Chidambaram, 1948; Kutty, 1962), while there was no trace of fish larvae in the food of the adults (Rao and Rao, 1957; Rao, 1964). Mackerel shows selectivity in feeding habit and avoid non-edible items in the water (Bhimachar and George, 1952; Pradhan, 1956; Kutty, 1962).

Diet composition in relation to size groups; group size 16 - 18 cm (total length) has the highest intestinal length 67 cm so possibly their prey preference could be plant matter or detritus. But, size group 18 - 21 cm has intestinal length 56 cm; this indicates that the larger ones are carnivores (Kuthalingam, 1956; Venkataraman and Mukundan, 1971, Nath *et al.*, 2015). Feeding is good in immature specimens while

maturing it is intense, and during mature feeding is poor (Pradhan, 1956; Noble, 1962). Therefore, availability of food controls the local migration and abundance of a different stage of mackerel in the ecosystem (Rao, 1962). The gut of mackerel is almost directly proportional to the production of plankton in the inshore area as (Chidambaram and Menon, 1945; Bhimachar and George; 1952; Chidambaram *et al.*, 1952; Noble, 1962).

#### **2.9.4. Spawning**

The peak of spawning is confined to a few months in the year *i.e.* a major peak during June - August and a minor one during March - April (Devanesan and John, 1940; Devanesan and Chidambaram, 1948; Bhimachar and George, 1952; Chidambaram *et al.*, 1952; Panikkar; 1952; Pradhan, 1956; Balakrishnan, 1957; Radhakrishnan, 1962; Bal and Rao, 1984; Pillai, 1991; Yohannan and Abdurahiman, 1998; Rohit and Gupta, 2004; Ganga, 2010; Das *et al.*, 2016; Sahadevan, 2017). However, mackerel is a prolific breeder starting spawning at the age of 8 months and continuing it for at least 6 months (Radhakrishnan, 1962; Yohannan and Abdurahiman, 1998). The spawning might synchronize with the onset of the south west monsoon (Nath *et al.*, 2015). A subsidiary spawning season was observed on the south west coast of India during January and February (George *et al.*, 1959).

Mackerel spawns nearshore water, therefore the occurrence of juveniles measuring 3.0 - 6.0 cm may be seen the inshore (Rao, 1962; Silas, 1974). The occurrence of small-sized mackerel during September indicates that they are spawned a few months earlier (Pradhan, 1956; George and Annigeri, 1960; George and Banarji, 1964). The spawning area is outside of the present fishing limits, but not too far from the 30 fathom area which is about 3 miles from the shore (Balakrishnan, 1957; Radhakrishnan, 1962). The fish occurring through May - November is almost immature and in stage I of sexual maturity. Though fish in stage II starts occurring then, their number increases to about one-fourth only by December and later during January - March above two-thirds is observed in this stage. Maturing individuals in stage III, in turn, make their appearance in January and increase to one-third by

March - April. But, further advancement in maturity is noticed in the fish as in May among adults 76% are in stage IV. Stage VII and spent recovering fish (Stage II) have been noticed in the landings in June - July and October (Noble, 1974).

### **2.9.5. Migration**

Hydrological and meteorological features seem to play an important role in the migration of the shoals of mackerel. Therefore, mackerel migrates to the deeper waters from coastal water during the summer season when SST increases to 33°C (Luther, 1995; Pour *et al.*, 2014). Yohannan and Abdurahiman, (1998) also reported that mackerel moves towards the bottom from surface water on increasing of temperature above 28°C and this fish become vulnerable to trawl fishing. Mackerel seems to have a higher susceptibility to variations in temperature than to salinity. It has been noticed that north easterly and easterly winds drive the mackerel shoals to inshore and close shore waters and that the movement of the shoals is usually along with the water current at high tides (Pradhan, 1956). Food and feeding habits support migratory and shoaling behavior of mackerel (Nath *et al.*, 2015). Devanesan and John (1940) and Radhakrishnan (1962) believed that the fish after spawning does not permanently retire to the deep sea but seek coastal waters and their spawning grounds are not very far from the coast. As Pradhan (1956) stated, the wind and current also influence their shoreward migration.

The fish performs a spawning migration to offshore regions after March (Radhakrishnan, 1962) and small juvenile of mackerel are found in the inshore water in the Arabian Sea (Rao, 1962). The large scale occurrence of juvenile mackerel in the inshore region during the period immediately following the monsoon is suggestive of migration of this fish from offshore to inshore waters (Venkataraman, 1970). After the monsoon, the upwelling ceases and plankton become less abundant, mackerel stock disperses. The juveniles move closer to the shore, but evidently, much of the adult stock remains in offshore waters (Pillai, 1991). Mackerel feeds intensely in the inshore areas, where they are fished and remains offshore to liberate their eggs (Vijayaraghavan, 1962).

### 2.9.6. Oceano-climatic parameters

Mackerel prefers temperatures lower than 28°C provided the oxygen concentration is 4 ml/l (Yohannan and Abdurahiman, 1998). Environmental parameters are known to influence the fishery of mackerel, often leading to wide seasonal and annual fluctuations in landings (Krishnakumar *et al.*, 2008). Climate change induces a progressive increase in SST, resulted in the northward extension of the distributional range of mackerel (Gosh *et al.*, 2016). Seasonal changes in the food constituents with salinity and rainfall has observed where green algae, copepod and rotifers show a significant positive correlation with salinity and negatively correlated with rainfall (Das *et al.*, 2016). However, Blue green algae (BGA), dinoflagellates and other algae and fish egg showed a significant positive and negative correlation with rainfall and salinity, respectively (Das *et al.*, 2016). Temperature, salinity and availability of food as factors, controlling mackerel abundance have also been indicated by Rao (1962).

The relation between the mackerel catches and annual rainfall shows that a good monsoon is followed by a season of good catch (Yohannan, 1977). Rainfall and ENSO not significantly correlating with mackerel catches, negative correlation between precipitation and catch rate in gillnets have been observed by Ghosh *et al.* (2016). Increase in precipitations, temperature and salinity adversely affect the catches of mackerel shoals (Pradhan and Reddy, 1962; Bennet, 1967; Ghosh *et al.*, 2016). The intensity of upwelling and plankton bloom plays a major role in the recruitment of mackerel to the fishery at the Malabar region with the corresponding intensity of spawning and survival of the larvae (Yohannan and Abdurahiman, 1998). Water temperature and salinity govern the migration of mackerel (Venkataraman, 1970). When the wind is in a north-easterly direction, mackerel shoals enter the inshore waters and when a strong wind is in easterly direction mackerel shoals come close to the shore through deeper layers of waters. But, the shoals normally move along the current of water at high tide (Pradhan, 1956). Younger fish have a narrower range of tolerance when compared with older fish (Pradhan and Reddy, 1962).

## 2.9.7. Summary on biological characteristics

The summary on biological characteristics for Indian mackerel is shown in table 2.

**Table 2. Summary of biological characteristics for Indian mackerel**

Biological parameters	Characteristics	References
Size of the first maturity	190 mm	Devanesan and John, 1940
	224 cm	Pradhan, 1956
	210 - 220 mm	Radhakrishnan, 1964
	210 mm	Yohannan and Abdurahiman, 1998
	170 - 180 mm	Sivadas <i>et al.</i> , 2006 and Rohit and Gupta, 2004
Environment factors for the larva	Prefers the above 30 m of the coastal water column with the temperature, salinity and dissolved oxygen range 28.6 - 29.89°C, 35.08-35.13‰ and 4.50 - 5.55 ml/l, respectively	Kramer, 1960; Silas, 1974
	Larvae and juveniles are most frequently observed between 09° and 13° N at depths of about 13 m	Pillai, 1991
	Dominated in the inshore water of size 40 - 70 mm	Balakrishnan, 1957
Sexual maturity	Oceano- climatic factors such as rainfall, salinity, water temperature, wind, act independently or in combination as a kind of stimulus for gonad development	Weber, 1974; Sundararaj, 1981; Lam, 1983; Peter and Yu, 1997; Nath <i>et al.</i> , 2007; Ganga 2010
	Gonadal maturity of mackerel may be observed during July - September	Hulkoti <i>et al.</i> , 2013

	The gonads with immature stage I and II in November and December and with the maturing stage III and above in February, but a very advance state of maturity in March	Sekharan,1958
	August to September, all mackerel were mature with gonad in stage VII	Supraba <i>et al.</i> , 2013
	Changes in feeding rate in their life cycle as quantitative feeding increases from immature to mature stage, but in an advanced stage of sexual maturity (stage V) feeding is poor	Noble,1962
	The juvenile grows to about 7 cm in 3 months between July - September	George and Banarji, 1964
	The fish occurring through May - November are almost immature (stage I). Though fish in stage II starts occurring then their number increases to about one-fourth only by December and later during January - March above two-thirds are observed in this stage. Maturing individuals in stage III, in turn, to make their appearance in January and increase to one-third by March - April	Noble, 1974
Spawning season	Intensive spawning during June - September	Yohannan and Abdurahiman, 1998; Prathibha and Gupta, 2004; Ganga 2010; Das <i>et al.</i> , 2016
Fishery	The spawning is synchronized with the onset of the southwest monsoon	Nath <i>et al.</i> , 2015
	Spawn nearshore water and juveniles measuring 3.0 - 6.0 cm at the inshore	Balakrishnan,1957; Radhakrishnan, 1962; Rao, 1962; Silas, 1974

	Dense shoals occur in 20 - 150 m depths forming a major fishery along the west coast of India	Sudarsan <i>et al.</i> , 1988; Ganga, 2010
	The post-monsoon period is considered as the peak fishing season along the southwest coast of India	Sekharan, 1958; Kutty 1962; Radhakrishnan 1962; Qasim, 1973; Prathibha and Gupta, 2004; Supraba <i>et al.</i> , 2013
Migration	Fish after spawning do not permanently retire to the deep sea but seek coastal waters and their spawning grounds are not very far from the coast	Devanesan and John, 1940
	Shoreward migration of mackerel observed during spawning season due to rich plankton production near the shore. A seasonal movement of mackerel shoals between nearshore and deeper waters are observed	Bhimachar and George, 1952; Panikkar, 1952; Luther, 1995
	Small juvenile of mackerel are found in the inshore water in the Arabian sea	Rao, 1962 and Venkataraman, 1970
	Mackerel feeds intensely in the inshore areas where they are fished and remains offshore to liberate their eggs	Vijayaraghavan, 1962
Feeding habitat	Mackerel is a plankton feeder and feeds chiefly on diatoms, BGA, copepods dinoflagellates, rotifers, fish egg etc, therefore, a higher density of these constituents provides better health condition and gonadal maturity of the fish	Bhimachar and George, 1952; Venketaraman, 1961; Kutty, 1962; Noble, 1962; Rao, 1965; Das <i>et al.</i> , 2016
	Mackerel is basically surface feeder and planktivorous, feeding mostly on zooplankton especially copepods and occasionally resorting to bottom feeding	Hardenberg, 1956; Sivadas and Bhaskaran, 2009; Supraba <i>et al.</i> , 2016; Sahadevan, 2017

	Stomach content analysis of mackerel southwest coast showed a dominant component of foraminifera, algae, sand and detritus during pre-monsoon season	Pradhan,1956; Ganga, 2010
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## 2.10. *Stolephorus* spp.

Anchovy fisheries are constituted by five genera belonging to Engraulidae family, but maximum catch is accounted by genus *stolephorus* in indian marine fishery (Luther, 1972). Genus *stolephorus* is commonly known as whitebait, which comprises about seven species in fishery along south west coast of India (Luther 1972; Rao, 1988a). *Stolephorus* spp. (hereafter referred to as *stolephorus*) inhabiting all tropical and subtropical waters supports a lucrative fishery along with three southern maritime states of India, namely, Andhra Pradesh and Tamil Nadu and Kerala along east and west coast of India, respectively (Luther, 1979). During 80's decades, about 70% of total landed *stolephorus* along the south west coast comprised from the coast extending from Cape Comorin to Quilon (Luther, 1979).

The importance of the anchovies in the fisheries along the south west coast of India with the biology and fishery of *stolephorus* were briefly reported by Luther (1972) and Menon and George (1975), have pointed out the existence of *stolephorus* in the sea not far from the shore. *Stolephorus* is found usually never grow larger than 20 cm. *Stolephorus* prefer the warmer waters around the world, where they swim in massive schools with varying production widely from year to year (Siriskar *et al.*, 2013). The variations in anchovy abundance are linked to environmental changes at spatial and temporal scales such as short, medium and long term changes (Silva *et al.*, 2015).

### 2.10.1. Fishery

Shore seine is the main gear operated along the coast and it lands the bulk of the *stolephorus* catches. Boat seine is the next important gear, but gillnet

locally known as Netholi vala is operated at many fishing centers during peak fishing season. It is, in fact, the main gear for this fishery at places where the shore is rocky as at Cape Comorin, Muttom, Vizhinjam, Poonthura, Anjanko, etc, in the southern region. The fishery for anchovies is based mainly on '0' year class fish. The shore seine covers a maximum distance of about 1 km from the shore during its operation, while the boat seine is operated between 1 km and 6 km distance from the shore, at depths of 14 - 40 m depending on the availability of fish. The gillnet is operated up to a distance of 5 km from the shore (Luther, 1979). The principal fishery season is September - October along south west coast with small quantity during January - March (Menon and George, 1975; Luther, 1979). Menon and George (1975) stated that the inshore fishing region north of Quilon is hardly significant for the fisher. Landing is shared by mainly Purse seines (53.6%) and trawls 46.3%) along the Karnataka coast (Rohit and Gupta, 2008).

The major peak fishing season along the coast between cap Comorin and Quilon were September - November period whereas minor peak period were considered as January - April/ May (Luther, 1979). However, stolephorus fishery shifts from south to north with progress in time (Luther, 1979). Therefore, peak landings is observed during November - April, which is coincided with the peak spawning period of the fish (Rohit and Gupta, 2008). The high concentration of stolephorus are found generally in two areas, 9° to 11° N and 13° to 14° N with vary from month to month (Menon and George, 1975). Mostly stolephorus are found in the areas with a bottom depth between 10 and 50 m and only occasionally in deeper waters (Pillai, 1991).

### **2.10.2. Growth and Maturity**

Size ranging between 25 mm and 40 mm length are available in the inshore catches sporadically during November - July. While mature, partially spent-recovering and spent fish are dominant in the inshore catches, only immature and early maturing fish predominate in offshore or deep sea fishery, indicating its exitance in an offshore or deep sea area (Luther, 1979). According to Rohit and Gupta (2008),

the gonads of *stolephorus* is classified into five groups and seven stages as follows: immature (stages I and II), developing (stages III and IV), mature or gravid (stages (V and VI), spent (stage VII) and resting.

*Stolephorus* are recruited into the fishing ground at about 30 - 35 mm total length at 2 - 3 months old. The fish from 40 - 55 mm length onwards (3 - 5 months old) are caught in greater abundance (Luther 1979; Rao, 1988 a & b; Luther *et al.*, 1992). Patadiya *et al.* (2018) reported the smallest and largest size of *stolephorus indicus* are 8.4 cm and 15.3 cm, respectively along the south west coast of India. According to Abdurahiman *et al.* (2004), the maximum length for male and female of *S. waitei* was 9.7 and 10.0 cm and for *S. commersoni* are 14.0 and 14.4 cm, respectively. Gopakumar and Pillai (2000) and Rohit and Gupta (2008) reported that the fishery of *S. waitei* supported by 35 - 133 mm length group, while fishery of *E. devisi* supported by 20 - 105 mm length group. *S. commersoni* is exploited along the south west coast of India has a maximum length 15.5 cm (Luther, 1979; Nair *et al.*, 2015).

### **2.10.3. Spawning**

The continuous distribution of immature, maturing and mature groups of ova, and the occurrence of the two types of partially spent-recovering ovaries indicate that *stolephorus* are multiple spawners, an individual fish spawning about three successive batches of egg in a spawning season. Sexes are generally equally distributed. The spawning season is a prolonged one. The spawning activity is generally low during July - September, fairly high from October/November to June of the following year. It is intense during December - March, maximum fish caught during the principal fishery season (September - October) have only maturing gonads. Also, the spawning grounds of *stolephorus* are not far away from the inshore waters (Luther, 1979).

However, Rohit and Gupta (2008) suggested the spawning seasons of *stolephorus* are during October-January and April. It was found that the main spawning was confined to the period before and after the south west monsoon

season (Pillai, 1991). These observations generally indicate that each species of *Stolephorus* has a prolonged spawning season (Luther, 1979). Luther (1979) noticed the mature and spent specimens of *S. indicus* were recorded during September - April / May at Vizhinjam coast; whereas only immature and maturing *S. Commersoni* was seen at Vizhinjam. Rao (1988a and 1988b) showed that *E. devisi* and *S. waitei* spawn more than once during the spawning season.

#### **2.10.4. Feeding habit**

*Stolephorus* are plankton feeders, subsisting mainly on zooplankton as also reported by Venkataraman (1960), Rabindranath (1966), Luther (1972) and Menon and George (1975) and mostly feed on copepods, cladocerans, lucifer, fish larvae. Kumar *et al.* (2015) reported that *Stolephorus* mainly is a planktivorous carnivore chiefly feeding in the pelagic zone on planktonic crustaceans, bivalves, gastropods, and miscellaneous food items. The copepods are the main prey item, contributing their maximum during November (47.55%) and lowest in December (24.21%).

#### **2.10.5. Migration**

Vertical and seasonal migration in *Stolephorus* is well known (Menon and George, 1975), thus annual and seasonal fluctuations in the catch are common to the fishery due to mainly the changes in physico-chemical environment (Luther, 1979; Rohit and Gupta, 2008). The northward transport and distribution of the *Stolephorus* stock in shallow shelf water from October onwards and the southwards displacement and distribution from March / April onwards are evidently governed by the strong southerly current in southwest monsoon and Northerly current in post-monsoon period (Menon and George, 1975). Thus the variation in the time, direction, strength and location of southerly current in south west monsoon and northerly current in post - monsoon period influence the distribution of *Stolephorus* and other pelagic resources.

During day time the concentrations are distributed close to the bottom, while during the night they are dispersed in mid-water (Pillai, 1991). It is possible that *Stolephorus* make the southerly migration during June - July mainly to avoid the comparatively high temperature (above 28°C) prevailing in the Ratnagiri-Karwar region (Pillai, 1991). When they reach further south the effect of the low temperature upwelled water possibly drives it further south and later towards south east where comparatively favourable temperature (between 24 and 27°C) prevailed (Pillai, 1991). In November/December more or less the whole *Stolephorus* stock is spread along the south west coast of India. In April a southward movement begins and the stock starts accumulating in the Gulf of Mannar during June - August/September. After the monsoon (June - August) the *Stolephorus* again disperse along the coast north of Quilon (9° N) during September/October - December. These seasonal movements of the *Stolephorus* stock have been found to be directly related to the transport of water masses along the west coast (Luther, 1990).

### 2.10.6. Summary biological characteristics

The biological characteristics of *Stolephorus* are briefly explained in table 3.

**Table 3. Summary of biological characteristics for *Stolephorus* spp.**

Biological parameters	Characteristics	References
Fishery	Fishery is near the shore	Luther, 1972; Menon and George, 1975
	The principal fishery season is September - October along south west coast	Menon and George, 1975; Luther, 1979
	Found in the areas with bottom depth between 10 and 50 m and only occasionally in deeper waters	Pillai, 1991
	The major peak fishing season along the coast	Luther, 1979

	between cap Comorin and Quilon were September - Noember period whereas minor peak period were considered as January - April/ May, and shifts from south to north with progress in time	
Sexual maturity	Matures at lengths 42 - 57 mm and 52 to 61 mm for male and female, respectively	Luther, 1979
Spawning season	The spawning grounds of the stolephorus are the inshore waters, where the spawning activity is generally low during July - September, fairly high from October/November to June of the following year It is intense during December-March	Luther ,1979
	Stolephorus are multiple spawners with a prolonged spawning period, where the main spawning was confined to the period before and after the south west monsoon	Luther, 1979; Pillai, 1991
	The gonads of stolephorus are classified into five groups and seven stages as follows: immature (stages I and II), developing (stages III and IV), mature or gravid (stages (V and VI), spent (stage VII) and resting	Rohit and Gupta, 2008
Feeding habitat	Stolephorus are plankton feeders, subsisting mainly on zooplankton with mostly feed on copepods, cladocerans, Lucifer and fish larvae	Venkataraman,1960; Rabindranath,1966; Luther, 1972; Menon and George, 1975
Migration	Vertical and seasonal migration in stolephorus is well known	Menon and George, 1975
	Annual and seasonal fluctuations in catch is common to the fishery due to changes in physico-chemical environment	Luther, 1979; Rohit and Gupta, 2008
	The northward distribution of the stolephorus stock in shallow shelf water from October onwards and the southwards distribution from March/April onwards	Menon and George, 1975

	During day time the concentrations are distributed close to the bottom while during night they are dispersed in mid water	Pillai, 1991
	Southerly migration during June - July mainly to avoid the comparatively high temperature (above 28°C) prevailing in the Ratnagiri-Karwar region. When they reach further south the effect of the low temperature upwelled water possibly drives it further south and later towards southeast where comparatively favourable temperature (between 24 and 27°C) prevailed	Pillai, 1991
	In November/December more or less the whole <i>stolephorus</i> stock is spread along the south west coast. In April a southward movement begins and the stock starts accumulating in the Gulf of Mannar during June-August/September. After the monsoon (June-August), disperse along the coast north of Quilon (9° N) during September/October - December.	Luther, 1990

### 2.11. *Thryssa* spp.

*Thryssa* spp. is a member of the family Engraulidae, which includes approximately 139 species in 16 genera distributed throughout the world's oceans (Baeck *et al.*, 2014). In Western Indian Ocean, about 11 species belonging to the genus *Thryssa* has been reported to commercial fishery (Pawase *et al.*, 2018). *Thryssa* spp. (hereafter referred to as *thryssa*) is a pelagic fish distributed throughout the tropical and temperate coastal waters (Baeck *et al.*, 2014). *Thryssa* is mostly marine, schooling and inshore pelagic fish. *Thryssa* is known as zooplankton feeder (Jugnu and Kripa, 2009). Some species of *thryssa* like *Thryssa malabarica* are found all along the Indian Coast, whereas *T. dayi* mostly restricted to the west coast of India (Froese and Pauly, 2017; Roul *et al.*, 2017).

Thryssa form a small scale clupeoid fishery along the south west coast due to local demand only. Roul *et al.* (2017) reported, the total length of thryssa was ranged from 20.5 to 25.5 cm, whereas Karna (2017) observed its total length from 6.3 to 21.1 cm. The size of *T. malabarica* and *T. dayi* are 8.6 - 20.5 mm and 9.5 - 25.5 mm, respectively. Similarly, the weight of *T. malabarica* and *T. dayi* are 5.50 - 78.8 g to 6.53 - 115 g, respectively. Male can attend the maximum size as 10.0 - 19.0 cm, while the female has the maximum size range from 12.0 to 20.5 cm (Abdurahiman *et al.*, 2004).

The major gears employed for thryssa fishery are boat seines, shore seines, bag nets and gillnets, operated mainly by the catamarans and plank-built boats, most of them fitted with outboard engines (Gopakumar and Pillai, 2000; Jayaprakash, 2003). Thryssa is fished up to a distance of 5 km from the shore and to a maximum depth of 50 m (Gopakumar and Pillai, 2000; Jayaprakash, 2003). The weight of thryssa are varied from 5.50 - 115 g, this species has asymptotic length of 224 mm with growth coefficient of 1.0 per year (Kende *et al.*, 2018). Thryssa fishery is influenced by salinity and dissolved oxygen Krishnakumar and Bhat (2008). Recently, thryssa has been reported in a huge quantity at Ratnagiri coast where it caught by a different combination of gears and craft such as mini trawl and purse seine (Kende *et al.*, 2018). In considering the feeding habit, Vivekanandan *et al.* (2009) have assigned the trophic level 11.0 for thryssa, when the mean trophic level is only 3.68 for pelagic finfishes. Summary of biological characteristics for thryssa has been given in table 4.

**Table 4. Summary of biological characteristics for *Thryssa* spp.**

Biological parameters	Characteristics	References
Total length	10.0 - 19.0 cm for male and 12.0 to 20.5 cm for female	Abdurahiman <i>et al.</i> , 2004
	20.5 - 25.5 cm	Roul <i>et al.</i> , 2017
	6.3 - 21.1 cm	Karna, 2017
	224 mm	Kende <i>et al.</i> , 2018
Fishery	Influenced by salinity and	Krishnakumar and Bhat

	dissolved oxygen	(2008)
	Fishery up to a distance of 5 km from the shore and to a maximum depth of 50 m	Gopakumar and Pillai, 2000; Jayaprakash, 2003
	Major gears are boat seines, shore seines, bag nets and gillnets	Gopakumar and Pillai, 2000; Jayaprakash, 2003
	Major crafts are catamarans and plank-built boats with outboard engines	Gopakumar and Pillai, 2000; Jayaprakash, 2003
Feeding habit	Trophic level is 11.0 when the mean trophic level is only 3.68 for pelagic finfishes	Vivekanandan <i>et al.</i> , 2009
	Zooplankton feeder	Jugnu and Kripa, 2009

## 2.12. Modelling on fisheries with climato-oceanographic features

Regression equation between the trends of fish catch and the monsoon intensity is useful for forecasting the main trend of the fishery based on observations over the Peninsular region of India (Murty and Edelman, 1970). The regional modeling with climate change undoubtedly helps to improve the ability to forecast likely consequences for ecosystems and fisheries (Brander, 2010). The time series data on primary productivity and nutrient dynamics have proved invaluable for identifying some dramatic consequences of climate change (Hays *et al.*, 2005). The shift in plankton and fish communities in the aquatic system is coupled with climate change and the concept for a shift of regime has been developed from mathematical models, which reveals how changes in particular components of communities with climate change (Hays *et al.*, 2005). Chlorophyll-a (a measure of primary productivity) was the best predictor in the regional-specific marine ecosystem (Martino *et al.*, 2019).

Long-term ecological datasets establish baseline conditions, which can be used to identify and isolate possible causes of change from the baseline and provide context for natural variability (Martino *et al.*, 2019). In relation to climate change, with the ocean forecast to warm by up to 3°C by 2100 and increasing occurrences of extreme climatic events, which will likely impact population functionality and productivity (Brander, 2010 and IPCC, 2014). Understanding long-term trends and stressors can add to guiding the sustainable management of fisheries to the benefit of fish populations, the fishing industry, and the general community (Martino *et al.*, 2019).

### **2.13. Remote sensing data**

Conventional methods to sampling the ocean using research vessels are limited in both time and space scales of coverage, making it difficult to study the entire ecosystem. Since the advent of satellite remote sensing, especially remote sensing of ocean color and temperature has become possible to sample the global ocean on synoptic scales and with acceptable temporal resolutions (Klemas, 2013). Airborne and satellite remote sensors are commonly used to measure the environmental parameters includes surface temperature; surface optical or bio-optical properties (ocean color, diffuse attenuation coefficient, total suspended matter, chlorophyll pigments); salinity; vertical and horizontal circulation, including fronts and gyres; wind and sea state (Chen *et al.*, 2005).

Algorithms are used by space agencies for atmospheric correction of ocean-color data. For example, National Aeronautics and Space Administration (NASA) uses the SeaDAS (SeaWiFS Data Analysis System, current version 7.3.1, SeaWiFS: Sea Wide Field-of-view Sensor) processor, based on the algorithm (Gordon *et al.*, 1997) with subsequent modifications and improvements (IOCCG, 2010). Satellites can measure local variations in sea surface height (SSH) to an accuracy of 1 - 2 cm; variations in SSH is associated with ocean circulation (Heck and Rummel, 1990). The instantaneous boundaries of ecological provinces provides to our understanding of ecosystem characteristics and ables to distinguish changes that

happen due to short- and long - term environmental variations which frequently be observes in satellite-derived patterns of ocean temperature and productivity, thus Remote sensing is used to manage fisheries at sustainable levels (Klemas, 2013).

Indian Space Research Organisation (ISRO) has successfully launched SARAL/AltiKa to explore the ocean surface topography in 2013 (Mahesh Kumar *et al.*, 2015). Altimeters like Topex / Poseidon, ERS, Jason-1, Envisat and Jason-2 provides good quality data pertaining to sea surface height. All these altimeters function in the Ku band. The satellite with Argos and AltiKa (SARAL) that operates in the Ka-band with a high frequency of 35.75 GHz was launched by SARAL mission of ISRO and the French space agency 'Centre National d'Etudes Spatiales' (CNES) on 25<sup>th</sup> February 2013 (Jayaram *et al.*, 2016). Ka-band altimeter provides the extremely good quality of the products, and is also capable of picking up accurate significant wave height (SWH) during extreme events (Jayaram *et al.*, 2016). The main sensors being used for satellite oceanographic observations are visible, thermal and microwave sensors such as Ocean Colour Monitor (OCM), Thermal Infrared Radiometer (TIR), Scatterometer (SCAT), Synthetic Aperture Radar (SAR), Altimeter (ALT), Microwave Radiometers, Imaging Spectrometers and High-Resolution Imagers and these sensors provide the information on diverse range of geophysical and biological parameters at surface or near-surface like colour, SST, wave fields, surface roughness, large-scale surface topography and wind speed (Desai *et al.*, 2000). Over the Indian region, microwave observations with wide swath and high-frequency channels from GPM and Megha-Tropiques offer an opportunity to augment rainfall estimation technique (Mishra and Rafiq, 2019).

The atmospheric and oceanic data can be accessed through the website of the AsiaPacific Data-Research Center (APDRC) availavle at <http://apdrc.soest.hawaii.edu/index.php>. The APDRC presently supportstwo access modes: Live Access Server (LAS) and Open-source Project for a Network Data Access Protocol (OPeNDAP). The LAS server is a user interface designed for the purpose of obtaining a quick graphical overview of gridded data fields. In the absence of knowledge on software such as Ferret, Grid Analysis and Display System (GrADS)

or Matrix Laboratory (MATLAB) software, the LAS provides a easy way of generating time series for individual grid points. It is possible to compute longitude, latitude or time-averages over any of the data fields and compare different fields with each other (Timm *et al.*, 2009). Th data extracted from APDRC website has been used for the study of tropical cyclone (Zhang *et al.*, 2007; Diamond *et al.*, 2012), global warming (Ghoshal *et al.*, 2014; Hausfather *et al.*, 2017), storm tide event (Ningsih *et al.*, 2011) and dyanamics of partial pressure of carbon-di-oxide with surface wind speed (Kanuri *et al.*, 2017).

## **2.14. Synoptic observations of the sensors**

Remote sensing using space-borne sensors is a tool for synoptic (with global coverage) observations repetitively with a time interval ranging from minutes to days (Navalgund *et al.*, 2007). Sensors used for remote sensing are broadly classified as optical operating in the visible, near, middle and thermal-infrared wavelength regions and microwave operating in the microwave region, where technology for developing microwave sensors is quite different compared to that for optical sensors (Joseph, 1996). However, Indian operational remote sensing arena was started by launching indigenously built satellite IRS-1A in 1988, thereafter, evolutionary effort in this area helps to achieve and operationalize the spatial resolution ability from 1 km to better than 1 m, also launched theme-specific satellites such as Oceansat-1, Resourcesat-1, Cartosat-1 and 2 (Navalgund *et al.*, 2007).

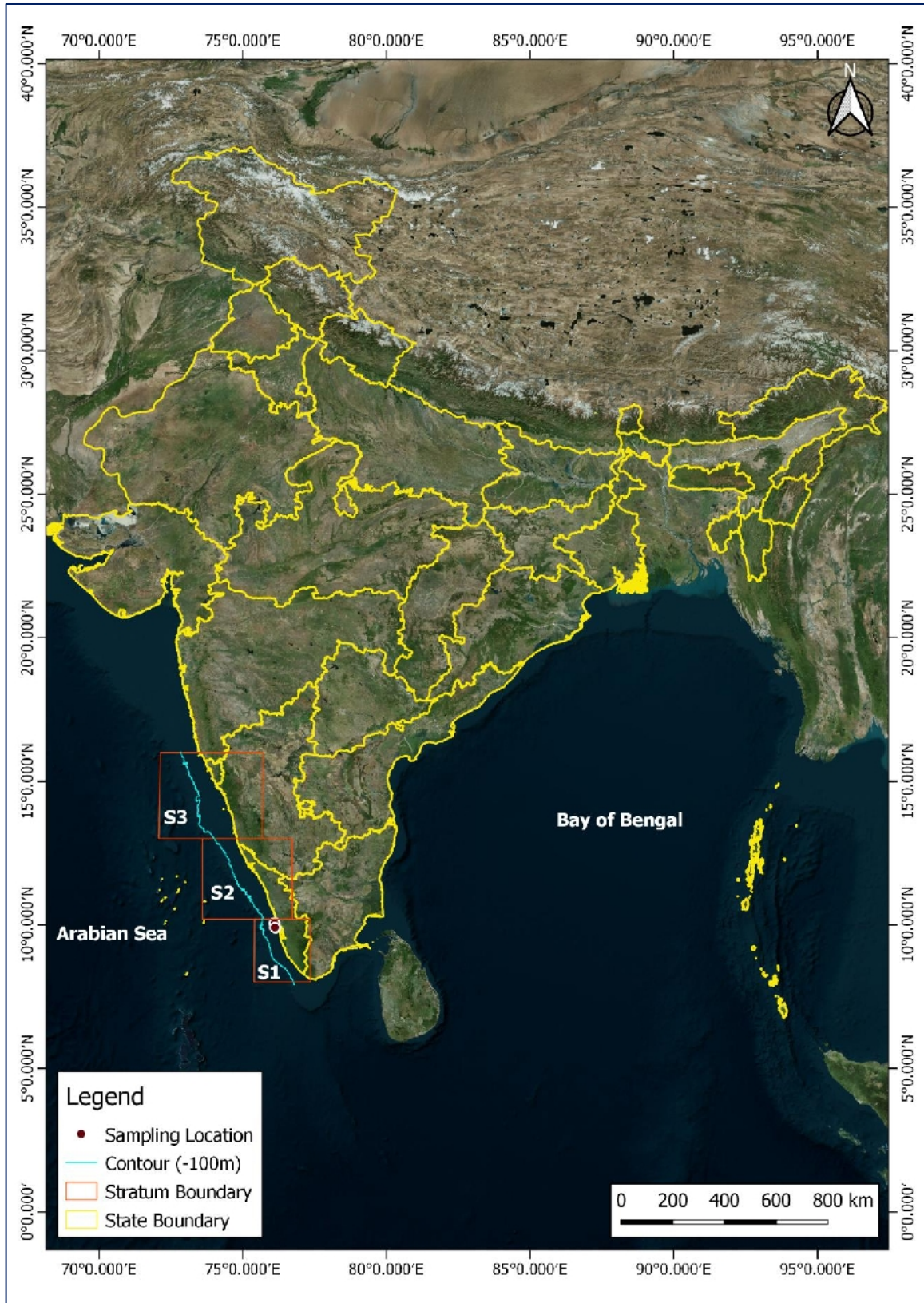
The launch of the SeaWiFS in 1997 escorted in a new era of long-term continuous ocean colour observations, with the whole globe sampled every two days, although that in some places cloud frequently obscures the surface (Perrette *et al.*, 2011). Therefore, ocean colour remote sensing starting in 1998 for the study of marine primary productivity through the accessing to biogeochemical proxies in harsh and remote areas, the potentially recurrent synoptic coverage of the whole basin numerous times in a days (Babin *et al.*, 2015). Satellite observations provide a also synoptic scale picture of algal blooms, necessary for the development of a theoretical understanding for their future forecasting (Perrette *et al.*, 2011). However, ocean colour remote sensing faces many limitations including the frequent occurrence of

clouds, especially during late summer and early fall, strongly limits the amount of available data (Perrette *et al.*, 2011; Babin *et al.*, 2015). Sea ice cover limits spatial coverage and complicates remote sensing of the key variables for primary productivity estimation (Bélanger *et al.*, 2007).

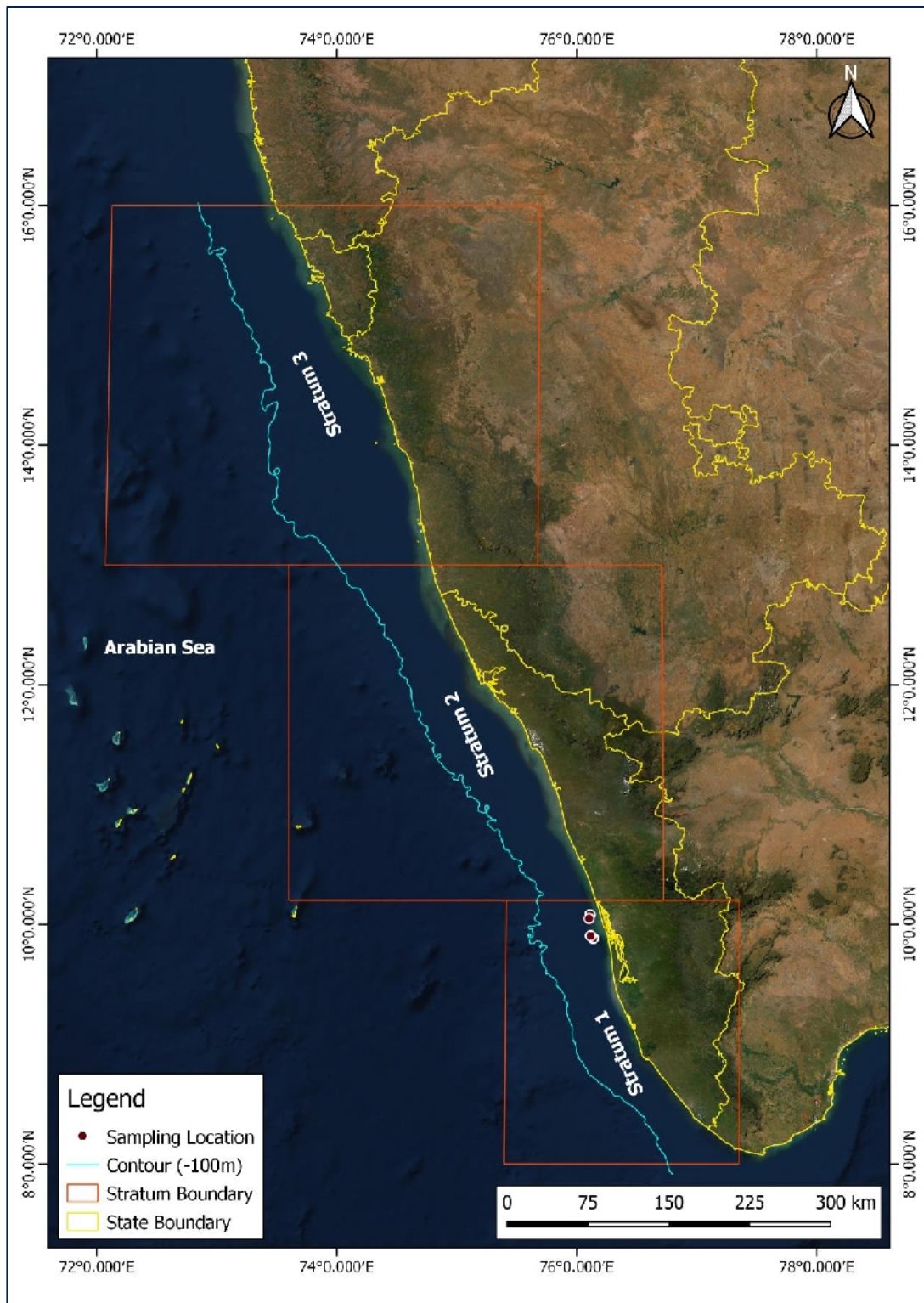
## 3.MATERIAL AND METHODS

### 3.1. Study area

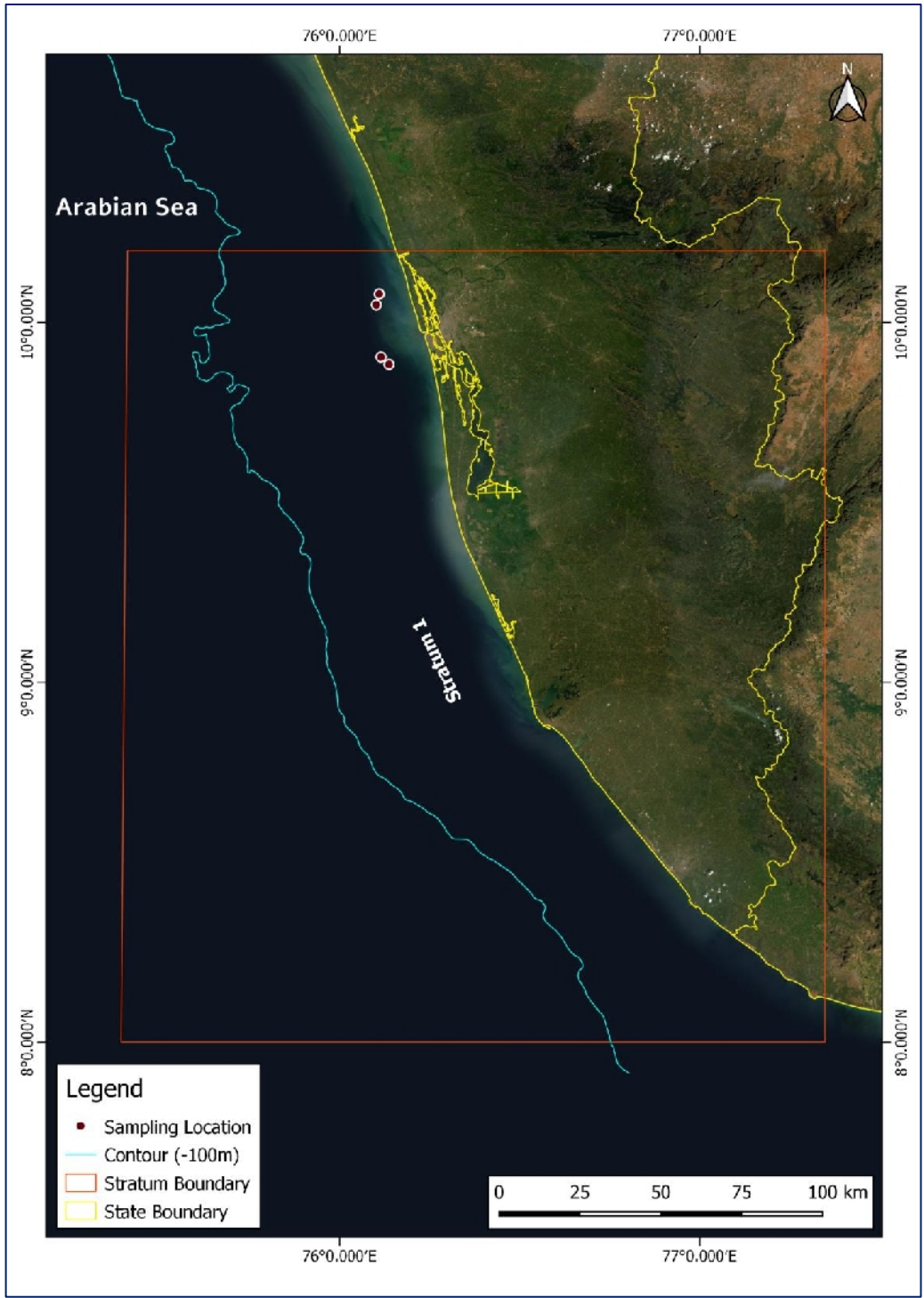
South west coast of India between 8° to 16° N latitude and 73° to 77° E longitude, up to 100 m depth was selected for the study. This coastal area is known as upwelling zone, which makes it the most productive amongst all other regions of Indian EEZ including offshore and onshore water. To assess the spatial study, the entire south west coast of India has been classified into three latitudinal strata *viz.* stratum\_1 (8 - 10.2° N, southern part, ST\_1), stratum\_2 (10.2 - 13° N, middle part, ST\_2) and stratum\_3 (13 - 16° N northern part, ST\_3), as shown in the figure 2, 3, 4, 5 and 6. South west coast of India is one of the important productive regions in the world due to existence of upwelling phenomena during south west monsoon period (Krishnakumar and Bhat, 2008; Manjusha *et al.*, 2013; Smitha *et al.*, 2014; Muni Krishna, 2016; Gireeshkumar *et al.*, 2017) and this region comprises of three maritime States of India namely Kerala, Karnataka and Goa with total coastline of 994 km, and a pronounced for contribution of about 31% to the marine fish catch of India (CMFRI, 2017).



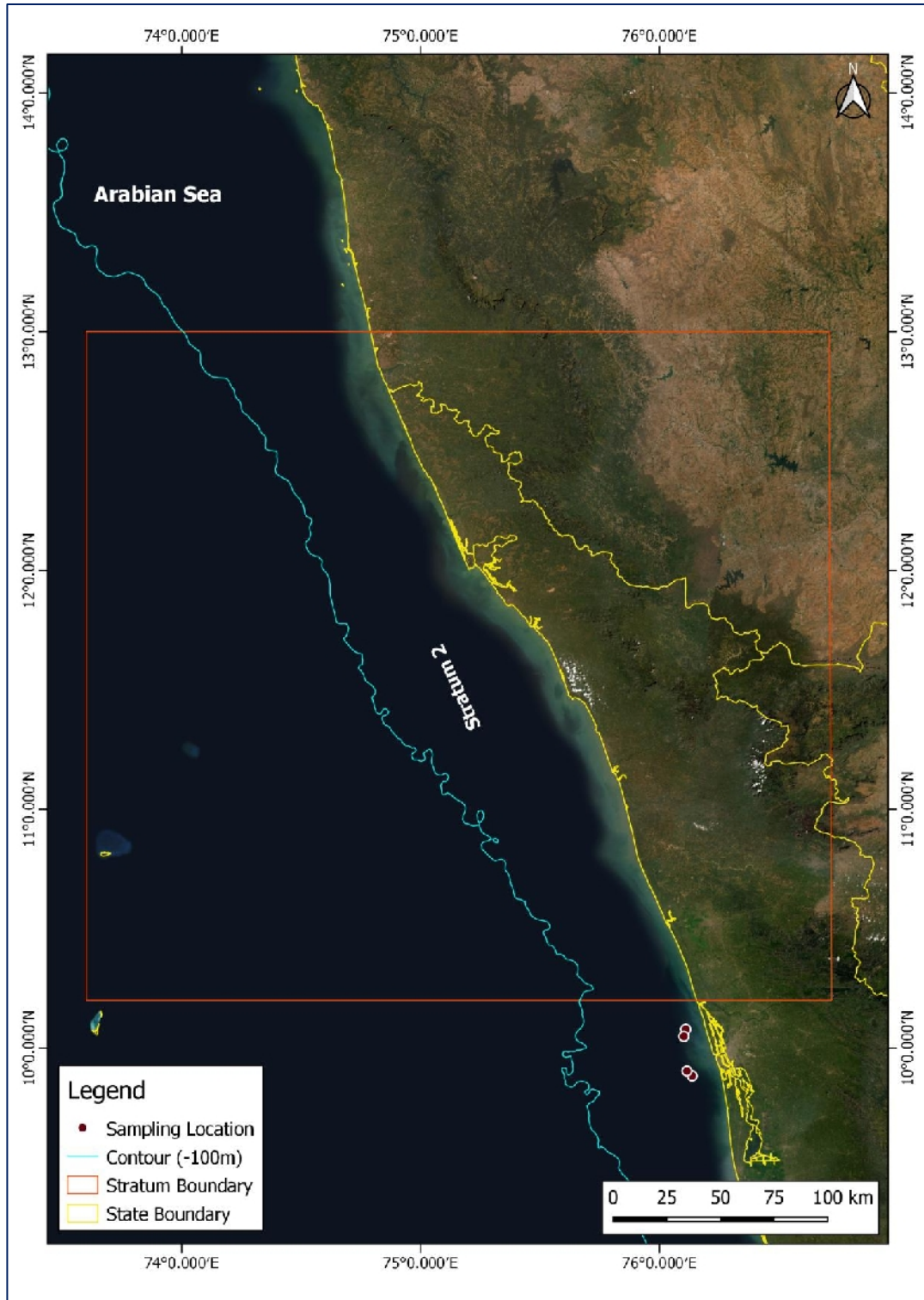
**Fig. 2: Indian map with study area**



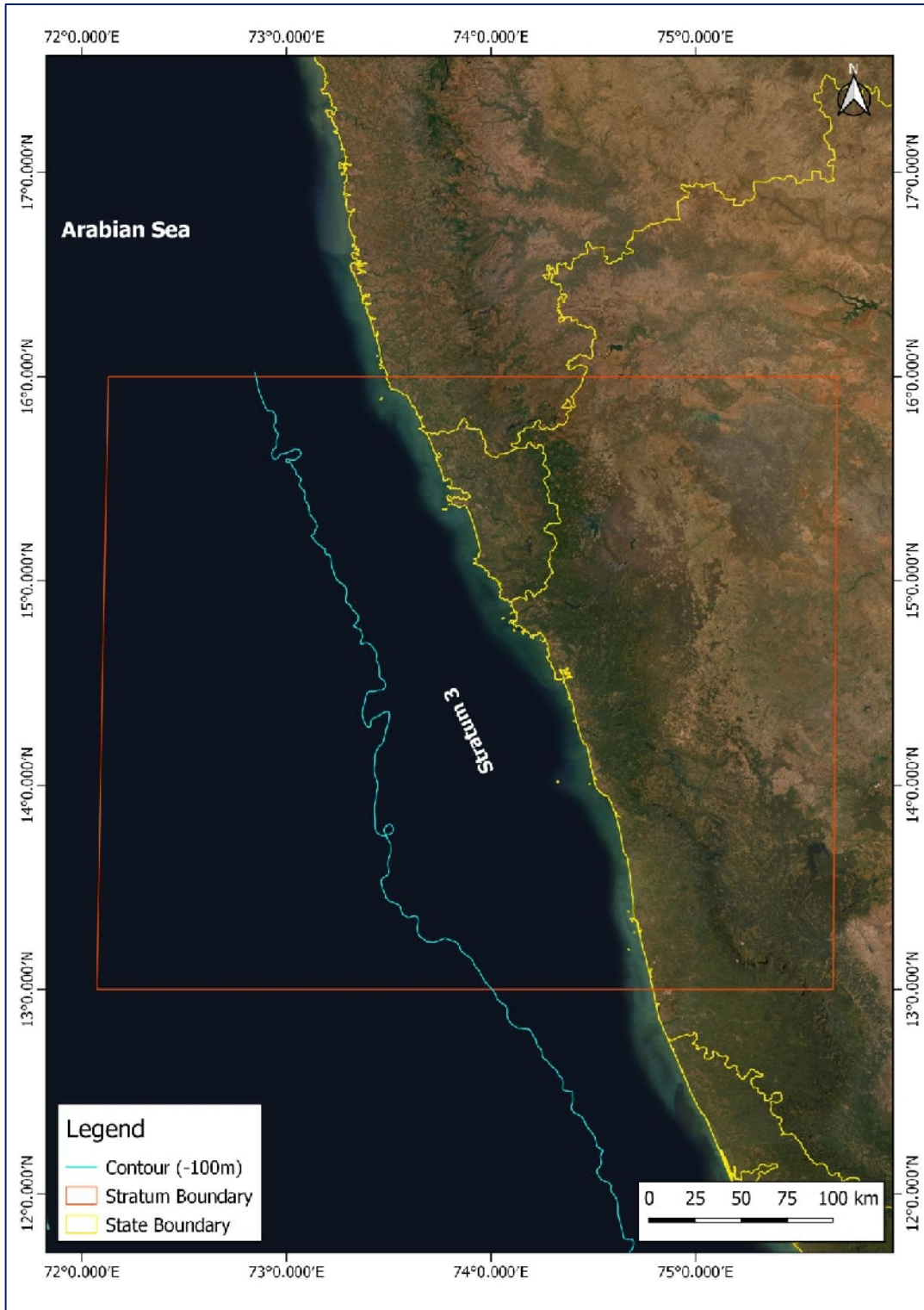
**Fig. 3: Map of south west coast of India showing three strata**



**Fig. 4: Map of Stratum\_1 at south west coast of India**



**Fig. 5: Map of Stratum\_2 at south west coast of India**



**Fig. 6: Map of Stratum\_3 at south west coast of India**

### 3.2. Data collection

#### 3.2.1. Ocean-climatic parameters from open access sources

The details of ocean-climatic parameters from open access sources are given in table 5, which covers the data observations, sources with period and spatial resolution of data.

**Table 5: Ocean-climatic parameters from open access sources**

Parameters	Data Observations	Sources	Period	Spatial resolution
Temperature	SST	NOAA (OI) SST, V2 (APDRC)	1987-2016 (Monthly)	1 × 1°
Chlorophyll-a	Chlorophyll-a	OC-CCI	1998-2016 (Monthly)	4 × 4 km
Surface wind	U and V wind component	CCMP, V2 (APDRC)	1988-2015 (Monthly)	0.25×0.25°
		QuikSCAT, LAS 8 (APDRC)	2000-2008 (Monthly)	0.25×0.25°
Current	U and V current component	SODA, v3.3.1 (APDRC)	1986-2015 (Monthly)	0.50×0.50°
Sea Level Anomaly	SLA	AVISO	1993-2015 (Daily)	0.25×0.25°
Rain rate	Precipitation rates(mm/hour)	TMI, V7.1 (APDRC)	1998-2014 (Monthly)	0.25×0.25°
Southern Oscillation Index	Southern Oscillation Index	Bureau of Meteorology, Australian Government	1950-2016 (Monthly)	Nil
Dipole Mode Index	Dipole Mode Index	NOAA, Global Climate Observing System	1950-2016 (Monthly)	Nil

### **3.2.1.1. Temperature**

The physical sciences division at NOAA has collected and made available monthly NOAA OI SST V2 data. The NOAA OI V2 SST monthly fields are derived by linear interpolation of the weekly optimum interpolation (OI) version 2 fields to daily fields then averaging the daily values over a month. Monthly data on Sea Surface Temperature (SST) was collected for the period of 1987 to 2016 from Asia-Pacific Data Research Center (APDRC) website (<http://apdrc.soest.hawaii.edu/las/v6/constrain?var=1271>). The data was collected in the format of a Network Common Data Form (NetCDF). The unit of the data was Degree Celsius (°C). The spatial resolution of the datasets is  $1 \times 1^\circ$  (Jayaram and Dinesh Kumar, 2018).

### **3.2.1.2. Chlorophyll- a concentration**

Chlorophyll-a concentration was downloaded from the Ocean Color Climate Change Initiative (OC-CCI) website ([ftp://oc-cci-data:ELaiWai8ae@oceancolour.org/occci-v4.2/geographic/netcdf/monthly/chlor\\_a/](ftp://oc-cci-data:ELaiWai8ae@oceancolour.org/occci-v4.2/geographic/netcdf/monthly/chlor_a/)). The OC-CCI chlorophyll product is a blended MODISAqua, SeaWiFS, VIIRS and MERIS data sets. The data was collected in NetCDF format. The unit of the data was in Milligram per meter cube ( $\text{mg}/\text{m}^3$ ). It is a level 2 data and the spatial resolution was  $4 \times 4$  km (Sathyendranath *et al.*, 2016).

### **3.2.1.3. Surface wind**

Monthly climatology data on wind speed was utilized for the period of 2000 to 2008 to plot the vector image for south west coast of India available at Asia-Pacific Data Research Center (APDRC) website ([http://apdrc.soest.hawaii.edu/dods/public\\_data/satellite\\_product/QSCAT/qscat\\_clim](http://apdrc.soest.hawaii.edu/dods/public_data/satellite_product/QSCAT/qscat_clim)). The zonal and meridional components of surface wind in NetCDF format of surface wind data on monthly basis for the from 1988 to 2015 was collected from Cross-Calibrated Multi-Platform (CCMP) V2 available at Asia-Pacific Data Research Center (APDRC) website (<http://apdrc.soest.hawaii.edu/las/v6/dataset?catitem=13037>). The V2 CCMP combines Version-7 RSS radiometer wind speeds, QuikSCAT and ASCAT

scatterometer wind vectors, moored buoy wind data, and ERA-Interim model wind fields using a Variational Analysis Method (VAM). The unit of the data was meter per second (m/s) (Jayaram and Dinesh Kumar, 2018).

#### **3.2.1.4. Surface Currents**

The zonal and meridional components of surface currents for the study were downloaded from Simple Ocean Data Assimilation (SODA) v3.3.1 available at APDRC website (<http://apdrc.soest.hawaii.edu/las/v6/dataset?catitem=4987>). The goal of SODA is to reconstruct the historical physical history of the ocean. Monthly data from 1986 to 2015 was collected NetCDF format for spatial resolution of  $0.50 \times 0.50^\circ$ . The unit of the data was meter per second (m/s) (Jackett *et al.*, 2006).

#### **3.2.1.5. Sea Level Anomaly**

Sea level anomaly was collected from open source AVISO (The Archiving, Validation, and Interpretation of Satellite Oceanographic) available at <https://www.aviso.altimetry.fr/en/home.html>. The daily data was collected in the Network Common Data Form (NetCDF) format and mean was taken to convert into monthly data. Unit of the data is centimeter (cm) and the spatial resolution is  $0.25 \times 0.25^\circ$  (Amores *et al.*, 2017).

#### **3.2.1.6. Rain rate**

The rain rate data was downloaded from the Tropical Rainfall Measuring Mission's (TRMM) Microwave Imager (TMI) V7.1, which is a multi-channel, dual polarized, conical scanning passive microwave radiometer designed to measure rain rates over a wide swath under the TRMM satellite and available at APDRC website (<http://apdrc.soest.hawaii.edu/las/v6/constrain?var=13330>). The monthly data from 1998 to 2014 downloaded in the form of NetCDF at a spatial resolution of  $0.25 \times 0.25^\circ$ . The unit of the data was millimeter per hour (mm/hour).

### **3.2.1.7. Southern Oscillation Index**

The Southern Oscillation Index (SOI) is a measure of the intensity or strength of the Walker Circulation. It is one of the key atmospheric indices for gauging the strength of El Niño and La Niña events and their potential impacts on the Australian region. The SOI measures the difference in surface air pressure between Tahiti and Darwin. Sustained positive SOI values above about +8 indicate a La Niña event while sustained negative values below about -8 indicate an El Niño (<http://www.bom.gov.au/>). The monthly SOI time series spans from 1<sup>st</sup> January 1950 to 31<sup>st</sup> December 2016 has collected from the open source website of Australian Government, Bureau of Meteorology available at <http://www.bom.gov.au/climate/current/soihtm1.shtml>, and yearly SOI was calculated by using the mean of monthly SOI.

### **3.2.1.8. Dipole Mode Index**

Dipole Mode Index (DMI) represents the strength of Indian Ocean Dipole mode (IOD). The DMI is the SST anomaly difference between the western (60-80° E, 10° S-10° N) and eastern (90-110° E, 10° S-Equator) Indian Ocean (Saji and Yamagata, 2003). When the DMI is positive then, the phenomenon is referred to as the positive IOD and when it is negative, it is referred to as negative IOD (Dwivedi, 2012). Positive IOD events are associated with the warm condition and reduced rainfall in the eastern Indian Ocean (Saji and Yamagata, 2003). The monthly DMI time series spans from 1<sup>st</sup> January 1950 to 31<sup>st</sup> December 2016 has collected from the open source website of NOAA Physical Sciences Laboratory available at [https://psl.noaa.gov/gcos\\_wgsp/Timeseries/Data/dmi.had.long.data](https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/dmi.had.long.data), and September and October DMI were used for analysis because these two months of DMI is significantly influences in the equatorial western Indian Ocean (Harou *et al.*, 2006).

### **3.2.1.9. Upwelling index calculation**

Ekman mass transport derived (Q) from the alongshore wind stress was taken for the study of coastal upwelling index (UI). Therefore, UI is defined as  $-Q$  ( $\text{m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-1}$ ); that is the volume transport per distance unit of an alongshore section.

The sign of Ekman transport is changed to define positive (negative) values of UI as a response of upwelling (downwelling) favourable winds (Gonzalez-Nuevo *et al.*, 2014). Along the southwest coast of India, the alongshore components ( $V_y$ ) and cross shore components ( $U_x$ ) of wind were computed as follows (Shah *et al.*, 2015):

$$V_y = V \cos \phi - U \sin \phi \quad \dots\dots\dots 3.2.1$$

$$U_x = U \cos \phi + V \sin \phi \quad \dots\dots\dots 3.2.2$$

Where, U and V are zonal, and meridional components of wind, respectively, and  $\phi$  is the inclination of the coast (Table 6).

**Table 6. Inclination (with respect to true north) along the southwest coast of India**

Latitude (° N)	Inclination (°)	Latitude (° N)	Inclination (°)
8-9	35	12-13	22
9-10	18	13-14	14
10-11	24	14-15	28
11-12	30	15-16	30

Sources: Shah *et al.*, 2015

The alongshore components ( $V_y$ ) and cross-shore components ( $U_x$ ) of wind were used to calculate the magnitude of wind speed (W) as given:

To estimate Ekman transport (Q), at first converted monthly wind components to wind stress ( $\tau_y$ ) using the formula:

$$\tau_y = \rho_a \cdot C_d \cdot W \cdot V_y \quad \dots\dots\dots 3.2.3$$

Where, constant air density ( $\rho_a = 1.22 \text{ kg m}^{-3}$ ) and constant drag coefficient ( $C_d = 0.0013$ ), alongshore components ( $V_y$ ) and magnitude of wind speed (W)

$$W = \sqrt{U_x^2 + V_y^2} \quad \dots\dots\dots 3.2.4$$

Ekman transport (Q,  $\text{m}^3 \cdot \text{s}^{-1} \cdot \text{km}^{-1}$ ) was calculated as follows (Gonzalez-Nuevo *et al.*, 2014):

$$Q = \frac{\tau_y}{f \cdot \rho_w} \cdot 10^3 \quad \dots\dots\dots 3.2.5$$

Where, seawater density ( $\rho_w = 1025 \text{ kg m}^{-3}$ ) and Coriolis parameter ( $f = 2\Omega \sin \phi$ ),  $\Omega$  is the angular frequency of the earth at  $\phi$  latitude.

### 3.2.2. Oceanic parameters from laboratory

The selected fishery environmental parameters such as Chlorophyll-a (mg/m<sup>3</sup>), water temperature (°C), nitrate (µg/L) and dissolved oxygen (mg/L) from the data sets collected by fisheries environment and management division (FEMD) of ICAR-CMFRI during the period from 2003 to 2013 had been utilized to observed the trend along Kochi coast. The data on fishery environmental parameters in FEMD are collected regularly at monthly interval with guidelines of the standard methods. The snapshot of filled datasheets for fishery environmental parameters collected by Fishery Environment Management Division has been shown in figure 7.

Date	Time	Salinity	Depth	Temp	Nitrate	Chlorophyll-a	Dissolved Oxygen	...
8/11/14	5:27	30.13	3.75	28.8	0.06	0.84	9.32	...
	8:05	30.49	3.51	28.7	0.27	0.82	9.32	...
	5:26	30.67	4.06	28.4	0.41	1.42	7.52	...
	8:08	30.85	4.27	28.8	0.46	1.42	8.43	...
	5:29	31.25	4.19	28.6	0.23	0.68	4.42	...
	8:05	32.11	4.27	28.5	0.32	0.20	4.62	...
	5:30	31.75	4.51	28.5	0.14	1.80	3.55	...
	8:05	31.91	4.65	28.5	0.14	0.84	3.46	...
	5:28	31.93	4.49	28.4	0.32	0.24	4.17	...
	8:02	31.93	5.02	28.2	0.09	0.04	3.14	...
	5:28	31.93	4.81	28.4	0.18	0.00	3.64	...
	8:04	32.11	4.41	28.4	0.32	0.09	4.08	...
	5:27	31.61	4.57	28.7	0.05	0.02	3.39	...
	8:04	31.79	4.78	28.4	0.21	0.02	3.45	...
	5:26	31.93	4.49	28.4	0.05	0.02	3.17	...
	8:04	32.11	4.41	28.4	0.32	0.09	4.08	...

Fig. 7: Snapshot of filled data sheets for fishery environmental parameters collected by Fishery Environment Management Division at ICAR-CMFRI

### 3.2.3. *In-situ* oceanic parameters

Four times depth profiling was carried out for physico-chemical water quality parameters at 20 m depth with the help of a portable multi-parameter logger (RBRmaestro, Serial No. 80299) (Plate 1 & 2). For the depth profiling, four cruises were made during 2018-19 along off Kochi coast, where two cruises on 28<sup>th</sup> April 2018 and 17<sup>th</sup> May 2018 were made for post-monsoon season in CMFRI fishing vessel *Silver Pompano* and rest two cruises on 18<sup>th</sup> December 2018 and 29<sup>th</sup> January 2019 for pre-monsoon period in a commercial fishing vessel. The parameters such as temperature (°C), chlorophyll-a concentration (µg/l), CDOM (ppb), PAR (µMol/m<sup>2</sup>/s), pH, turbidity (NTU), sea pressure (dbar), salinity (PSU), dissolved oxygen (mL/L), conductivity (mS/cm), specific conductivity (µS/cm), speed of sound (m/s), density anomaly (kg/m<sup>3</sup>) and depth (m) were recorded during the cruise.

The calculation of depth in RBRmaestro requires a pressure input from the logger. Atmospheric pressure is a required input to correct the pressure measurements during the depth calculation; this defaults to 10.132500 deciBar. The logger software assumes a gravitational constant of 0.980665 m/s<sup>2</sup> for the simplified case. Salinity is calculated according to the Practical Salinity Scale. Oxyguard Sensor in RBRmaestro provides a measure of the oxygen saturation (%) and a value of the oxygen concentration is derived from the saturation using the Weiss equation. The calculation of oxygen concentration requires temperature and salinity.



**Plate. 1: Depth profiling by RBR**



**Plate. 2: Data collection from RBR**

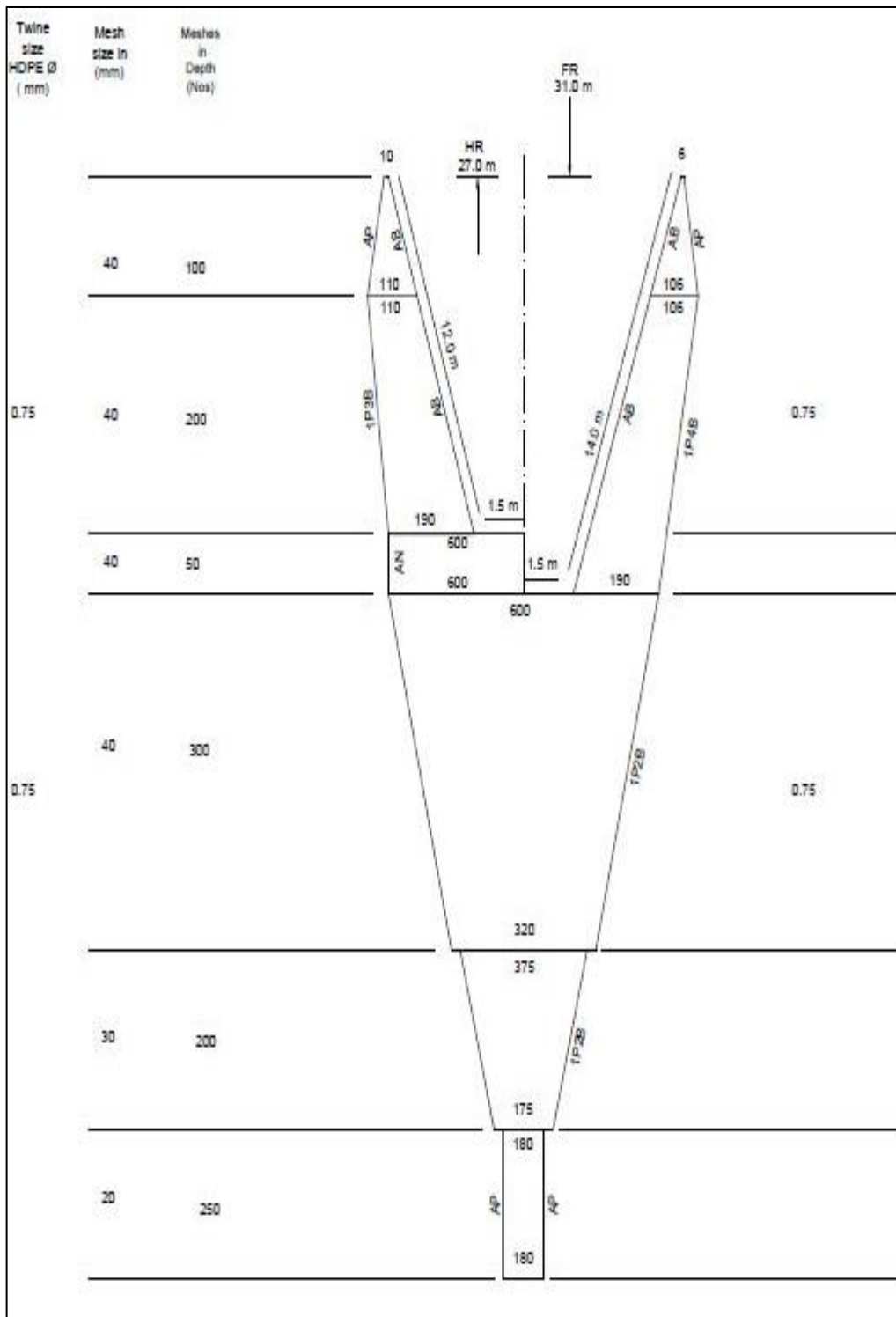
### 3.2.4. Data on fish landings and effort

Four small pelagic resources selected for the study viz. Indian oil sardine (Plate 3), Indian mackerel (Plate 4), *Stolephorus* spp. (Plate 5) and *Thryssa* spp. (Plate 6). The gear wise quarterly catch and effort data for three maritime states for the period of 1986 to 2017 was collected from the National Marine Fishery Resources Data Centre (NMFDC) of the Central Marine Fisheries Research Institute, Kochi, which is an internationally accepted statistically sound repository of data on marine fish landings collected by multistage stratified random sampling design (Srinath *et al.*, 2005). The format of survey sheet data collection for the estimation of marine fish landing used in Central Marine Fisheries Research Institute has been shown in figure 8. However, the monthly catch and effort data for each the zone was used for the period from 1997 to 2017 to study the variation in the technical approach in fishing along the south west coast of India (table 7). All gears operated along south west coast of India were classified into seven major generic gears categories, viz. mechanized purse seine (MPS), mechanized ring seine (MRS), mechanized trawl net (MTN), outboard ring seine (OBRS), outboard gill net (OBGN), outboard trawl net (OBTN) and non-mechanized gears (NM). The representative designs of trawl net, seine net and gillnet along the south west coast are depicted in figure 9, 10 and 11, respectively. Also the representative gears such trawl net, seine net and gillnet operated along South west coast of India have been shown in the plate 7, 8 and 9, respectively.

**Table 7: Fish catch and effort data**

Data	Source	Period	Spatial resolution
Gear-wise catch and effort (hours)	NMFDC, CMFRI	1986 to 2017 (Quarterly)	State wise
Gear-wise catch and effort (hours)	NMFDC, CMFRI	1997 to 2017 (Monthly)	Zone wise





**Fig. 9: Representative design of trawl net operated at Kerala**

**Source: Jha et al., 2019**



Plate. 7: Trawl net operated at off Kochi water

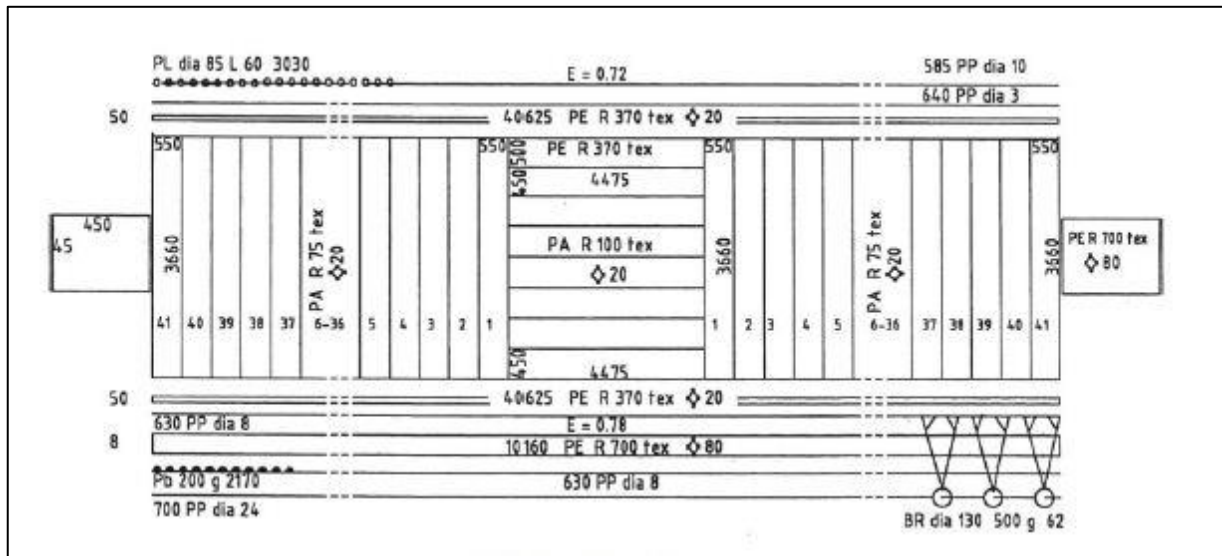
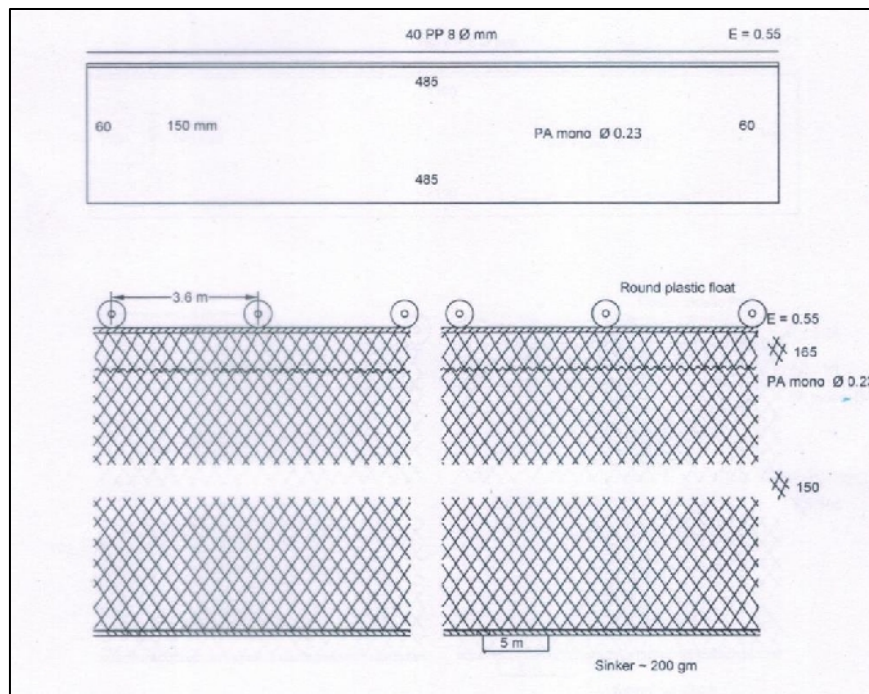


Fig. 10: Representative design of seine net operated at Kerala  
Source: Boopendranath and Hameed, 2012



**Plate. 8: Ring seine operated at Chellanam fishing harbour**



**Fig. 11: Representative design of gillnet operated at Kerala**



**Plate. 9: Gillnet operated at Chellanam fishing harbour**

### **3.2.5. Historical data on biological aspects**

Details on fishery, habitat, food and feeding behaviour, maximum size, size at first maturity, reproductive behaviour, optimum water quality parameters and migration for all selected species were collected from a survey of published literature.

### **3.3. Methodology**

#### **3.3.1. Standardization of effort**

In multispecies and multi-gear fisheries at the tropical region, the standardized fishing effort plays a pivotal role before estimation of catch per unit effort. Standardization of commercial catch and effort data is important in fisheries where standardization minimizes bias due to the confounding of apparent abundance patterns with fishing power. Therefore, there are the following steps for standardized fishing effort in hour (Sparre and Venema, 1992; Stamatopoulos and Abdallah, 2015; Varghese *et al.*, 2020):

**Catch proportion (P)**

Catch proportion can be calculated by total catch of the particular species on the given gear and time divided by total catch in same gear and time

$$P_{ijk} = \frac{C_{ijk}}{C_{ij}} \dots\dots\dots 3.3.1$$

Where,  $C_{ij} = \sum_{k=1}^s C_{ijk}$

$C_{ijk}$  = Catch of  $k^{th}$  species in  $i^{th}$  gear at  $j^{th}$  period ( $k=1, 2, \dots,s$ ;  $i= 1, 2 \dots\dots\dots g$ ;  $j=1, 2,\dots\dots\dots t$ )

**Weighting factor (F)**

The weighting factor is the proportion of total catch by each gear for each year. Therefore

$$F_{i.k} = \frac{\bar{p}_{ik}}{(S_{ik}^2+1)_{ij}} \dots\dots\dots 3.3.2$$

$$F'_{i.k} = \frac{F_{ik}}{\sum_{i=1}^g F_{ik}}$$

Where,  $\bar{p}_{ik}$  = Mean proportion for  $k^{th}$  species caught in the  $i^{th}$  gear

$S_{ik}$  = Standard deviation of  $P_{ijk}$  for  $k^{th}$  species in the  $i^{th}$  gear

**Gear wise standardized fishing effort (SE)**

The gear wise standardized fishing effort for the species can be calculated by multiplying the corresponding total fishing effort for the gear in the year with the proportion of the species for the year corresponding to the same gear and the weighting factor

$$SE_{ik} = F'_{ik} \times P_{ijk} \times E_{ij} \dots\dots\dots 3.3.3$$

Where,  $E_{ij}$  = Fishing effort in hours for  $i^{th}$  gear in  $j^{th}$  period

**Catch per hour (kg/hours) by different fishing gears (CH)**

Catch per hour by different fishing gears may be estimated by dividing with the total fishing effort of the particular gear in the given time period into a total catch in that gear during the same period. Therefore, the equation is the following:

$$CH_{i,j} = \frac{C_{i,j}}{E_{ij}} \dots\dots\dots 3.3.4$$

**Multiplication factor (MF)**

Since, the efficiency of gears may vary, so also the capability to catch in an hour which demands to scale the fishing efforts into a single scale. Therefore, the least efficient gears among all gears can be expressed in terms of least gear effort by deriving a suitable multiplication factor for each fishing gear. The average catch rate of gears is used to derive the multiplication factor (MF) as following:

$$MF_i = \frac{\overline{CH}_i}{CH'_i} \dots\dots\dots 3.3.5$$

$$\overline{CH}_i = \frac{CH_{ij}}{t} \dots\dots\dots 3.3.6$$

Where  $\overline{CH}_i$  = lowest mean catch among all gears.

**Standardized fishing effort (SE)**

The gear wise standardized fishing efforts for each year can be recalculated by multiplication of initial gear wise standardized fishing effort (equation 3.3.3) with multiplication factor (MF).

$$SE_{ij} = MF_i \times SE_{ijk} \dots\dots\dots 3.3.7$$

**Region wise standardized fishing effort (SE<sub>r</sub>)**

Region wise standardized fishing effort may find out by adding standardized fishing effort for gears in the particular years used in fishing for the particular species.

$$SE_{jr} = \sum_{i=1}^g SE_{ij} \dots\dots\dots 3.3.8$$

## Region wise catch per unit effort (CPUE)

Region wise catch per unit effort for a species is estimated by following equation:

$$CPUE_{jr} = \frac{\sum_{i=1}^g C_{ijk}}{SE_{jr}} \dots\dots\dots 3.3.9$$

### 3.3.2. Data processing

At initial stage, all remote sensed ocean-climatic data was collected from respective open sources website on a monthly basis for the latitude between 8° to 16° N and longitude between 73° to 77° E. Further, NOAA - bathymetric maps in R (library Marmap) was used to partition data by depth up to 100 m isobaths (Pante Simon-Bouhet, 2013 and R Core Team, 2018). The partitioned data was again segregated at stratum level to observe stratum-wise climate change effect on ocean-climatic parameters. The collected monthly data on ocean-climatic parameters again grouped into three seasons *viz.* pre-monsoon (February - May), monsoon (July - September) and post-monsoon (October - January) for analysis of seasonal variation.

To observe the technical attribute of fish caught, the standardization of catch for each gear was carried out. Further, the zone wise data was assembled into three strata and month wise data was converted into three seasons.

### 3.3.3. Statistical analysis

#### 3.3.3.1. Cluster analysis and stratum selection

Total four resources were considered in the clustering exercise along with their landings the effort expended by gillnet, seine net and trawl net at all major landing centers of the south west of India. There is a total of 12 major landing centres at an the entire region which has been stratified on the basis of daily landed marine fish (Srinath *et al.*, 2005). Kerala has a total of five major landing centres and rest of seven major landing centres belong to Karnataka. Euclidean method of cluster analysis of landing centres was formed to know the homogeneity among them, where the fish landings and their effort for three years from 2014 to 2016 at the landing centre were used. The average catch of sardine, mackerel, stolephorus and thryssa

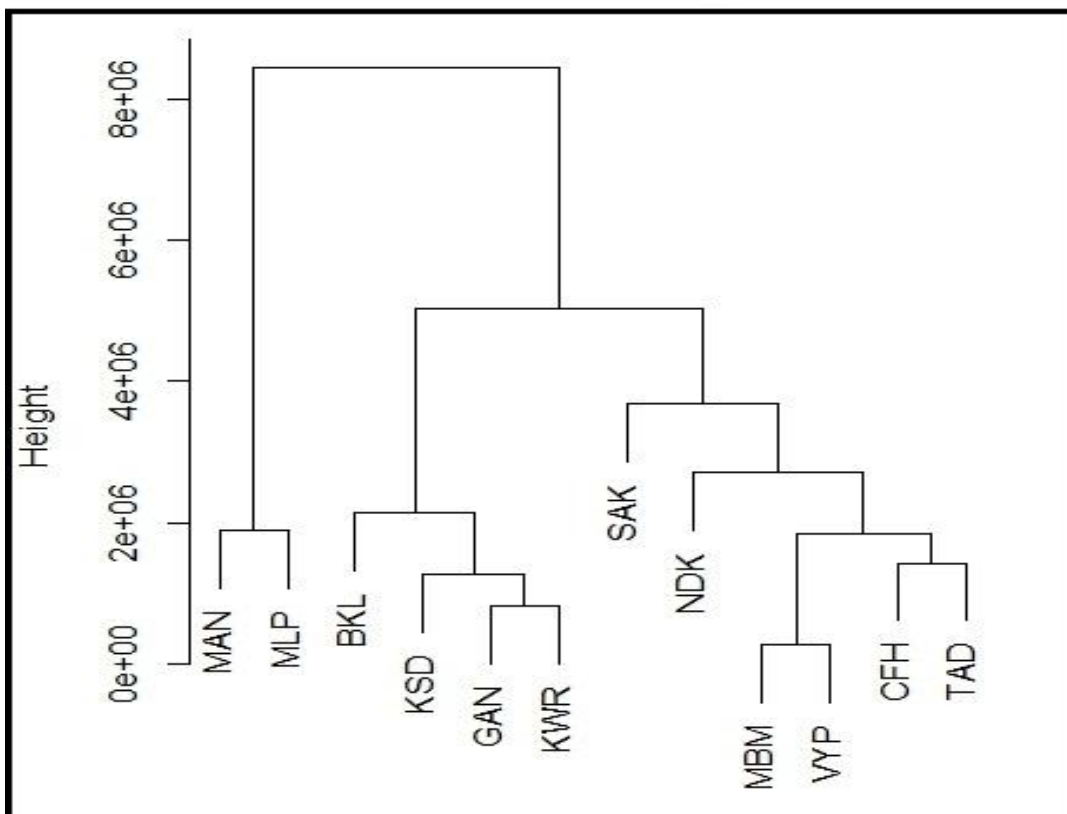
at the south west coast of India was 423.06 tonnes during the last three years. Year wise catch contribution of these fishes were 593.52, 339.00 and 336.67 tonnes, where only major landing centers accounted 34.40%, 35.38% and 43.93% during the year 2014, 2015 and 2016, respectively (Table 9). A dendrogram with three clusters was obtained after cluster analysis, where the first cluster included the SAK, NDK, MBM, VYP, CHF, and TAD; the landing centres in the second cluster were BKL, KSD, GAN, and KWR and third cluster were composed with MLP and MAN landing centres (Fig. 12). Table 8 gives the list of districts and the major landing centres/ fishing harbours tagged by a unique acronym for further ease of use in this discussion. The grouping and segregation exercise resulted in three latitudinal strata viz. stratum\_1 (8 - 10.2° N, southern region), stratum\_2 (10.2 - 13° N, middle region) and stratum\_3 (13 - 16° N northern region).

**Table 8: Marine fish landing centres along the south west coast of India**

State	Coastal district	Major landing centres	Acronym of landing centres
Kerala	Kollam	Neendakara fishing harbour	NDK
Kerala	Kollam	Shakthikunagara fishing harbour	SAK
Kerala	Ernakulam	Cochin fishing harbour	CFH
Kerala	Ernakulam	Munanbam fishing harbour	MBM
Kerala	Ernakulam	Vypeen fishing harbour	VYP
Karnataka	South Kanara	Mangalore fishing harbour	MAN
Karnataka	Udupi	Gangooli fishing harbour	GAN
Karnataka	Udupi	Malpe fishing harbour	MLP
Karnataka	North Kanara	Bhatkal fishing harbour	BKL
Karnataka	North Kanara	Kasarkode fishing harbour	KSD
Karnataka	North Kanara	Karwar fishing harbour	KWR
Karnataka	North Kanara	Tadri fishing harbour	TAD

**Table 9: Landing profile of the selected resources at the south west coast of India**

Year	The total catch of selected resources (Tonnes)	Catch contribution by major landing centers (%)
2014	593.52	34.40
2015	339.00	35.38
2016	336.67	43.93
Average	423.06	37.91



**Fig. 12: Dendrogram of major landing centres at south west coast of India**

### 3.3.3.2. Time series analysis

#### 3.3.3.2.1. Homogeneity test of time series

To know the homogeneity in the trend of time series for remote sense ocean-climatic parameters, three homogeneity tests namely Pettitt's test (Pettitt,

1979), Buishand range test (Buishand, 1982) and Standard normal homogeneity test (SNH) (Alexandersson, 1986) were performed at 5% level of significant by using trend library in R. These basically non-parametric tests were selected due to their usefulness in evaluating trend shifts independent of underlying distributional strappings and by way of evaluating a significant change in the mean of a time series of climatic features (Kang and Yusof, 2012; Jaiswal *et al.*, 2015; Pohlert, 2018).

#### **3.3.3.2.2. Changepoint analysis of time series**

Changepoint analysis of time series is used for identification of shifts in mean and/or variance in a time series at a 5% level of significant. A linear regression model using the strucchange package in R software was used for changepoint analysis. In strucchange package, structural breaks approach consists for detecting structural changes the monthly time series data, which tests for structural changes in linear regression models, estimating the number of segments and the breakpoints, minimizing the Bayesian information criterion (BIC) and the residual sum of squares (RSS) (Goela *et al.*, 2016).

To observe the spatial and seasonal variation in all oceano-climatic as well as fisheries data, the line plot for annual data for each season and stratum was made by taking mean of monthly data. Again time series plot of annual data for gear-wise catch per hour (CPH) was plotted to analyze the iner-annual variation in CPH in the southwest coast of India over the study period. The yearly data in line graph was smoothed to visualise the trend with LOcally WEighted Scatter plot Smoother (LOWESS) function in R3.4.4 software for Windows. The LOWESS smoother uses locally-weighted polynomial regression (Ruckstuhl *et al.*, 2001). The smoothed trend lines were compared among strata as well as season.

#### **3.3.3.3. Line graph and student t-test for *In-situ* data**

Line graph was plotted to observe the variation in temperature, chlorophyll-a concentration, dissolved oxygen, and nitrate concentration in seawater along off Kochi water between the periods from 2003 to 2013. The collected monthly

data was converted into years before plotting by using mean and smoothed to visualise the trend with LOWESS function.

A statistical tool as student's t-test was performed for the seasonal analysis of *in-situ* water quality as temperature, chlorophyll-a concentration, CDOM, PAR, pH, turbidity, sea pressure, salinity, dissolved Oxygen, conductivity, specific conductivity, speed of sound, density anomaly and depth collected during the period from 2018 to 2019.

#### **3.3.3.4. Correlation**

Pearson correlation analysis was used to find out the inter-relation between inter-annual, seasonal and spatial oceano-climatic parameters and CPH. Pearson correlation analysis was also used to observe the inter-relation of CPH between various gears for selected species in the study. Pearson correlation is a widely accepted method to find out the strength of the relationship between the variables of interests.

#### **3.3.3.5. Cross-correlation**

One of the most powerful and useful output measures resulting from cross-correlation is the temporal shift or phase delay, of one signal parameter to the other. The temporal shift provides information about when signal events are happening relative to each other in each of the signals used for the cross-correlation. In this study, the cross-correlation between monthly data of upwelling index (UI) and CPH of four species was conducted with a lag of 6. Before applying cross-correlation, the Augmented Dickey-Fuller Test was performed to find out the stationary time series with the help of R library (tseries).

#### **3.3.3.6. Step wise regression**

A stepwise regression model was applied in the study, which is a combination of forward selection and backward elimination. Stepwise regression constructs a model by successively adding or removing variables based on the p-values associated with the F-statistic, which allows them to compare the fits of different linear models. Stepwise regression is a method of fitting regression models,

where the choice of predictive variables is carried out by an automatic procedure. In each step, a variable is considered for addition to or subtraction from the set of explanatory variables based on some pre-specified criterion as F-tests, adjusted R<sup>2</sup> and Akaike information criterion (AIC). As the stepwise regression model progresses, the variable with the lowest F-to-remove statistic is deleted at each step from the model. This F-to-remove statistic is estimated by calculating the t-statistic for the estimated coefficient of every variable in the model squaring the t-statistic to create the F-to-remove statistic. Therefore, the stepwise regression model was applied in this study to know the controlling ocean-climatic parameters in the prediction of landings of fishes (Ghani and Ahmad, 2010).

Before the application of the model, all four assumptions such as normality, linearity, heteroscedasticity and multicollinearity were checked. Global validation of linear model assumptions was tested as kurtosis, skewness, and heteroscedasticity by using R library (gvlma). The last suspicion of multicollinearity in the data leading to redundant factor variables was checked by analyzing the value of variation inflation factor (VIF) in the library (car) in R software, where the value of VIF is more than 10 was taken in consideration. Since the value of VIF is less than 5, hence multicollinearity is not serious. While if VIF is more than 5, then multicollinearity is substantial. Multicollinearity will be more serious whenever the value of VIF is more than 10 (Ghani and Ahmad, 2010). On violation of normality, removal of an outlier was done by the library (car) in R. Finally, stepwise regression was carried out to find out the predictive model for each species by using the library (MASS) in R. The model of multiple linear regressions can be represented as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \epsilon \quad \dots\dots\dots 3.3.9$$

Where Y = Response variable (CPUE),

$\beta_0$  = Intercept,

$\beta_1$  = Coefficient of first control variable, X<sub>1</sub> (Chlorophyll-a),

$\beta_2$  = Coefficient of second control variable, X<sub>2</sub> (SST),

$\beta_3$  = Coefficient of third control variable, X<sub>3</sub> (Wind\_U),

$\beta_4$  = Coefficient of third control variable, X<sub>4</sub> (Wind\_V),

$\beta_5$  = Coefficient of third control variable,  $X_5$  (Current\_U),

$\beta_6$  = Coefficient of third control variable,  $X_6$  (Current\_V),

$\beta_7$  = Coefficient of third control variable,  $X_7$  (SLA),

$\beta_8$  = Coefficient of third control variable,  $X_8$  (Precipitation rate) and

$\varepsilon$  = Error

Multiple coefficients of determination ( $R^2$ ) and adjusted multiple coefficient of determination (adjusted  $R^2$ ) was used in this study to predict the model.  $R^2$  means the proportion of the total variation in the  $n$  observed values of the dependent variable that is explained by the overall regression model. The higher  $R^2$  gives the better the model fits for the data (Ghani and Ahmad, 2010).

### **3.3.3.7. Logistic regression**

Logistic regression is a statistical method for analyzing a dataset in which there are one or more independent variables that determine an outcome. The outcome is measured with a dichotomous variable (in which there are only two possible outcomes). In logistic regression, the dependent variable is binary or dichotomous, *i.e.* it only contains data coded as 1 (True, success.) or 0 (False, failure). The goal of logistic regression is to find the best fitting (biologically reasonable) model to describe the relationship between the dichotomous characteristic of interest (dependent variable = response or outcome variable) and a set of independent (predictor or explanatory) variables. Logistic regression generates the coefficients (and its standard errors and significance levels) of a formula to predict a logit transformation of the probability of the presence of the characteristic of interest. Rather than choosing parameters that minimize the sum of squared errors (like in ordinary regression), estimation in logistic regression chooses parameters that maximize the likelihood of observing the sample values. The logistic regression model uses logit transform and formula represented as

$$\ln \frac{p_i}{1-p_i} = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \dots + \beta_k x_{ki} \quad \dots\dots\dots 3.3.10$$

Where  $p_i = P(Y_i=1) = 1 - P(Y_i=0)$  with  $P(Y_i=1)$  and  $P(Y_i=0)$  the probability of success and failure of observation  $i$  respectively.

$\beta_0$  = log-odds when all  $x_{ji}$  are 0

$\beta_j$  = increase in log-odds when  $x_{ji}$  is increased by one unit,  $j=1, \dots, k$

For the dependent variable coefficients in logit are the effects of the predictor on log-odds.

Multicollinearity among independent variables was checked out by performing Variance Inflation Factor (VIF). The score of VIF greater than 10 is often used as an indication of potential multicollinearity in this study (Ghani and Ahmad 2010). Finally, the logistic regression model was performed in this study by using the library (aod) in R. The existence of the significant relationship between the dependent variable and independent variable(s) in the logistic model was analyzed by using wald test.

### 3.3.4. Software

#### 3.3.4.1. R V3.5.2 along with RStudio V1.1.456

R is a widely known statistical programming language for statistical computing and creating graphics. R provides many varieties of statistical and graphical techniques and methods. R has the ability to create publication-ready plots, including mathematical symbols, special characters and formulae. It runs on a wide variety of Linux-based platforms, Windows and MacOS. RStudio is a free available Integrated Development Environment for R and it helps to work with R interactively and user-friendly.

#### 3.3.4.2. Excel 2013

Microsoft Excel is a widely accepted spreadsheet developed by Microsoft and it compatible with Windows, MacOS and Android. It helps in various, data arranging, calculations, statistical analysis and create graphics.

#### **3.3.4.3. ArcGIS 10.0**

ArcGIS software is used for analysis, weighted overlay for optimal site selection. In this study, ArcGIS 10.0 software was used for map creation of study area.

# 4.RESULTS

## 4.1. Ocean-climatic parameters

### 4.1.1.Open access-derived parameters

#### 4.1.1.1. Chlorophyll-a concentration

The change in time series of chlorophyll-a concentration in seawater was detected at stratum level along with the entire the south west coast of India (SW). At ST\_1, all three homogeneity tests for time series as Pettitt's test, Buishand range test, and SNH test detected a significant shift in chlorophyll-a concentration during the period 2012. In the case of ST\_2, a significant shift was found in chlorophyll-a concentration during 2016 by SNH test. At ST\_3, a significant shift in chlorophyll-a concentration was detected during 2010 by Pettitt's test and Buishand range test, while the SNH test noticed that shift during 2011. But, in the consideration of all strata together, these three homogeneity tests observed three different points for the significant shifting in the trend of chlorophyll-a concentration over the SW as during 2010, 2011 and 2016 by Pettitt's test, Buishand range test and SNH test, respectively (Table 10).

According to changepoint analysis, a significant shift in time series of chlorophyll-a concentration was observed along ST\_1, ST\_2, ST\_3, and SW. A significant shift in time series of chlorophyll-a concentration at ST\_1 was found during 2002 and 2012 (Fig. 13), at ST\_2 during 2013 (Fig. 14), at ST\_3 during 2011 (Fig. 15) and SW during 2002 and 2011 (Fig. 16). In a strata-wise study of chlorophyll-a concentration, a significant correlation was observed between ST\_1 and ST\_3 (Table 19). The highest chlorophyll-a concentration was recorded along ST\_3 over the study period. The chlorophyll-a concentration was decreased continuously at both ST\_1 and ST\_3 after 2005 (Fig.17).

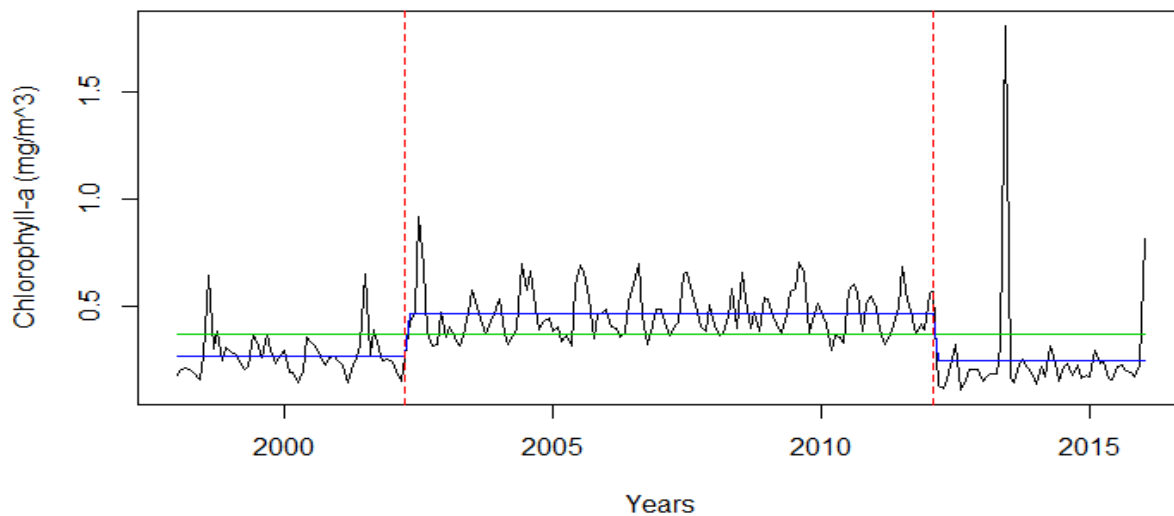
In the case of seasonal study for the chlorophyll-a concentration, monsoon showed the highest concentration in comparison to the other two seasons. A significant positive correlation was noticed between the pre-monsoon and post-monsoon period. Monsoon season also showed a continuously increasing trend, but

both pre-monsoon and post-monsoon had an increasing trend prior to 2010 and decreasing trend since 2010. However, the chlorophyll-a concentration was higher during post-monsoon prior to 2010 in comparison to pre-monsoon, but after 2010 a higher concentration of chlorophyll-a was noticed during pre-monsoon than that of post-monsoon (Fig. 18).

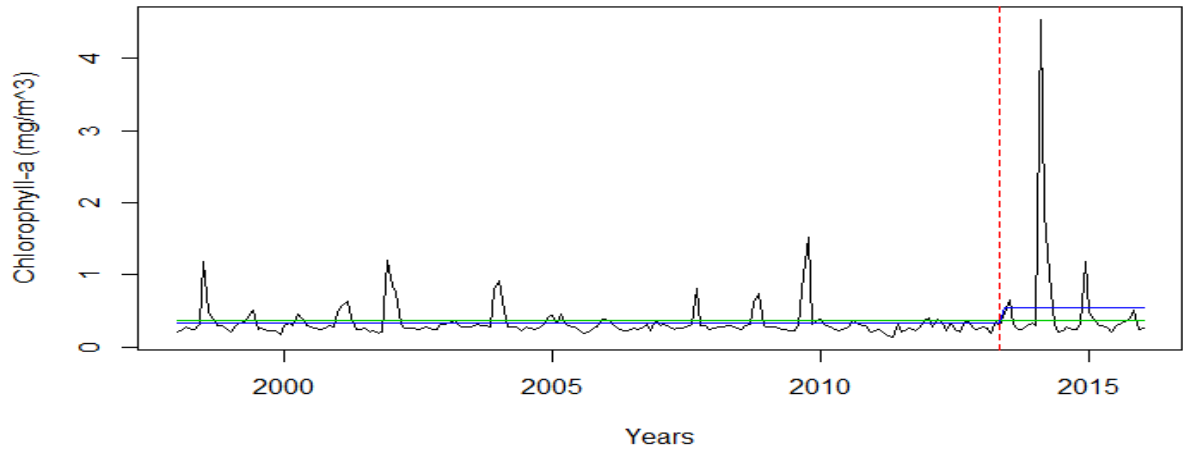
**Table 10: Homogeneity tests for chlorophyll-a concentration**

Tests	Regions			
	ST_1	ST_2	ST_3	SW
Pettitt's test	K=170 (2012) p = 6.913e-10	K=183 (2015) p = 0.6969	K=154 (2010) p = 0.00019	K=170 (2012) p = 1.598e-05
Buishand range test	K =170 (2012) p = 2.2e-16	K=193 (2016) p = 0.3202	K=153(2010) P = 0.00445	K=166(2011) p = 0.0428
Standard normal homogeneity (SNH) test	K=170 (2012) p = 5e-05	K=193 (2016) p = 2.2e-16	K=165 (2011) p = 0.0065	K=223 (2016) p = 2.2e-16

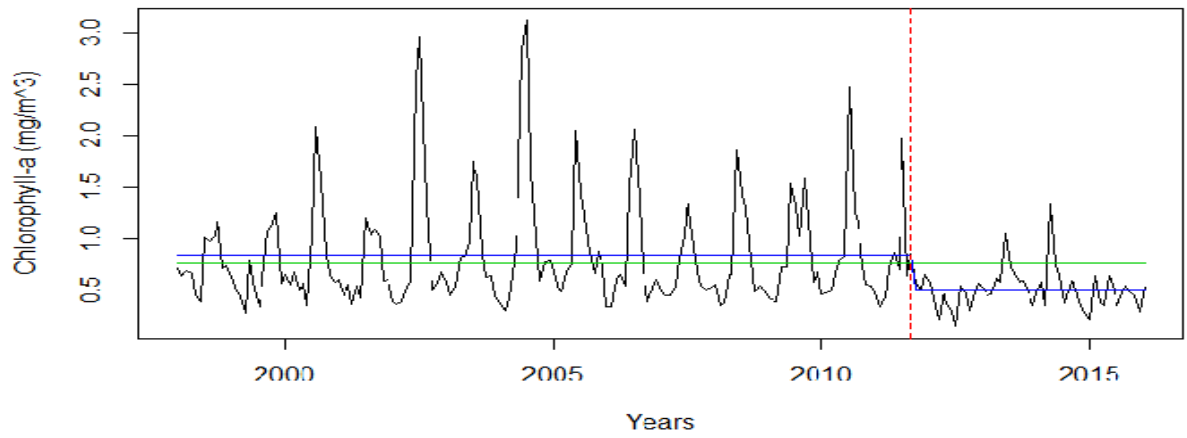
Where, K= Pettitt's test statistic, Buishand range test statistic and SNH test statistic



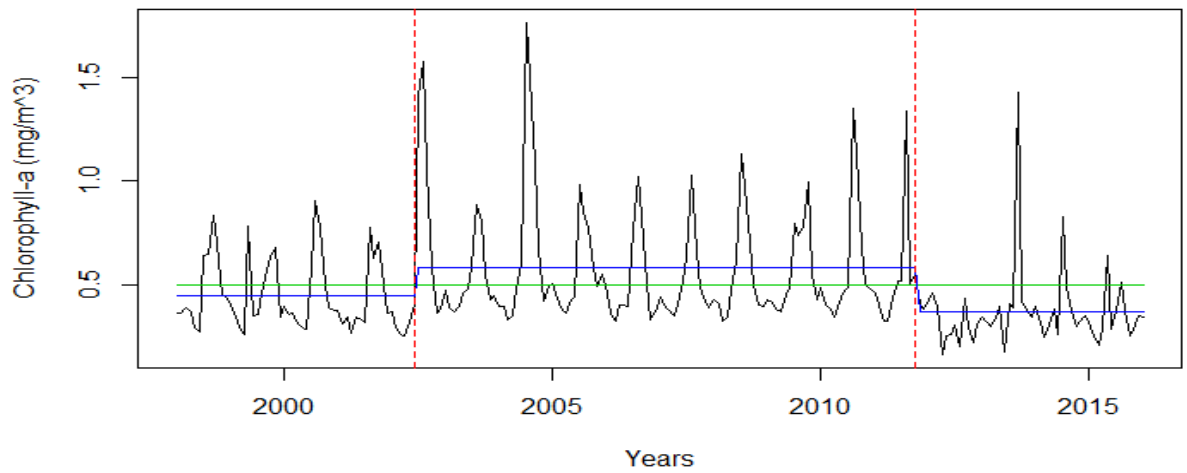
**Fig. 13: Trend of chlorophyll-a concentration at ST \_1**



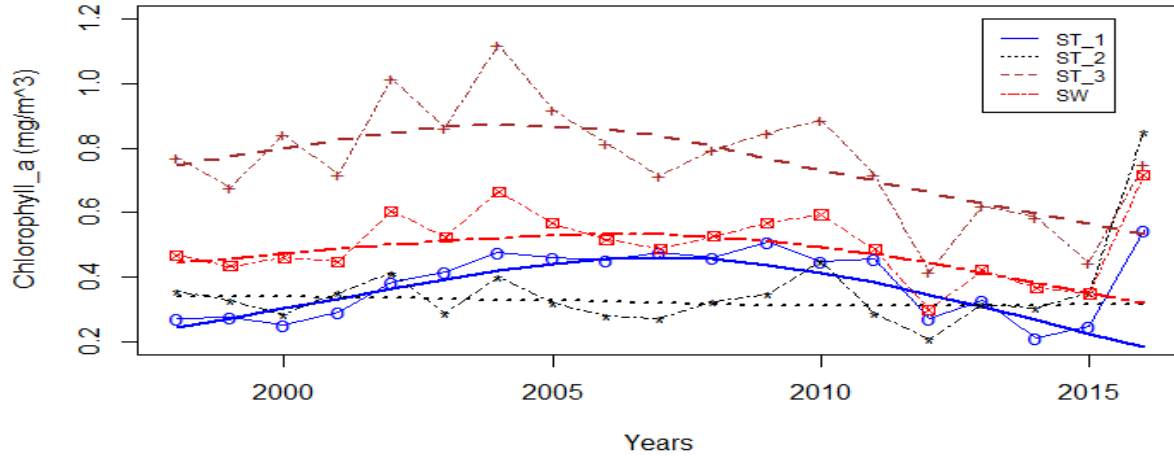
**Fig. 14: Trend of chlorophyll-a concentration at ST\_2**



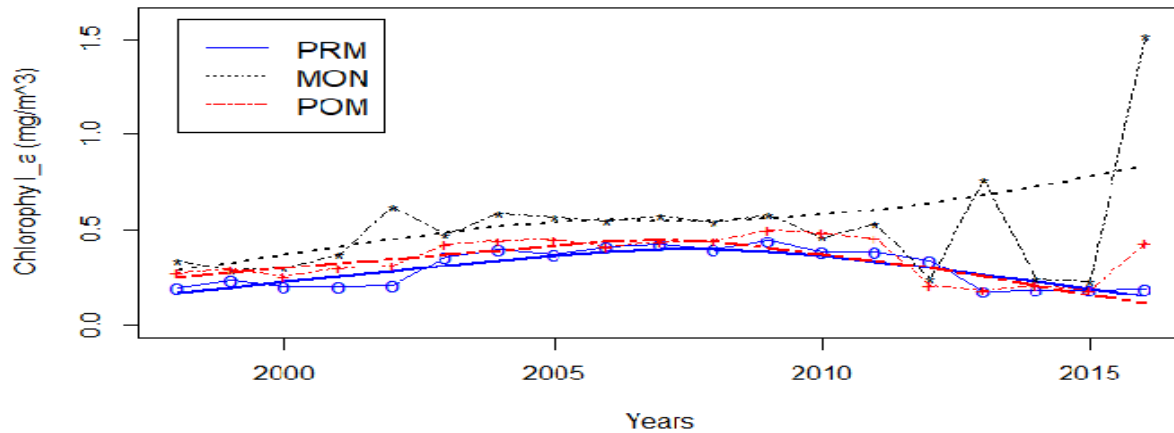
**Fig. 15: Trend of chlorophyll-a concentration at ST\_3**



**Fig. 16: Trend of chlorophyll-a concentration at SW**



**Fig. 17: Spatial comparison in the trend of chlorophyll-a concentration**



**Fig. 18: Temporal comparison in the trend of chlorophyll-a concentration**

#### 4.1.1.2. Sea Surface Temperature

Two homogeneity tests *i.e.* Pettitt's test and Buishand range tests showed the possibility of a slight shift in time series of SST at ST\_1 and ST\_2 during 1997 (Table 11), which was also supported by changepoint analysis where the possibility of the slight shift was recorded with higher SST after 1997 (Fig. 19 and 20). At ST\_3, the possibility of a slight shift in SST was detected in 2008 by two homogeneity tests including Pettitt's test and Buishand range test. The changepoint analysis also showed the possibility of a shift in SST during 2008 at ST\_3, where a higher SST was noticed after 2008 in comparison to the previous period (Fig. 21). Similar to ST\_1 and ST\_2, SW also showed the possibility of shifting in SST time

series during 1997 by Pettitt's test and Buishand range test. Furthermore, according to changepoint analysis, a possible shift with higher SST time series was observed during 1997 at the entire southwest coast of India (Fig.22).

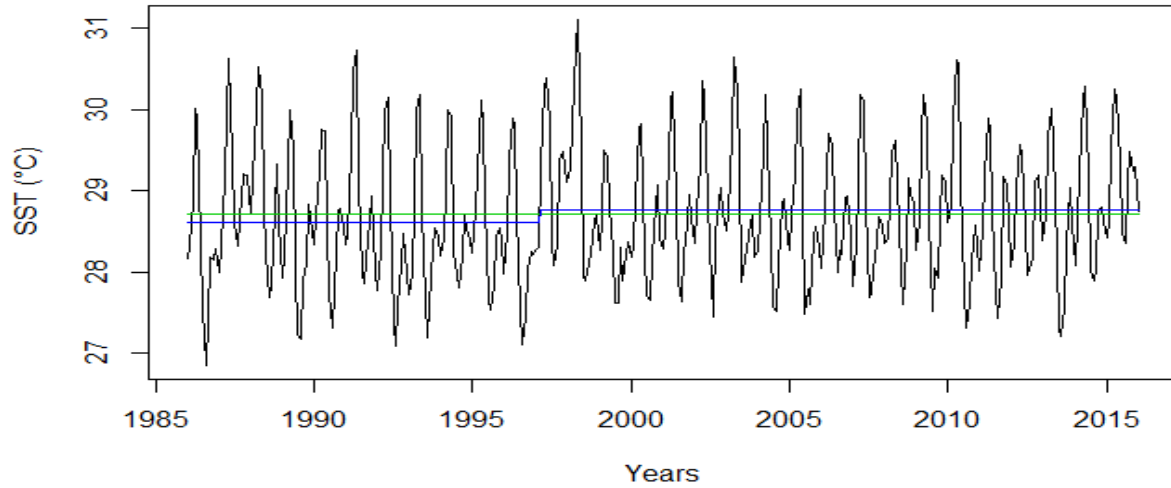
A significant correlation was found among strata for SST. The SST along all strata increased continuously during the study period since 1995. Southwest coast of India has a detectable latitudinal gradient in SST because SST reduced from its southern to the northern region. A very high and positive correlation in SST among strata was found in this study (Table 19), therefore the spatial plot for SST showed a similar pattern for rising in the temperature at three different strata (Fig. 23).

The season-wise trend of SST along the south west coast of India indicated a clear difference in SST during pre-monsoon, monsoon and post-monsoon, where SST of pre-monsoon and monsoon were the highest and lowest, respectively. Also, the SST of post-monsoon was always higher than that of monsoon. The seasonal plot of SST showed a rise in temperature for all seasons in this study after 1995 (Fig. 24), where a significantly positive correlation was also noticed for SST between pre-monsoon and monsoon, and monsoon and post-monsoon (Table19).

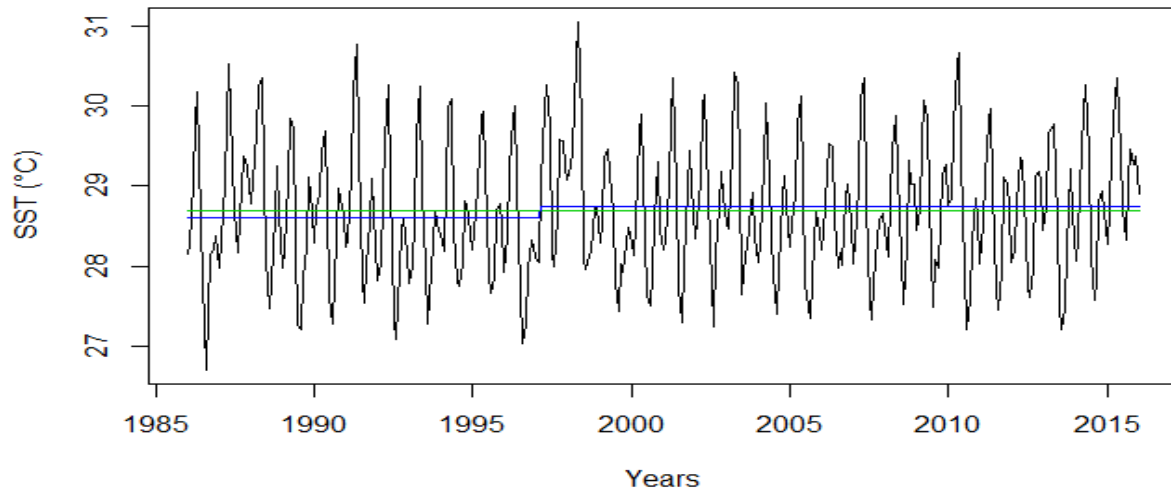
**Table 11: Homogeneity tests for sea surface temperature**

Tests	Regions			
	ST_1	ST_2	ST_3	SW
Pettitt's test	K=134(1997) p = 0.2933	K=134(1997) p = 0.5309	K=266(2008) p = 0.22871	K=134(1997) p = 0.3806
Buishand range test	K=134(1997) p = 0.4694	K=134(1997) p = 0.587	K=266(2008) p = 0.2243	K=134 (1997) p = 0.4663
SNH test	K=366(2016) p = 0.5207	K=366(2016) p = 0.5247	K=367(2016) p = 0.3269	K=366(2016) p = 0.4175

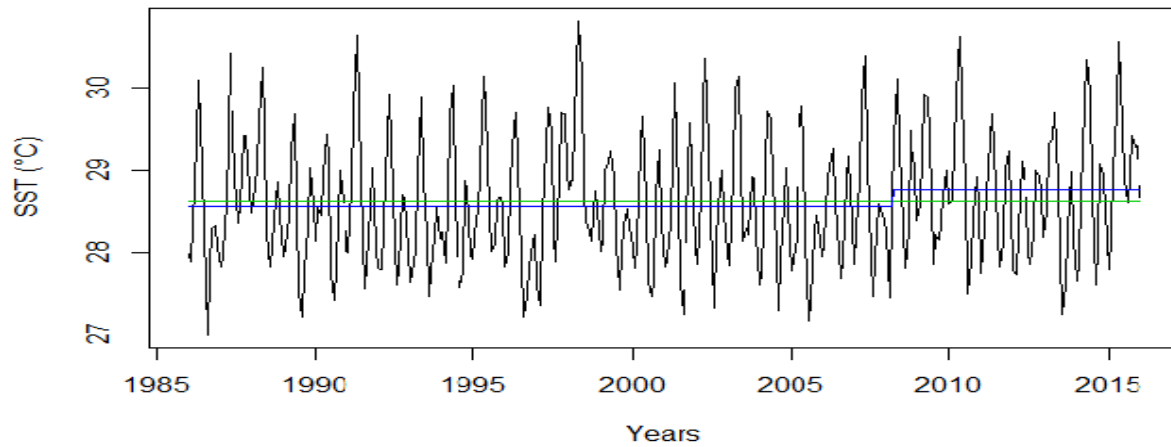
Where, K= Pettitt's test statistic, Buishand range test statistic and SNH test statistic



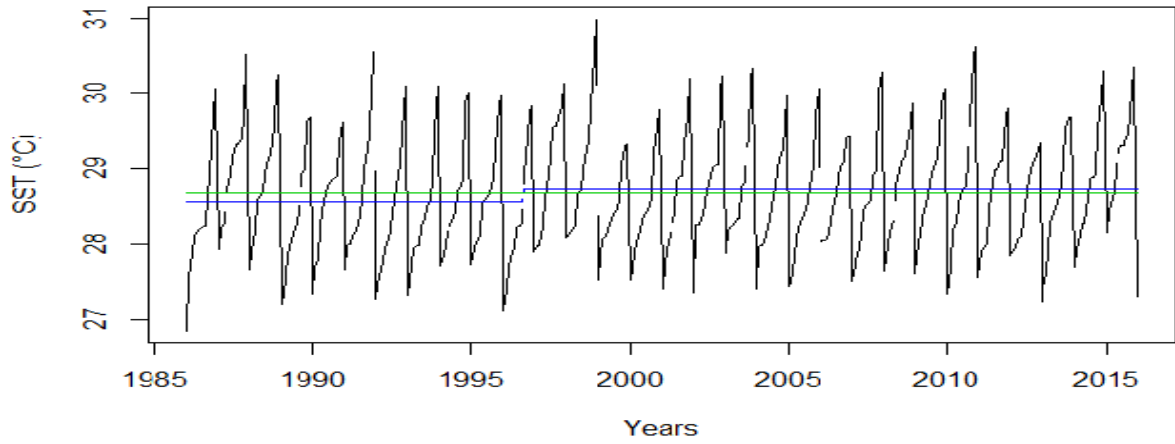
**Fig. 19: Trend of SST at ST\_1**



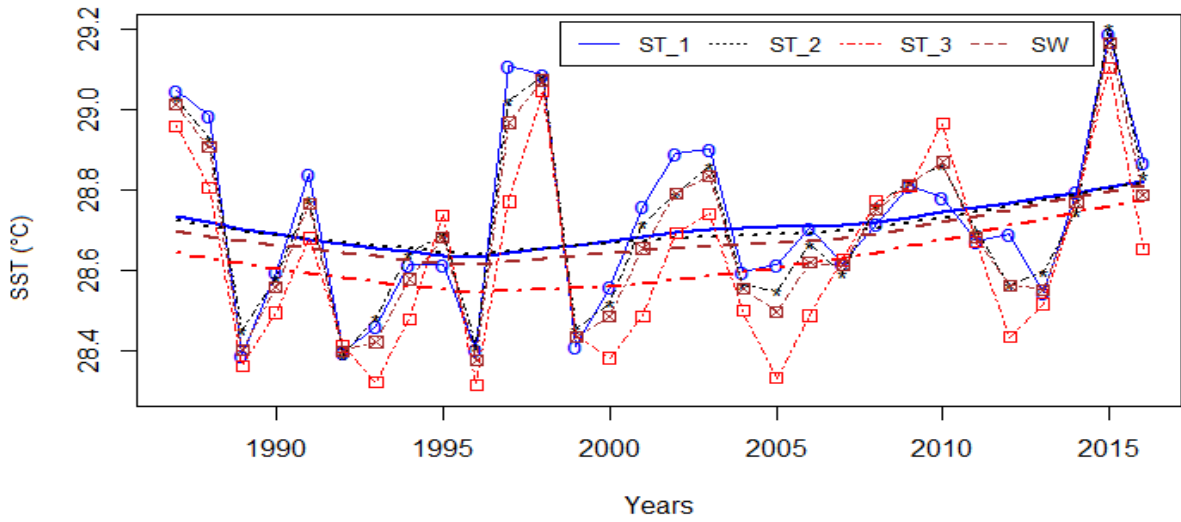
**Fig. 20: Trend of SST at ST\_2**



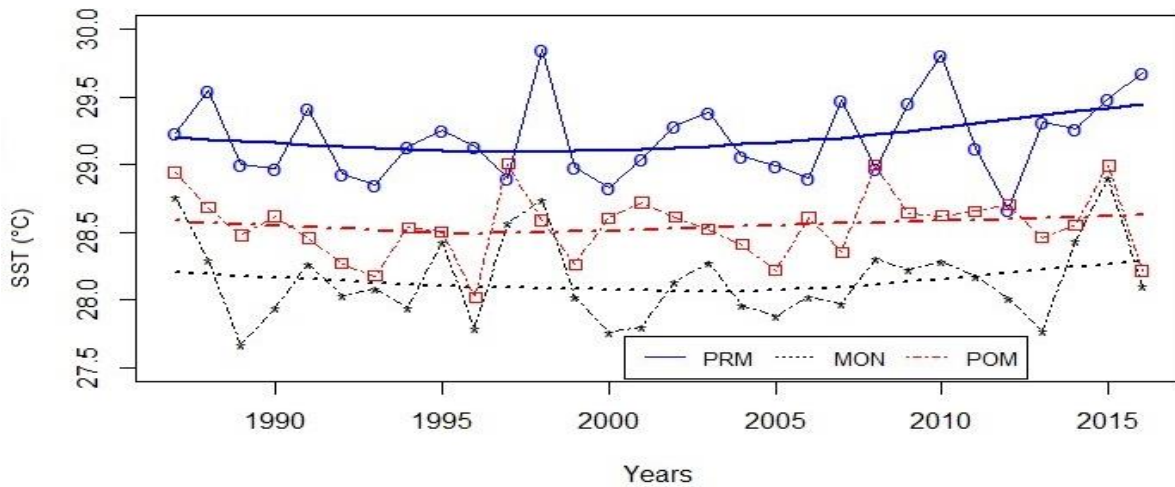
**Fig. 21: Trend of SST at ST\_3**



**Fig. 22: Trend of SST at SW**



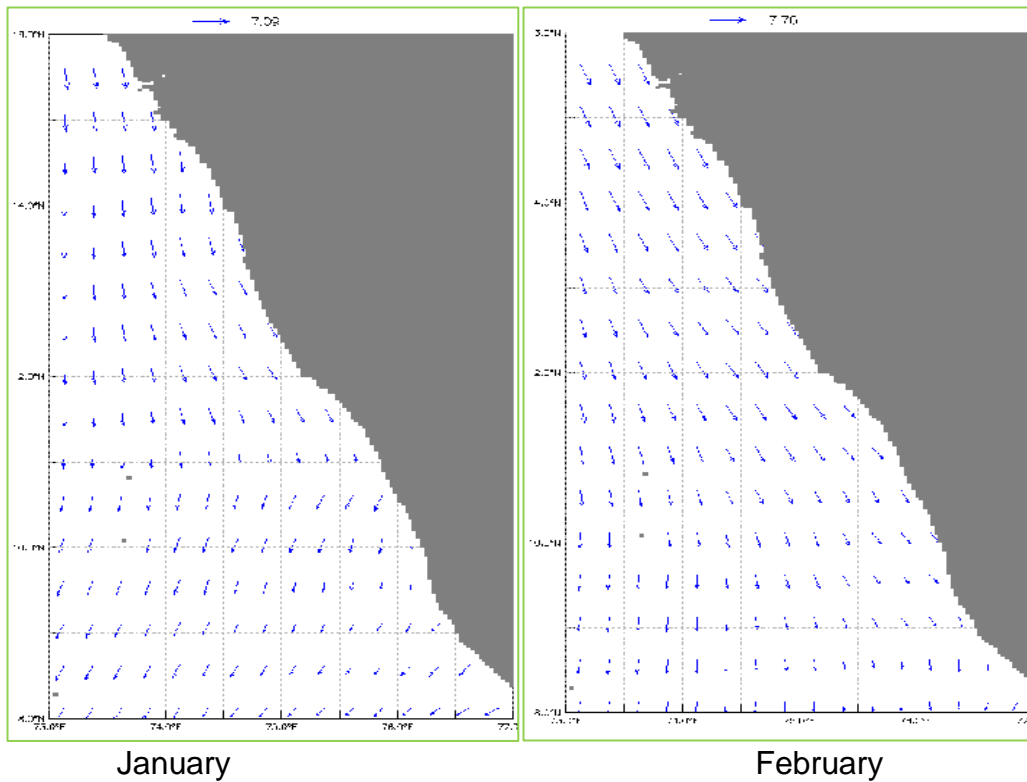
**Fig. 23: Spatial comparison in the trend of SST**



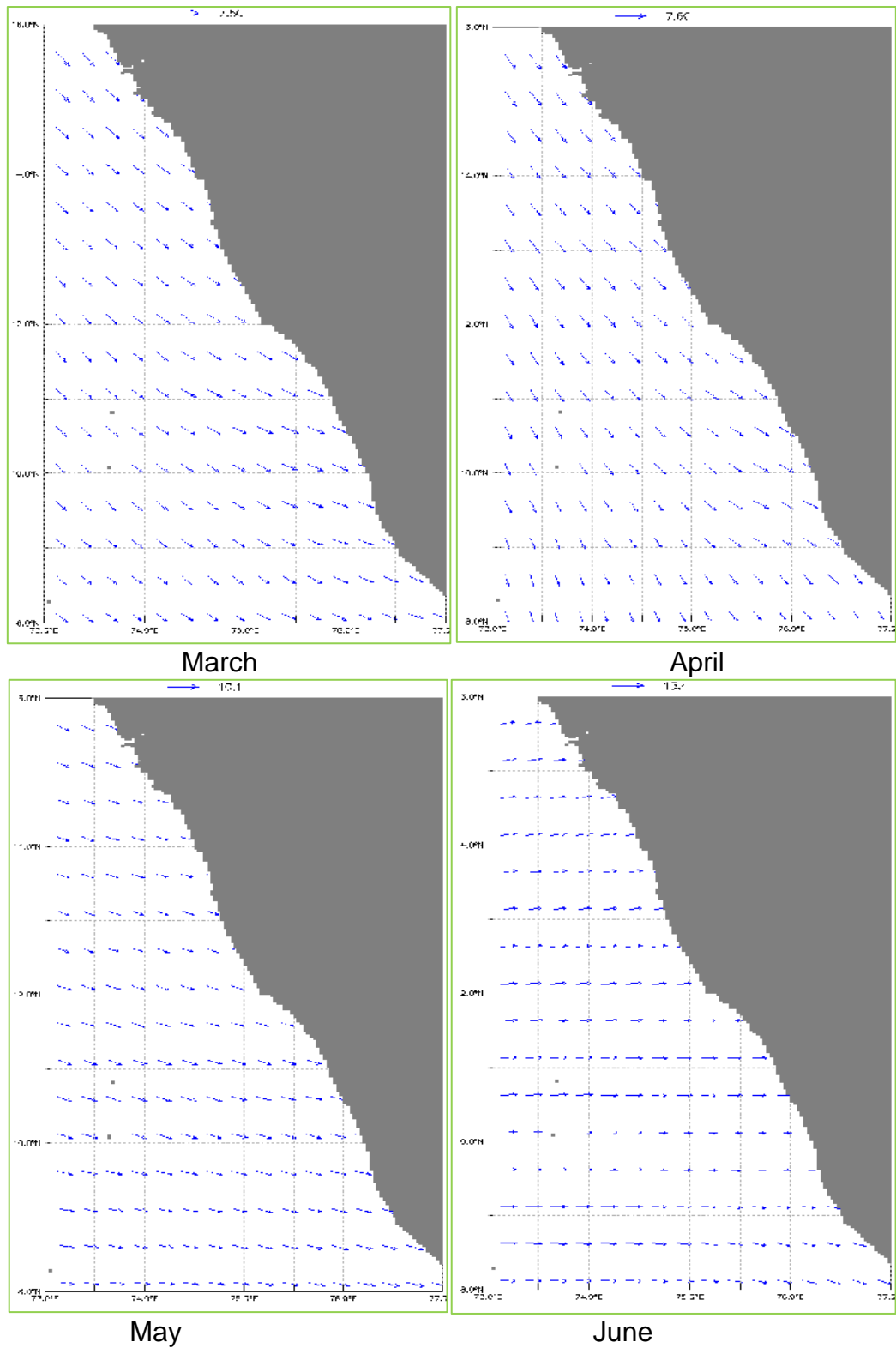
**Fig. 24: Temporal comparison in the trend of SST**

#### 4.1.1.3. Wind speed

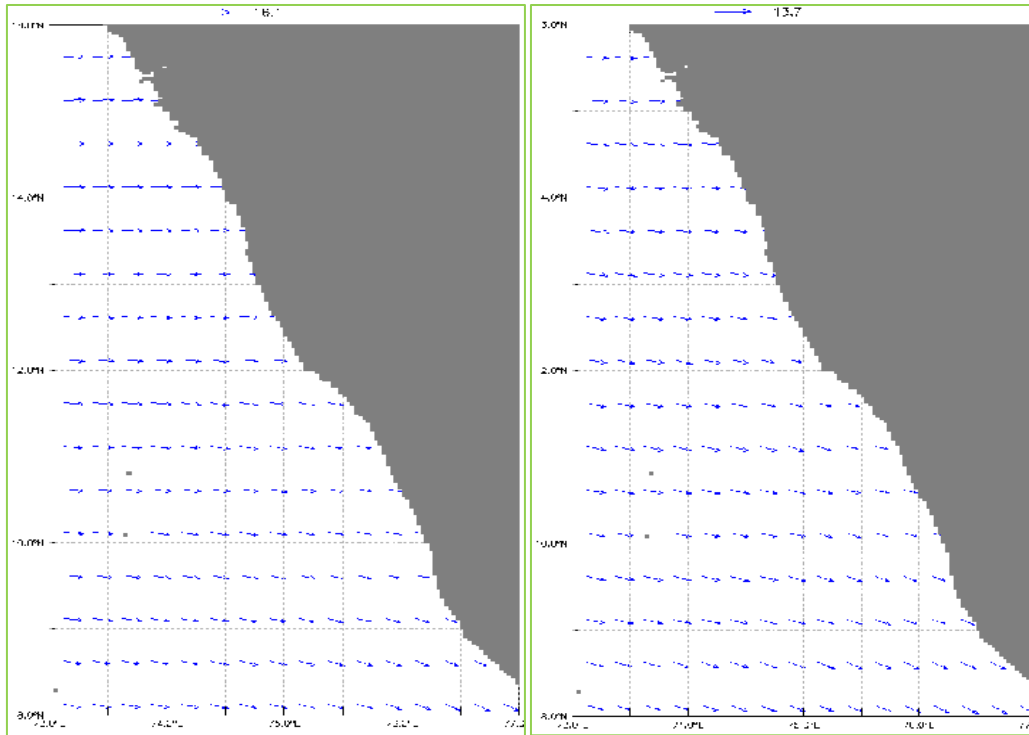
The wind speed started to increase from May (10.1 m/s) along south west coast of India and the speed reached at peak during July (16.1 m/s). The wind speed remained at high level up to August, but its speed was started to reduce from September after cessation of monsoon period. The month wise wind velocity has been shown in the figure 25, 26, 27 and 28.



**Fig. 25: Wind speed along south west coast of India during January and February**

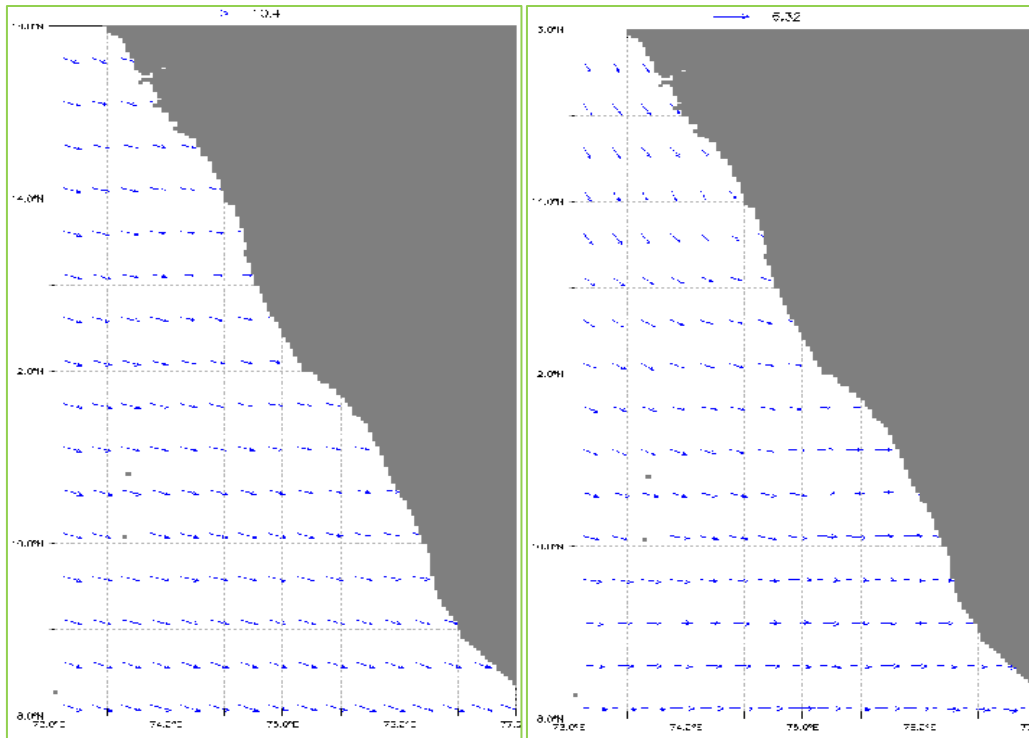


**Fig. 26: Wind speed along south west coast of India during March, April, May and June**



July

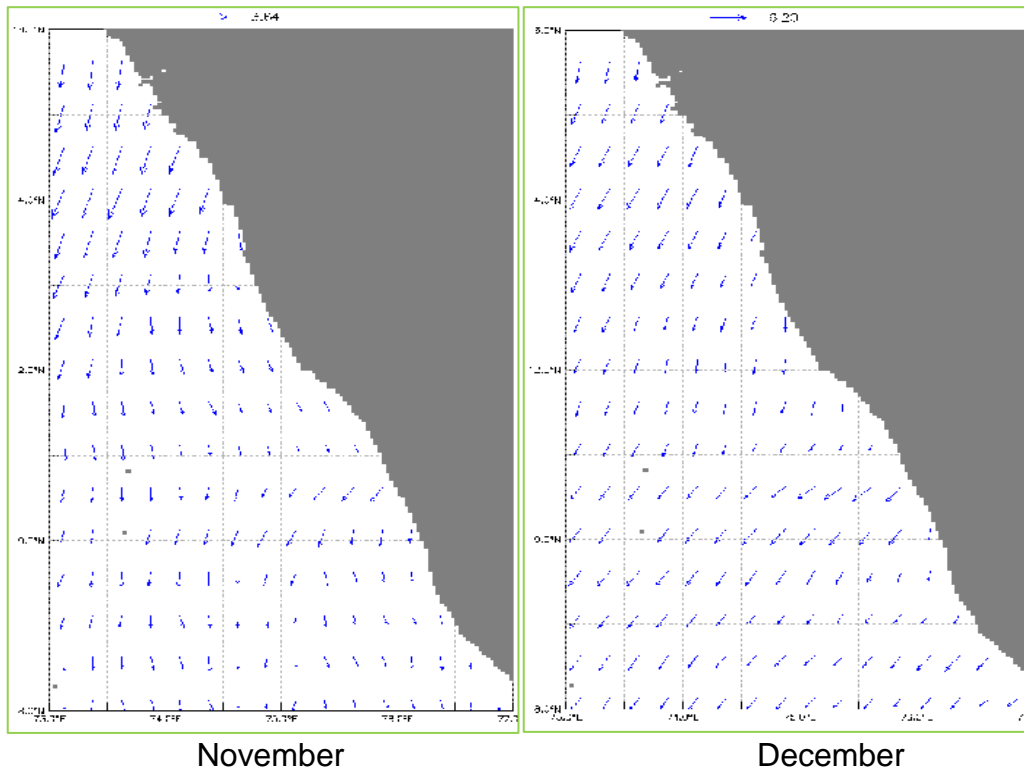
August



September

October

**Fig. 27: Wind speed along south west coast of India during July, August, September and October**



**Fig. 28: Wind speed along south west coast of India during November and December**

#### 4.1.1.3.1. Zonal wind speed

All homogeneity tests (Table 12) did not show any significant shift in the zonal wind at the south west coast of India during the study period. However, a small shift was found during 1994 at ST\_1 where the zonal wind speed was slightly lower after 1994 (Fig. 29). Similarly, the slightly lower zonal wind speed was noticed at ST\_2 (Fig. 30) and ST\_3 (Fig. 31) after 1993. Thus the overall reduction in zonal wind speed was observed at the south west coast of India after 1994 (Fig. 32). A significantly positive correlation among three strata has observed for the zonal wind speed, where the spatial plot of zonal wind speed also showed that the zonal wind speed was reduced over the period. In a comparison of zonal wind speed at strata, the result showed the lowest zonal wind at ST\_2 (Fig. 33).

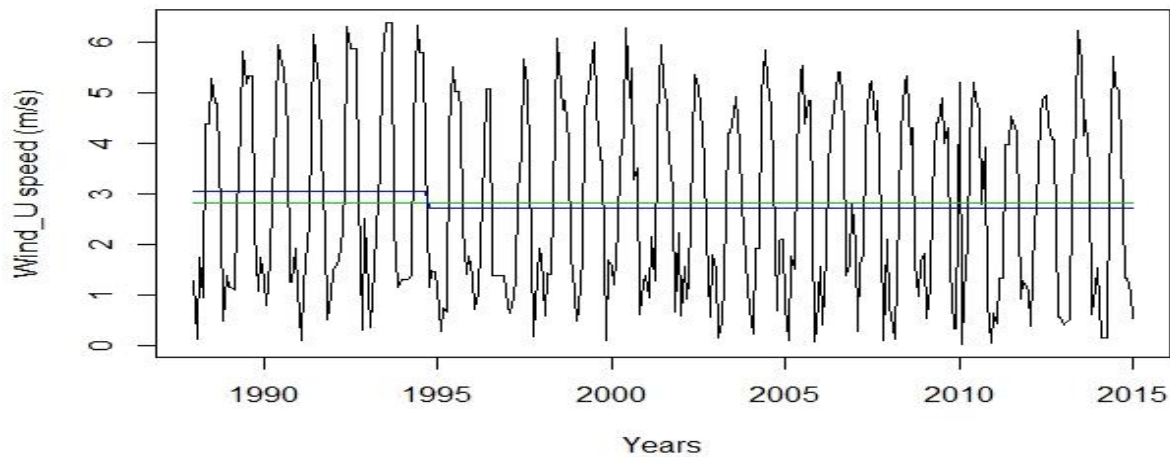
The seasonal analysis of zonal wind speed showed a significant correlation between monsoon and post-monsoon. The highest wind speed can be noticed during monsoon, followed by pre-monsoon and post-monsoon period. The

seasonal plot on zonal wind speed showed a decreasing trend during the monsoon period (Fig. 34).

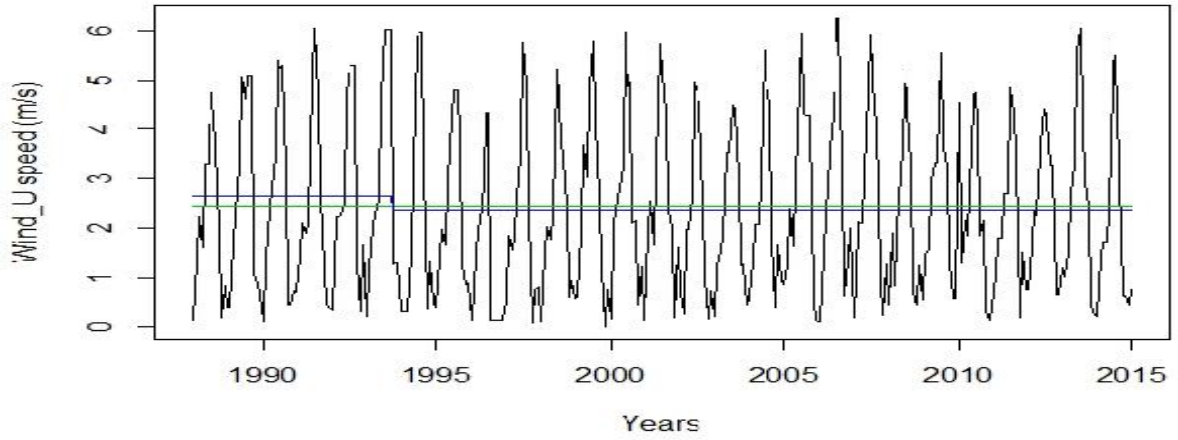
**Table 12: Homogeneity tests for zonal wind speed**

Tests	Regions			
	ST_1	ST_2	ST_3	SW
Pettitt's test	K=237 (2007) p = 0.4758	K=69 (1993) p = 1.367	K= 69 (1993) p = 1.458	K= 81 (1994) p = 1.04
Buishand range test	K =237 (2007) p = 0.9398	K=81 (1994) p = 0.9738	K=81(1994) p = 0.972	K=81 (1994) p = 0.96
SNH test	K= 4 (1988) p = 0.7351	K=321 (2014) p = 0.8974	K= 321 (2014) p = 0.9067	K=321 (2014) p = 0.9125

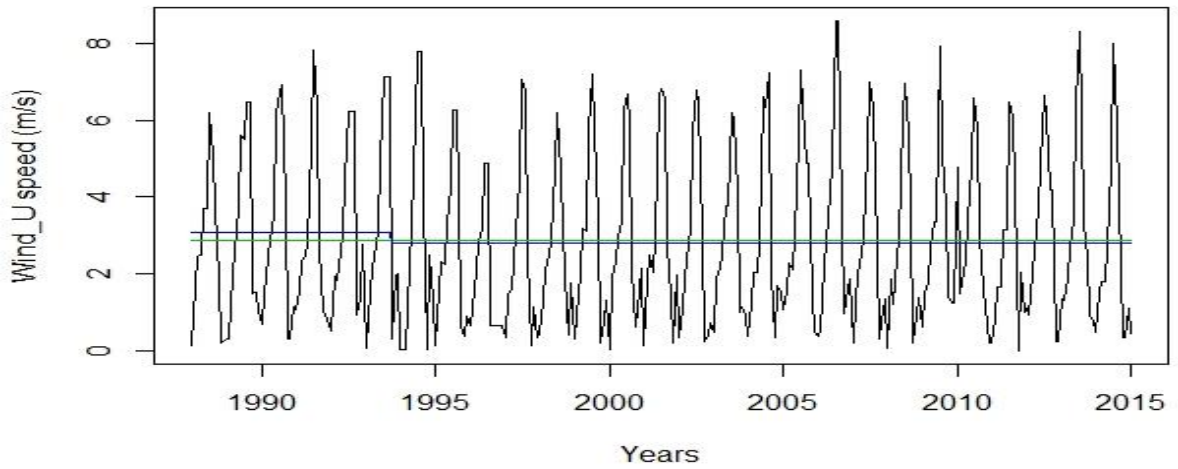
Where, K= Pettitt's test statistic, Buishand range test statistic and SNH test statistic



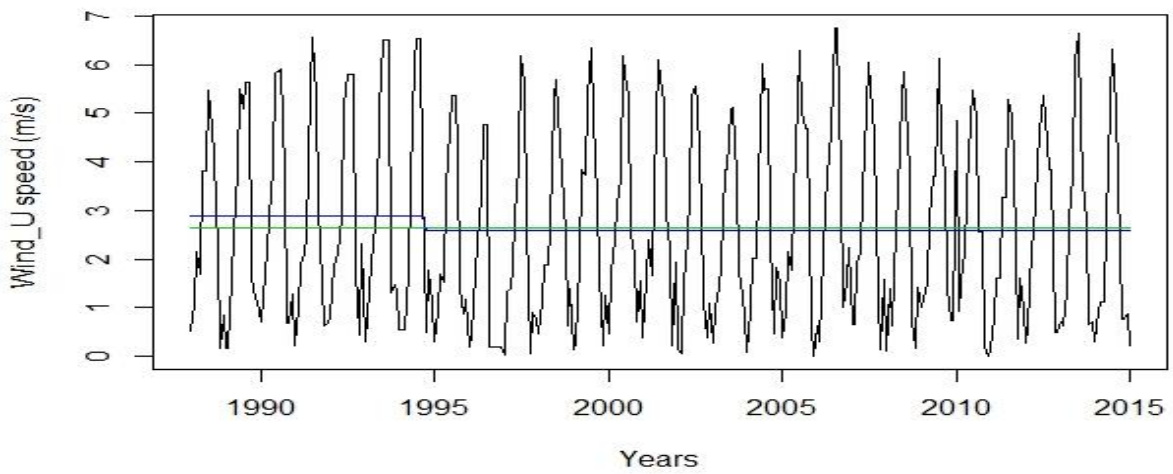
**Fig. 29: Trend of zonal wind speed at ST\_1**



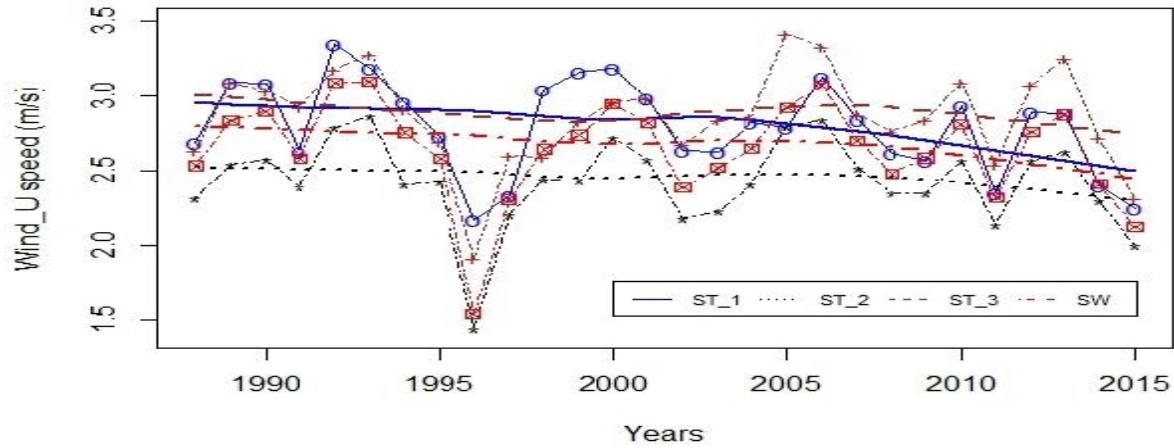
**Fig. 30: Trend of zonal wind speed at ST\_2**



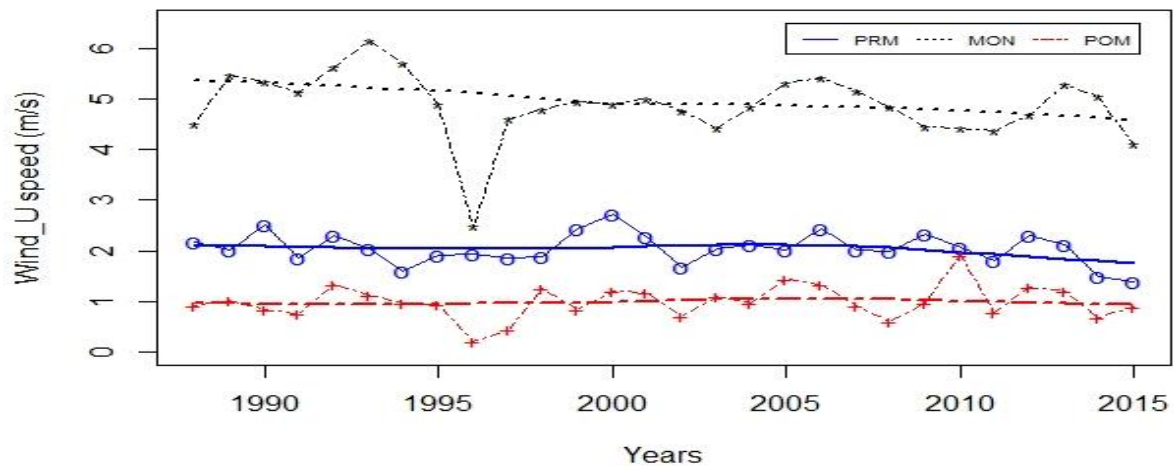
**Fig. 31: Trend of zonal wind speed at ST\_3**



**Fig. 32: Trend of zonal wind speed at SW**



**Fig. 33: Spatial comparison in the trend of zonal wind speed**



**Fig. 34: Temporal comparison in the trend of zonal wind speed**

#### 4.1.1.3.2. Meridional wind speed

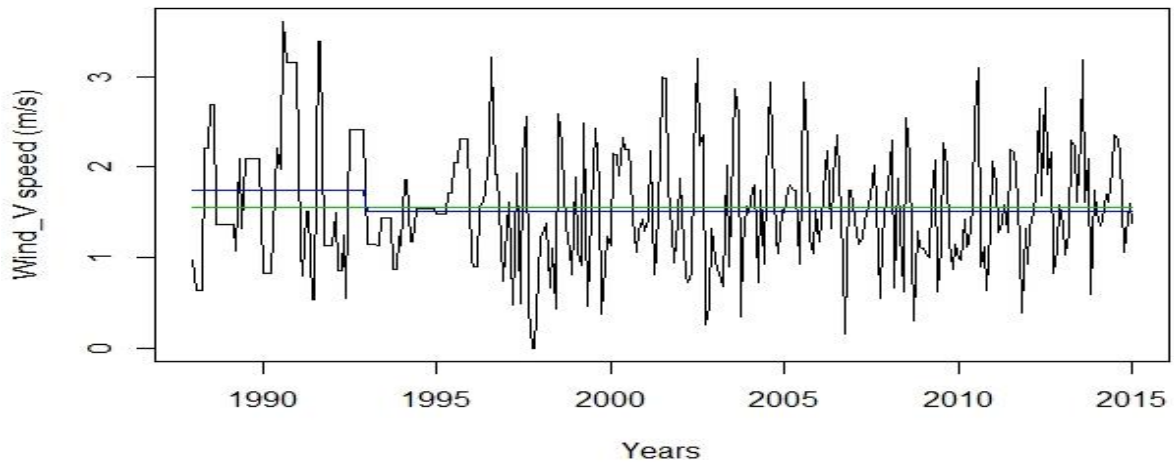
All three homogeneity tests and changepoint analysis did not show any significant shift in meridional wind speed over the study period along ST\_1 (Fig. 34) ST\_2 (Fig. 35) and SW (Fig. 36). But, according to both Pettitt's test and Buishand range test, a significant shift in meridional wind speed was observed during 2002, but SNH test detected a significant shift in 1992 at ST\_3 (Table 13). Similar to SNH test, the changepoint analysis found a significant shift at ST\_3 during 1992 (Fig. 37). Spatial plot over the period indicated the meridional wind speed was sliding downward at both ST\_1 and ST\_2, while the same had an upward trend at ST\_3 (Fig. 38). The significant positive correlations (0.62) were found between ST\_1 and ST\_2.

According to seasonal study, the meridional wind speed was continuously increasing during the pre-monsoon season, while that was continuously decreased during the monsoon period. Also, a negative correlation of meridional wind speed (-0.23) was found between pre-monsoon and monsoon season. On the other hand, a significant positive correlation (0.49) was noticed between monsoon and post-monsoon season. The result found that the meridional wind speed was higher during the pre-monsoon period compared to the other two seasons *i.e.* monsoon and post-monsoon. However, a seasonal change was observed in the plot for monsoon and post-monsoon meridional wind speed, where the meridional wind speeds during monsoon were higher in comparison to that of post-monsoon before 2000. But, a seasonal change brought a higher and lower meridional wind speed during post-monsoon and monsoon after 2000, respectively (Fig. 39).

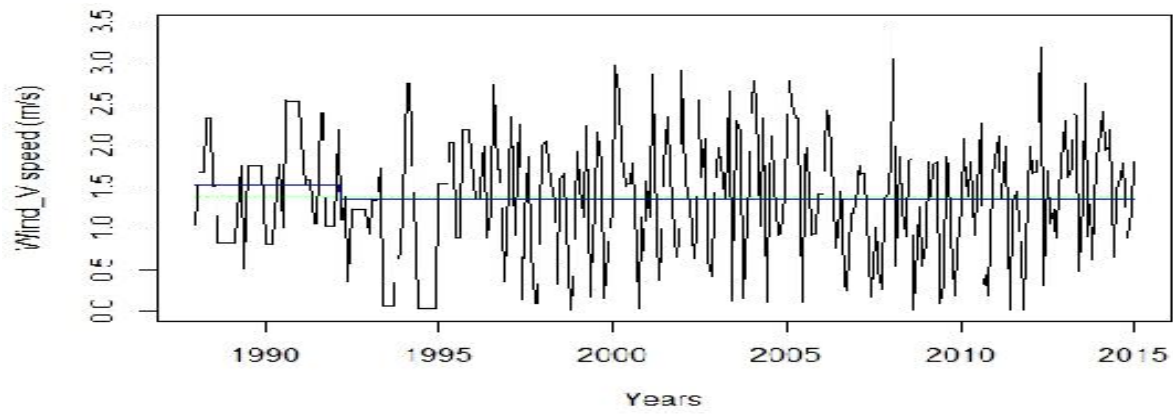
**Table 13: Homogeneity tests for meridional wind speed**

Tests	Regions			
	ST_1	ST_2	ST_3	SW
Pettitt's test	K=106 (1996) p = 0.4648	K=145 (2000) p = 0.5701	K= 179 (2002) p = 0.02144	K= 144 (1999) p = 0.1486
Buishand range test	K =106 (1996) p = 0.3157	K=145 (2000) p = 0.2132	K=179 (2002) p = 0.01185	K=144 (1999) p = 0.0747
SNH test	K= 37 (1991) p = 0.1689	K=288 (2011) p = 0.5668	K= 60 (1992) p = 0.00935	K=144 (1999) p = 0.2962

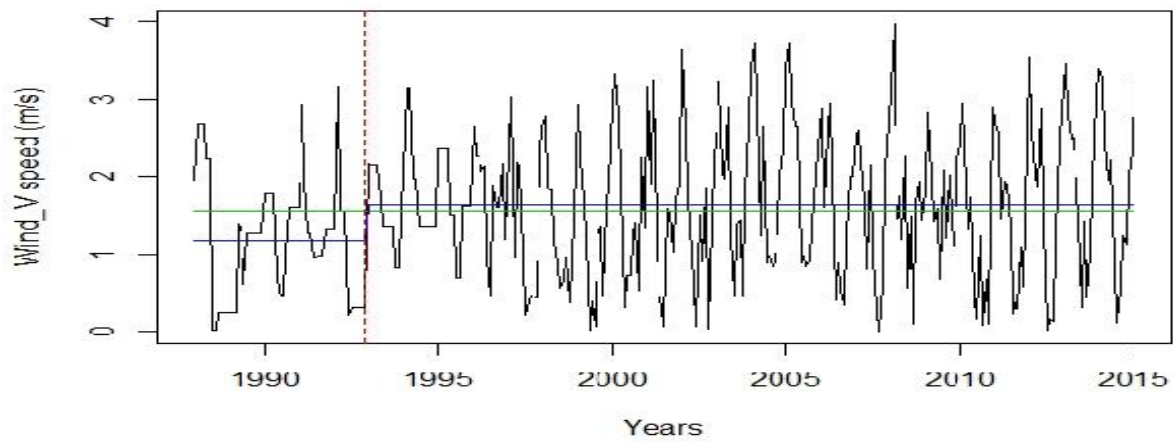
Where, K= Pettitt's test statistic, Buishand range test statistic and SNH test statistic



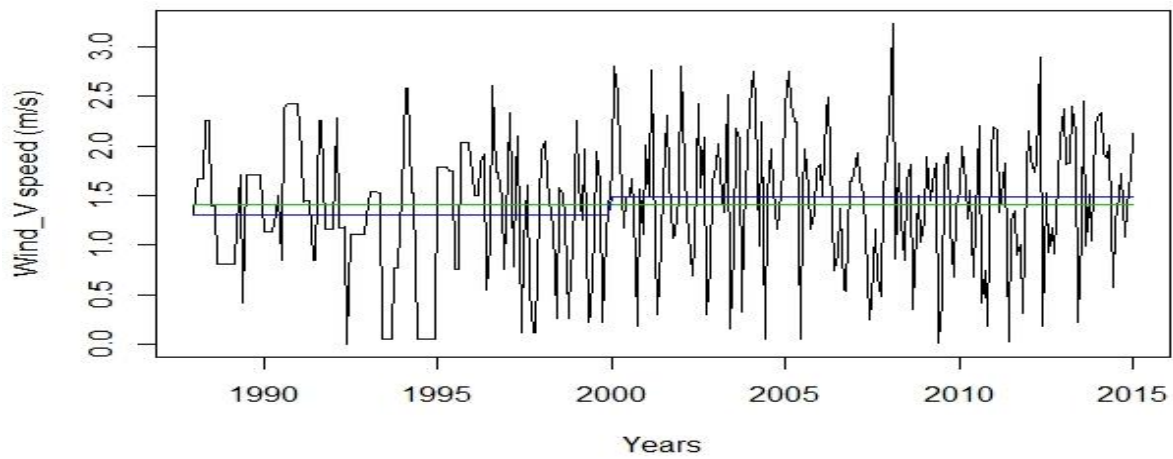
**Fig. 34: Trend of meridional wind speed at ST\_1**



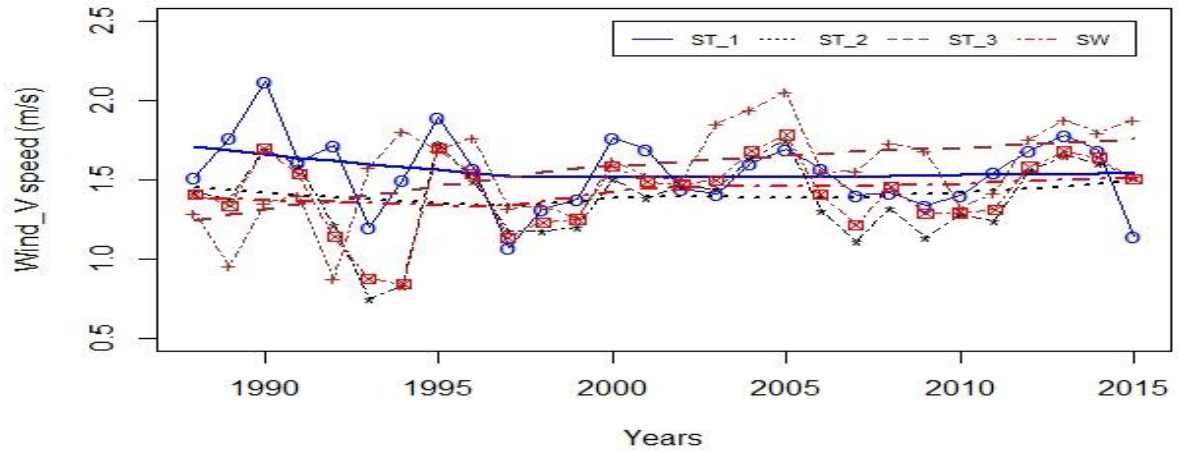
**Fig. 35: Trend of meridional wind speed at ST\_2**



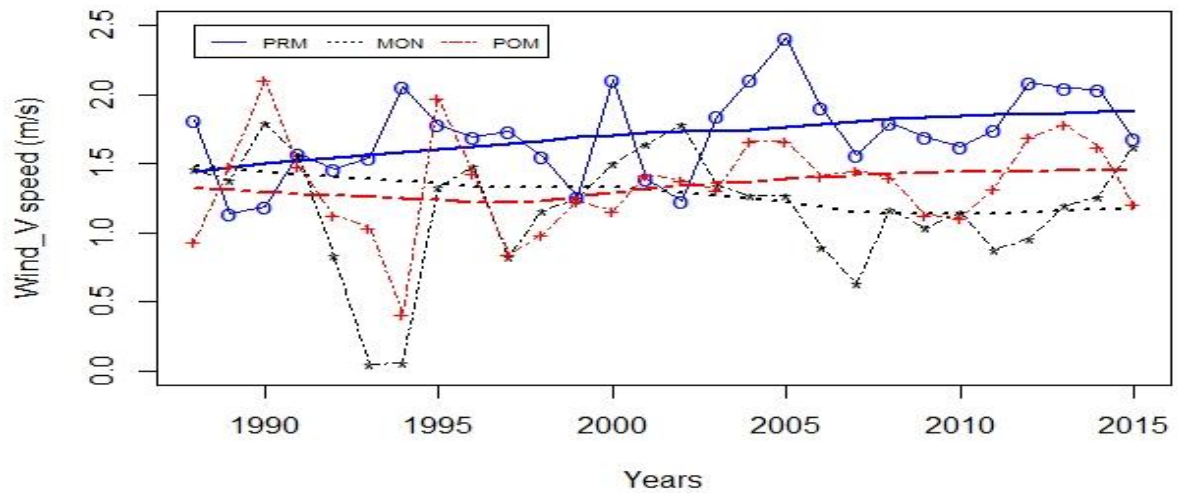
**Fig. 36: Trend of meridional wind speed at ST\_3**



**Fig. 37: Trend of meridional wind speed at SW**



**Fig. 38: Spatial comparison in the trend of meridional wind speed**



**Fig. 39: Temporal comparison in the trend of meridional wind speed**

#### 4.1.1.4. Upwelling index

All three homogeneity tests (Table 14) and changepoint analysis did not show any significant change in upwelling index within the study period along ST\_1 (Fig. 40) ST\_2 (Fig. 41), ST\_3 (Fig. 42) and SW (Fig. 43).

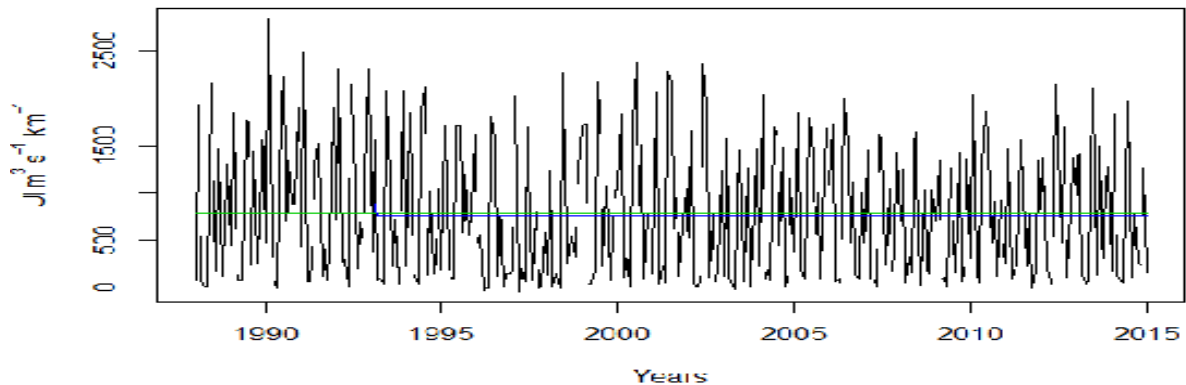
Proceeding with the stratum-wise study of upwelling index along the south west coast of India, it was found that ST\_1 had much higher upwelling index in comparison to other strata. The trend of upwelling index along ST\_1, ST\_2 and ST\_3 were more closely associated with each other, where the significant positive correlation was recorded between ST\_1 and ST\_2 (0.80), ST\_1 and ST\_3 (0.33), and

ST\_2 and ST\_3 (0.76). Spatial plot for upwelling index showed a continuously decreasing trend in upwelling index at all strata except from 1995 to 2000 at both ST\_2 and ST\_3 (Fig. 44). The seasonal comparison of upwelling index showed, the highest upwelling index was found during the monsoon period compare to other seasons. A decreasing trend was found for the upwelling index during both the pre-monsoon and monsoon season after 2005 (Fig. 45). All three seasons showed a positive correlation with each other in respect to the upwelling index.

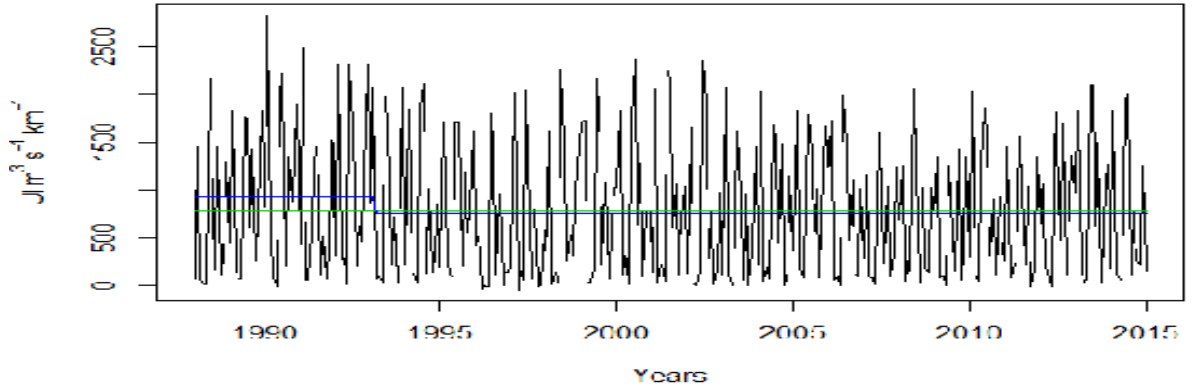
**Table 14: Homogeneity test for upwelling index**

Tests	Regions			
	ST_1	ST_2	ST_3	SW
Pettitt's test	K=95 (1995) p = 0.6881	K=45 (1991) p = 1.232	K=144 (1999) p = 0.1212	K=141 (1999) p = 1.025
Buishand range test	K =69 (1993) p = 0.8171	K=224 (2006) p = 0.8929	K=137(1999) p = 0.06575	K=230 (2007) p = 0.751
SNH test	K=4 (1988) p = 0.7503	K=333 (2015) p = 0.5694	K=137 (1999) p = 0.1738	K=2(1988) p = 0.4915

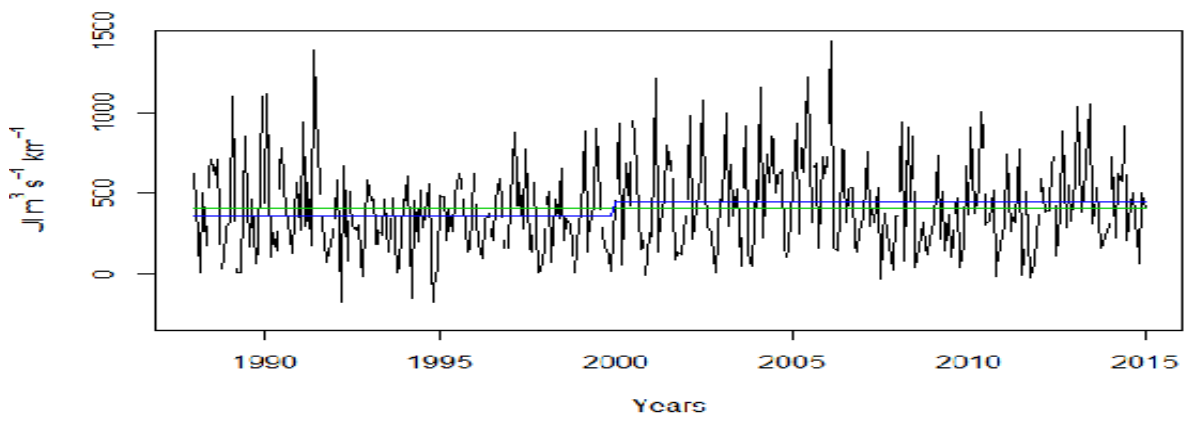
Where, K= Pettitt's test statistic, Buishand range test statistic and SNH test statistic



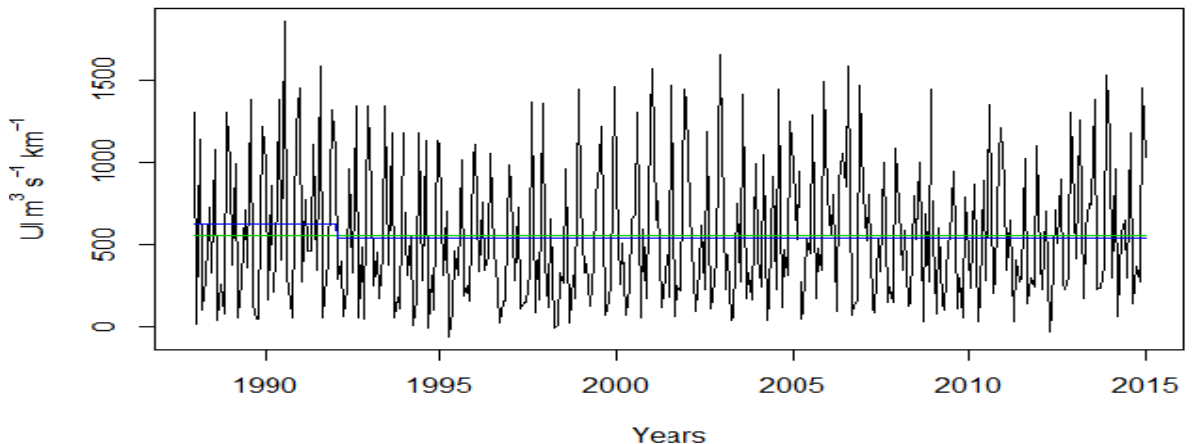
**Fig. 40: Trend of upwelling index at ST\_1**



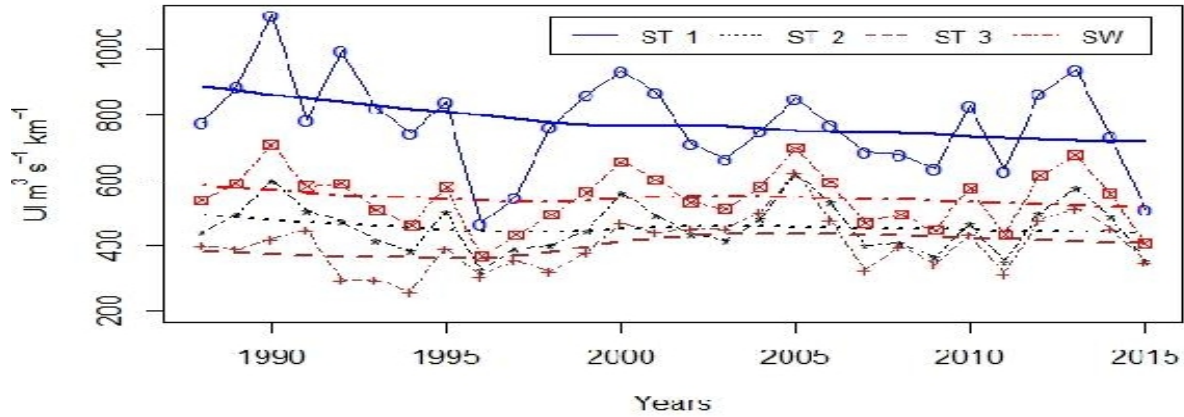
**Fig. 41: Trend of upwelling index at ST\_2**



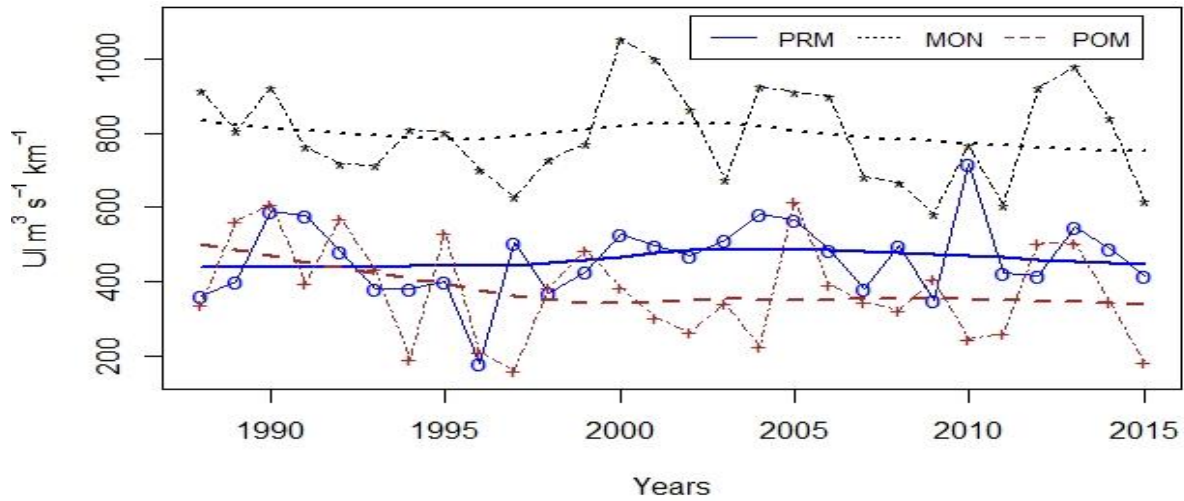
**Fig. 42: Trend of upwelling index at ST\_3**



**Fig. 43: Trend of upwelling index at SW**



**Fig. 44: Spatial comparison in the trend of upwelling index**



**Fig. 45: Temporal comparison in the trend of upwelling index**

#### 4.1.1.5. Zonal current speed

All three homogeneity tests for time series of zonal current speed found significant shifting at ST\_1 during 2000 (Table 15). Similarly, changepoint analysis detected the significant shift in time series of zonal current speed at ST\_1 during 2000. The zonal current speed at ST\_1 was significantly lower after 2000 as compared to the previous period (Fig. 46). In regards to ST\_2 (Fig. 47), ST\_3 (Fig. 48) and SW (Fig. 49), there was a slight shift in the zonal current speed.

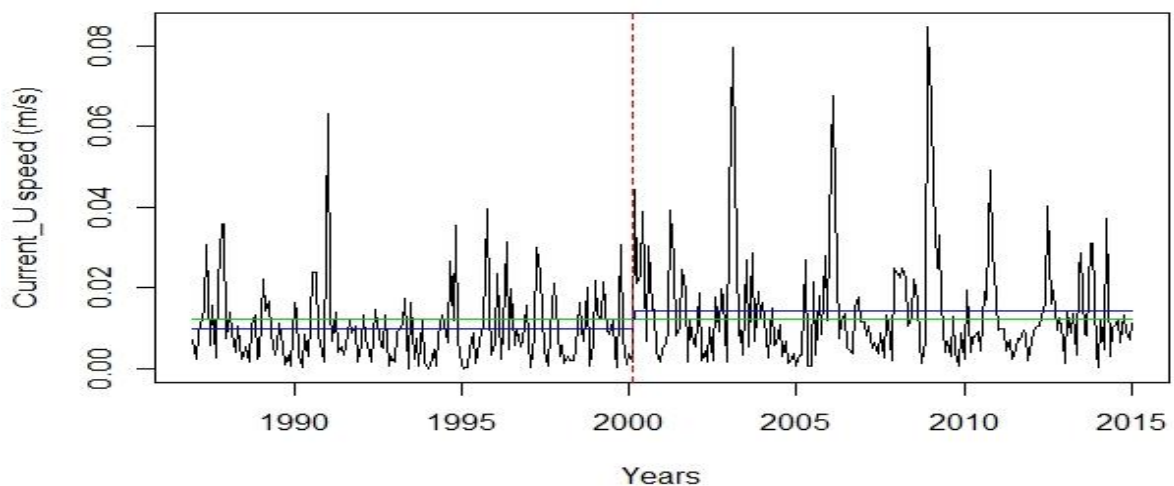
The study showed that the zonal current speed along ST\_1 and ST\_2 had an increasing trend up to 2005, later on, it decreased throughout of study period. In the case of ST\_3, zonal current speed had a continuous decreasing trend. A

positive correlation (0.24) was found in zonal current speed between ST\_1 and ST\_3. Among all three strata, the highest zonal current speed was found at ST\_2, followed by ST\_3 and ST\_1 (Fig. 50). In the case of seasonal study of zonal current speed, the major changes were found during monsoon season, where the zonal current speed has decreased continuously. However, the zonal current speed during both pre-monsoon and post-monsoon showed the increasing trend (Fig. 51). A significantly negative correlation between zonal current speed of pre-monsoon and monsoon (-0.37) as post-monsoon and monsoon (-0.31) was found in this study (Table 19).

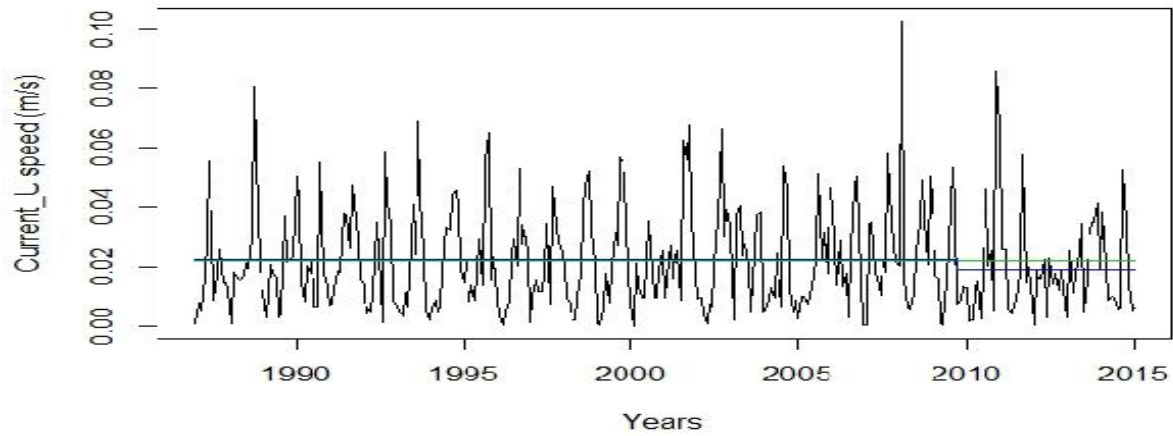
**Table 15: Homogeneity test for zonal current speed**

Tests	Regions			
	ST_1	ST_2	ST_3	SW
Pettitt's test	K= 158 (2000) p = 0.01589	K=265 (2009) p = 0.6393	K=270 (2009) p = 0.6456	K=262(2008) p = 0.7278
Buishand range test	K=158 (2000) p = 0.0137	K=265 (2009) p = 0.6546	K=104 (1995) p = 0.8371	K= 254 (2008) p = 0.5761
SNH test	K= 158 (2000) p = 0.04155	K=291 (2011) p = 0.8036	K=104 (1995) p = 0.9207	K= 262 (2008) p = 0.7115

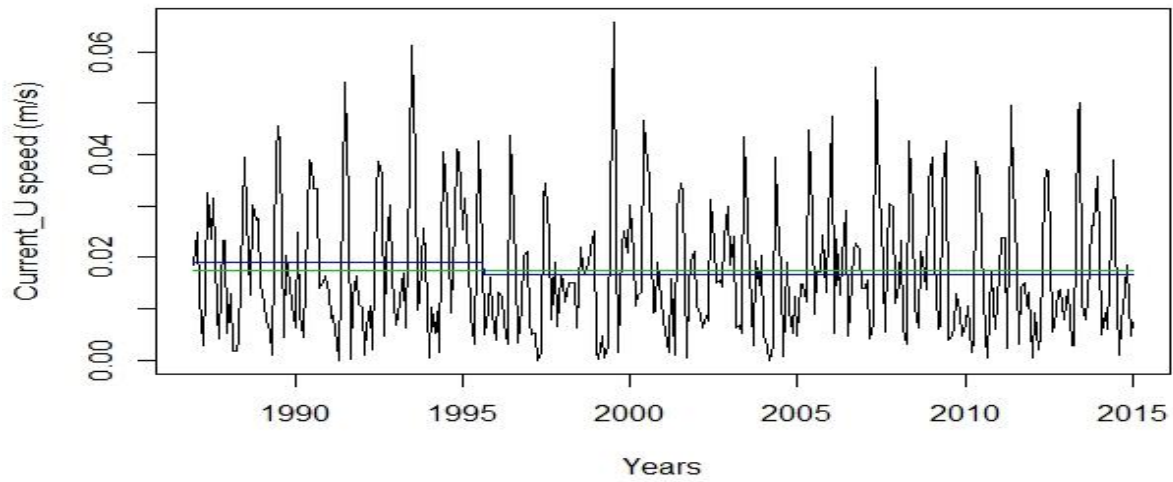
Where, K= Pettitt's test statistic, Buishand range test statistic and SNH test statistic



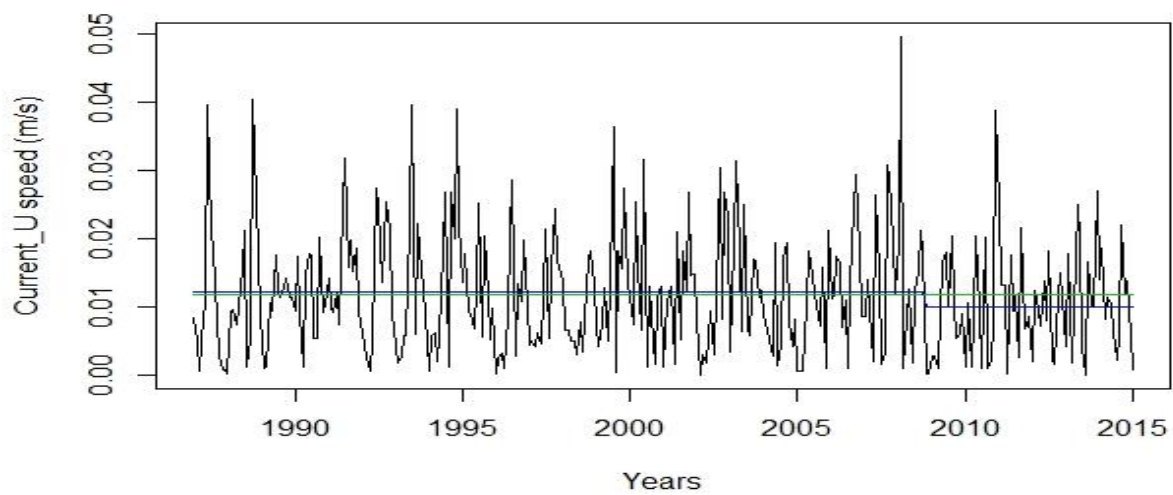
**Fig. 46: Trend of zonal current speed at ST\_1**



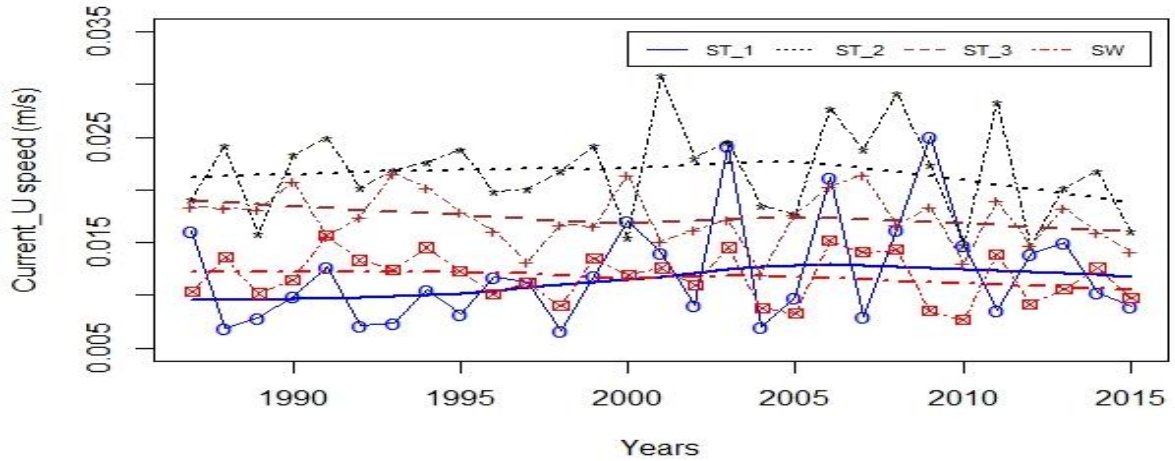
**Fig. 47: Trend of zonal current speed at ST\_2**



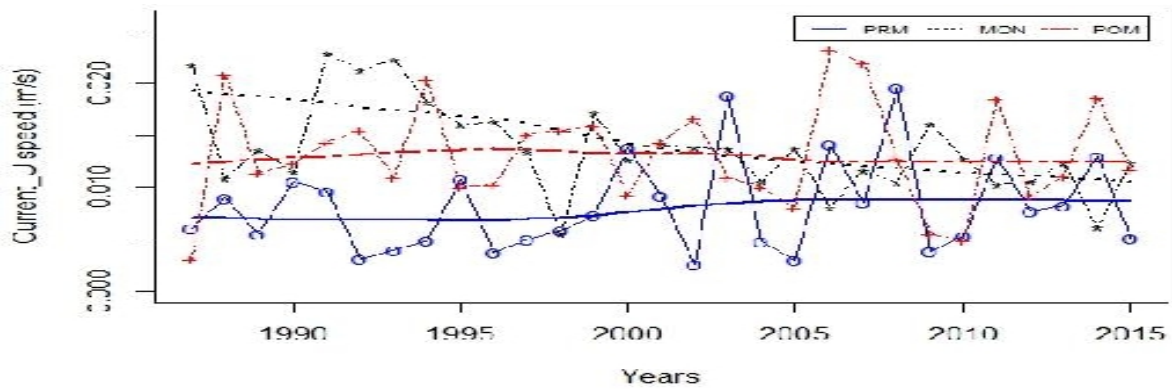
**Fig. 48: Trend of zonal current speed at ST\_3**



**Fig. 49: Trend of zonal current speed at SW**



**Fig. 50: Spatial comparison in the trend of zonal current speed**



**Fig. 51: Temporal comparison in the trend of zonal current speed**

#### 4.1.1.6. Meridional current speed

The meridional current speed at ST\_1 had a significant shift by Pettitt's test during 2005 (Table 16). However, SNH test and changepoint analysis also detected a small shift in the time series data during 2005, where changepoint analysis showed slightly higher meridional current speed after 2005 (Fig. 52). Similar to ST\_1, meridional current speed was higher at ST\_2 (Fig. 53), ST\_3 (Fig. 54) and SW (Fig. 55) after 2010, 2006 and 2008, respectively.

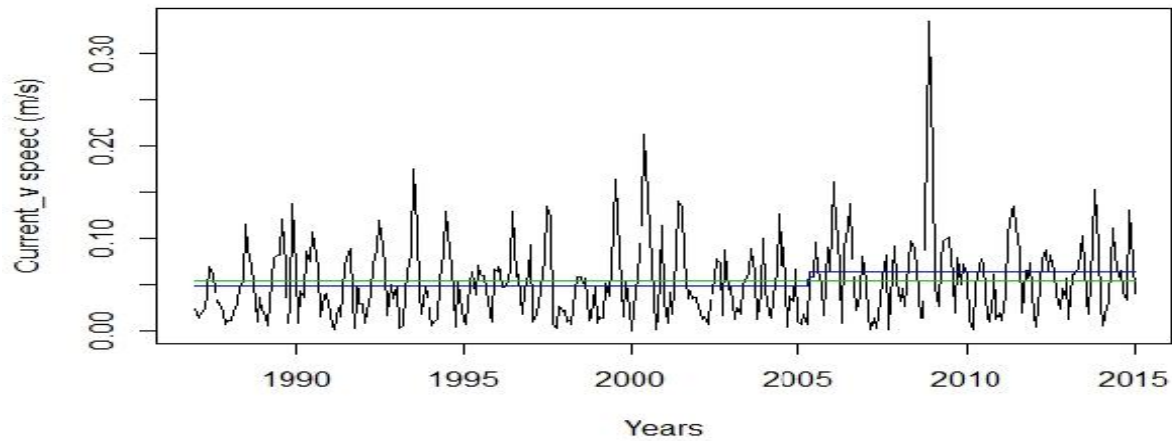
Among three strata, the lowest meridional current speed was found at ST\_2. A decreasing and increasing trend of meridional current speed was for ST\_3 and ST\_1 (Fig. 56). In the case seasonal analysis, The meridional current speed in the study showed the increasing trend for post-monsoon, at the same period

monsoon and pre-monsoon had decreasing trend of meridional current speed (Fig. 57).

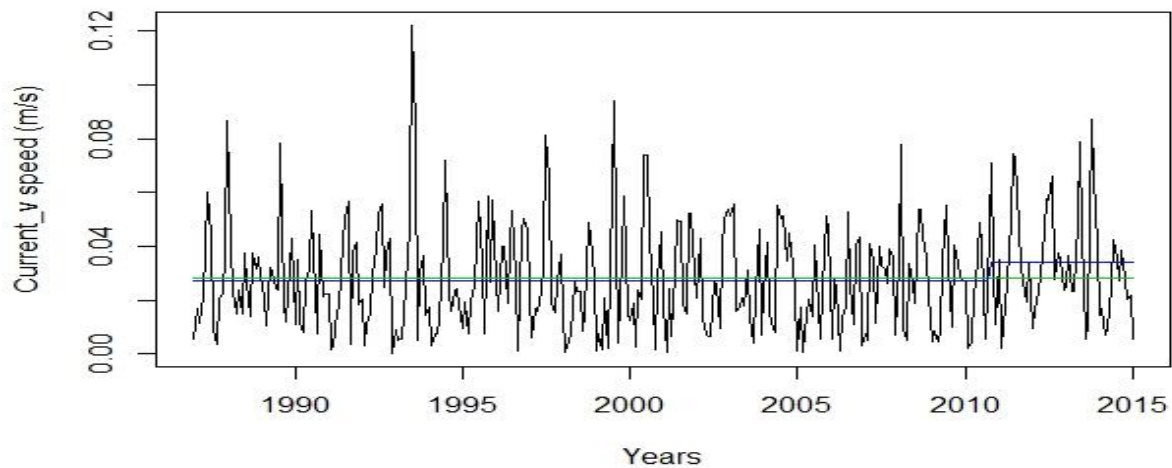
**Table 16: Homogeneity test for meridional current speed**

Tests	Regions			
	ST_1	ST_2	ST_3	SW
Pettitt's test	K=220 (2005) p = 0.0397	K=242 (2007) p = 0.5016	K=83 (1993) p = 0.9613	K=245 (2007) p = 0.4318
Buishand range test	K=149 (1999) p = 0.1689	K=281 (2010) p = 0.7078	K=229 (2006) p = 0.6614	K=149 (1999) p = 0.8902
SNH test	K=220 (2005) p = 0.1381	K=292 (2011) p = 0.7029	K=229 (2006) p = 0.9819	K= 28 (1989) p = 0.8222

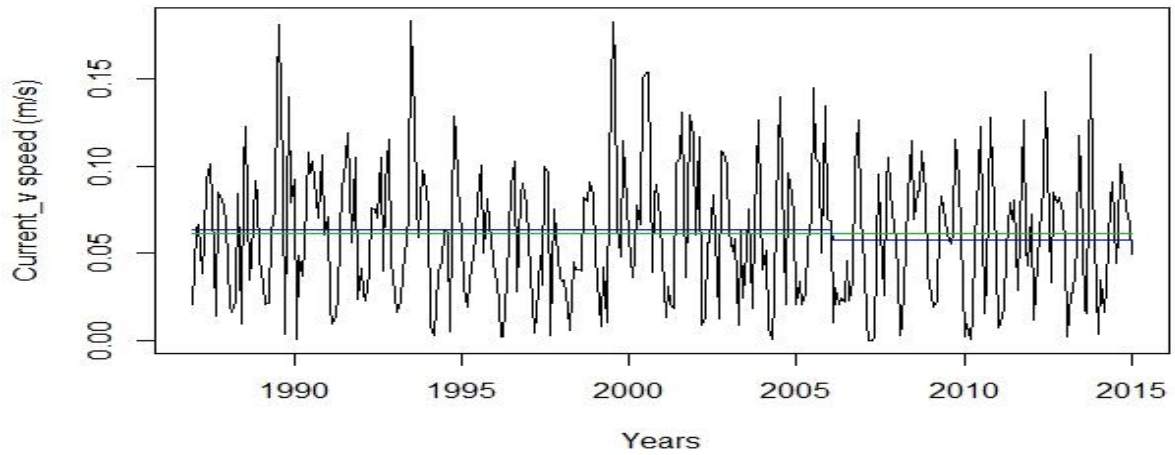
Where, K= Pettitt's test statistic, Buishand range test statistic and SNH test statistic



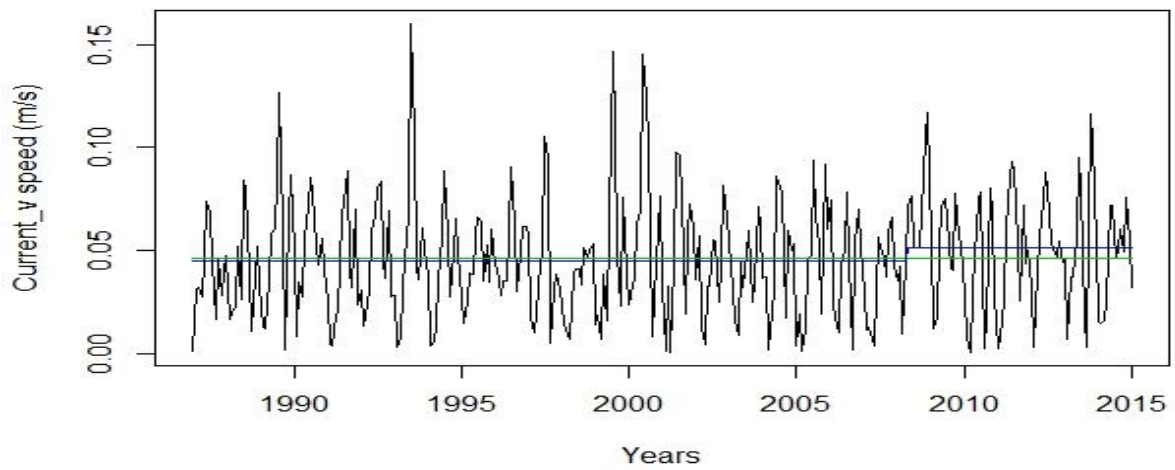
**Fig. 52: Trend of meridional current speed at ST\_1**



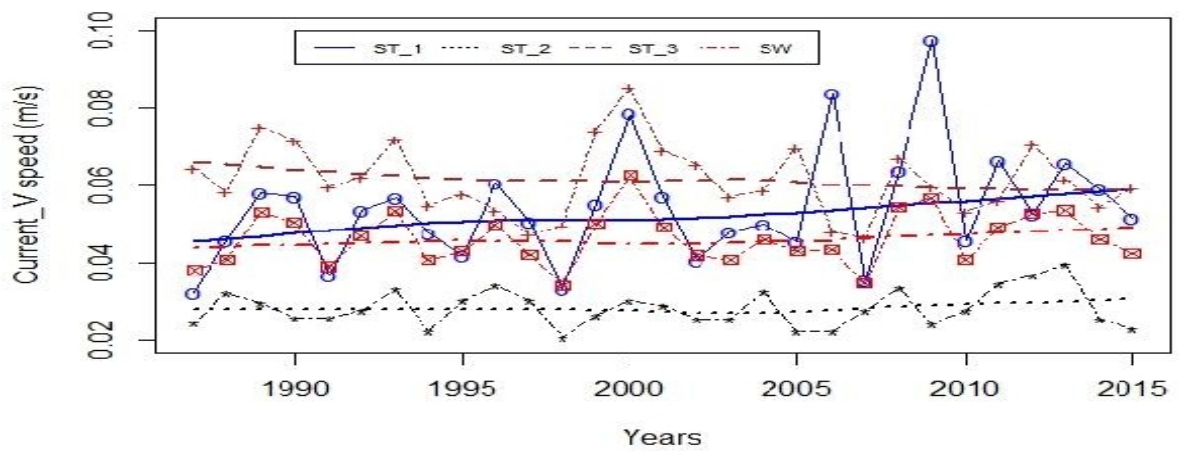
**Fig. 53: Trend of meridional current speed at ST\_2**



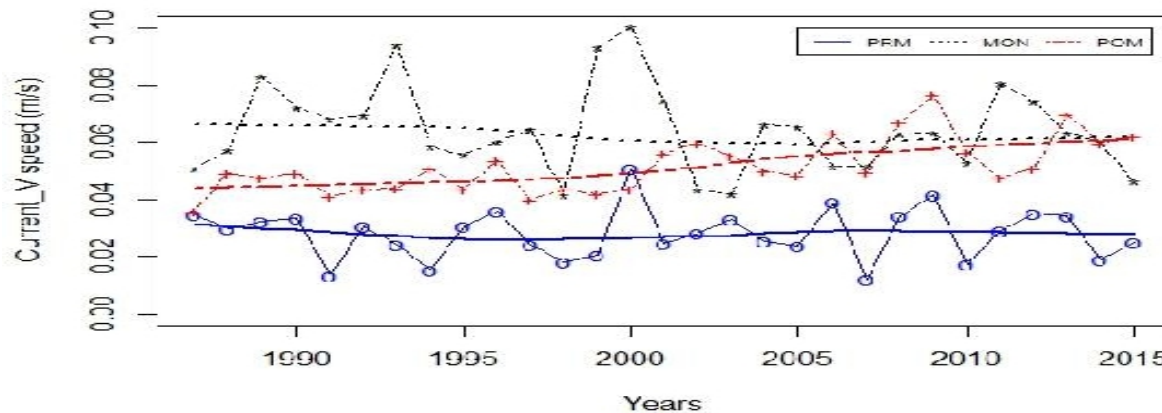
**Fig. 54: Trend of meridional current speed at ST\_3**



**Fig. 55: Trend of meridional current speed at SW**



**Fig. 56: Spatial comparison in the trend of meridional current speed**



**Fig. 57: Temporal comparison in the trend of meridional current speed**

#### 4.1.1.7. Sea level anomaly

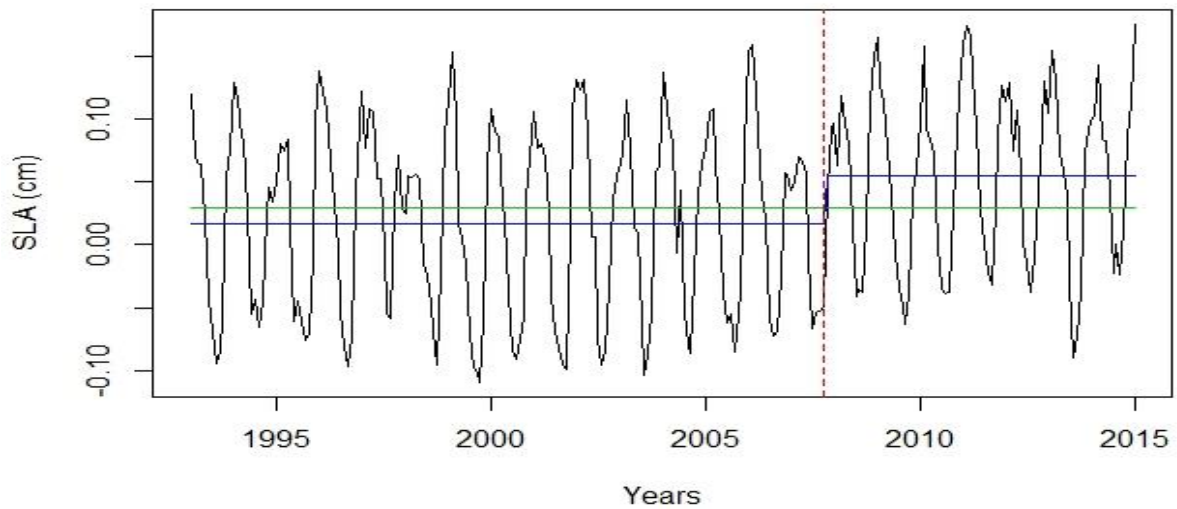
A significant shift in time series of sea level anomaly (SLA) was detected all strata and the entire south west coast of India by all three homogeneity tests (Table 17) and changepoint analysis. Both homogeneity tests and changepoint analysis found a significant shift in time series of SLA at ST\_1 (Fig. 58), ST\_2 (Fig. 59), ST\_3 (Fig. 60) and entire south west coast of India (Fig. 61) during 2007. A significant increase in the trend for time series of SLA was recorded after 2007 at strata and the entire southwest coast of India.

In a comparison of spatial SLA at the southwest coast of India, the trends of SLA along all three strata were similar to each other and also SLA trend remained very close to each other throughout the study period. A continuous rising in SLA was observed at all strata since 2003 (Fig. 62). A significantly positive correlation was found between ST\_1 and ST\_2 (0.98), ST\_1 and ST\_3 (0.97) and, ST\_2 and ST\_3 (0.98). In consideration of seasonal study of SLA, all seasons existed a significantly positive correlation in each other, this correlation was as pre-monsoon and monsoon (0.80), pre-monsoon and post-monsoon (0.79) and, monsoon and post-monsoon (0.77). The pattern of the trend for SLA was similar for three seasons, where the SLA was increased after 2003. This study also indicated that SLA along the southwest coast of India was always highest during pre-monsoon (Fig. 63).

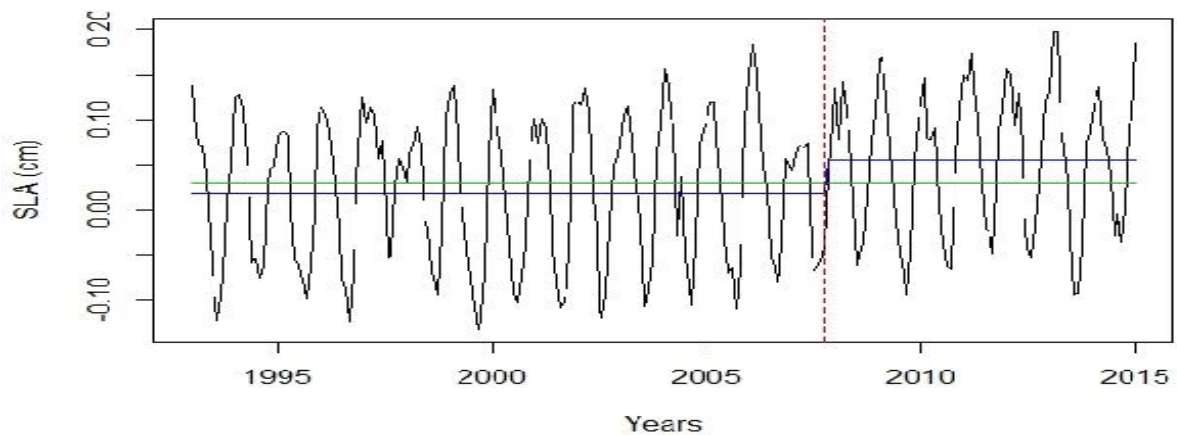
**Table 17: Homogeneity test for sea level anomaly**

Tests	Regions			
	ST_1	ST_2	ST_3	SW
Pettitt's test	K=178 (2007) p = 7.56e-05	K=179 (2007) p = 0.000521	K=179 (2007) p = 0.001175	K=179 (2007) p = 0.0004757
Buishand range test	K =178 (2007) p = 0.00015	K=178 (2007) p = 0.00105	K=179 (2007) p = 0.00195	K=179 (2007) p = 0.0014
SNH test	K=178 (2007) p = 0.00015	K=178 (2007) p = 0.00075	K=179 (2007) p = 0.00235	K=179 (2007) p = 0.00065

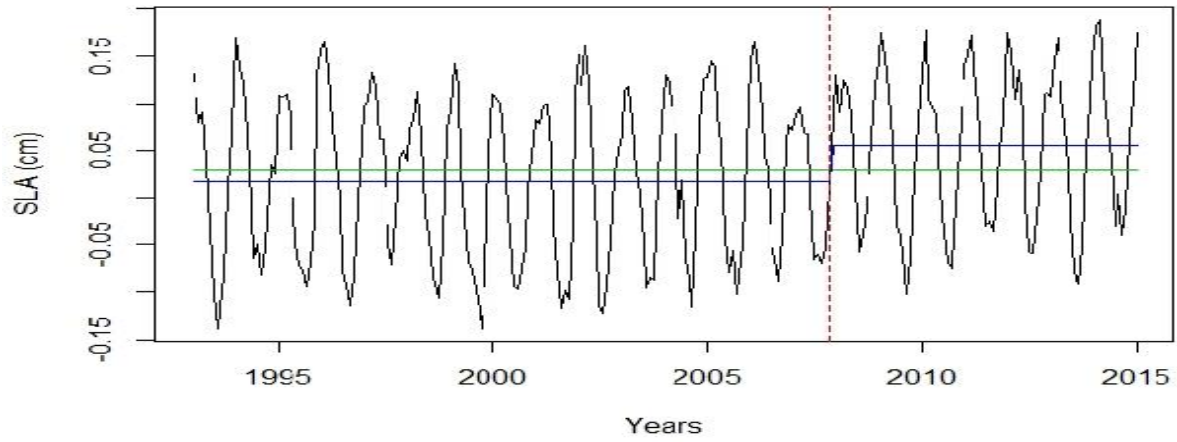
Where, K= Pettitt's test statistic, Buishand range test statistic and SNH test statistic



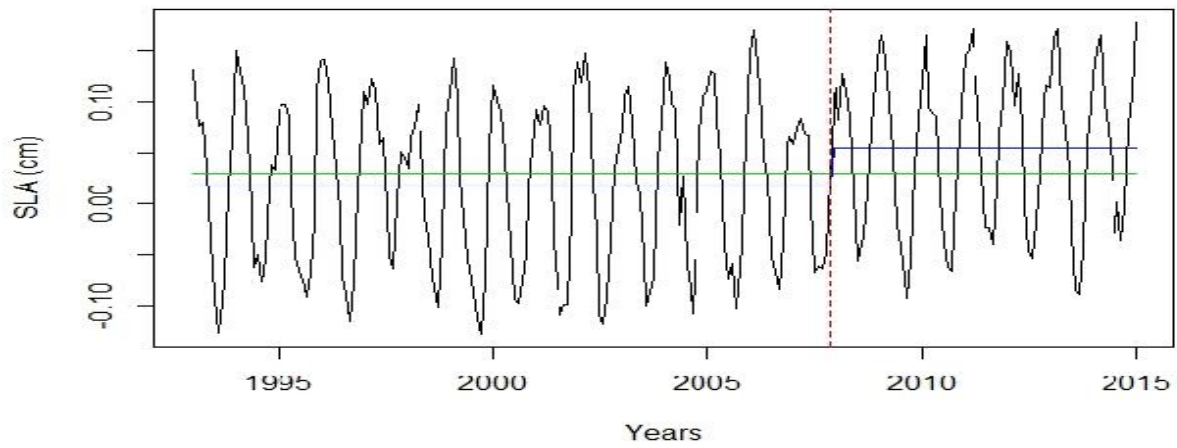
**Fig. 58: Trend of sea level anomaly at ST\_1**



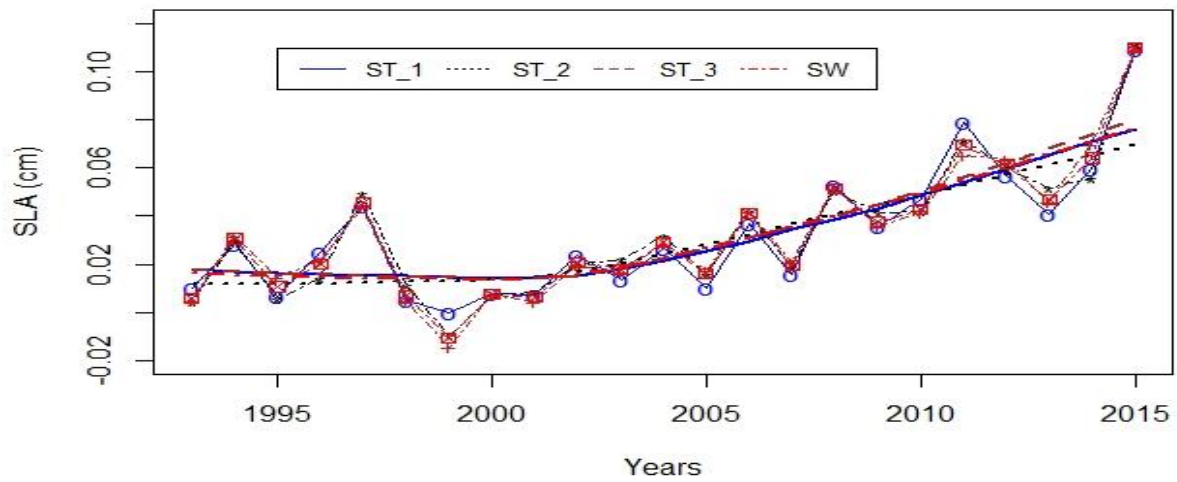
**Fig. 59: Trend of sea level anomaly at ST\_2**



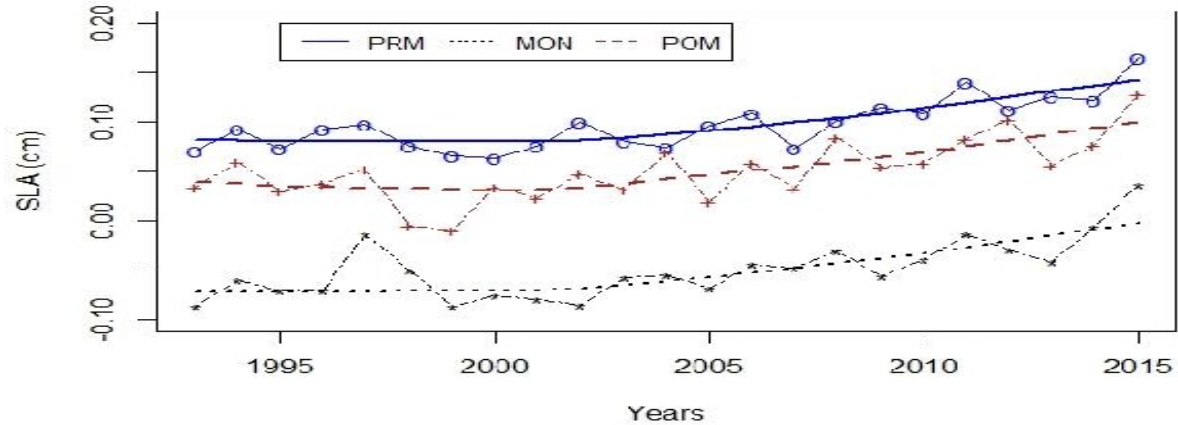
**Fig. 60: Trend of sea level anomaly at ST\_3**



**Fig. 61: Trend of sea level anomaly at SW**



**Fig. 62: Spatial comparison in the trend of sea level anomaly**



**Fig. 63: Temporal comparison in the trend of sea level anomaly**

#### 4.1.1.8. Precipitation rate

In the case of precipitation rate, all three homogeneity tests (Table 18) did not show any significant shift in the precipitation rate over the period. However, all homogeneity tests showed a possibility of a shift in the time series of precipitation rate during 2005, because the trend precipitation rate was slightly higher after 2005 at ST\_1 (Fig.64) and ST\_3 (Fig. 66). Along ST\_2, Pettitt's test and Buishand range test showed a possible shift in precipitation rate during 2007 as a slightly decreasing trend in precipitation rate was found in changepoint analysis after 2007 (Fig. 65). Therefore, the result showed a slight increase in precipitation rate along ST\_1 and ST\_3, where the slightly decreasing trend in precipitation rate along ST\_2 was noticed in this result. For SW, the changepoint analysis showed a decreased precipitation rate after 2009 (Fig. 67).

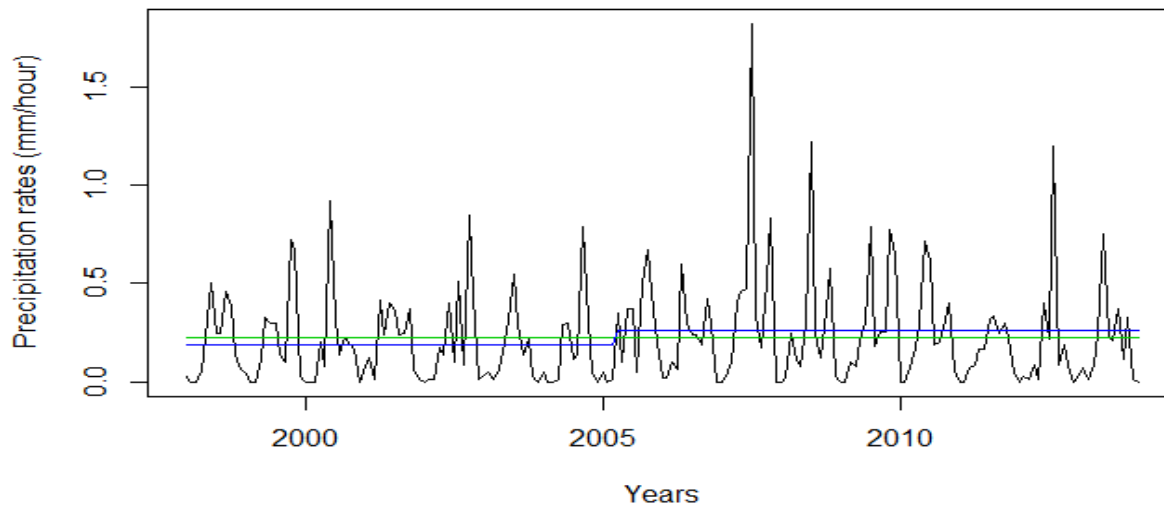
In seasonal plot for the precipitation rate, the highest and lowest precipitation rate was noticed along the SW during monsoon and pre-monsoon. The precipitation rate during monsoon was decreased up to 2005 and then it showed an increasing trend. In contrast to the monsoon, the precipitation rate was increased up to 2005 during the pre-monsoon season, but then it had a decreasing trend. However, the post-monsoon showed a decreasing trend in regards to precipitation rate along SW after 2008 (Fig. 68). In a spatial comparison of precipitation rate, this result found a significant positive correlation among strata such as ST\_1 and ST\_3 (0.52) and, ST\_2 and ST\_3 (0.52). The spatial trend of precipitation rate was showed that

maximum precipitation rate was recorded at ST\_2 in this study except for a shift in precipitation rate during the period from 2005 to 2010 when it became the lowest among all strata (Fig. 69).

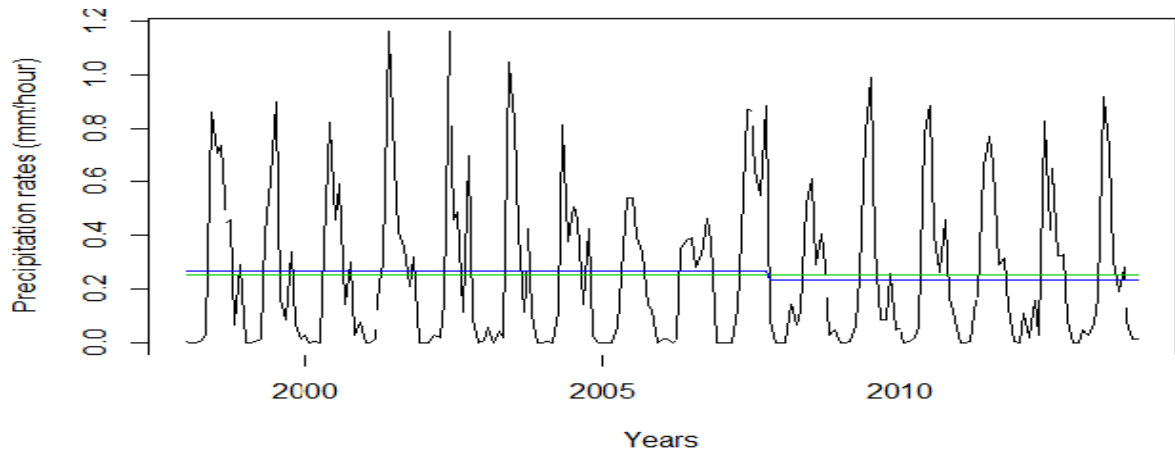
**Table 18: Homogeneity test for precipitation rate**

Tests	Regions			
	ST_1	ST_2	ST_3	SW
Pettitt's test	K=87 (2005) p = 0.3549	K=111 (2007) p = 0.9539	K=87 (2005) p = 0.9306	K=90 (2005) p = 0.777
Buishand range test	K =89 (2005) p = 0.2902	K=112 (2007) p = 0.9959	K=89 (2005) p = 0.7945	K=113 (2007) p = 0.8732
SNH test	K=89 (2005) p = 0.6593	K=5 (1998) p = 0.6785	K=89 (2005) p = 0.8396	K=6 (1998) p = 0.5423

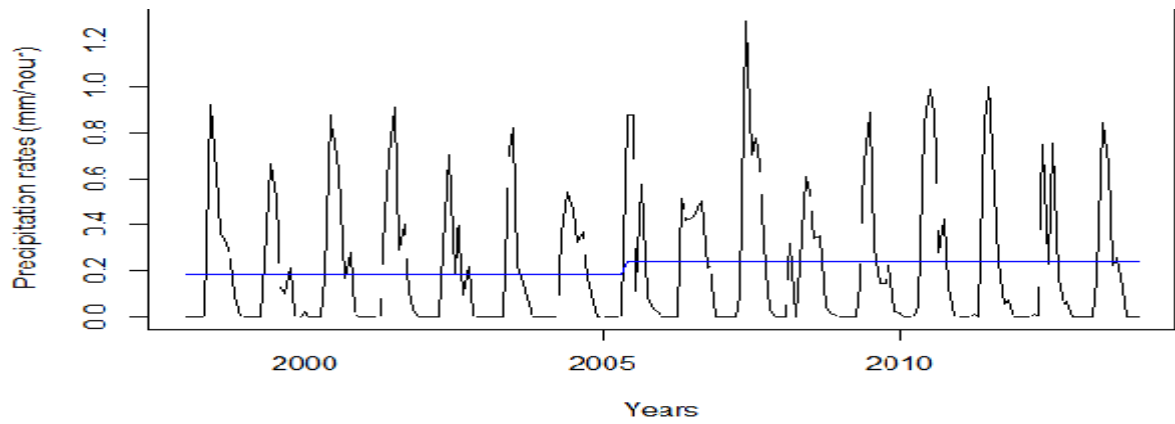
Where, K= Pettitt's test statistic, Buishand range test statistic and SNH test statistic



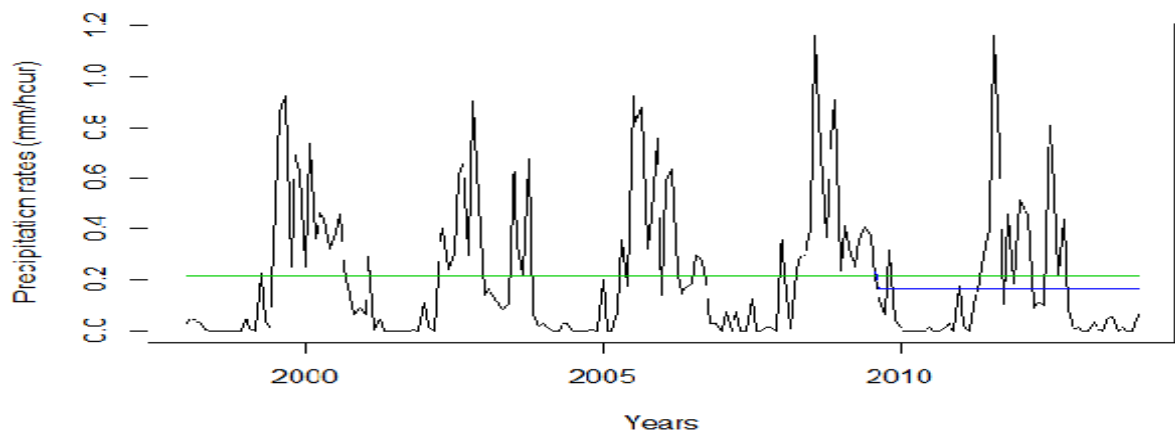
**Fig. 64: Trend of precipitation rate at ST\_1**



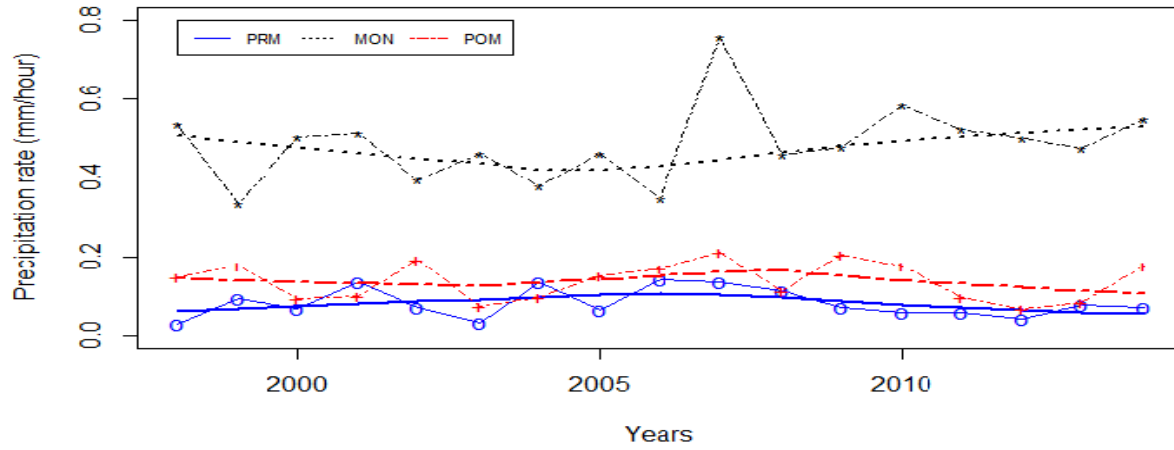
**Fig. 65: Trend of precipitation rate at ST\_2**



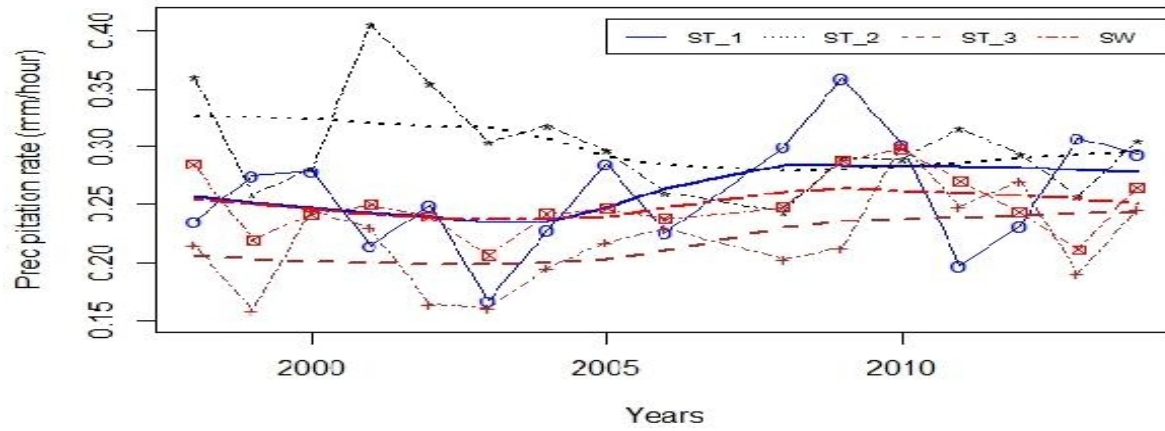
**Fig. 66: Trend of precipitation rate at ST\_3**



**Fig. 67: Trend of precipitation rate at SW**



**Fig. 68: Temporal comparison in the trend of precipitation rate**



**Fig. 69: Spatial comparison in the trend of precipitation rate**

**Table 19: Stratum and season wise correlation for oceano-climatic parameters**

Parameters	Strata	Strata				Season	Season		
		ST_1	ST_2	ST_3	SW		PRM	MON	POM
Chlorophyll-a	ST_1	1.00	0.41	0.56*	0.81***	PRM	1.00	0.00	0.79**
	ST_2		1.00	0.21	0.67**	MON		1.00	0.41
	ST_3			1.00	0.82***	POM			1.00
	SW				1.00				
SST	ST_1	1.00	0.97***	0.85***	0.97***	PRM	1.00	0.45*	0.017
	ST_2		1.00	0.92***	0.99***	MON			0.59***
	ST_3			1.00	0.95***	POM			1.00
	SW				1.00				
Wind_U	ST_1	1.00	0.83***	0.74***	0.89***	PRM	1.00	0.17	0.36
	ST_2		1.00	0.94***	0.98***	MON		1.00	0.42*
	ST_3			1.00	0.93***	POM			1.00
	SW				1.00				
Wind_V	ST_1	1.00	0.62***	-0.03	0.59***	PRM	1.00	-0.23	0.004
	ST_2		1.00	0.31	0.97***	MON		1.00	0.51**
	ST_3			1.00	0.43*	POM			1.00
	SW				1.00				
Current_U	ST_1	1.00	0.14	0.07	0.07	PRM	1.00	-0.37*	0.22
	ST_2		1.00	0.24	0.70***	MON		1.00	-0.31
	ST_3			1.00	0.42*	POM			1.00
	SW				1.00				
Current_V	ST_1	1.00	0.18	0.21	0.76***	PRM	1.00	0.23	0.26
	ST_2		1.00	0.20	0.51***	MON		1.00	-0.31
	ST_3			1.00	0.68***	POM			1.00
	SW				1.00				
SLA	ST_1	1.00	0.99***	0.97***	0.99***	PRM	1.00	0.66***	0.62***
	ST_2		1.00	0.99***	0.99***	MON		1.00	0.77***
	ST_3			1.00	0.99***	POM			1.00
	SW				1.00				
Precipitation rate	ST_1	1.00	0.44	0.52*	0.86***	PRM	1.00	-0.09	0.20
	ST_2		1.00	0.52*	0.76***	MON		1.00	0.18
	ST_3			1.00	0.81***	POM			1.00
	SW				1.00				
Upwelling Index	ST_1	1.00	0.80***	0.33*	0.89***	PRM	1.00	0.35*	0.12
	ST_2		1.00	0.76***	0.97***	MON		1.00	0.32*
	ST_3			1.00	0.72***	POM			1.00
	SW				1.00				

‘\*’, ‘\*\*’ and ‘\*\*\*’ Significant at 0.5, 0.01 and 0.001, respectively

#### **4.1.1.9. Correlation among the oceano-climatic parameters along the south west coast of India**

This study also analyzed the correlation among the oceano-climatic parameters such as chlorophyll-a concentration, SST, zonal wind speed, meridional wind speed, zonal current speed, meridional current speed, SLA, precipitation rate and UI for the entire southwest coast of India, which is depicted in table 20.

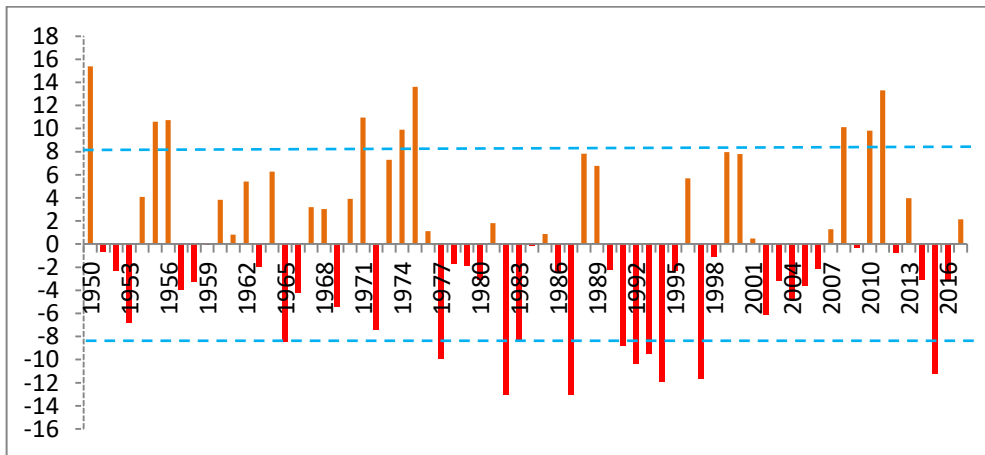
**Table 20: The correlation among the oceano-climatic parameters along the south west coast of India**

Parameters	Chlorophyll-a Concentration	SST	Zonal wind	Meridional wind	Zonal current	Meridional current	SLA	Precipitation rate	UI
Chlorophyll-a Concentration	1.00	-0.17*	0.08	-0.03	-0.03	0.07	-0.18*	0.12	0.07
SST		1.00	-0.22*	-0.10	-0.08	-0.40****	0.28***	-0.24***	-0.24***
Zonal wind			1.00	-0.25***	-0.08	0.32***	-0.72***	0.71***	0.26***
Meridional wind				1.00	-0.15*	-0.12	-0.28***	0.56***	-0.06
Zonal current					1.00	-0.06	0.02	0.15*	-0.03
Meridional current						1.00	-0.24***	0.34***	0.22**
SLA							1.00	-0.65***	-0.06
Precipitation rate								1.00	0.26***
UI									1.00

\*, \*\* and \*\*\*\* significant at 0.5, 0.01 and 0.001, respectively

#### 4.1.1.10. El Niño

The time series analysis of Southern Oscillation Index (SOI) indicated that the highly intense El Niño appeared during 1965, 1977, 1982, 1983, 1987, 1991, 1992, 1993, 1994, 1997 and 2015. Therefore, this result showed that the frequency of outbreak of high intensity of El Niño was increased after 1980. A total of five years as 1991, 1992, 1993, 1994 and 1997 was well known for high intense El Niño only within the period from 1980 to 1990. After 2000, the highest El Niño was recorded in 2015. The trend of time series analysis of SOI showed that El Niño appeared on the scarfying of La Niña. Therefore, the frequency for appearing of La Niña was reduced after 1980. Also, completely absence of La Niña was seen during the period from 1990 to 1995 and, 2000 to 2006. This indicated that the frequency of El Niño and La Niña has increased and decreased after 1980 (Fig. 70).

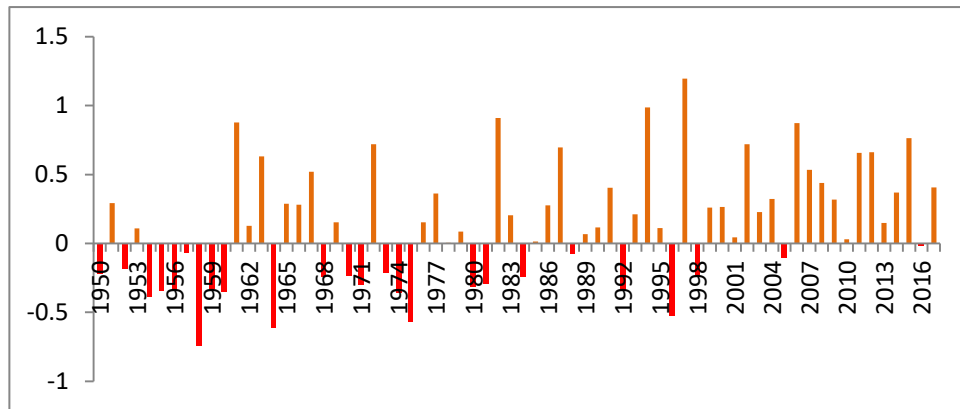


**Fig. 70: Southern Oscillation Index**

#### 4.1.1.11. Indian Ocean Dipole mode

The result showed that during the 1950's decade, the existence of the Dipole Mode Index (DMI) was negative in most of the year. But the frequency of appearing negative and positive DMI were decreased and increased on the progression of time. The maximum positive DMI was recorded after 1995 (Fig. 71). Therefore, the increase in frequency in occurrence of positive DMI in the last two

decades is linked with rising in faster SST over the same period, which may be the indication of climate change in the recent period.

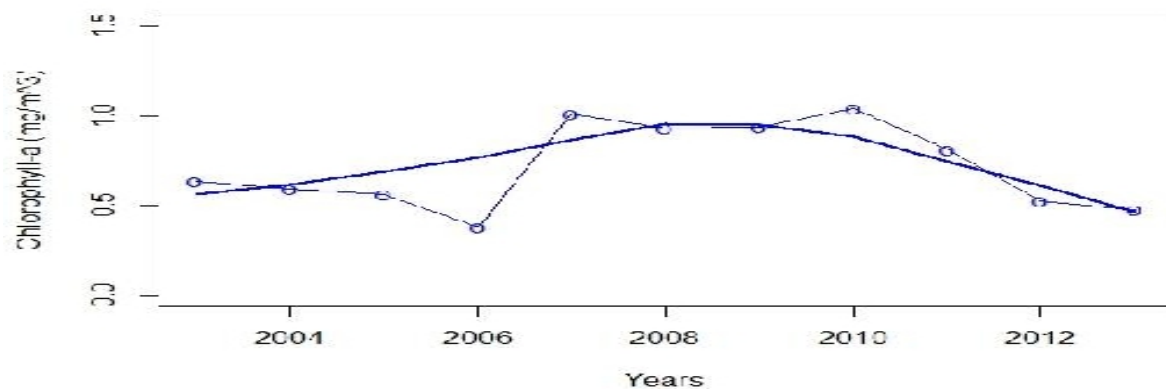


**Fig. 71: Dipole Mode Index**

#### 4.1.2. Observation of laboratory oceanic parameters

##### 4.1.2.1. Chlorophyll-a concentration

Chlorophyll-a concentration along off Kochi water showed an increasing trend from 2003 to 2008. But, the trend followed a downward movement from 2008 and showed continuously as downward trend up to 2013. However, the lowest concentration of Chlorophyll-a was observed in 2006 (Fig. 72).



**Fig. 72: Trend of Chlorophyll-a concentration off Kochi coast**

#### 4.1.2.2. Temperature

This result showed that SST along off Kochi had an increasing trend from 2003 to 2010 continuously. Therefore, the highest SST was observed in 2010. After reaching its peak, SST showed a decreasing trend up to 2013 in the study. The lowest SST was observed in 2004 during the study periods (Fig. 73).

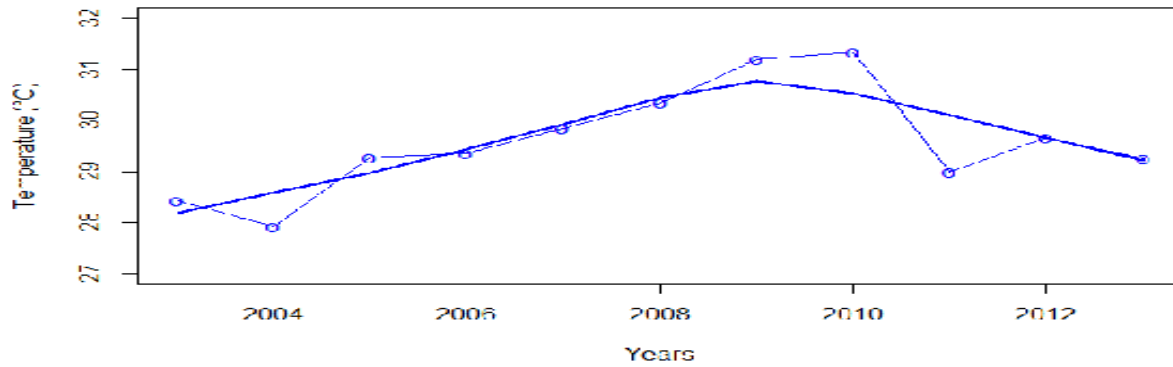


Fig. 73: Trend of temperature off Kochi coast

#### 4.1.2.3. Dissolved oxygen

The trend of dissolved oxygen (DO) reached a peak in 2008 from the lowest DO in 2003. After attending its peak concentration, DO had a decreasing trend, which remained continued up to 2013. The trend showed the lowest DO in surface off Kochi water in 2013 (Fig. 74). DO have a significantly positive correlation with chlorophyll-a concentration (Table 21).

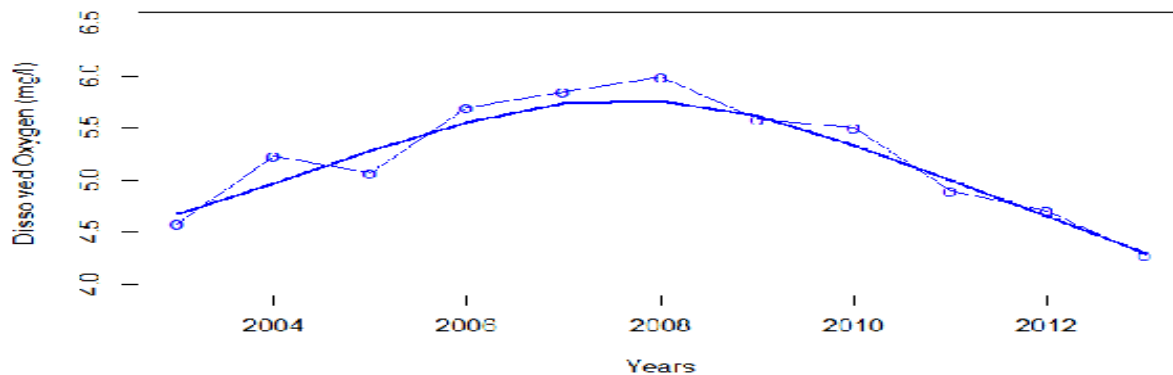
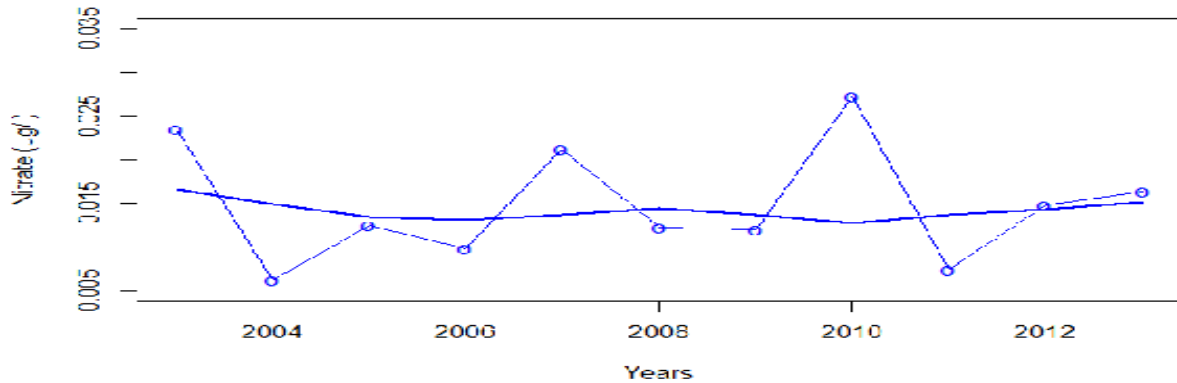


Fig. 74: Trend of dissolved oxygen off Kochi coast

#### 4.1.2.4. Nitrate

An analysis of nitrate concentration in surface water along the Kochi coast from 2003 to 2013 was carried out. There was not much variation in nitrate concentration during the study period (Fig. 75). However, the nitrate concentration had a positive correlation with both chlorophyll-a concentration and DO (Table. 21).



**Fig. 75: Trend of nitrate off Kochi coast**

**Table 21. Correlation among oceanic parameters off Kochi coast**

Parameters	Chlorophyll-a (mg/m <sup>3</sup> )	Temperature (°C)	Dissolved oxygen (mg/l)	Nitrate (µg/l)
Chlorophyll-a (mg/m <sup>3</sup> )	1.00	0.39	0.65*	0.56
Temperature (°C)		1.00	0.38	-0.059
Dissolved oxygen (mg/l)			1.00	0.50
Nitrate (µg/l)				1.00

\* significant at 0.05

#### 4.1.3. *In-situ* observation of oceanic parameters

All oceanic parameters such as temperature, chlorophyll-a concentration, CDOM, PAR, pH, turbidity, sea pressure, salinity, conductivity, specific conductivity, speed of sound, DO and density anomaly showed a statistically significant difference between pre-monsoon and post-monsoon season along off Kochi water. The parameters like temperature, CDOM, PAR, pH, turbidity, sea

pressure, salinity, conductivity, specific conductivity, speed of sound and density anomaly were significantly higher during pre-monsoon period as compared to post-monsoon season (Table 22).

**Table 22: Physico-chemical properties of seawater during pre-monsoon and post-monsoon period along off Kochi coast**

Parameters	Pre-monsoon	Post-monsoon	DF	p-value
Temperature (°C)	29.85 (29.58-32.19)	28.70 (28.25-29.05)	1437	2.2e-16
Chlorophyll-a (µg/l)	0.82 (0.05-0.94)	2.23 (0.15-4.92)	1437	2.2e-16
CDOM (ppb)	8.75 (0.17-14.98)	0.86 (0.06-1.90)	1437	2.2e-16
PAR (µMol/m <sup>2</sup> /s)	4.75 (1.32-47.07)	3.15 (0.97-23.59)	1437	9.005e-06
pH	8.08 (8.04-8.33)	7.99 (6.78-8.06)	1437	2.2e-16
Turbidity (NTU)	9.89 (0.06-22.23)	9.26 (0.12-39.15)	1437	0.1169
Sea pressure (dbar)	16.41 (0.21-20.05)	11.29 (0.12-39.15)	1437	2.2e-16
Salinity (PSU)	34.42 (33.53-34.66)	33.63 (33.32-33.94)	1437	2.2e-16
Dissolved O <sub>2</sub> (mL/L)	1.49 (1.11-1.80)	1.78 (1.09-2.58)	1437	2.2e-16
Conductivity (mS/cm)	57.35 (56.52-58.72)	54.96 (54.86-55.40)	1437	2.2e-16
Specific conductivity (µS/cm)	52492.01 (51387.22-52793.13)	51359.16 (50955.41-51756.77)	1437	2.2e-16
Speed of sound (m/s)	1544.97 (1544.23-1548.54)	1541.61 (1540.81-1542.22)	1437	2.2e-16
Density anomaly (kg/m <sup>3</sup> )	21.42 (19.87-21.69)	21.18 (20.82-21.55)	1437	2.2e-16
Depth (m)	16.28 (0.21-19.89)	11.20 (0.14-15.90)	1437	2.2e-16

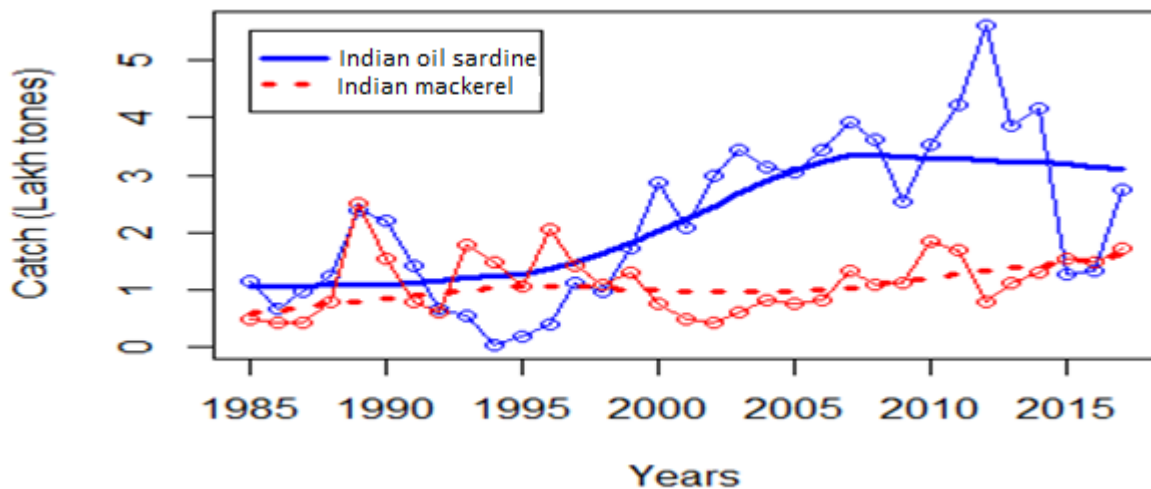
Out side of bracket represents mean and inside of bracket represents range

## 4.2. Fisheries

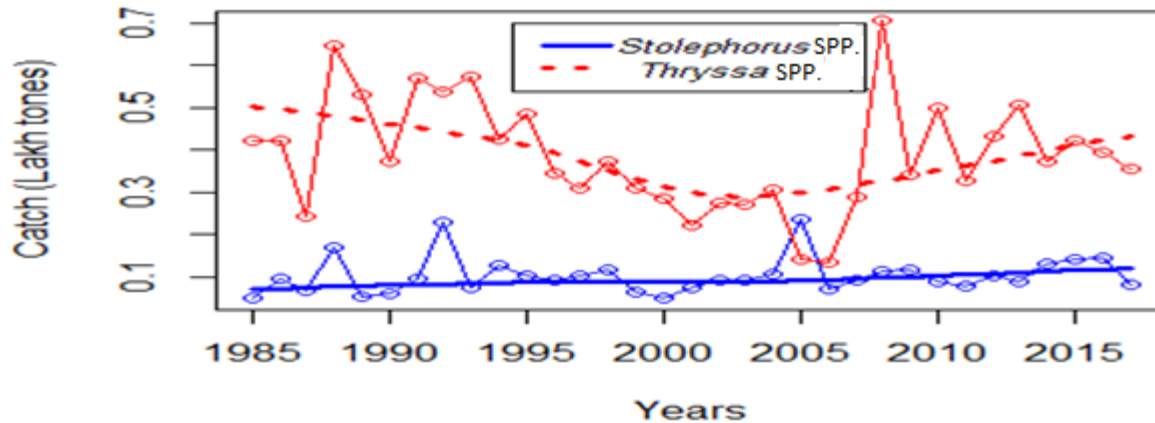
### 4.2.1. Small pelagic catch analysis along south west coast of India

The total landings of sardine were always higher than that of mackerel in the study. In the case of sardine, the total landings increased continuously from 1995 and reached a peak position during 2012. On the other hand, the landings of mackerel slowly increased from 1985 to 1995 and the landings had a downward trend after 1995 (Fig. 76). However, the result did not found any significant correlation in the landings of sardine and mackerel along south west coast of India

The landings trend of thryssa was always higher than that of stolephorus during the study period from 1985 to 2017, but it was a discontinuous trend, where the catch was decreased from 1985 to 2005, and again, its catch showed the upwards movement for the remaining period. Stolephorus landings did not show a variation in its trend during the study period (Fig. 77). However, correlation analysis of catch among four species as sardine, mackerel, stolephorus, and thryssa did not show any significant correlation in each other as shown in table 23.



**Fig. 76: Trend for total landings of Indian oil sardine and Indian mackerel along south west coast of India**



**Fig. 77: Trend for total landings of *Stolephorus* spp. and *Thryssa* spp. along south west coast of India**

**Table 23: Correlation of total landings for selected fishes along south west coast of India**

Species	Indian oil sardine	Indian mackerel	<i>Stolephorus</i> spp.	<i>Thryssa</i> spp.
Indian oil sardine	1.00	-0.02	-0.20	-0.11
Indian mackerel		1.00	0.24	-0.17
<i>Stolephorus</i> spp.			1.00	0.13
<i>Thryssa</i> spp.				1.00

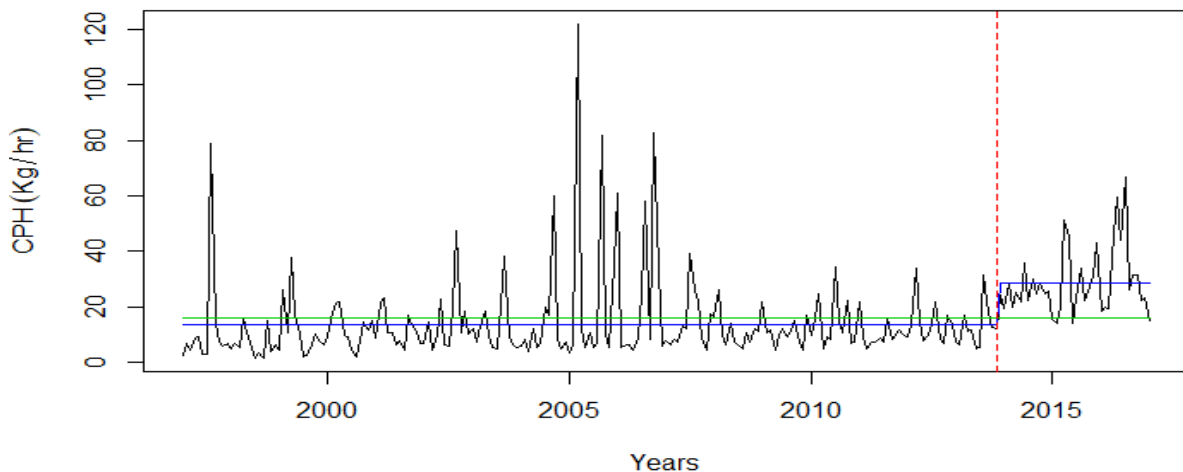
## 4.2.2. Indian oil sardine

### 4.2.2.1. Technical attributes

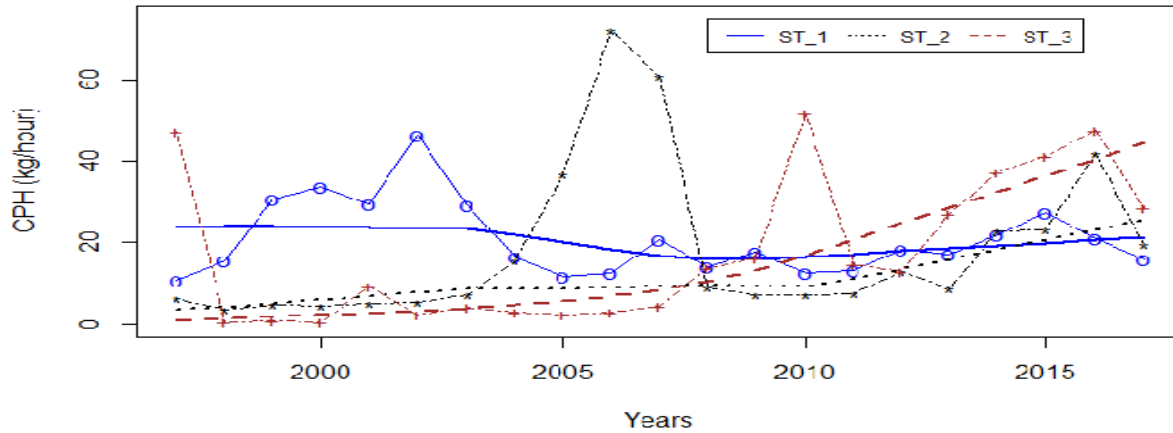
The standardized catch per unit hour (CPH) of SW showed a break point in time series trend by changepoint analysis, where a significantly higher CPH was observed after 2013 (Fig. 78). In regard to stratum wise variation in the CPH, the study found that the highest and lowest CPH were along ST\_1 and ST\_3 at the starting period of the study, but the same were interchanged each other and became as lowest and highest during 2010 onwards, respectively (Fig. 79). Further, the spatial comparison of CPH at SW showed that the CPH along ST\_1 was continuously decreased over the study, but at the same time, the CPH of ST\_2 and ST\_3 had an increasing trend. A negative correlation between ST\_1 and ST\_2 (-0.26); ST\_1 and ST\_3 (-0.30) in respect to CPH was also found in this study (Table 24).

In the study of the temporal distribution of CPH, the result found the highest CPH was during pre-monsoon up to 2002, while later on, monsoon showed the maximum CPH. However, the trend of CPH during all three seasons as pre-monsoon, monsoon, and post-monsoon was continuously increased over the study period (Fig. 80). A positive correlation was found between pre-monsoon and post-monsoon (0.47) and monsoon and post-monsoon (0.22) in this study (Table 24). The seasonal shifting in sardine distribution was found as CPH was decreased and increased during pre-monsoon and monsoon, respectively, where pre-monsoon may not be proven as a favorable season in the effect of rising SST on the impact of global warming, therefore sardine might have temporal extension toward monsoon season.

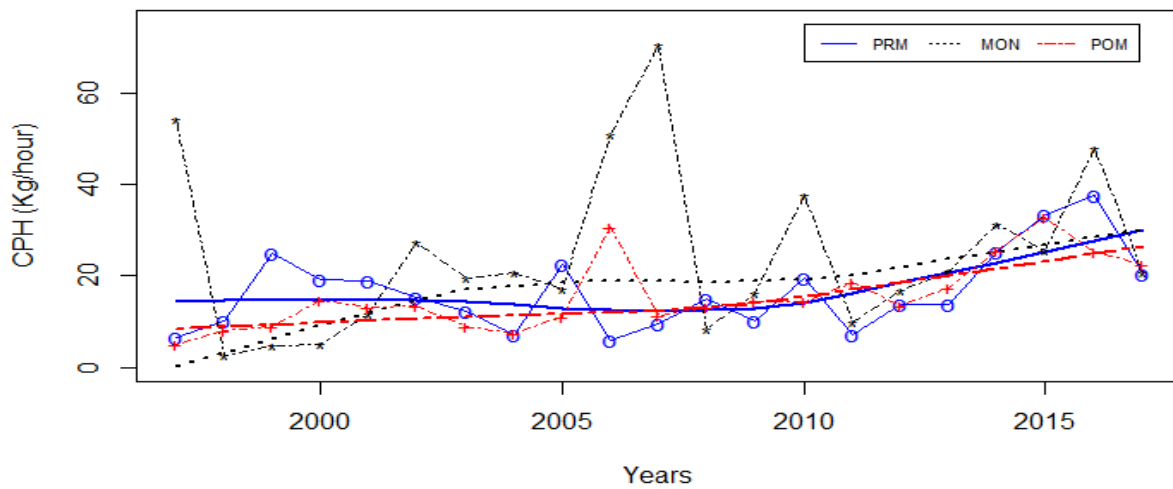
In a gear-wise analysis of catch, an increasing trend in the CPH of all mechanized gear such as MTN, MPS and MRS was noticed (Fig. 81). Again in the case of motorized gears, the CPH of OBRS was increased continuously, while that for OBGN and OBTN had the decreasing trend over the study period (Fig. 82). In case of correlation among CPH for different gears operated along the coast, a significantly negative correlation was observed between the CPH in two gears such as MRS and OBTN (-0.49), MTN and OBTN (-0.60) and, OBRS and OBTN (-0.53). Similarly, the positive correlation for CPH in two gears such as MRS and OBGN (0.52), MRS and OBRS (0.74), MTN and NM (0.73) and, MTN and OBRS (0.56) were found (Table 25).



**Fig. 78: Trend for CPH of Indian oil sardine at SW**



**Fig. 79: Stratum wise trend for CPH of Indian oil sardine**



**Fig. 80: Season wise trend for CPH of Indian oil sardine**

**Table 24: Stratum wise and season wise correlation of CPH for Indian oil sardine**

Strata	Strata			Seasons	Seasons		
	ST_1	ST_2	ST_3		PRM	MON	POM
ST_1	1.00	-0.26	-0.30	PRM	1.00	-0.048	0.47
ST_2		1.00	-0.031	MON		1.00	0.22
ST_3			1.00	POM			1.00

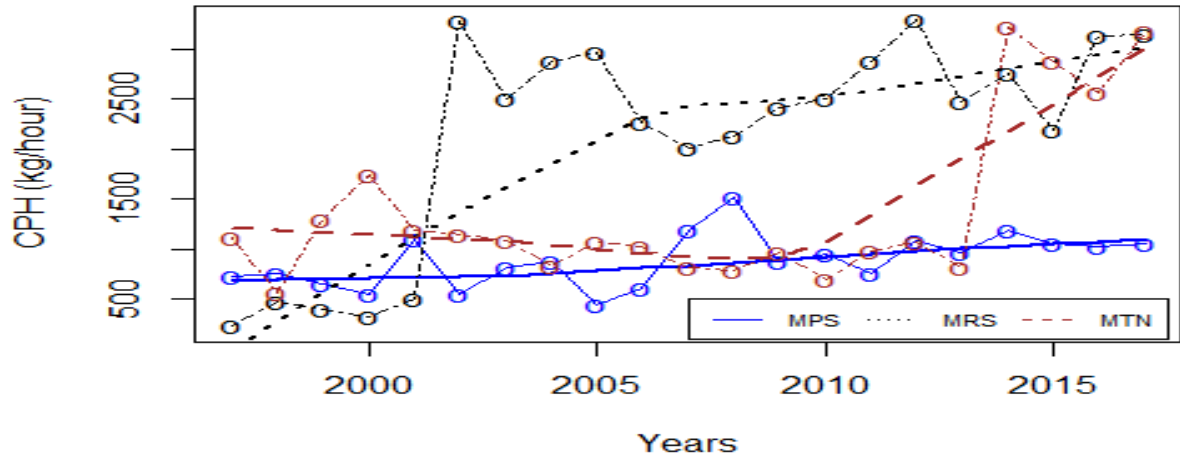


Fig. 81: Gear-wise trend for CPH of Indian oil sardine (mechanized)

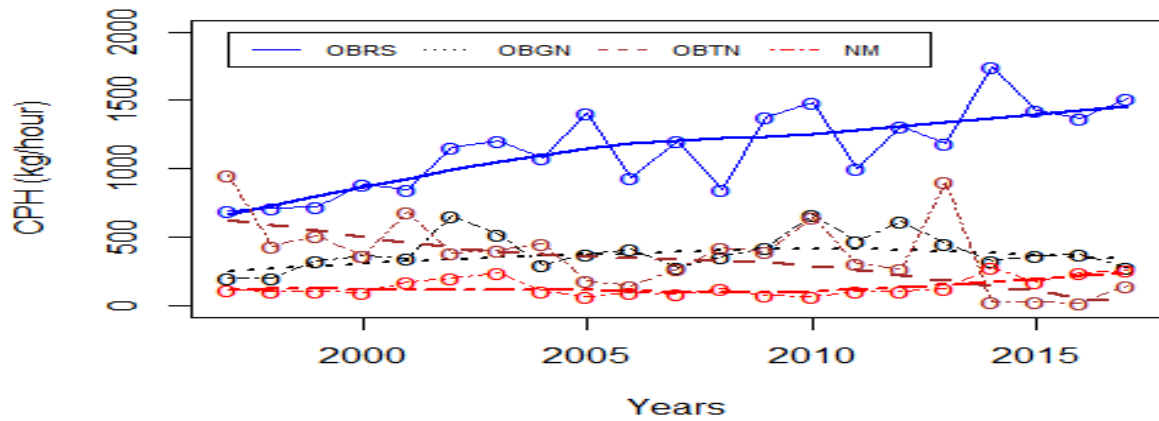


Fig. 82: Gear-wise trend for CPH of Indian oil sardine (motorized and non-mechanized)

Table 25: Gear-wise correlation of CPH for Indian oil sardine

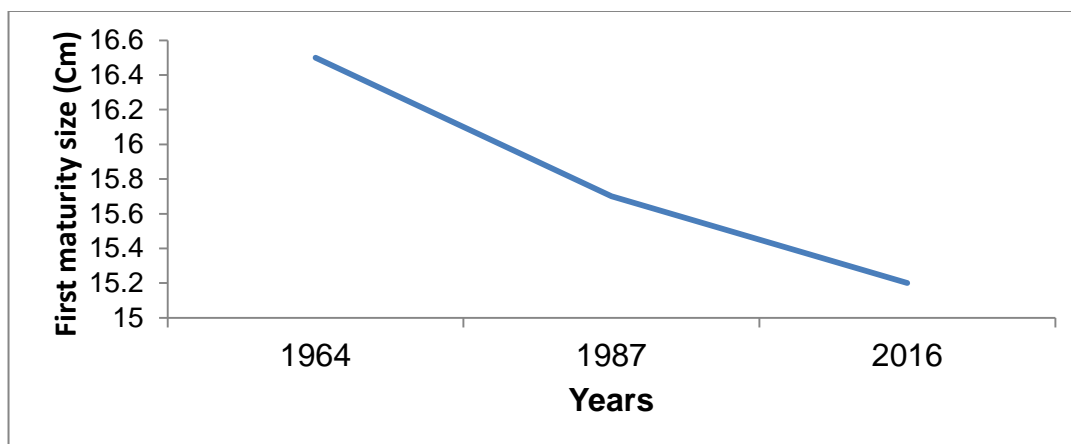
Gears	MPS	MRS	MTN	NM	OBGN	OBRS	OBTN
MPS	1.00	0.19	0.23	0.30	-0.10	0.28	-0.10
MRS		1.00	0.20	0.27	0.52*	0.74***	-0.49*
MTN			1.00	0.73***	-0.22	0.56**	-0.60**
NM				1.00	-0.03	0.39	-0.35
OBGN					1.00	0.34	0.01
OBRS						1.00	-0.53*
OBTN							1.00

\*, \*\* and \*\*\* Significant at 0.5, 0.01 and 0.001, respectively

#### 4.2.2.2. Biological attributes

The detailed study on history on biological characteristics of sardine such as maximum size, sexual maturity size, spawning season, fishery, ovaries stage, phyco-chemical factors for affecting fishery, migration and feeding habit conducted to observe the biological behaviour in response to climate change. First maturity size over the years for sardine recorded and found that the size of the first maturity was continuously decreased over the time period, where it was 16.5, 15.7 and 15.2 cm on 1964, 1987 and 2016, respectively (Fig. 83). Table 26 showed the timeline for the spawning season of sardine. During 1924, sardine was starting to spawn their eggs from September and continued to spawn up to October month. The spawning season started on early month *i.e.* August during 1949 and 1959. During 1964, the study found that sardine has been started to spawn even in July. A recent observation on spawning season showed that sardine can spawn even during May, which is considered as early starting of spawning season compared to an earlier period. Fluctuations in the completion of spawning period were also noticed in the study. The spawning season was continued up to October and November during 1924 and 1949. But, it had been noticed that spawning season was completed even during August month during 2004 and 2016 (Table 26). Thus, this study showed that sardine completed its spawning season earlier compared to the historical period by starting in May and completed in August.

During the pre-monsoon period, sardine attains its maturity in offshore water and starts to move toward inshore water for spawning in May-July on lowering of temperature with arriving of monsoon. Spawning takes place in lower temperature and salinity in inshore water during July-September and at spawning ground. The larvae remain in spawning ground where high larval food available under the influence of southwest monsoon upwelling. Upon cessation of southwest monsoon and rising temperature, juveniles start to move towards offshore water from September and this movement continues up to December. During the post-monsoon period, juveniles attend maturing stage and further, they become mature in the pre-monsoon period at feeding ground in higher temperature period of the year (Fig. 84).



**Fig. 83: First maturity size of Indian oil sardine**

**Table 26: Year-wise spawning season of Indian oil sardine**

Years	Starting month	Ending month
1924	September	October
1949	August	November
1959	August	September
1964	July	September
1967	June	October
1969	June	October
1970	June	December
2003	June	August
2016	May	August

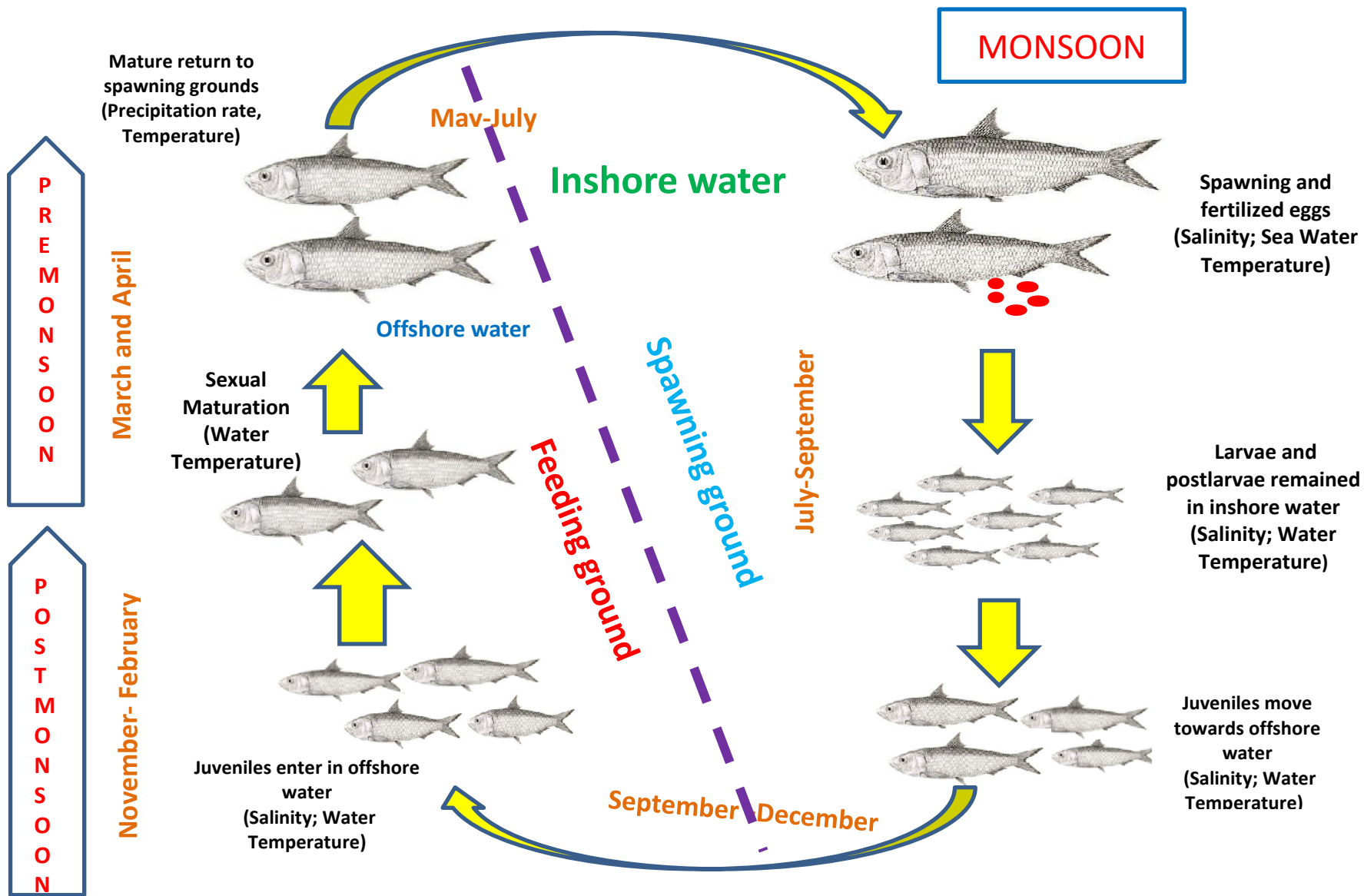


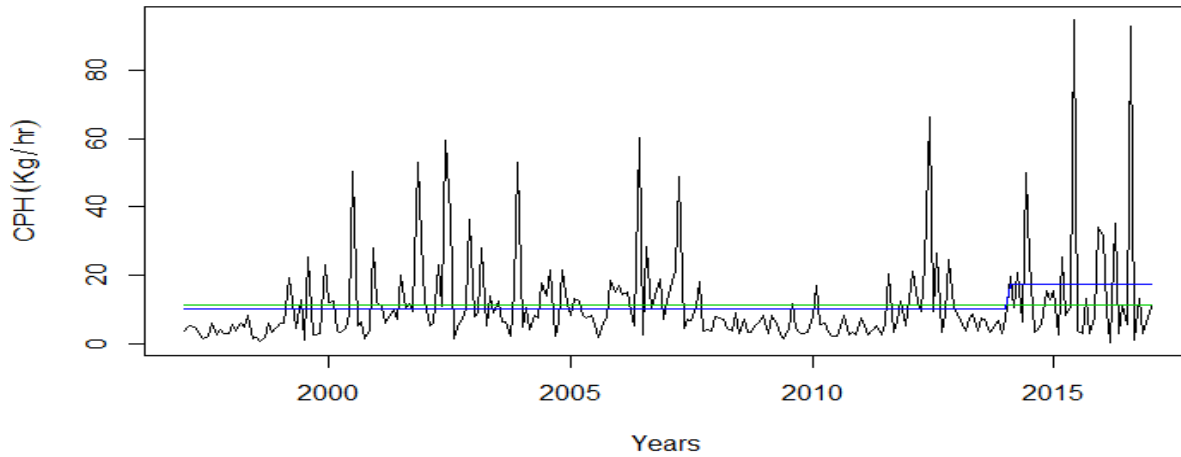
Fig. 84: Life cycle model of Indian oil sardine

### 4.2.3. Indian mackerel

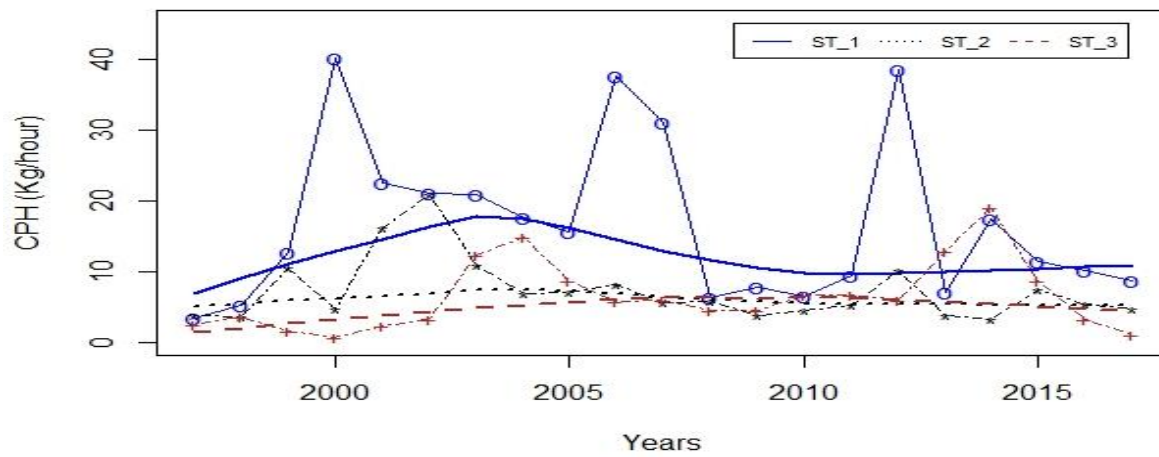
#### 4.2.3.1. Technical attributes

The changepoint analysis of standardized CPH of mackerel at SW showed a break point in the trend during 2014 and higher CPH was observed after 2014 (Fig. 85). On the basis of spatial observation at SW, this study indicated that the highest CPH was along ST\_1 throughout the study period. The decreasing trend of CPH at both ST\_1 and ST\_2 was similar to each other over the study period. However, CPH at ST\_3 also had decreasing trend, but this decreasing trend started after 2010 (Fig. 86). On correlation analysis, a positive correlation (0.34) between ST\_1 and ST\_2 and negative correlation (-0.20) between ST\_2 and ST\_3 were recorded (Table 27). In the case of seasonal study, the trend of CPH distribution followed similar pattern during all three seasons *i.e.* pre-monsoon, monsoon, and post-monsoon. In seasonal comparison, the CPH was always highest during monsoon among three seasons. The pattern of plot and correlation analysis demonstrated that the CPH of mackerel increased upon both monsoon and post-monsoon season (Fig. 87). The correlation analysis also showed a significantly positive correlation (0.40) between CPH of monsoon and post-monsoon (Table 27).

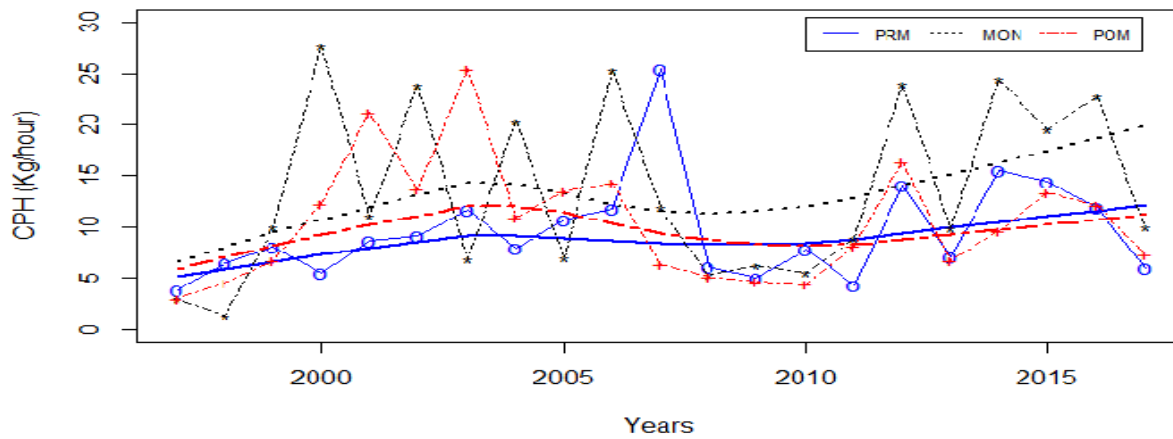
In a gear-wise analysis of catch, the CPH in all mechanized gears as MPS, MRS, MGN (Fig. 88) and MTN (Fig. 89) had an increasing trend. In contrast to mechanized gears, the CPH of motorized and non-mechanized gears showed a decreasing trend over the period (Fig. 90). The correlation analysis of CPH in different gears showed a significantly positive correlation between MPS and MRS (0.58), and MPS and OBRS (0.50). Similarly, a significantly negative correlation between MPS and OBTN (-0.54), MRS and OBTN (-0.38), and OBGN and OBTN (-0.52) as in table 28.



**Fig. 85: Trend for CPH of Indian mackerel at SW**



**Fig. 86: Stratum wise trend for CPH of Indian mackerel**

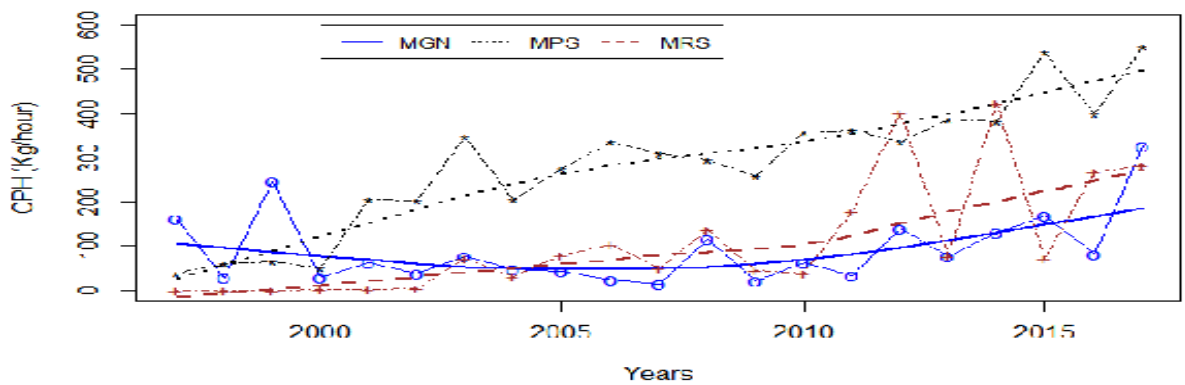


**Fig. 87: Season wise trend for CPH of Indian mackerel**

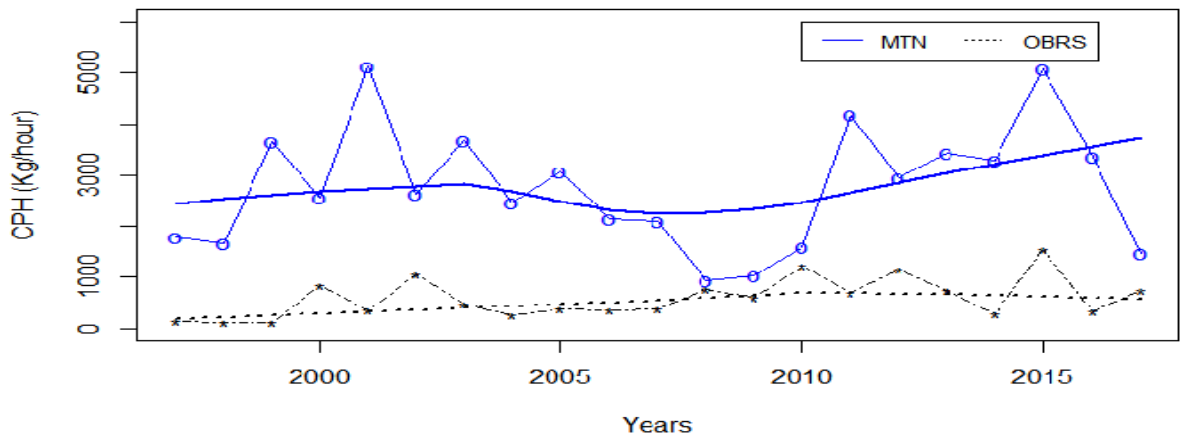
**Table 27: Stratum wise and season wise correlation of CPH for Indian mackerel**

Strata	Strata			Seasons	Seasons		
	ST_1	ST_2	ST_3		PRM	MON	POM
ST_1	1.00	0.34	-0.03	PRM	0.35	0.27	0.35
ST_2		1.00	-0.20	MON		1.00	0.40*
ST_3			1.00	POM			1.00

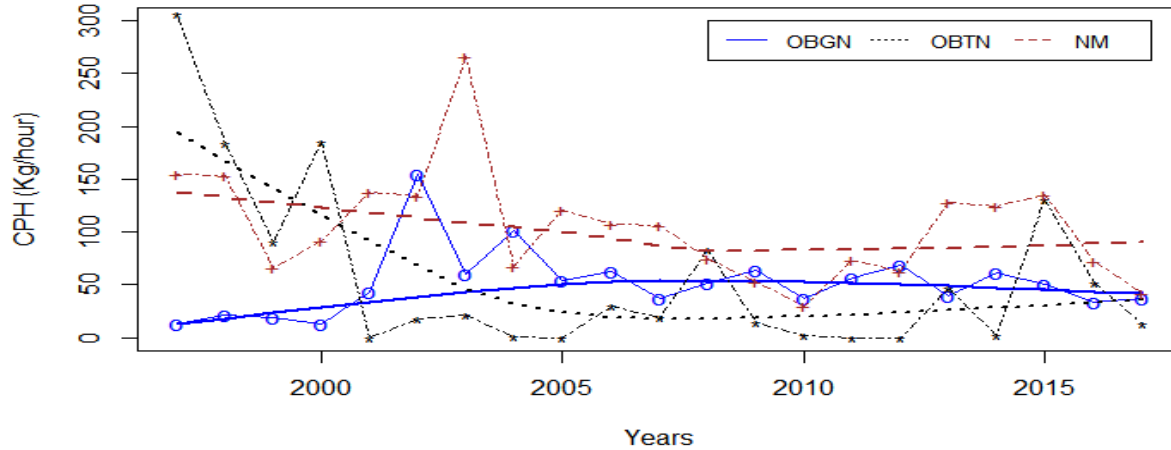
(\*') Significant at 0.5



**Fig. 88: Gear-wise trend for CPH of Indian mackerel (MGN, MPS and MRS)**



**Fig. 89: Gear-wise trend for CPH of Indian mackerel (MTN and OBRS)**



**Fig. 90: Gear-wise trend for CPH of Indian mackerel (OBGN, OBTN and NM)**

**Table 28: Gear-wise correlation of CPH for Indian mackerel**

Gears	MGN	MPS	MRS	MTN	NM	OBGN	OBRS	OBTN
MGN	1.00	0.26	0.35	0.042	-0.18	-0.26	0.082	0.16
MPS		1.00	0.58**	0.20	-0.13	0.16	0.50*	-0.54*
MRS			1.00	0.052	-0.25	0.068	0.13	-0.38*
MTN				1.00	0.36	0.025	0.12	-0.16
NM					1.00	0.051	-0.21	0.25
OBGN						1.00	0.27	-0.52*
OBRS							1.00	-0.16
OBTN								1.00

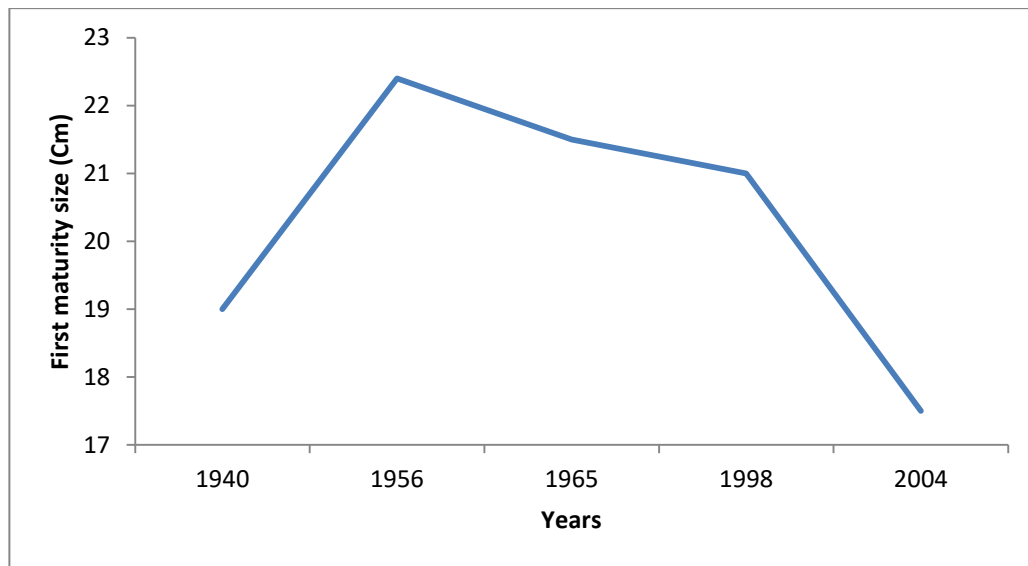
‘\*\*’ and ‘\*\*\*’ Significant at 0.5 and 0.01, respectively

#### 4.2.3.2. Biological attributes

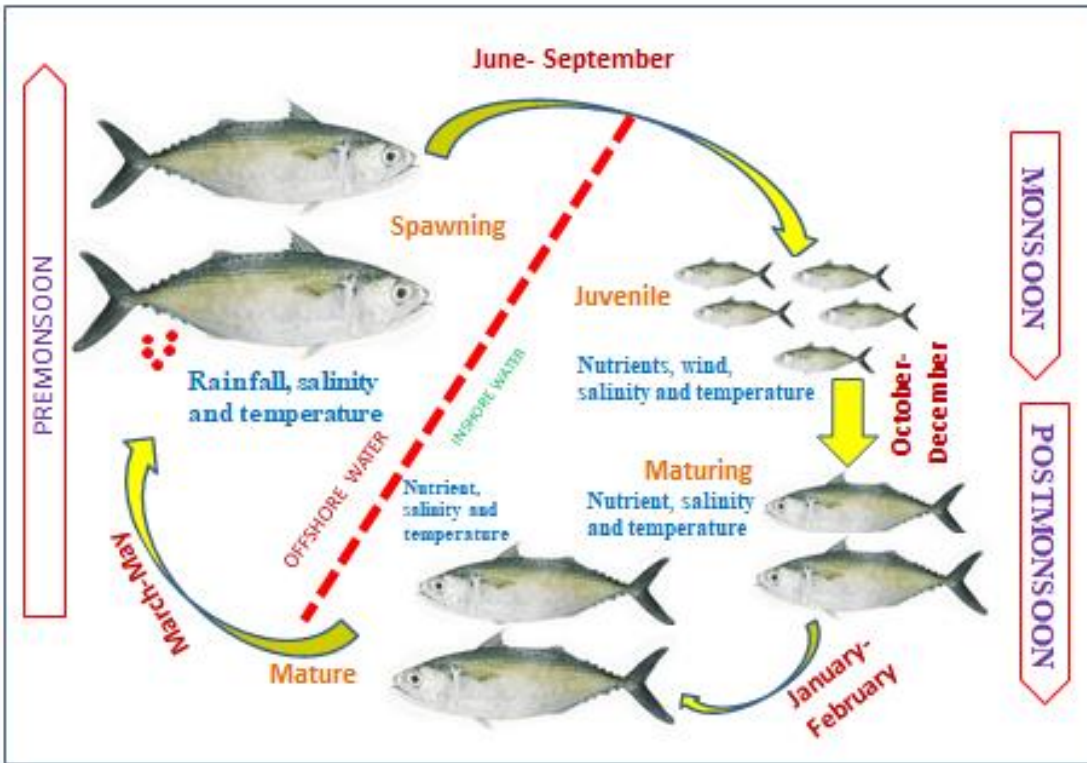
The size of the first maturity of mackerel was continuously decreased over the period. Mackerel could attend the first maturity at 22.4 cm during 1956. Further, maturity size was decreased and the study found that 21.5 cm was minimized for attending the first maturity in 1965. But, the decreasing trend in maturity size found that mackerel could able to mature at even 17.5 cm in 2004 (Fig. 91).

Mackerel starts to spawn in June at offshore water after onset of monsoon, which provides lower salinity and temperature in comparison to pre-monsoon condition. After spawning, the larvae and juveniles move towards

inshore water to feed on high biomass of phytoplankton during southwest monsoon season when intense upwelling brings high primary productivity. The movements of larvae and juveniles are continued up to September, where sea surface wind, nutrient, salinity, and temperature could have an important role in the suitable ground for better survival of larvae. Up to post-monsoon, juveniles attend to maturing and mature stages in inshore water under high nutrient condition. Finally, when temperature increased further in the pre-monsoon period, the mature mackerels move towards offshore water region in search of optimum environmental conditions (Fig. 92).



**Fig. 91: Observation on the trend of the first maturity of Indian mackerel**



**Fig. 92: Life cycle model for Indian mackerel**

#### 4.2.4. *Stolephorus* spp.

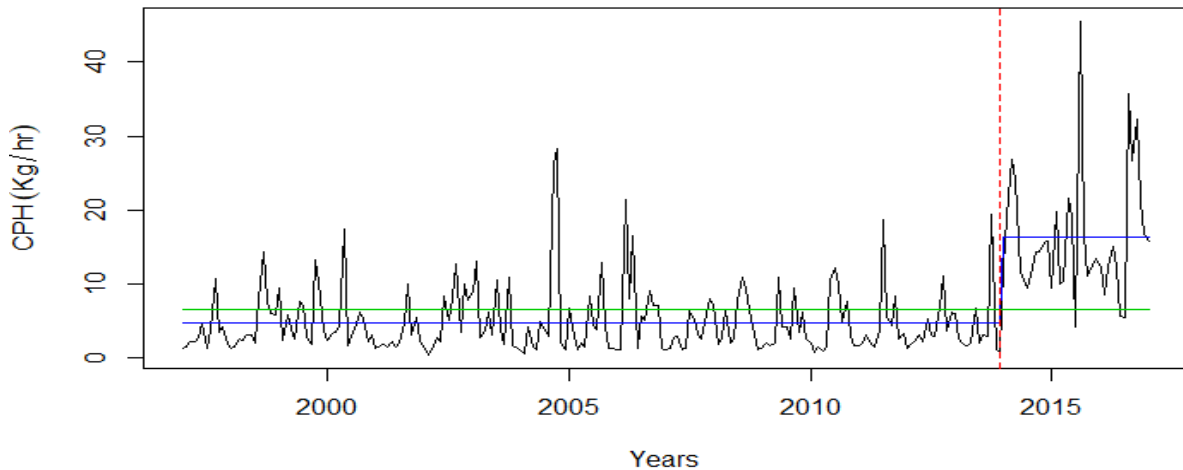
##### 4.2.4.1. Technical attributes

The changepoint analysis was applied to observe the trend in the time series CPH of *Stolephorus* spp. A significant shift was found in the time series for CPH of *Stolephorus* spp. in the study with a significant break in CPH along entire SW during 2013 as CPH was significantly lower before 2013 in comparison to same of after 2013 (Fig. 93). In a spatial comparison of CPH of *Stolephorus* spp. at SW, the result showed an upward sliding trend at two strata as ST\_2 and ST\_3. At the initial period of study, the highest CPH was observed along ST\_1, but ST\_3 showed the highest CPH after 2007 with the intermediate position of ST\_2. Therefore, CPH was continuously increased from southern to the northern region (Fig. 94). The correlation (0.77) between ST\_2 and ST\_3 was significantly positive (Table 29).

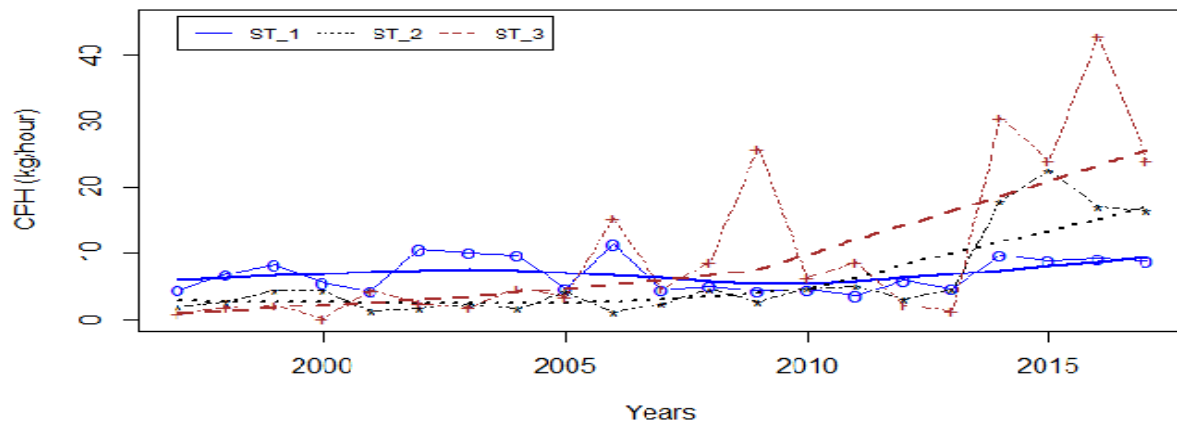
Seasonal analysis of CPH for *Stolephorus* spp. demonstrated that the increasing trend of CPH during all three seasons *i.e.* pre-monsoon, monsoon and

post-monsoon in the study (Fig. 95). The CPH was always lower during pre-monsoon compared to the other two seasons. The seasonal trend of CPH showed a significantly positive correlation in each other, where the significant correlation between pre-monsoon and monsoon, pre-monsoon and post-monsoon and post-monsoon and monsoon were 0.71, 0.63 and 0.89, respectively (Table 29).

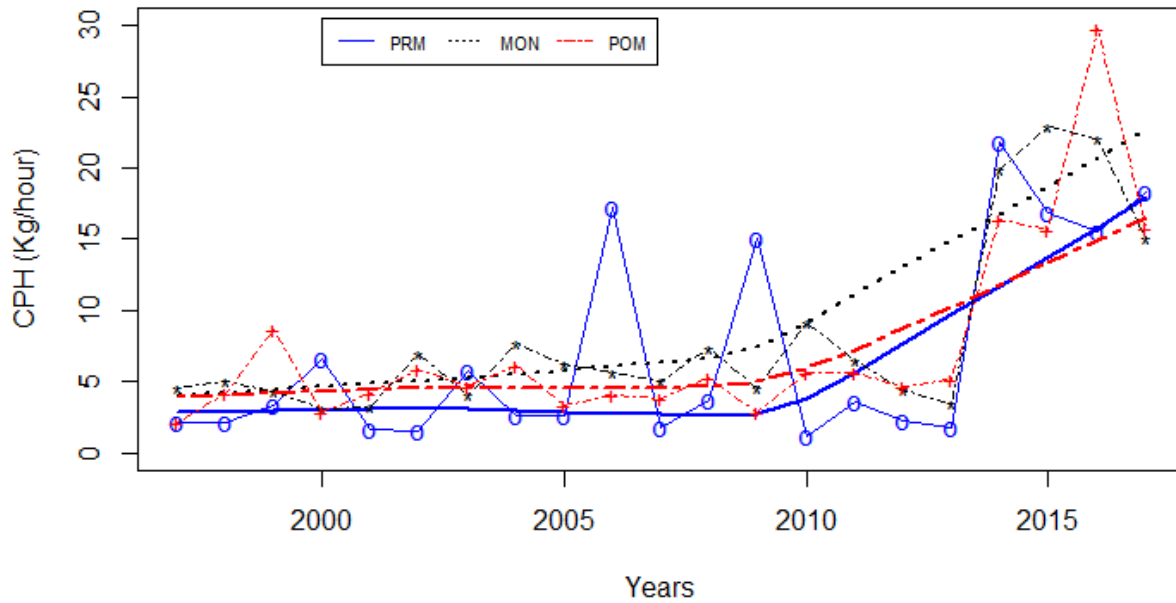
The plot for time series CPH of MRS showed a continuously increasing trend (Fig. 96), while that for MTN had also an upward sliding since 2010 (Fig. 84). On the other hand, the CPH of OBRS (Fig. 97), OBTN and NM (Fig. 98) had a decreasing trend in the result. The correlation analysis for CPH among different gears for *Stolephorus* spp. did not record any significant correlation during the study period (Table 30).



**Fig. 93: Trend for CPH of *Stolephorus* spp. at SW**



**Fig. 94: Stratum wise trend for CPH of *Stolephorus* spp.**

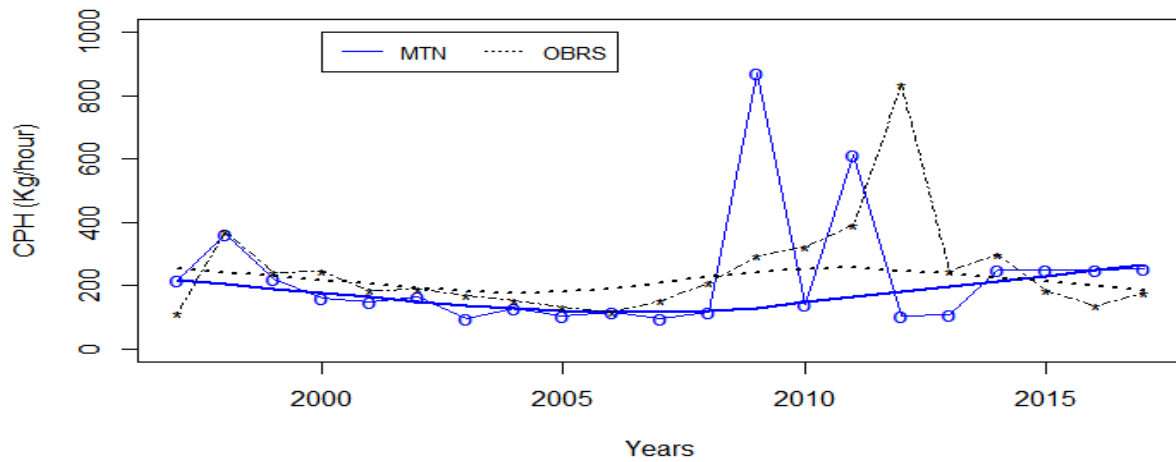


**Fig. 95: Season wise trend for CPH of *Stolephorus* spp.**

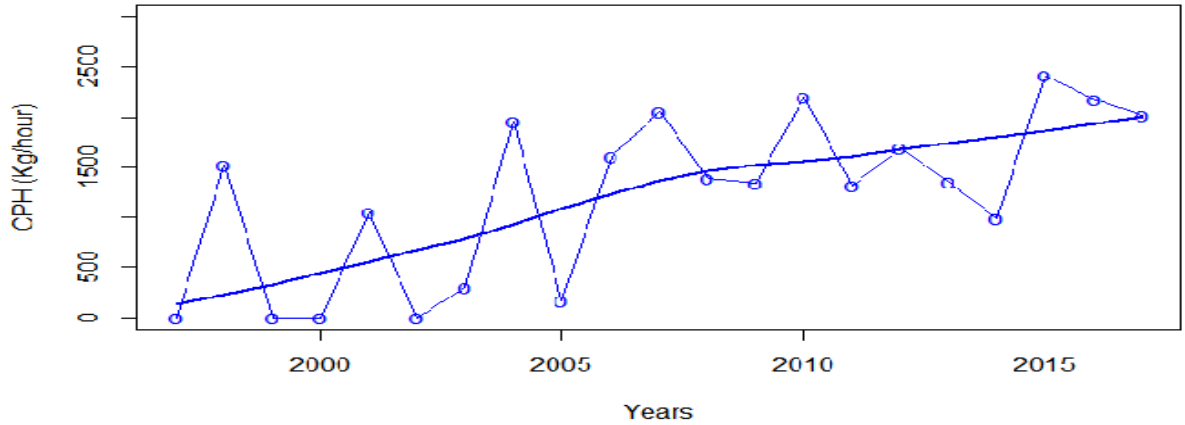
**Table 29: Stratum wise and season wise correlation of CPH of *Stolephorus* spp.**

Strata	Strata			Seasons	Seasons		
	ST_1	ST_2	ST_3		PRM	MON	POM
ST_1	1.00	0.32	0.34	PRM	1.00	0.71***	0.63***
ST_2		1.00	0.77*	MON		1.00	0.89***
ST_3			1.00	POM			1.00

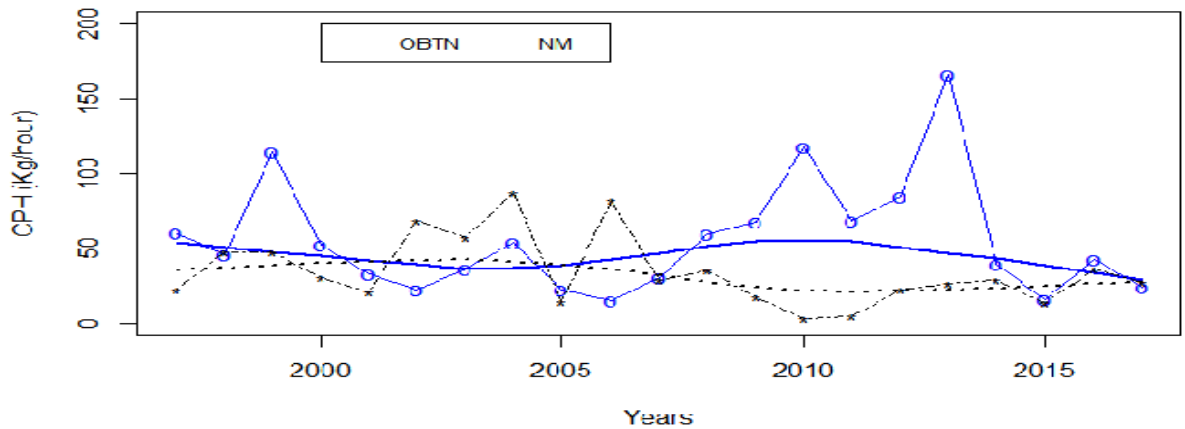
“\*\*\*” 0.001 level of significant



**Fig. 96: Gear-wise trend for CPH of *Stolephorus* spp. (MTN and OBRS)**



**Fig. 97: Trend for CPH of *Stolephorus* spp. in MRS**



**Fig. 98: Gear-wise trend for CPH of *Stolephorus* spp. (OBTN and NM)**

**Table 30: Gear-wise correlation of CPH of *Stolephorus* spp.**

Gears	MRS	MTN	NM	OBRS	OBTN
MRS	1.00	0.081	-0.13	0.16	-0.001
MTN		1.00	-0.31	0.16	0.035
NM			1.00	-0.29	-0.26
OBRS				1.00	0.36
OBTN					1.00

#### 4.2.4.2. Biological attributes

*Stolephorus* spp. are present at the southeast coast of India from June to September, where they get a chance to find the optimum temperature. By October

the temperature starts to increase at south west coast after cessation of upwelling, *Stolephorus* spp. move from south east to south west region to exploit the abundance planktonic food organism. After entering in the south west region, it spreads at the entire stratum\_1 area by November. Further, It's movement keeps on continued towards the northern region with decreasing temperature on progressing of the winter season, and it reaches up to stratum\_3 by the end of February. Further, the temperature starts to increase at southwest coast region on approaching of the summer season, which forces *Stolephorus* spp. to move again towards southwards. Therefore, *Stolephorus* spp. again aggregated at stratum\_2 and stratum\_3 by the end of May. After May, the upwelling phenomenon appears at the southwest coast, which reduces the temperature and dissolved oxygen (DO) at surface water. To prevent the adverse effects of low temperature and DO at the south west coast, *Stolephorus* spp. accumulates in the south east region (Fig. 99).

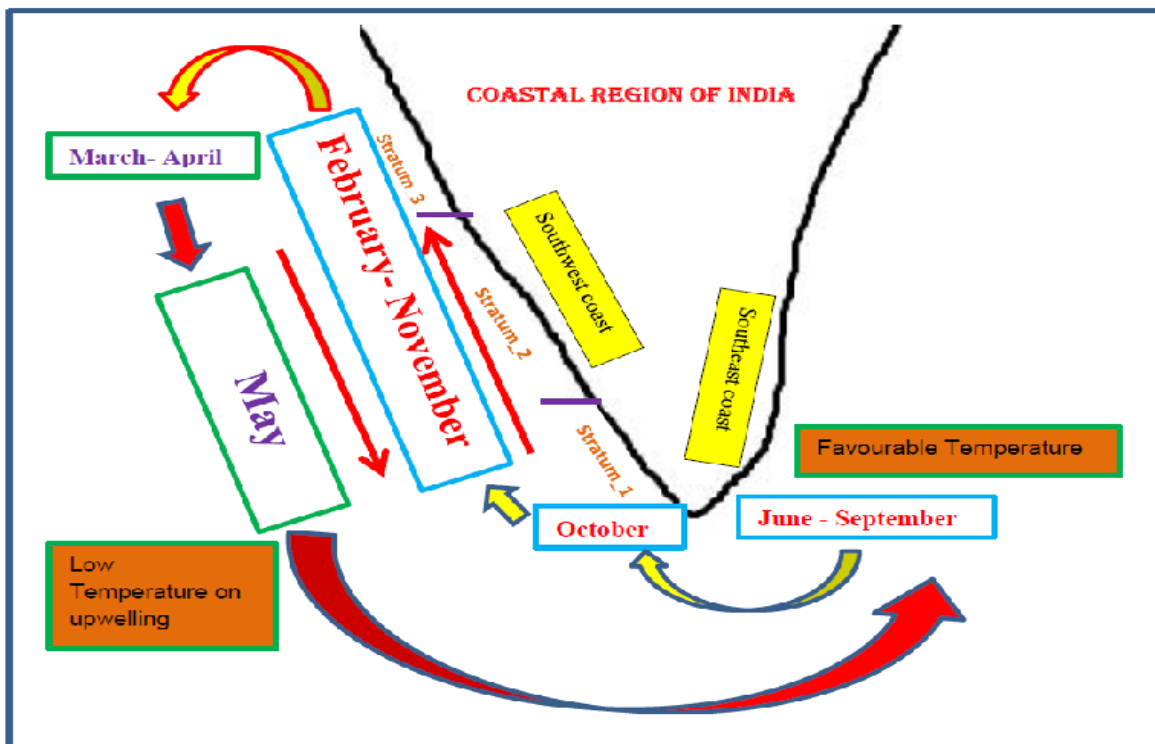


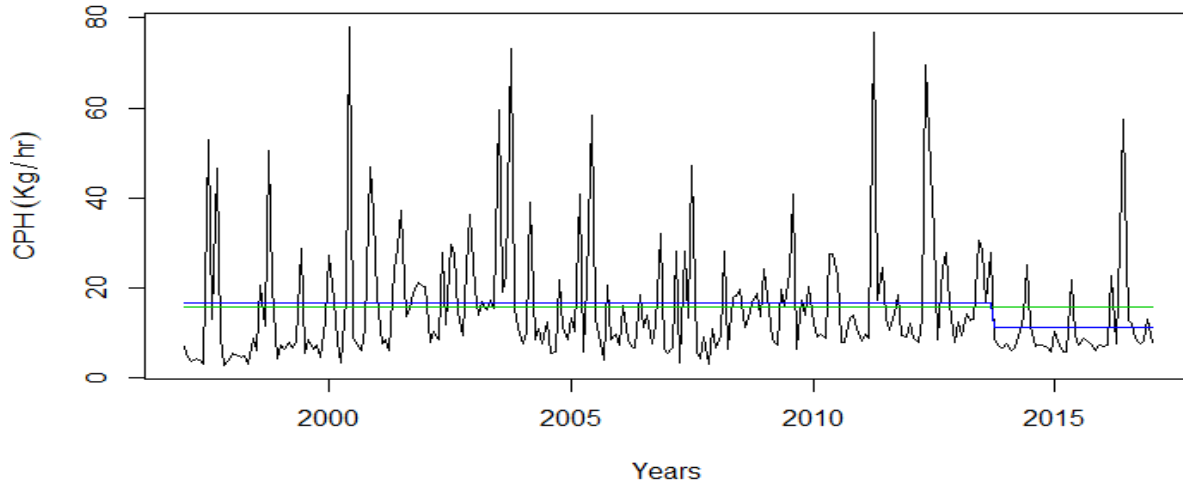
Fig. 99: Life cycle model for *Stolephorus* spp.

#### 4.2.5. *Thryssa* spp.

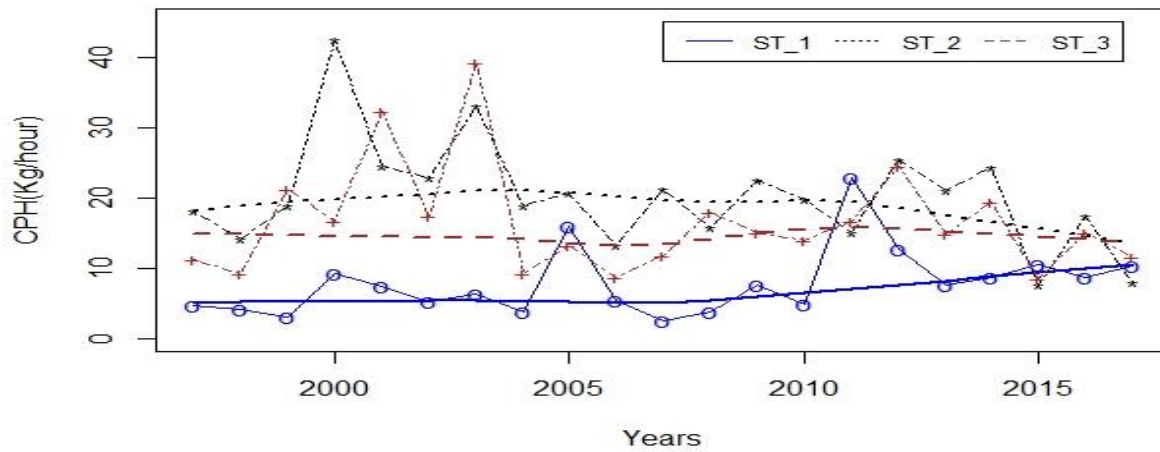
The changepoint analysis of time series CPH for *Thryssa* spp. along entire SW was performed to find out the shift in CPH over the study period, the possibility of shifting in CPH was found during 2013 as CPH was lower after 2013 in comparison to same before 2013 (Fig. 100). The spatial trend of CPH for *Thryssa* spp. indicated that the highest CPH was along ST\_2, followed by ST\_3 and ST\_1. However, the CPH of both ST\_2 and ST\_3 was observed as a decreasing trend, while that for ST\_1 had an increasing trend in the study (Fig. 101). The correlation analysis between CPH of ST\_2 and ST\_3 also showed a significant positive correlation as 0.57 (Table 31).

The seasonal study showed the highest CPH was during the monsoon period. However, CPH for monsoon season had an increasing trend. But, time series of CPH for both pre-monsoon and post-monsoon plotted as a decreasing trend after 2005 (Fig. 102). A significant positive correlation (0.55) was also seen between CPH of pre-monsoon and post-monsoon (Table 31).

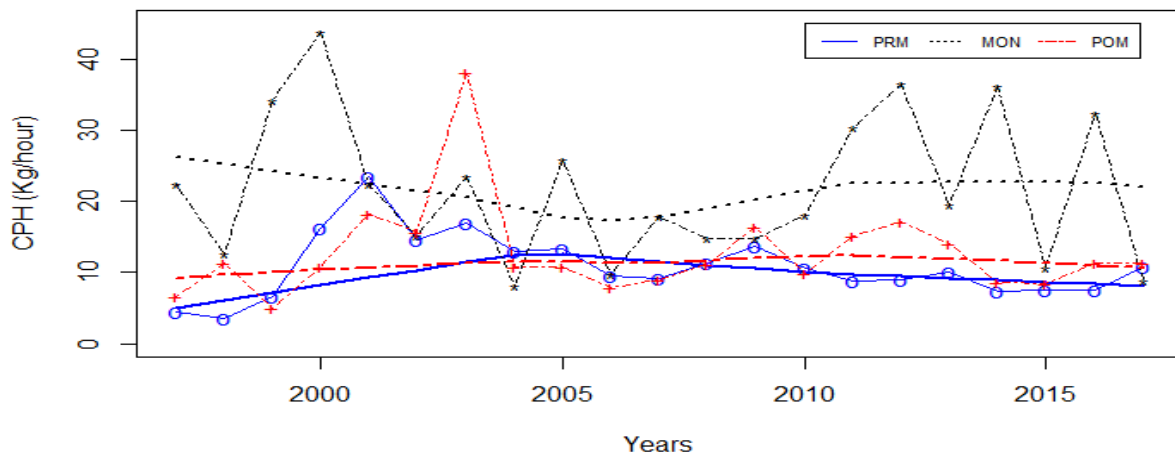
In a gear-wise analysis of catch, the time series of CPH in mechanized gear such as MRS (Fig.103) and MTN (Fig.104) had an increasing and decreasing trend, respectively. On the other hand, the time series of CPH for motorized gears such as OBRS and OBTN (Fig.105) showed a decreasing trend and at same time OBGN indicated an increasing trend over the study period. Non-mechanized gears also an increasing trend for the time series of CPH at SW after 2005 (Fig.106). Correlation analysis was also carried out to observe the relationship between the CPH of different gears. A significantly positive correlation between MRS and OBGN (0.41), and OBRS and OBTN (0.40) was found as depicted in table 32.



**Fig. 100: Trend for CPH of *Thyrysa* spp. at SW**



**Fig. 101: Stratum wise trend for CPH of *Thyrysa* spp.**

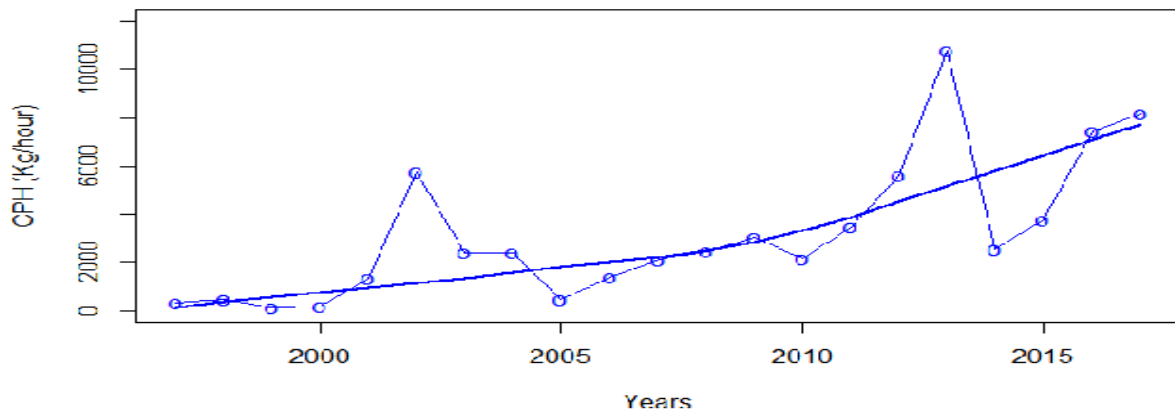


**Fig. 102: Season wise trend for CPH of *Thyrysa* spp.**

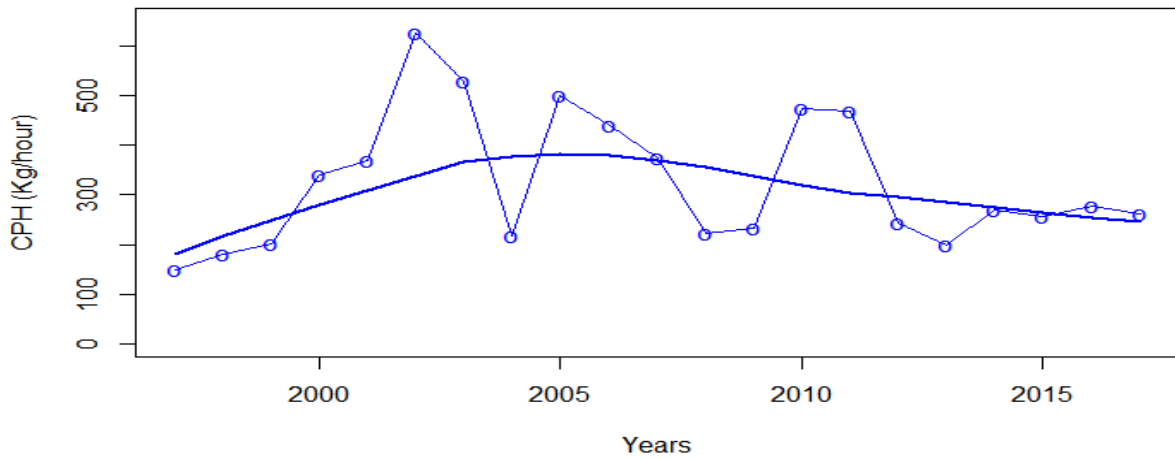
**Table 31: Stratum wise and season wise correlation of CPH for *Thryssa* spp.**

Strata	Strata			Seasons	Seasons		
	ST_1	ST_2	ST_3		PRM	MON	POM
ST_1	1.00	-0.05	-0.06	PRM	1.00	0.01	0.55**
ST_2		1.00	0.57**	MON		1.00	0.04
ST_3			1.00	POM			1.00

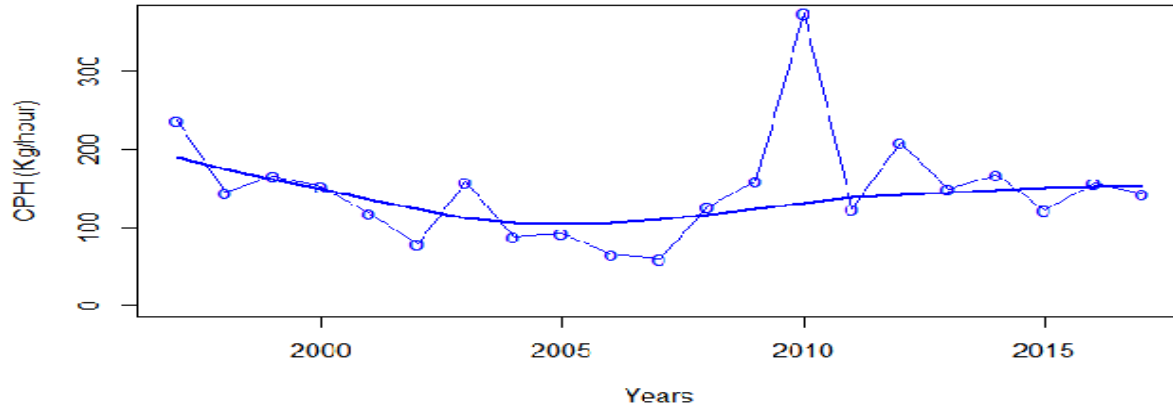
'\*' and '\*\*' Significant at 0.5 and 0.01, respectively



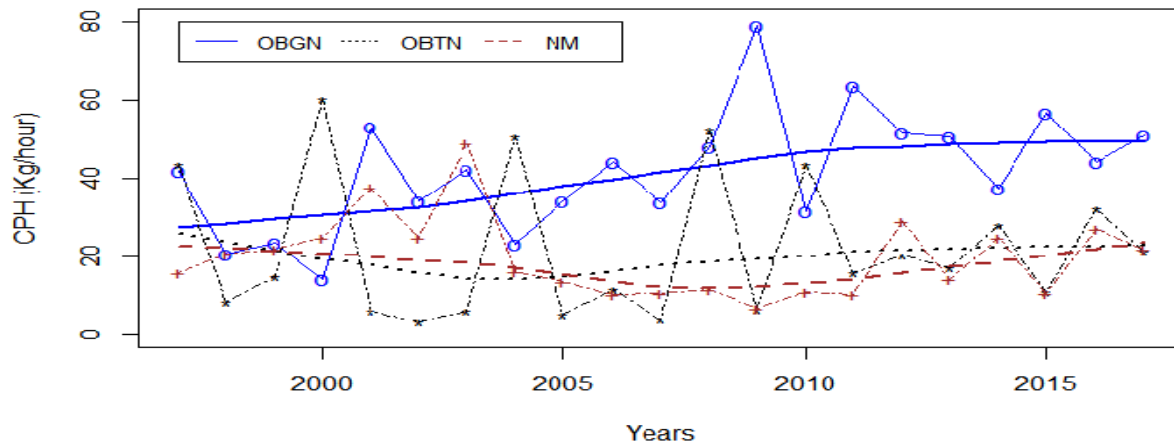
**Fig. 103: Trend for CPH of *Thryssa* spp. in MRS**



**Fig. 104: Trend for CPH of *Thryssa* spp. in MTN**



**Fig. 105: Trend for CPH of *Thryssa* spp. in OBRS**



**Fig. 106: Trend for CPH of *Thryssa* spp. in OBGN, OBTN and NM**

**Table 32: Gear-wise correlation of CPH for *Thryssa* spp.**

Gears	MRS	MTN	NM	OBGN	OBRS	OBTN
MRS	1.00	-0.08	0.03	0.41*	-0.02	-0.11
MTN		1.00	0.20	-0.05	-0.15	-0.34
NM			1.00	-0.19	0.04	-0.12
OBGN				1.00	-0.03	-0.35
OBRS					1.00	0.40*
OBTN						1.00

\*\* Significant at 0.5

### 4.3. Model

Logistic regression model, stepwise regression model and cross-correlation model were model used in this study to find out the relationship between catch per unit effort of small pelagic fishes and oceano-climatic parameters. Before performing the regression model, the assessment of multicollinearity among the independent variable was conducted by using the score of the Variance Inflation Factor (VIF).

#### 4.3.1. Logistic regression model

##### 4.3.1.1. Indian oil sardine

The score of the Variance Inflation Factor (VIF) for sardine has been given table 33. Since VIF score is below to 10, hence any parameter did not show multicollinearity.

**Table 33: VIF score of independent variables for Indian oil sardine**

VIF score	Chlorophyll-a	SST	Wind_U	Wind_V	Current_U	Current_V	SLA	Precipitation rate	UI
Initial	1.10	1.60	6.87	2.13	2.00	5.75	4.26	3.79	1.19

The CPH of sardine along SW was categorized by the probability of success (1) as CPH 22.95 kg per hour (covers 80 percentile of CPH) or more, and the probability of failure (0) as CPH less than 22.95 kg per hour. The result found per unit increase in logit score governed by a change in log odds of chlorophyll-a concentration, SST, wind\_U, wind\_V, current\_U, current\_V, SLA and precipitation rate with 0.34, -0.23, 0.11, -1.07, 6.17, 8.01, -0.01 and 1.87, respectively. The meridional wind had a significant influence on the logistic model at 5% level of significance (Table 34). The Wald test had chi-square 31.6 and degree of freedom 9, indicated a significant logistic model for sardine.

**Table 34: Coefficients of logistic regression model for Indian oil sardine**

Model	Estimate	Std. Error	z value	Pr(> z )
Intercept	2.75	9.48	0.29	0.77
Chlorophyll_a	0.34	0.28	1.19	0.23
SST	-0.23	0.32	-0.72	0.47
Wind_U	0.11	0.20	0.54	0.59
Wind_V	-1.07	0.40	-2.65	0.008 **
Current_U	6.17	18.4	0.34	0.74
Current_V	8.01	7.76	1.03	0.30
SLA	-0.01	4.37	-0.00	0.99
Precipitation rate	1.87	1.36	1.38	0.17
UI	0.00	00	0.11	0.91

\*\*\* Significant at 0.001

Null deviance: 204.72 on 203 degrees of freedom, Residual deviance: 189.33 on 194 degrees of freedom, AIC: 209.33 and Number of Fisher Scoring iterations: 4

The logistic regression model uses logit transform and formula represented as

$$\ln\left(\frac{p_i}{1-p_i}\right) = 2.75 + 0.34(\text{Chlorophyll} - a) - 0.23(\text{SST}) + 0.11(\text{Wind}_U) - 1.07(\text{Wind}_V) \\ + 6.17(\text{Current}_U) + 8.01(\text{Current}_V) - 0.01(\text{SLA}) \\ + 1.87(\text{Precipitation rate})$$

Wald test:

Chi-squared test:

$X^2 = 33.2$ ,  $df = 9$ ,  $P(> X^2) = 0.00012$

#### **4.3.1.2. Indian mackerel**

The VIF score had more than 10 for wind\_U in the case of mackerel. Hence wind\_U was removed before performing the logistic regression. After removing the wind\_U again VIF score was estimated (Table 35).

**Table 35: VIF score of independent variables for Indian mackerel**

VIF score	Chlorophyll-a	SST	Wind_U	Wind_V	Current_U	Current_V	SLA	Precipitation rate	UI
Initial	1.71	2.23	10.38	3.21	4.73	6.10	5.62	6.09	2.08
Final	1.70	2.11	-	3.19	4.45	3.37	5.22	5.46	2.06

The CPH of mackerel along SW was categorized as the probability of success (1) as CPH 43.71 kg per hour (included 97 percentile of CPH) or more and probability of failure (0) as CPH less than 43.71 kg per hour. The result depicted as per unit increase in logit score of mackerel was taken place with change in log odds of chlorophyll-a concentration, SST, wind\_V, current\_U, current\_V, SLA, precipitation rate and UI by -6.07, -0.41, 0.64 -152, -25.7, 10.9, 2.35 and 0.003, respectively (Table 36). Zonal current speed and upwelling index had a significant influence on the logistic model at 5% level of significance. The Wald test had chi-square 25.2 and degree of freedom 8, indicated a significant logistic model for mackerel.

**Table 36: Coefficients of the logistic regression model for Indian mackerel**

Model	Estimate	Std. Error	z value	Pr(> z )
Intercept	7.63	28.3	0.27	0.7873
Chlorophyll_a	-6.07	4.62	-1.315	0.1885
SST	-0.41	0.96	-0.429	0.6679
Wind_V	0.64	0.93	0.687	0.4922
Current_U	-152	66.3	-2.295	0.0217*
Current_V	-25.7	15.1	-1.704	0.0883
SLA	10.9	14.4	0.76	0.4474
Precipitation rate	2.35	3.30	0.714	0.4754
UI	0.003	0.001	2.275	0.0229*

‘\*’ Significant at 0.05

Null deviance: 60.968 on 203 degrees of freedom, Residual deviance: 38.589 on 195 degrees of freedom, AIC: 56.589 and Number of Fisher Scoring iterations: 9

The logistic regression model uses logit transform and formula represented as

$$\ln\left(\frac{p_i}{1-p_i}\right) = 7.63 - 6.07(\text{Chlorophyll} - a) - 0.41(\text{SST}) + 0.64(\text{Wind}_V) - 152(\text{Current}_U) - 25.7(\text{Current}_V) + 10.9(\text{SLA}) + 2.35 (\text{Precipitation rate}) + 0.003(\text{UI})$$

Wald test:

Chi-squared test:

$$\chi^2 = 25.2, df = 8, P (> X^2) = 0.0014$$

#### 4.3.1.3. *Stolephorus* spp.

The VIF score was higher than 10 in wind\_U and UI for *Stolephorus* spp., hence wind\_U and UI were removed before performing the logistic regression. After removing the wind\_U again VIF score was estimated (Table 37).

**Table 37: VIF score of independent variables for *Stolephorus* spp.**

VIF score	Chlorophyll-a	SST	Wind_U	Wind_V	Current_U	Current_V	SLA	Precipitation rate	UI
Initial	1.05	1.87	21.56	5.81	1.40	5.89	1.35	6.09	20.51
Final	1.05	1.64	-	2.19	1.40	2.24	1.38	4.10	-

The CPH of *stolephorus* along SW was categorized by the probability of success (1) as CPH 16.98 kg per hour or more (included 97 percentile of CPH) and the probability of failure (0) as CPH less than 16.98 kg per hour. The increase in logit score of *Stolephorus* spp. was taken place by a change in log odds of chlorophyll-a concentration, SST, wind\_V, current\_U, current\_v, SLA and precipitation rate with 0.53, 1.17, -1.14, 14.64, 8.13, 4.24 and 4.58, respectively (Table 38). SST had a significant influence on the logistic model at 5% level of significant. The Wald test had chi-square 70.3 and degree of freedom 7, indicate a significant logistic model for *Stolephorus* spp.

**Table 38: Coefficients of the logistic regression model for *Stolephorus* spp.**

Model	Estimate	Std. Error	z value	Pr(> z )
Intercept	-40.03	15.31	-2.614	0.00894**
Chlorophyll_a	0.53	0.34	1.549	0.12129
SST	1.17	0.50	2.36	0.0183*
Wind_V	-1.14	0.70	-1.635	0.10212
Current_U	14.64	28.56	0.513	0.60826
Current_V	8.13	9.41	0.863	0.38797
SLA	4.24	4.49	0.944	0.34537
Precipitation rate	4.58	2.22	2.063	0.03909*

‘\*’ and ‘\*\*’ Significant at 0.05 and 0.01

Null deviance: 85.641 on 203 degrees of freedom,

Residual deviance: 73.862 on 196 degrees of freedom,

AIC: 89.862 and Number of Fisher Scoring iterations: 6

The logistic regression model uses logit transform and formula represented as

$$\ln\left(\frac{p_i}{1-p_i}\right) = -40.03 + 0.53(\text{Chlorophyll} - a) + 1.17(\text{SST}) - 1.14(\text{Wind}_V) \\ + 14.64(\text{Current}_U) + 8.13(\text{Current}_V) + 4.24(\text{SLA}) \\ + 4.58(\text{Precipitation rate})$$

Wald test:

$X^2 = 46.4$ ,  $df = 7$ ,  $P(> X^2) = 7.3e-08$

#### 4.3.1.4. *Thryssa* spp.

The VIF for wind\_U had more than 10, hence wind\_U was removed before performing the logistic regression. After removing the wind\_U again VIF score was estimated (Table 39).

**Table 39: VIF score of independent variables for *Thryssa* spp.**

VIF score	Chlorophyll-a	SST	Wind_U	Wind_V	Current_U	Current_V	SLA	Precipitation rate	UI
Initial	1.81	1.79	10.24	1.99	2.53	7.65	4.96	3.40	1.27
Final	1.71	1.73	-	2.02	2.35	3.07	4.40	3.08	1.28

The CPH of *Thryssa* spp. along SW was categorized by the probability of success (1) as CPH 29.06 kg per hour (included 90 percentile of CPH) or more and probability of failure (0) as CPH less than 29.06 kg per hour. The per unit increase in logit score controlled by change in log odds of chlorophyll-a concentration, SST, wind\_V, current\_U, current\_V, SLA and precipitation rate with -2.29, -0.85, -0.31, -16.1, -4.43, -13.2, 2.45 and 0.0008, respectively (Table 40). SLA had a significant influence on the logistic model at 5% level of significant. The Wald test had chi-square 41.5 and degree of freedom 8, indicate a significant logistic model for *Thryssa* spp.

**Table 40: Coefficients of logistic regression model for *Thryssa* spp.**

Model	Estimate	Std. Error	z value	Pr(> z )
Intercept	22.8	16.29	1.399	0.1617
Chlorophyll_a	-2.29	1.22	-1.876	0.0606
SST	-0.85	0.56	-1.518	0.1291
Wind_V	-0.31	0.541	-0.567	0.5706
Current_U	-16.1	27.87	-0.578	0.5631
Current_V	-4.43	7.65	-0.58	0.5621
SLA	-13.2	6.43	-2.044	0.041*
Precipitation rate	-2.45	1.93	-1.271	0.2036
UI	0.0008	0.00	1.22	0.2226

\* Significant at 0.05

Null deviance: 135.25 on 203 degrees of freedom, Residual deviance: 109.57 on 195 degrees of freedom, AIC: 127.57 and Number of Fisher Scoring iterations: 6

The logistic regression model uses logit transform and formula represented as

$$\ln\left(\frac{p_i}{1-p_i}\right) = 22.8 - 2.29(\text{Chlorophyll}_a) - 0.85(\text{SST}) - 0.31(\text{Wind}_V) \\ - 16.1(\text{Current}_U) - 4.43(\text{Current}_V) - 13.2(\text{SLA}) \\ - 2.45(\text{Precipitation rate}) + 0.0008(\text{UI})$$

Wald test:

Chi-squared test:

$$\chi^2 = 41.5, \text{ df} = 8, P(> \chi^2) = 1.7e-06$$

### 4.3.2. Stepwise regression model

#### 4.3.2.1. Indian oil sardine

The coefficient value for all variables at the initial stage of the stepwise regression model for CPH at SW for sardine has been given in table 41, where the CPH of sardine significantly and positively depends on two parameters as chlorophyll\_a concentration and meridional current. However, this result indicated that the model was significant (p-value: 0.001687) even at the initial stage, where the model explained only 12% of CPH.

**Table 41: Fit summary of a complete model for Indian oil sardine**

Model	Estimate	Std. Error	t value	Pr(> t )
Intercept	5.3171283	17.0170425	0.312	0.7552
Chlorophyll_a	4.195867	1.7817348	2.355	0.0199*
Wind_U	0.1544095	0.5706172	0.271	0.7871
SST	0.2798555	0.3380596	0.828	0.4092
Wind_V	1.4848122	0.6401043	2.32	0.0218*
Current_U	18.798839	36.9358885	0.509	0.6116
Current_V	23.4275681	13.2819919	1.764	0.08
SLA	7.8659808	8.2884587	0.949	0.3443
Precipitation rate	-2.253523	2.6716133	-0.844	0.4004
UI	-0.0015684	0.0008508	-1.844	0.0674

‘\*’ Significant at 0.05

Residual standard error: 3.919 on 137 degrees of freedom, Multiple R-squared: 0.172, Adjusted R-squared: 0.1176, F-statistic: 3.163 on 9 and 137 DF, p-value: 0.001687

Since stepwise variable selection tends to pick models that are smaller than desirable for prediction purposes. Therefore, five steps were followed to find out the best predictive model with a combination of backward elimination and forward selection. Each step delivered the value of Akaike's Information Criteria (AIC) as shown in table 42. AIC values in step\_1, step\_2, step\_3, step\_4 and step\_5 were found as 411.23, 409.31, 407.55, 406.23 and 404.77, respectively. The lowest AIC value was observed in the case of step\_5, which delivered the best predictive model for sardine.

**Table 42: Stepwise selected variables in the regression model for Indian oil sardine**

Steps	Selected variables	AIC
Step_1	Chlorophyll_a, SST, Wind_U, Wind_V, Current_U, Current_V, SLA, Precipitation rate and UI	411.23
Step_2	Chlorophyll_a, Wind_U, Wind_V, Current_U, Current_V, SLA Precipitation rate and UI	409.31
Step_3	Chlorophyll_a, Wind_U, Wind_V, Current_V, SLA, Precipitation rate and UI	407.55
Step_4	Chlorophyll_a, Wind_U, Wind_V, Current_V, SLA and UI	406.23
Step_5	Chlorophyll_a, Wind_V, Current_V, SLA and UI	404.77

The final result of stepwise regression of CPH for sardine explained that CPH of sardine significantly depends on only five variables as chlorophyll\_a concentration, meridional wind and current speed, sea level anomaly and upwelling index. Therefore, the coefficient value for final stepwise regression model for CPH at SW for sardine was estimated as in table 43, where the predictive model were significantly (p-value: 0.0001165) depends on only five parameters as chlorophyll\_a concentration, meridional wind and current speed, sea level anomaly and upwelling index. Again result showed that the final stepwise regression model significantly and positively influenced by three parameters such as chlorophyll\_a concentration,

meridional wind, and meridional current speed. The final stepwise regression model was able explained 13% of CPH, since the result showed multiple R-squared and adjusted R-squared as 0.1633 and 0.1336, respectively.

**Table 43: Fit summary of the final model for Indian oil sardine**

Model	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	9.5765163	1.1716932	8.173	1.56E-13***
Chlorophyll_a	4.2921342	1.6550537	2.593	0.01051*
Wind_V	1.3938757	0.4908392	2.84	0.00518**
Current_V	14.7434239	6.7479925	2.185	0.03055*
SLA	11.2237235	6.017336	1.865	0.06423
UI	-0.0016432	0.0007531	-2.182	0.03076*

‘\*’, ‘\*\*’ and ‘\*\*\*’ significant at 0.05, 0.01 and 0.001

Residual standard error: 3.884 on 141 degrees of freedom, Multiple R-squared: 0.1633, Adjusted R-squared: 0.1336, F-statistic: 5.504 on 5 and 141 DF, and p-value: 0.0001165

#### 4.3.2.2. Indian mackerel

The summary of coefficient value for all variables at the initial stage of the stepwise regression model for CPH at SW of mackerel has been given in table 44. The initially stepwise regression model did not show any parameters which affect the CPH of mackerel significantly. However, even at the initial stage, the model was significant, where the model explained 14 % CPH.

**Table 44: Fit summary of a complete model for Indian mackerel**

Model	Estimate	Std. Error	t value	Pr(> t )
Intercept	34.2	15.8	2.165	0.0319
Chlorophyll-a	-1.97	1.78	-1.106	0.2704
SST	-0.10	0.05	-1.821	0.0705
Wind_V	-0.06	0.05	-1.114	0.2669
Current_U	-13.2	2.87	-4.599	0.6458
Current_V	-5.94	0.86	-6.907	0.4905
SLA	1.35	0.71	1.892	0.0604
Precipitation rate	-1.44	2.13	-0.673	0.5017
UI	-0.00	0.00	-0.345	0.7305

Residual standard error: 3.667 on 157 degrees of freedom, Multiple R-squared: 0.1813, Adjusted R-squared: 0.1396, F-statistic: 4.346 on 8 and 157 DF, and p-value: 9.349e-05

Seven steps were followed to find out the best predictive model with a combination of backward elimination and forward selection. Total seven steps were delivered the AIC value for mackerel as shown in table 45. AIC values were in step\_1, step\_2, step\_3, step\_4, step\_5, step\_6 and step\_7 as 440.11, 438.24, 436.51, 434.74, 433.28, 432.38 and 432.13, respectively. The lowest AIC value was observed in the case of step\_7, which delivered the best predictive model for CPH of mackerel.

**Table 45: Stepwise selected variables in the regression model for Indian mackerel**

Steps	Selected variables	AIC
Step_1	Chlorophyll_a, SST, Wind_V, Current_U, Current_V, SLA, Precipitation rate and UI	440.11
Step_2	Chlorophyll_a, SST, Wind_V, Current_U, Current_V, SLA and Precipitation rate	438.24
Step_3	Chlorophyll_a, SST, Wind_V, Current_V, SLA and Precipitation rate	436.51
Step_4	Chlorophyll_a, SST, Wind_V, SLA and Precipitation rate	434.74
Step_5	Chlorophyll_a, SST, Wind_V and SLA	433.28
Step_6	SST, Wind_V and SLA	432.38
Step_7	Wind_V and SLA	432.13

The final result of stepwise regression for CPH of mackerel explained that CPH significantly depends on only two variables as meridional wind speed and sea level anomaly. Therefore, the coefficient value for final stepwise regression model for CPH at SW for mackerel was estimated as in table 46, where the final regression model were significantly (p-value: 5.987e-07) depends on both parameters as meridional wind speed and sea level anomaly. Again result showed the final regression model strongly and positively influenced by sea level anomaly and

negatively as well as weakly affected with meridional wind speed. The final stepwise regression model was able explained 15% of CPH.

**Table 46: Fit summary of the final model for Indian mackerel**

Model	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	4.80	0.62	7.692	1.3e-12 ***
Wind_v	-1.15	0.41	-2.819	0.00542 **
SLA	12.40	3.73	3.328	0.00108 **

‘\*\*\*’ significant at 0.001

Residual standard error: 3.642 on 163 degrees of freedom,

Multiple R-squared: 0.1612, Adjusted R-squared: 0.1509,

F-statistic: 15.67 on 2 and 163 DF, and p-value: 5.987e-07

#### 4.3.2.3. *Stolephorus* spp.

The summary of coefficient values for all selected variables used in the initial stage of the stepwise regression model for CPH at SW for *Stolephorus* spp. has been given in table 47. The initially stepwise regression model showed that two variables as zonal current and precipitation rate had a significant influence on the CPH of *Stolephorus* spp. The initial stage of the model was significant, where the model explained 20% of CPH.

**Table 47: Fit summary of complete model for *Stolephorus* spp.**

Model	Estimate	Std. Error	t value	Pr(> t )
Intercept	3.25042	6.82245	0.476	0.63444
Chlorophyll_a	1.13857	0.71338	1.596	0.11252
SST	-0.07097	0.22484	-0.316	0.75271
Wind_V	-0.27324	0.25519	-1.071	0.28594
Current_U	-27.00588	11.20642	-2.41	0.01713*
Current_V	-0.77535	3.44169	-0.225	0.82206
SLA	1.14255	1.8751	0.609	0.5432
Precipitation rate	3.45758	0.92213	3.75	0.00025***

‘\*’ and ‘\*\*\*’ significant at 0.05 and 0.001

Residual standard error: 1.709 on 155 degrees of freedom, Multiple R-squared: 0.2386, Adjusted R-squared: 0.2042, F-statistic: 6.94 on 7 and 155 DF, and p-value: 3.456e-07

Total four steps were followed to find out the best predictive model with a combination of backward elimination and forward selection. The AIC values of step\_1, step\_2, step\_3 and step\_4 and were found as 182.4, 180.53, 178.61 and 177.15, respectively. The lowest AIC value was observed in the case of step\_4, where four parameters as chlorophyll-a, wind\_V, current\_U and precipitation rate were used for prediction of CPH of *Stolephorus* spp. (Table 48).

**Table 48: Stepwise selected variables in the regression model for *Stolephorus* spp.**

Steps	Selected variables	AIC
Step_1	Chlorophyll_a, SST, Wind_V, Current_U, Current_V, SLA and Precipitation rate	182.4
Step_2	Chlorophyll_a, SST, Wind_V, Current_U, SLA and Precipitation rate	180.53
Step_3	Chlorophyll_a, Wind_V, Current_U, SLA and Precipitation rate	178.61
Step_4	Chlorophyll_a, Wind_V, Current_U and Precipitation rate	177.15

The final result of stepwise regression for CPH of *Stolephorus* spp. explained that CPH significantly depends on only four variables chlorophyll\_a, wind\_V, current\_U and precipitation rate. Therefore the coefficient values for final stepwise regression model for CPH at SW of *Stolephorus* spp. were estimated (Table 49). The final regression model were significantly ( $p=1.204e-08$ ) influenced by chlorophyll\_a, current\_U and precipitation rate. The final stepwise regression model was able to explain 22% of CPH.

**Table 49: Fit summary of the final model for *Stolephorus* spp.**

Model	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	1.0267	0.4908	2.092	0.038
Chlorophyll_a	1.366	0.614	2.225	0.0275*
Wind_V	-0.3394	0.2215	-1.533	0.1273
Current_U	-26.5111	10.3843	-2.553	0.0116*
Precipitation rate	3.5524	0.7162	4.96	1.81E-06***

\*, \*\* and \*\*\* significant at 0.05, 0.01 and 0.001

Residual standard error: 1.696 on 158 degrees of freedom, Multiple R-squared: 0.2355, Adjusted R-squared: 0.216, F-statistic: 12.17 on 4 and 158 DF, and p-value: 1.204e-08

#### 4.3.2.4. *Thryssa* spp.

At the initial stage, eight variables were used in the prediction of CPH of phryssa after checking of multicollinearity. The coefficient value for all variables used in the initial stage of the stepwise regression model for CPH at SW for *Thryssa* spp. has been given in table 50. The initially stepwise regression model showed that two variables such as chlorophyll\_a concentration and sea level anomaly significantly influenced on CPH of *Thryssa* spp. At the initial stage, the model was significant, where the model explained 62% of CPH.

**Table 50: Fit summary of a complete model for *Thryssa* spp.**

Model	Estimate	Std. Error	t value	Pr(> t )
Intercept	9.37E+00	1.52E+01	6.16E-01	0.53896
Chlorophyll_a	1.76E+01	1.73E+00	1.02E+01	< 2e-16***
SST	-3.27E-01	5.03E-01	-6.50E-01	0.51779
Wind_V	-3.65E-01	6.07E-01	-6.01E-01	0.54877
Current_U	3.63E+00	2.78E+01	1.31E-01	0.89626
Current_V	-1.14E+01	8.90E+00	-1.28E+00	0.20215
SLA	2.36E+01	7.60E+00	3.11E+00	0.00243**
Precipitation rate	3.96E+00	2.26E+00	1.75E+00	0.08245
UI	-8.86E-04	7.45E-04	-1.19E+00	0.23665

‘\*\*\*’ Significant at 0.001 and ‘\*\*’ significant at 0.01

Residual standard error: 3.132 on 111 degrees of freedom, Multiple R-squared: 0.6396, Adjusted R-squared: 0.6137, F-statistic: 24.63 on 8 and 111 DF, and p-value: < 2.2e-16

Toal six steps were followed to find out the best predictive model with a combination of backward elimination and forward selection based on AIC values, where AIC values in step\_1, step\_2, step\_3, step\_4, step\_5, and step\_6 were found as 1049.60, 1047.60, 1045.96, 1044.38, 1042.71 and 1042.09, respectively. The

lowest AIC value was observed in the case of step\_6, where two parameters as SST and SLA were used for prediction of CPH of *Thryssa* spp. (Table 51).

**Table 51: Stepwise selected variables in the regression model for *Thryssa* spp.**

Steps	Selected variables	AIC
Step_1	Chlorophyll_a, SST, Wind_V, Current_U, Current_V, SLA, Precipitation rate and UI	282.65
Step_2	Chlorophyll_a , SST, Wind_V, Current_V, SLA, Precipitation rate and UI	280.67
Step_3	Chlorophyll_a, SST, Current_V, SLA, Precipitation rate and UI	279.04
Step_4	Chlorophyll_a, Current_V, SLA, Precipitation rate and UI	277.93
Step_5	Chlorophyll_a, Current_V, SLA and Precipitation rate	277.01

The final result of stepwise regression for CPH of *Thryssa* spp. explained that CPH significantly depends on only four variables as chlorophyll\_a concentration, current \_V, SLA and precipitation rate. Therefore, the coefficient values in the final stepwise regression model for CPH at SW for *Thryssa* spp. were estimated (Table 52). The final regression model was significantly ( $p= 2.2e-16$ ) influenced by chlorophyll\_a and sea level anomaly. The final stepwise regression model was able to explain 63% of CPH.

**Table 52: Fit summary of the final model for *Thryssa* spp.**

Model	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	-0.04931	1.10694	-0.045	0.96455
Chlorophyll_a	18.34665	1.50756	12.17	< 2e-16****
Current _V	-12.01414	6.45664	-1.861	0.065335
SLA	23.19238	6.02887	3.847	0.000197***
Precipitation rate	2.72733	1.76392	1.546	0.12481

\*\*\*\* significant at 0.001

Residual standard error: 3.107 on 115 degrees of freedom, Multiple R-squared: 0.6325, Adjusted R-squared: 0.6297, F-statistic: 49.48 on 4 and 115 DF, and p-value: < 2.2e-16

#### 4.4. Cross-correlation

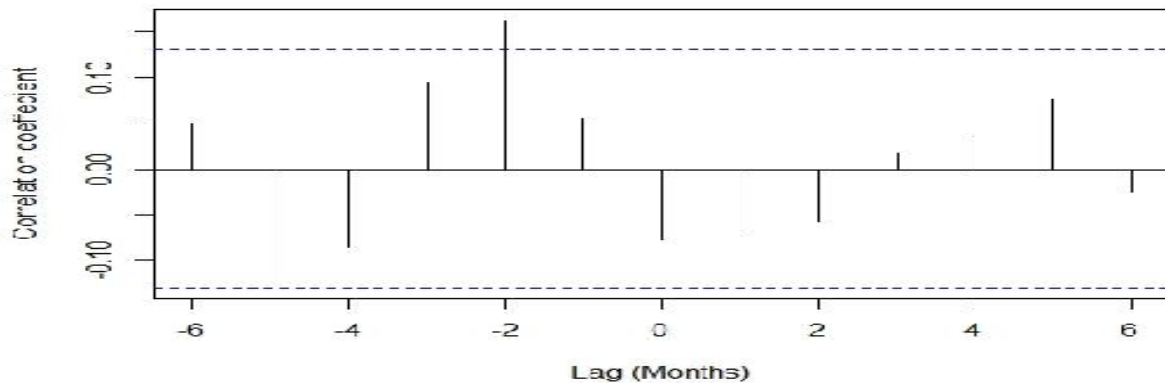
Augmented Dickey-Fuller Test was performed to find out the stationary time series data before applying cross-correlation. The time series data for UI and CPH of sardine, mackerel, *Stolephorus* spp. and *Thryssa* spp. were stationary at a 5% significance level (Table 53).

**Table 53: Augmented Dickey-Fuller Test of selected parameters**

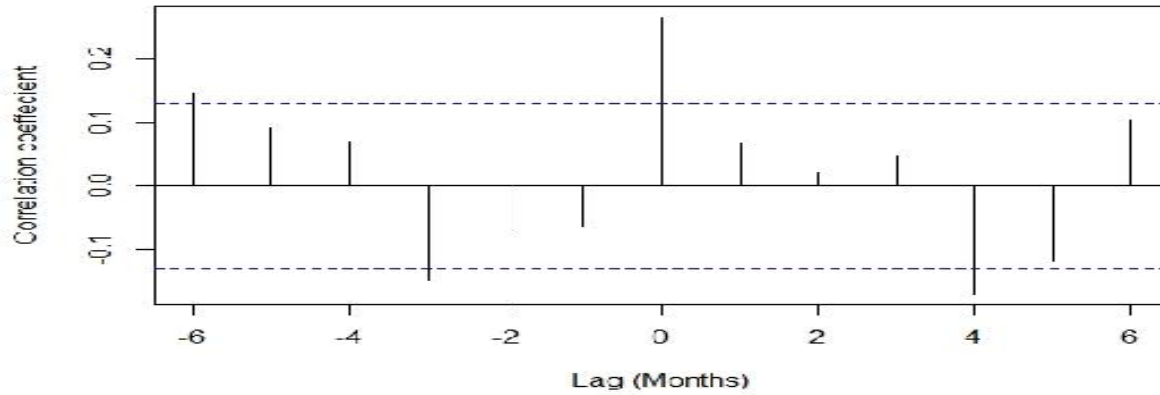
Variables	Dickey-Fuller	Lag order	P- value
UI	-4.6042	6	0.01**
CPH of Indian oil sardine	-4.6917	6	0.01**
CPH of Indian mackerel	-3.5569	6	0.03823*
CPH of <i>Stolephorus</i> spp.	-3.9749	6	0.01113*
CPH of <i>Thryssa</i> spp.	-5.3859	6	0.01**

'\*' and '\*\*' significant at 0.05 and 0.01

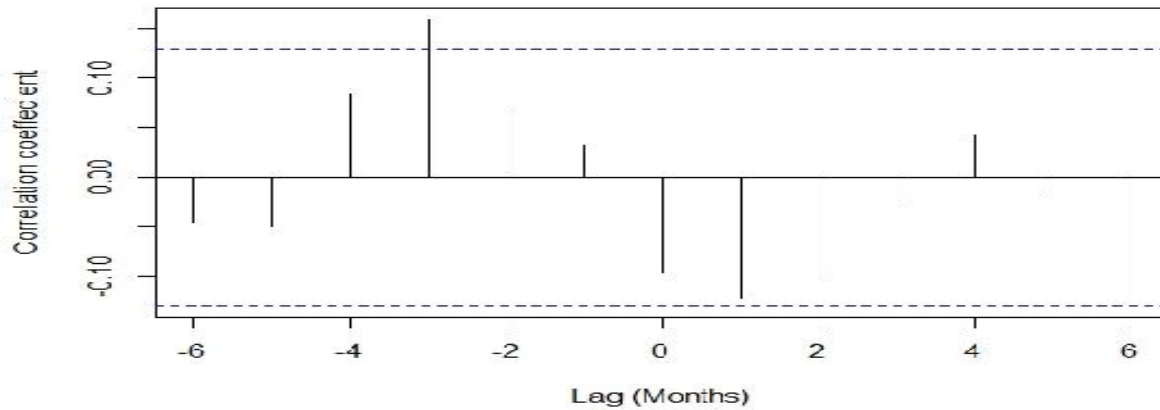
The cross-correlation was performed for UI with CPH of sardine and the result found the upwelling index leads CPH of sardine by two months (Fig. 107). In the case of mackerel, the result found the upwelling index leads CPH of mackerel by zero, three and six months (Fig. 108). Similar to sardine, the cross-correlation was performed for upwelling index with CPH of *Stolephorus* spp. and *Thryssa* spp., the result showed that the upwelling index leads CPH of both by three (Fig. 109) and four months (Fig. 110), respectively.



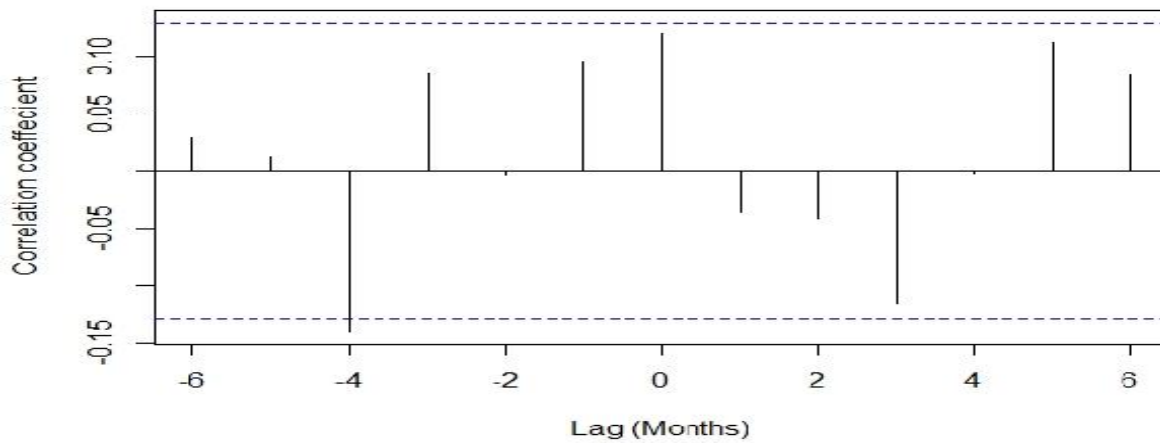
**Fig. 107: Cross-correlation between upwelling index and Indian oil sardine CPH**



**Fig. 108: Cross-correlation between upwelling index and Indian mackerel CPH**



**Fig. 109: Cross-correlation between upwelling index and *Stolephorus* spp. CPH**



**Fig. 110: Cross-correlation between upwelling index and *Thryssa* spp. CPH**

## 5. DISCUSSION

### 5.1. Open access oceano-climatic parameters

Global warming is one of the most important anthropogenic factors for climate change after the industrial revolution by adding carbon dioxide in an accelerated way. The effect of climate change on SST has been observed in the study at the south west coast of India, but not the same effect simultaneously at the entire south west coast of India. For SST, the time series trend shows a continuously increasing trend along all strata. The possibility of a slight shift in SST was found at both ST\_1 and ST\_2 during 1997, but in the case of ST\_3 again small shift was appeared with few years delay as during 2008. The time series trend of SST indicated a small warmer at both ST\_1 and ST\_2 and, at ST\_3 after 1997 and 2008, respectively. Therefore, small coastal warming has detected all three strata might have appeared different period due to a detectable latitudinal gradient in SST over entire SW as mean of SST reduced from southern to northern region and also geographical and topographical distribution of the strata are different to each other.

The season-wise trend of SST along the south west coast of India indicated a clear difference in SST during pre-monsoon, monsoon and post-monsoon, where SST of pre-monsoon and monsoon were the highest and lowest, respectively. Also, the SST of post-monsoon was always higher than that of monsoon. The seasonal plot of SST showed an upward trend for all seasons in this study after 1997 with a significantly positive correlation between pre-monsoon and monsoon, and monsoon and post-monsoon due to rapid rise in global greenhouse gas sharing of India by booming developmental and industrialization activities after 1990 onwards (Sathaye *et al.*, 2006). Also, rates of change in SST have been highly heterogeneous in both spatial and seasonal in this study, which is supported by Lima and Wethey (2012) .

The study reveals that a significant shift in chlorophyll-a concentration in the sea water along the south west coast of India has observed during the study period. Considering homogeneity tests and changepoint analysis, a significant shift in chlorophyll-a concentration have taken pace during 2012, 2013 and 2011 at ST\_1,

ST\_2 and ST\_3, respectively. It means shifting in chlorophyll-a concentration was noticed at first along the northern region and then along the southern region, where this shifting indicated as significantly lower the concentration of chlorophyll-a in seawater during last five recent years along ST\_1 and ST\_3. This significant shifting in chlorophyll-a concentration at ST\_2 appeared after ST\_1 and ST\_3, where the sea water chlorophyll-a concentration has increased during recent years. Furthermore, the shifting in chlorophyll-a concentration along ST\_2 is opposite to that of ST\_1 and ST\_3. The relation between southern and northern region in respect to chlorophyll-a concentration is also supported by the correlation analysis, where a significant correlation was existed between them. In a comparison of the spatial distribution, of chlorophyll-a concentration was always highest at ST\_3. However, in the view of the entire south west coast of India, this result found a decreasing trend in the chlorophyll-a concentration.

Again, seasonal distribution of the chlorophyll-a concentration shows the highest concentration during the monsoon season. The upward movement of chlorophyll-a concentration during monsoon and downward sliding in both pre-monsoon and post-monsoon seasons has been observed during in recent five years. It is be possible only on the shifting in abundance and biomass of primary producer *i.e.* phytoplankton. On the influence of climate change, the early outbreak of primary production have carried out along the south west coast of India, resulted increasing and decreasing of chlorophyll-a concentration during monsoon and post-monsoon after 2010, respectively. Therefore, by observation of time series trend of chlorophyll-a concentration, it is said that spatial-temporal shift in chlorophyll-a concentration along the south west coast of India has been taken place during the period of 2010. An inverse relationship between in trend of chlorophyll-a concentration and SST along stratum\_1 and stratum\_3 along the south west coast of India has been clearly observed in the study. But, in case of ST\_2, chlorophyll-a concentration has increasing trend after 2013, bcause sometimes rising in SST enhances the proliferation of phytoplankton via increasing metabolic rates of phytoplankton (Lewandowska *et. al.*, 2014).

In the consideration of changepoint analysis, it seems the small shift in time series of zonal wind speed have taken place during the period from 1993 to 1994 along the south west coast of India, as thereafter; zonal wind speed has slightly reduced. Therefore, ocean warming affects the zonal wind speed, where SST and zonal wind shows a significantly negative correlation to each other. Similar result has been found by Palipane *et al.* (2017).

Similar to zonal wind speed, the meridional wind speed had slight reduction after 1992 at ST\_1 and ST\_2. However, considering the entire south west coast of India, both zonal and meridional wind speed showed a negatively significant correlation to each other. Also, this result showed that the northern region's meridional wind is more susceptible to environmental variation in comparison to other two regions of the south west coast of India, where the meridional wind speed has significantly increased after 1992. A variation was found in consideration of seasonal meridional wind speed, where the meridional wind speed was continuously increasing during the pre-monsoon season, while that was continuously decreased during the monsoon period. This result is supported with finding of Rashmi *et al.* (2016) as a decreasing trend in both zonal and meridional wind speed during monsoon period at the south west coast of India. The SST-induced modification of the surface wind stress depends on the orientation of the wind stress relative to perturbations of the SST gradient, and also global warming is negatively correlated with wind speed change over the tropics.

The result of this study with highest upwelling index during monsoon is supported by the finding of Smitha *et al.* (2008). At the initial period, the upwelling index of pre-monsoon period showed an increasing trend, but later that dipped continuously. In the case of spatial study, upwelling index decreased from southern to the northern region. But this study also show the strength of upwelling index at all strata was slightly decreased after 2000, since coastal upwelling index is governed by the direction of the upwelling-favorable winds and the local configuration of the coast. In contrast to the prediction of an increase in upwelling by Bakun (1990) under the global warming, this result shows a significant negative correlation between SST and upwelling index. But, this result supports the observaton of Varela *et al.* (2016) as a

decrease in upwelling index along the South Coast of Java due to even small coastal warming.

Small coastal warming was detected over the upwelling season (July-October) along with a moderate decrease in upwelling index. This study found that upwelling index decreased from southern to northern region of south west coast of India, due to difference in topography of south west coast of India, where presence of a parallel to the coast of western ghats range continuously except a 30-km wide Palghat gap at 11° N which may affect the wind blow. Similarly, latitudinal different in upwelling along the south west coast of India was also observed by Smitha *et al.* (2008), where three different patterns of upwelling along southwest coast of India *viz.* moderate upwelling occurs between 9° N to 13° N due to the combined action of the alongshore wind stress, the coastally trapped Kelvin waves, and the offshore propagating Rossby waves.

However, this study found a significant upward shifting in zonal current at ST\_1 during 2000, but other two strata as ST\_2 and ST\_3 showed a slightly downward trend after 2005 as seen for zonal wind speed. A significant positive correlation in zonal current speed was found between ST\_1 and ST\_2. The fluctuation in seasonal zonal current also governs by sea surface wind because a continuous decreasing trend in time series of zonal wind speed during the monsoon season has been found in this study. The decreasing of zonal current during monsoon and increasing during pre-monsoon is the result of the impact of climate change. Surface waters of the ocean are moved primarily by winds. Winds blow in the same direction for a long period, currents develop and transport large masses of water over long distances.

In the case of meridional current, there was a significant shift in the time series during 2005 at ST\_1. As wind change leads to variations of the oceanic circulation (Kämpf and Kavi, 2018). However, meridional current shows a significant positive and negative correlation with zonal wind and SST, respectively. At entire south west coast of India, a zonal current speed has reduced, but meridional current speed is increased on the in the influence of warming climate, which is similar to the finding of Stouffer *et al.*, (2006) on the meridional ocean current.

The importance of changes to the wind-driven ocean circulation in influencing sea level anomaly variability was also emphasized by observations of Suzuki and Ishii (2011). Long time scales both wind stress and salinity variability, in addition to ocean heat content variability, are important in causing sea level anomaly variability (Fasullo and Gent, 2017). Even though, this result indicates a continuous upward sloping in SLA at all strata and seasons since 2003, but a significant shift in time series of SLA has detected all strata and entire south west coast of India during 2007, where SLA was significantly higher after 2007 in comparison previous period. This study also reveals that SLA along the south west coast of India is always highest during pre-monsoon when the SST is highest among all three seasons. A similar result was obtained by Piontkovski and Al-Jufaili (2013), where these changes are mediated by the atmospheric anomalies. For instance, a declining trend pronounced from 1993 to 2000, has a local peak in 1997 which was the year of the strongest El Niño reported for the recent years. The year 2000 was a key point of a dramatic switch, in which the declining trend of SLA changed to the rising one.

All homogeneity tests and changepoint analysis showed a slight shift in precipitation rate along all strata and also the entire south west coast of India. The impact of climate change on precipitation rate of the south west coast of India is visible in this study, where precipitation rate at ST\_1 and ST\_3 has slightly increased after 2005 and that has reduced at ST\_2 after 2007. This indicates a non-homogenous influence of climate change on the precipitation rate at the entire south west coast of India. The increased in precipitation rate must have associated with a lower frequency of outbreak of El Niño during 2000's decade and also the high intensity of La Niña was appeared after 2005.

In considering the entire south west coast of India, the precipitation rate has reduced after 2009 in spite of increasing the precipitation rate at ST\_1 and 3. It means the precipitation rate of the south west coast of India depends on ST\_2, where Palghat gap in Western Ghat range is responsible for heavy rain fall at the immediate northern southwest coast of 10° N. Besides, spatial changes in precipitation rate of the south west coast of India, the seasonal shift in precipitation rate have also recorded in this study. The precipitation rate during monsoon was decreased up to

2005 and then it showed an increasing trend. In contrast to the monsoon, the precipitation rate was increased up to 2005 during the pre-monsoon season, but then it had a decreasing trend. However, the post-monsoon showed a decreasing trend in regards to precipitation rate after 2008. Furthermore, the trend of SST and DMI indicates the rising SST after 2005, which is the reason in the change in precipitation along with the upwelling index. However, the DMI index implied abrupt changes in its dynamics in the year 2000 (Piontkovski and Al-Jufaili, 2013). A positive DMI ends up with severe droughts over eastern Indian Ocean, resulting delay in summer monsoon over Kerala region (Bala and Singh, 2008).

## **5.2. Laboratory and *In-situ* observation of oceanic parameters**

Chlorophyll-a concentration along off Kochi water showed an increasing trend from 2003 to 2008. But, the trend followed a downward movement from 2008 and showed continuously as downward trend up to 2013. But, the lowest concentration of chlorophyll-a was observed in 2006. Similar, trend was also found for open access-derived chlorophyll-a at ST\_1. In the case of SST, trend along off Kochi increased trend from 2003 to 2010 continuously. After reaching its peak in 2010., SST showed a decreasing trend up to 2013 in the study. However, open access-derived SST and chlorophyll-a have a significantly negative correlation at south west coast of India, but laboratory observation shows a positive correlation between SST and chlorophyll-a concentration along Kochi coast. Also, laboratory data correlation is true for spatial study on open access-derived SST and chlorophyll-a concentration at both ST\_1 and ST\_3.

In contrast to the finding of Parthasarathy *et al.* (1992), the solubility of DO decreases with increase temperature, thus heat stress is commonly accompanied by hypoxia stress. Universal theory as a negative relationship between DO and temperature, these results show a positive relationship between the trend of DO and SST. Moreover, DO had a positive correlation with chlorophyll-a concentration and nitrate. It means the primary productivity is more responsible for DO in this coastal water, rather the fluctuation in temperature. In the case of seasonal study, SST for

both *In-situ* and open access-derived data showed a similar result as higher in pre-monsoon than post-monsoon. Similarly, chlorophyll-a concentration was higher during post-monsoon as compared to pre-monsoon for both *In-situ* and open access-derived data.

### **5.3. Small pelagic resources**

The trend analysis of total landings of sardine has increased in SW after 1995. Furthermore, the catch of sardine is closely associated with the El Niño effect, where sardine catch had downward sliding trend in 1990's decade during intense El Niño period (Srinath *et al.*, 2003). Again the minimum catch recorded during 2015, where a large El Niño effect was known found in this result. In contradiction to Thara (2011) finding, this result did not find an inverse relationship of mackerel to sardine fisheries. However, this result supported by the study of Sahadevan (2017) as no negative relationship between the landings of sardine and mackerel in India. A negative correlation with landings of sardine with both *Stolephorus* spp. and *Thryssa* spp. indicates that the higher biomass availability of *Stolephorus* spp. and *Thryssa* spp. on declining the biomass of sardine at south west coast of India due to coincidences of geographical range and season, hence competition for food and space. The existent of both *Stolephorus* spp. and *Thryssa* spp. at south west coast of India is found by a positive correlation between them in this study.

#### **5.3.1. Indian oil sardine**

The standardized CPH of sardine at south west coast of India was significantly higher after 2013, which is due to the extension of sardine population towards the northern region. The northward extension of sardine is also explained by the observing of stratum wise variation in the CPH. The highest and lowest CPH were along ST\_1 and ST\_3 at the starting period of the study, but the same were interchanged each other and became as lowest and highest during 2010 onwards, respectively. The upward trend of CPH along ST\_3 was slow at the initial period but, it was accelerated during the period of 2005 and also at the same time CPH started to decrease along ST\_1. Also, the negative correlation between strata is due to the

extension of sardine from southern to the northern region. The acceleration in rising SST during 2000 to 2005 along southern region is the unfavourable temperature for sardine, which forces to move the sardine population towards northward according to its tolerance limit of environmental condition, resulted in sharp diminishing and increasing CPH along the southern and northern region, respectively. A significant impact of temperature at fish distribution pattern is observed, where even slight rise in temperature plays noticeable effects on the geographical distributions of fish as being a poikilothermic organism (Perry *et al.*, 2005). Rohit and Bhat (2003) also reported that the landings of sardine have increased in 2000's decade in the northern part of south west coast of India.

Besides spatial changes in the distribution of CPH for sardine under the impact of climate change, a seasonal variation in the CPH has also been observed in the study. The highest CPH was during pre-monsoon up to 2002, while later on, monsoon showed the maximum CPH. However, the CPH during post-monsoon had continuously increased trend. The seasonal differences in sardine distribution is found as CPH decreases and increases during pre-monsoon and monsoon, respectively, where pre-monsoon is not proven as a favourable season in the effect of rising of SST on the impact of global warming, therefore sardine showed temporal extension during monsoon to complete the life cycle in optimal environmental condition.

The extension of sardine in deeper water region in effect of global warming is the reason for increasing of CPH in mechanized gears as MTN, MRS and MPS, which are able to operate in deeper water areas. A continuous increasing trend of CPH in MPS, which is mainly operated along ST\_3, also indicates the spatial extension of sardine population towards northern latitude. Again in the case of motorized gears, the CPH of OBRS was increased continuously, while that for OBGN and OBTN had the decreasing trend over the study period. According to marine fisheries census 2010 (Anon, 2012), the operation of ring seiners is mainly concentrated along central region in south west coast of India. Among outboard motor operated gears, the maximum CPH was noticed for OBRS over the study period with a continuously increasing trend. Therefore, the trend of CPH of both MRS and OBRS

also reveals the extension of sardine population from ST\_1 to ST\_2 with rising of SST over time. The limitation in the operational depth of OBTN seems to show a decreasing trend in CPH for OBTN. Similar to OBTN, CPH of OBN also showed a downward trend after 2010. A significantly negative correlation between CPH of MRS and OBTN (-0.49) and, also MTN and OBTN (-0.60) in the study indicates also the moving of sardine population to deeper water in search of optimum physiological temperature. According to marine fisheries act of maritime state along south west coast of India, mechanized fishing vessels are prohibited for fishing operation near coastal water. The combination of gears in NM is the reason for showing a significant correlation with a mechanized trawl net, where NM is dominated by bottom operated gears. The moving of sardine in deeper water is also seen by CPH of mechanized trawl net, where the CPH has increased from 2010 onward. Similar observation noticed by Vivekanandan *et al.* (2009), where the sardine has extended its distribution toward northern and deeper water along the Indian coast due to the impact of global warming.

First maturity size over the years for sardine recorded and found that the size of the first maturity was continuously decreased over the time period, where it was 16.5, 15.7 and 15.2 cm on 1964, 1987 and 2016, respectively. Therefore, the result indicated that size of maturity for sardine has reduced in recent time as compare to the historic period. An increase in temperature results in a decrease in the length and age at first maturation, affecting the growth of adults as surplus energy is channeled into reproduction at an earlier age and smaller size.

During 1924, sardine was starting to spawn their eggs from September and continued to spawn up to October month. Further progression of time, sardine has started to spawn even in July during 1964. Similarly, the fluctuation in completion of spawning period was also noticed, where spawning season was continued up to October and November during 1924 and 1949. But, it had been noticed that spawning season was completed even during August month in the recent period. Thus, this study showed that sardine completed its spawning season earlier compare to historical period by starting in May and completed in August. Fishes shift the seasonal

timing (phenology) of crucial events such as spawning in response to climate change (Sims *et al.*, 2004). However, the influence of human activities such as commercial fishing also observes on life-history traits of commercially harvested fish, but its affecting rate on the life-history parameters such as size at maturation, consumption, and gonad investment is very low as per the study of Andersen and Brander (2009).

Life cycle model of sardine showed the fishes spawn during monsoon season when the water temperature is low. A slight rise in SST may have an adverse effect on spawning and thereafter, recruitment. According to Pankhurst and Munday (2011), eggs are one of the most thermally sensitive life stages in fishes, therefore even a slight increases in temperature escalates egg mortality. The rising SST affects the primary and secondary productivity, resulting in scarcity of juvenile's thrive food at coastal region. Also, the rising temperature and decreasing precipitation rate, which is responsible for increasing the high level of salinity in the southern region, resulting for less recruitment in the southern region. Therefore, juvenile abundance of sardine is regulated by optimum precipitation rate during the monsoon period.

Kripa *et al.* (2018) suggested that fishery independent factors including the environmental and biological variations and the biotic pressures are observed on sardine population along the south west coast of India. Longhurst and Wooster (1990) have argued that events taking place during the early part of the year, especially March/April, have more influence on the success of sardine fishery, since the gonads start increasing from these months clearly indicating the relationship between, nutrient enrichment from upwelling followed by diatom bloom leading to maturation. Lack of food during this period leads to gonad atrophy or even poor maturation as was observed low catch during 2015 in El Niño year. Thus, the result suggests the precipitation during the pre-monsoon period is important. A good monsoon by itself cannot guarantee successful recruitment if good gonad maturation has not taken place during the pre-monsoon period. Hence, initiation of upwelling during pre-monsoon (for maturation); followed by normal monsoon (for spawning); which increases the food availability in the near shore waters for the growth of juveniles (for recruitment) is key to the overall success of the sardine fishery.

### 5.3.2. Indian mackerel

Similar to sardine, the changepoint analysis of standardized CPH showed a break point in time series trend during 2014 and higher CPH was observed after 2014. On the basis of spatial study at south west coast of India, this study indicated that the highest CPH were along ST\_1 throughout the study period. The decreasing trend of CPH at both ST\_1 and ST\_2 has started after 2005, while the same has noticed after 2010 at ST\_3. However, on the effect of global warming, mackerel has the capacity to substitute food with high energy value and modify its feeding habit depending on the availability of different organisms in the environment as facultative feeding habit of mackerel and hence can be considered as one of the resilient species (Supraba *et al.*, 2016). But, the decreasing trend in CPH at both ST\_1 and ST\_2 in 2005 and later at ST\_3 in 2010 infer the influence of global warming at the south west coast of India.

A positive correlation (0.34) between ST\_1 and ST\_2 and negative correlation (-0.20) between ST\_2 and ST\_3 indicates extension of mackerel population towards the northern region, where mackerel had decreasing CPH at ST\_1 and ST\_2 after 2005 and increasing CPH at ST\_3 up to 2010. SST was positively correlated with fish growth but negatively correlated after temperature reached optimum thermal maxima, which suggests individuals in warmer regions is under thermal stress (Martino *et al.*, 2019).

The gear-wise analysis shows that CPH in all mechanized gears has increased after 2005, while CPH of motorized and non-mechanized gears has decreased at the same time. It infers the extension of mackerel in deeper water under effect of warming environment. This result is supported by the finding of Sumaila *et al.* (2011) as many marine species have moved towards the poles and into deeper waters under ocean warming, such as in the Northeast Atlantic, US East Coast, the Bering Sea and Australia. For instance, in response to warming, the center of distribution of demersal fishes in the North Sea shifted latitudinally and some species shifted into deeper waters.

The result reveals the size of the first maturity of mackerel at the south west coast of India has reduced at a recent time in comparison to the historical period. During 1956, mackerel could attend the first maturity at a length of 22.4 cm. However, it has been found that mackerel gets maturity size even at 17.5 cm in the recent condition. van Rijn *et al.* (2017) has also confirmed that global warming leads to a widespread reduction in the maximal size of natural fish. In higher temperatures, there was a reduction of physical condition in larval/juvenile stages, such as reduced food intake due to increased competition, which constrained lifetime growth development (Martino *et al.*, 2019).

South west monsoon season is preferred condition for the development of larval stage of mackerel, where low salinity and temperature, as well as high phytoplankton during coastal upwelling, are found. The rising SST, shifting in precipitation rate and sea surface wind lead to phenological changes in growth and recruitment of mackerel. The increasing SST facilitates early migration for juvenile and mature fish from coastal region to deeper optimum environmental conditions. Therefore, this result found that the CPH of mechanized gears as operated in deeper water is showing an increasing trend and CPH of coastal operated gears such as motorized and non-mechanized are at decreasing trend.

### **5.3.3. *Stolephorus* spp.**

The assemblage of *Stolephorus* spp. seems at the south west coast of India by starting October, when the temperature becomes slightly higher after cessation of south west monsoon. After entering in the southwest region, it spreads at entire ST\_1 area by November. Its movement is continued towards the northern region with decreasing of temperature with the onset of the winter season at the northern region of the south west coast of India and reaches up to stratum\_3 by the end of February. Further, the temperature starts to increase at south west coast region on approaching of the summer season at the northern region of the south west coast of India, which forces to move *Stolephorus* spp. again towards southwards. Therefore, *Stolephorus* spp. again aggregated at stratum\_2 and stratum\_3 by the end of May month. After May, the upwelling phenomenon appears

at the south west coast, which reduces the temperature and dissolved oxygen at surface water. To prevent the adverse oceanic condition, *Stolephorus* spp. accumulates in the south east region.

The rising SST under global warming phenomenon forces *Stolephorus* spp. to appear at south west coast comparatively earlier at the recent time. Therefore, a sharp increasing trend in CPH of *Stolephorus* spp. is visible in this study. To minimize the adverse effect of global warming, *Stolephorus* spp. utilizes both possibilities by expending their existence vertically in deeper water and horizontally towards the northern region. This is the reason for the upward sliding trend of CPH of *Stolephorus* spp. at both strata ST\_2 and ST\_3. The highest CPH was observed along ST\_1 at the initial period of study, but ST\_3 showed the highest CPH after 2007 with the intermediate position of ST\_2. Therefore, this result demonstrated the increasing of *Stolephorus* spp. population from southern to northern region, where a significantly positive correlation between ST\_2 and ST\_3 was found, which is similar to the observation of Raybaud *et al.* (2017).

The result also found an increasing trend of CPH for *Stolephorus* spp. during all three seasons *i.e.* pre-monsoon, monsoon, and post-monsoon. However, the CPH was always lower during pre-monsoon compared to the other two seasons, but the CPH had an increasing trend even in the pre-monsoon season. It means *Stolephorus* spp. tends to remain at south west coast during the pre-monsoon season, but shifted toward deeper water to avoid high temperature at both south west and south east region.

In the case of gear-wise study of CPH, the result shows that CPH of mechanized is continuously increasing over the study period. In contrast to mechanized gears, while CPH of motorized and non-mechanized gears has a decreasing trend. It means the catch rate of *Stolephorus* spp. are increasing at deeper water and decreasing at coastal region. This is possible only when *Stolephorus* spp. population shifts towards deeper water. The result infers a significant shift in the trend in the time series CPH of *Stolephorus* spp. before and after 2013. The CPH of *Stolephorus* spp. has increased along the south west coast

of India after 2013. Silva *et al.* (2015) also found that variations in anchovy abundance are linked to environmental changes.

#### **5.3.4. *Thryssa* spp.**

A clear impact of climate change is visible on CPH for *Thryssa* spp. along the south west coast of India. Time series of CPH for *Thryssa* spp. indicates small shifting with lower CPH in 2013 with comparison to before 2013. Anchovy show changes in the distribution, which is associated with environmental variability (Yáñez *et al.*, 2017). The spatial distribution of CPH shows the highest CPH along ST\_2, followed by ST\_3 and ST\_1. However, the CPH of both ST\_2 and ST\_3 in this result has a decreasing trend with a significant positive correlation in each other. Thus, this decreasing trend is due to the expansion of *Thryssa* spp. population from ST\_2 and ST\_3 region to another nearby region. However, the highest CPH of *Thryssa* spp. was found during monsoon among three seasons. This indicates the *Thryssa* spp. prefer lower temperature season for their life cycle. Under the global warming condition, *Thryssa* spp. do not find the optimum environmental condition during pre-monsoon and post-monsoon season. Therefore, a seasonal shift in the recruitment of *Thryssa* spp. is the reason for the decreasing trend during both pre-monsoon and post-monsoon season, while an increasing trend in monsoon after 2005. This result also found a significant positive correlation for CPH of *Thryssa* spp. during pre-monsoon and post-monsoon.

Gear-wise study on catch found increasing and decreasing trend of CPH in MRS and MTN, respectively. At the same time, CPH for motorized gears as OBRs and OBTN had a decreasing trend. This is due to the shifting of *Thryssa* spp. from coastal to offshore water region. Furthermore, the horizontal shifting rather than vertical shifting is a reason for increasing and decreasing trend of MRS and MTN. SST are responsible for the shifting and expansion of recruitment of *Thryssa* spp. along the south west coast of India as the observation of Martino *et al.* (2019), the increases in water temperature beyond the optimum temperature have significant

ecological consequences by hindering physiological processes and an adaption or shift in organism habitat range.

#### 5.4. Model

Logistic regression model, being based on the probability of an event occurring, allows us to calculate an odds ratio, which is the ratio of the odds of an event occurring to it not occurring. The result shows a significant logistic model for sardine, mackerel, *Stolephorus* spp. and *Thryssa* spp. The increase in logit score per unit of sardine CPH depends on the increase of odds ratio in chlorophyll-a concentration, SST, wind\_U, wind\_V, current\_U, current\_V, SLA and precipitation rate by 0.34, -0.23, 0.11, -1.07, 6.17, 8.01, -0.01 and 1.87, respectively. The meridional wind had a significant influence on the logistic model at 5% level of significant.

The increase in logit score per unit of mackerel CPH depends on the increase of odds ratio in chlorophyll-a concentration, SST, wind\_V, current\_U, current\_V, SLA, precipitation rate and UI with -6.07, -0.41, 0.64 -152, -25.7, 10.9, 2.35 and 0.003, respectively. Current\_U and UI had a significant influence on the logistic model at 5% level of significant.

Similarly, the increase in logit score per unit of *Stolephorus* spp. CPH depends on the increase of odds ratio in chlorophyll-a concentration, SST, wind\_V, current\_U, current\_V, SLA and precipitation rate were 0.53, 1.17, -1.14, 14.64, 8.13, 4.24 and 4.58, respectively. Logistic regression model demonstrates that only SST significantly influences the CPH of *Stolephorus* spp. among various ocean-climatic variables. In the case of *Thryssa* spp., the increase in logit score per unit of *Thryssa* spp. CPH depends on the increase of odds ratio in chlorophyll-a concentration, SST, wind\_V, current\_U, Current\_V, SLA, precipitation rate and UI were -2.29, -0.85, -0.31, -16.1, -4.43, -13.2, 2.45 and 0.0008, respectively. However, the result shows that only SLA had a significant influence on the logistic model at 5% level of significance among all used variables.

Stepwise regression model reveals that the CPH of sardine significantly depends on five climatic variables as chlorophyll\_a concentration, meridional wind and current speed, sea level anomaly and upwelling index. However, this predictive

model explained only the 13% of variables, but support a finding of Kumaran *et al.* (1992), who did not find any direct relationship between sardine landings and the total rainfall on annual basis. The peak of chlorophyll (in July - September) has been increased supported by negative SLA anomalies indicating the divergence of waters due to developing coastal upwelling as the study of Piontkovski and Al-Jufaili (2013).

Similar to sardine, mackerel CPH was influenced by mainly two variables as meridional wind speed and sea level anomaly. In the case of *Stolephorus* spp., CPH significantly depends on only four variables chlorophyll\_a, wind\_V, current\_U and precipitation rate. Again, *Thryssa* spp. CPH significantly depends on only four variables Chlorophyll\_a concentration, current \_V, SLA and precipitation rate. However, the final predictive regression model of *Thryssa* spp. was significantly influenced by only chlorophyll\_a concentration and sea level anomaly, where this predictive model could able to explain 63% of CPH.

This result infers that the oceano-climatic variables used in the study could explain 13% 14% and 20% of CPH of sardine, mackerel, and *Stolephorus* spp. This means other phycosico-chemical variable such details of zooplankton and phytoplankton, salinity and other related parameters are required to improve the predictive capacity of the model. Among all four species, these oceano-climatic variables are able to predict 63% of CPH along the south west coast of India, where chlorophyll\_a concentration plays a significant role and result show a decreasing trend of chlorophyll\_a concentration along the south west coast. This is the reason for the CPH has come down after 2013 as compared to the previous year.

The cross-correlation in this study reveals that CPH of small pelagic fishes significantly influenced by the appearance of upwelling along the south west coast of India. But, a high catch of small pelagic fishes is not observed at the immediate appearance of upwelling phenomenon as visible in this study. The CPH of sardine, *Stolephorus* spp. and *Thryssa* spp. lags of two, three and four months with the upwelling index, respectively. However, in case of mackerel, the cross-correlation was performed for upwelling index with CPH, and the result found the upwelling index leads CPH of mackerel by zero, three and six month.

Chlorophyll-a concentration has a close direct relationship with primary production, therefore, with the expectation that increasing chlorophyll-a leads to higher growth and biomass. But the time lag in appearance of primary and secondary productivity after the outbreak of upwelling is the reason for the lag in CPH of sardine, *Stolephorus* spp. and *Thryssa* spp. The result support the observation of Krishnakumar *et al.* (2008) as the catch rate of sardine showed a negative correlation with upwelling index and also the concurrence of upwelling index. Therefore, this result suggests that the outbreak of upwelling lead higher primary productivity is associated with greater food availability, facilitating recruitment by allowing a larger number of better-conditioned fish to exist in the populations.



## 6. SUMMARY

Climate change refers to the gradual change in the Earth's climate and physical geography that accompany an increase in the Earth's temperature. It is one of the greatest challenges facing life on the Earth and therefore, it has emerged as an important area of both international as well as domestic, research, policy making and development planning recently. A systematic observation, recording, and processing of the climatic elements such as temperature, rainfall, atmosphere, pressure, humidity, wind, sunshine and clouds are always required to ascertain the climatic condition of a place. Global climate change is the best estimates of ocean warming in the top 100 m are about 0.6°C (RCP2.6) to 2.0°C (RCP8.5) by the end of the 21<sup>st</sup> century. This unprecedented increase is expected to have severe impacts on the global hydrological system, ecosystems, sea level, crop production, and related processes. The impacts have particularly severe in tropical areas, which mainly consist of developing countries, including India.

Recently, climate change has been recognized as one of the critical issues in Indian marine fisheries because the biological activities of the marine organism depend on climate-oceanographic features and these features vary regionally and seasonally in the ocean. An early or late onset of south west monsoon or its failure affects the abundance of various fishery resources. There is strong evidence that species have changed the timing of their life cycles during the year and shifted their geographic distributions toward higher latitudes and elevations. The effects of climate reduce the age, size, and geographic diversity of populations and the biodiversity of marine ecosystems. Therefore, to understand the mechanism of interactions between global change events on the distribution of marine ecosystem and its organisms, this study was conducted along the south west coast of India. The objectives were proposed as to ascertain the extent of the impact of the change in climato-oceanographic features between epochs, to study the impact of climate change on the biological aspect of the small pelagic resources and to establish the relationship in dynamics between climato-oceanographic features and small pelagic resources.

The study was carried out by collecting at time series data on the climato-oceanographic parameters including SST, chlorophyll-a concentration, seas surface wind (U and V component), sea surface current (U and V component), sea level anomaly, precipitation rate, southern oscillation index and dipole mode index from open sources. The time series trend on SST shows a continuously increasing trend along all strata. The possibility of slightly shift in time series of in SST was found at both ST\_1 and ST\_2 during 1997, while at ST\_3 this shift appeared with few years delay as during 2008. In the case of the seasonal plot of SST, the result found an upward trend for all seasons after 1997. A significant shift in chlorophyll-a concentration have been taken pace during 2012, 2013 and 2011 at ST\_1, ST\_2, and ST\_3, respectively. It means shifting in chlorophyll-a concentration was noticed at first along the northern region and then along the southern region. Furthermore, the shifting in chlorophyll-a concentration along ST\_2 is opposite to that of ST\_1 and ST\_3.

In the view of the entire south west coast of India, the result of time series analysis revealed a decreasing trend in the chlorophyll-a concentration. Besides, spatial shifting, a temporal shift in chlorophyll-a concentration was also taken place along the south west coast of India during 2010. A slight reduction in zonal wind speed have been taken place during the period from 1993 to 1994. Similar to zonal wind speed, the meridional wind speed had slight reduction after 1992 at ST\_1 and ST\_2. This result showed that the northern region's meridional wind is more susceptible to environmental variation in comparison to the other two regions of the south west coast of India where the meridional wind speed has increased after 1992.

The result of this study found the highest upwelling index during monsoon. At the initial period of the study, the upwelling index of pre-monsoon period showed an increasing trend, but later that dipped continuously. In the case of spatial study, upwelling index decreased from southern to the northern region. Present study found a significant upward shifting in zonal current at ST\_1 during 2000, but other two strata as ST\_2 and ST\_3 showed slightly downward trend after 2005 as seen for zonal wind speed. In the case of meridional current, there was a significant shift in the

time series during 2005 at ST\_1. For SLA, a significant shift has been detected at all strata during 2007, where SLA was significantly higher after 2007 in comparison previous period. The impact of climate change on precipitation rate of the south west coast of India is visible, where precipitation rate at ST\_1 and ST\_3 has slightly increased after 2005 and that has reduced at ST\_2 after 2007.

This study indicated that total landings of sardine and *Stolephorus* had increased in south west coast of India after 1995. The catch of sardine is influenced by the El Niño effect. The standardized CPH of south west coast of India a significantly higher CPH was observed after 2013, which is due to the extension of sardine population towards the northern region. Similar to sardine, the standardized CPH of *Stolephorus* spp. at south west coast of India was significantly higher after 2014. In the case of sardine, the highest and lowest CPH were along ST\_1 and ST\_3 at the starting period of the study, but the rising trend of CPH of sardine along ST\_3 was accelerated during the period of 2005, and finally, the highest CPH was observed at ST\_3 in last decade. A continuous increasing trend of CPH in MPS, which is mainly operated along ST\_3, also indicates the spatial extension of the sardine population towards northern latitude.

Besides spatial changes in the distribution of CPH sardine under the impact of climate change, there are seasonal variation in CPH has also been observed in the study. The seasonal differences in sardine distribution is found as CPH decreases and increases during pre-monsoon and monsoon, respectively, where pre-monsoon does not proven as a favorable season in the effect of rising of SST on the impact of global warming, therefore sardine has temporal extension during monsoon to complete the life cycle in optimal environmental condition. To cope with climate change in the effect of global warming sardine has extended in deeper water as the result was showing an increasing CPH in mechanized gears as MTN, MRS and MPS operated in deeper water. A clear change in the sardine's phenology also has been found in the study where its size of the first maturity has reduced and in recent time as compare to the historic period. Recently, sardine completes its spawning season earlier compare to historical period by starting on May and completed in August.

The spatial study on CPH of mackerel demonstrated a decreasing trend in CPH at both ST\_1 and ST\_2 in 2005 and later at ST\_3 in 2010. This infers extension of mackerel population from southern to northern region under the influence of global warming at the south west coast of India. The gear-wise analysis shows that CPH of mackerel in all mechanized gears has increased after 2005, while CPH of motorized and non-mechanized gears has decreased at the same time. It is possible on the extension of mackerel population in deeper water under the effect of a warming environment. The result also reveals that the size of the first maturity of mackerel at the south west coast of India has reduced at a recent time in comparison to the historical period. During 1956, mackerel could attain the first maturity at a length of 22.4 cm. However, it has been found that mackerel can get maturity size even at 17.5 cm in the recent condition.

The rising sea surface temperature under global warming phenomenon forces to *Stolephorus* spp. to appear at south west coast comparatively earlier at the recent time. Therefore, a sharp increasing trend in CPH of *Stolephorus* spp. is visible in his study. To minimize the adverse effect of global warming, *Stolephorus* spp. have utilized both possibilities by expending their existence vertically in deeper water and horizontally towards the northern region. This is the reason for the upward sliding trend of CPH of *Stolephorus* spp. at both strata ST\_2 and ST\_3. At the initial period of study, the highest CPH was observed along ST\_1, but ST\_3 showed the highest CPH after 2007. Both horizontal and vertical shifting in *Thryssa* spp. also found in the study, where an increasing and decreasing trend of CPH in MRS and MTN, respectively and CPH for motorized gears as OBRS and OBTN had decreasing trend at the same time. Result found a decreasing trend in the CPH of *Thryssa* spp. at both ST\_2 and ST\_3. A seasonal shift in the recruitment of *Thryssa* spp. is the reason the result of decreasing trend during both pre-monsoon and post-monsoon season, while an increasing trend in monsoon after 2005.

The increase in logit score per unit of sardine CPH increase in chlorophyll-a concentration, SST, wind\_U, wind\_V, current\_U, current\_V, SLA and precipitation rate were 0.34, -0.23, 0.11, -1.07, 6.17, 8.01, -0.01 and 1.87,

respectively. The increase in logit score per unit of mackerel CPH increase in chlorophyll-a concentration, SST, wind\_V, current\_U, current\_V, SLA and precipitation rate were -6.07, -0.41, 0.64 -152, -25.7, 10.9, 2.35 and 0.003, respectively. The increase in logit score per unit of *Stolephorus* spp. CPH increase in chlorophyll-a concentration, SST, wind\_V, current\_U, current\_V, SLA and precipitation rate was 0.53, 1.17, -1.14, 14.64, 8.13, 4.24, and 4.58, respectively. The increase in logit score per unit of *Thryssa* spp. CPH increase in chlorophyll-a concentration, SST, wind\_V, current\_U, current\_V, SLA and precipitation rate were -2.29, -0.85, -0.31, -16.1, -4.43, -13.2, 2.45 and 0.0008, respectively.

The stepwise regression model in the result infers that the oceanoclimatic variables used in the study explains only 13% 14% and 20% of CPH of sardine, mackerel and *Stolephorus* spp. But, the stepwise regression model explained that thryssa were significantly influenced by only chlorophyll\_a concentration and sea level anomaly, where this predictive model is able to explain 63% of CPH by using only four variables as chlorophyll\_a concentration, current \_V, SLA and precipitation rate.

The following conclusions are drawn from the present study:

- The SST is continuously rising over the south west coast of India.
- The rising SST leads to change in the trend of chlorophyll-a, wind and current speed, upwelling index, sea level anomaly and precipitation rate along south west coast of India.
- Shifting in chlorophyll-a concentration at south west coast of India has been taken pace during the period 2011-13.
- Study shows a spatial and seasonal changes in the pattern of all environmental parameters at the south west coast of India.
- Chlorophyll-a concentration has reduced at both southern and northern region, while the same has increased middle region.

- Both horizontal and vertical expansion of sardine, mackerel, *Stolephorus* spp. and *Thryssa* spp. are observed under the influence of changed pattern in oceanic features.
- The seasonal shift in the CPH of selected fish has been also found at the south west coast of India.
- The size of the first maturity of sardine and mackerel has been reduced in the recent period.
- The CPH of *Thryssa* spp. may be predicted up to 63% with the help of the stepwise regression model by using chlorophyll-a concentration, current \_V, SLA and precipitation rate.

For ground truthing observation, data on dataset repository of Fishery Environment Management division of CMFRI for Chlorophyll-a concentration, temperature, nitrate and dissolved oxygen concentration have been utilized in this study for the period from 2003 to 2013. However, for *in situ* observation of fishery environmental parameters, an on-going project “Chlorophyll based remote sensing assisted Indian marine Fisheries Forecasting System (ChloRIFFS)” at CMFRI was selected. The design of the work plan in ChloRIFFS project is only one sampling grind on monthly basis along Kochi coast in Kerala. But, only three cruises could be conducted during 2018 and one cruise in 2019 for the sampling at 20 m depth. The limitation on sampling cruise was due to rough sea condition during the monsoon period, large number forecasted warning signal, availability of vessel for sampling, willingness of cruise member to venture the cruise for sampling. Further, a long dry docking process for Silver Pomapo (Fishing Vessel of CMFRI) from 2018 onward was also the reason for few sampling cruise during 2018 to 2019 period. However, further study on validation of data available on open access sources, monthly data collection will be done for the comprehensive understanding of seasonal variation in water quality parameters along off Kochi coast.

It is suggested that further the study on improvement of a predictive model for sardine, mackerel, *Stolephorus* spp. and *Thryssa* spp. will aid to formulate the

judicious management plans for their sustainability, which one the challenging task for fisheries stakeholder in tropical water due to prevailing of multi-species and multi-gears fisheries. Developing the linkage of physico-chemical properties of an ecosystem with the life cycle of fish as flagged in this study, provides a basic concept of its migration between spawning and feeding ground and also offers the spatial and temporal information on the density of fish. Therefore, in addition to sardine, mackerel and *Stolephorus* spp., the study on developing the life cycle model for *Thryssa* spp. will be conducted that can be used for developing ecosystem-based fisheries management models.

Satellite remote sensing is able to provide data on oceano-climatic parameters for the global ocean on synoptic scales and with acceptable temporal resolutions based on algorithms applied specific parameters. Therefore, the advantages of remote sensing include the ability to collect information over large spatial areas on a systematic basis, which can be used for monitoring environmental changes over time. The modeling on fisheries studies requires systematic observation on fishery environmental parameters. Therefore, past secondary data collected has been retrieved from various open access sources such as APDRC, AVISO, OC-CCI website. These sources provide the benchmark platform to researchers with the scope of climate change study. But, the knowledge on the credibility of a dataset for must be judged in terms of the specific application. To take forward, therefore, the study, the large numbers of sampling will be conducted for the validation of satellite products for oceanic parameters with *in-situ* data, prior to modeling on fisheries management.



## 7. REFERENCES

- Abdurahiman, K. P., Harishnayak, T., Zacharia, P. U. and Mohamed, K. S., 2004. Length-weight relationship of commercially important marine fishes and shellfishes of the southern coast of Karnataka, India. *NAGA, World Fish Center Quarterly*, 27: 1-2.
- Adams, P. B., 1980. Life history patterns in marine fishes and their consequences for fisheries management. *Fish. Bull.*, 78: 1-12.
- Ahirwal, S. K., Jaiswar, A. K. and Chakraborty, S. K., 2017. Biometric analysis of oil sardine *Sardinella longiceps* (Valenceinns, 1847) from Mumbai coast of Maharashtra. *Indian J. Geo-Mar. Sci.*, 46 (9): 1810-1817.
- Ahmad, N. N. N. and Hossain, D. M., 2015. Climate change and global warming discourses and disclosures in the corporate annual reports: A study on the Malaysian companies. *Procd. Soc. Behv.*, 172: 246-253.
- Alexandersson, H., 1986. A homogeneity test applied to precipitation data. *Int. J. Climat.*, 6: 661-675.
- Alheit, J. and Niquen, M., 2004. Regime shifts in the Humboldt Current ecosystem. *Prog. Oceanogr.*, 60: 201-222.
- Al-Jufaili, S., 2011. Weight-length relationships, gonado-somatic indices, sex ratios and relative weight of the Omani-Indian oil sardine, *Sardinella longiceps* (Valenciennes, 1847) from Al-Seeb area, Sultanate of Oman. *Adv. J. Food Sci. Technol.*, 3(4): 238-244.
- Amores, A., Monserrat, S., Melnichenko, O. and Maximenko, N., 2017. On the shape of sea level anomaly signal on periphery of Mesoscale Ocean eddies. *Geophys. Res. Lett.* <https://doi.org/10.1002/2017GL073978>.
- Andersen, K. H. and Brander, K., 2009. Expected rate of fisheries-induced evolution is slow. *P. Natl. Acad. Sci. USA* 106:11657-11660.
- Anon, 2012. Fisheries Census 2010 Part I India Ministry of Agriculture, Krishi Bhavan, New Delhi and CMFRI, Kochi, pp. 98.
- Antony Raja, B. T., 1970. *Estimation of age and growth of the Indian oil sardine, Sardinella longiceps Val.* *Indian J. Fish.*, 17 (1&2): 26-42.
- Antony Raja, B. T., 1966. On the maturity stages of Indian oil-sardine, *Sardinella longiceps* Val., with notes on incidence of atretic follicles in advanced ovaries. *Indian J. Fish.*, 13 (1 & 2): pp. 27-47.
- Antony Raja, B. T., 1972. A forecast for the ensuing oil-sardine fishery. *Seafood Exp. J.*, 4 (10): 27-33.
- Antony Raja, B. T., 1973. The Indian Oil-Sardine Fishery: Problems in Perspective. *J. Mar. Biol. Ass. India*, 15 (2): 735-749.
- Antony Raja, B. T., 1964. Some aspects of spawning biology of Indian oil sardine *Sardinella longiceps* Valenciennes. *Indian J. Fish.*, 11A (1): 45-120.

- Antony Raja, B. T., 1967. Length-weight relationship in the oil-sardine, *Sardinella longiceps* Val. *Indian J. Fish.*, 14 (1&2): 159-170.
- AsiaPacific Data-Research Center, 2017. <http://apdrc.soest.hawaii.edu/index.php>.
- Asia-Pacific Data Research Center, NOAA Optimum Interpolation (OI) SST, V2, 2017. <http://apdrc.soest.hawaii.edu/las/v6/constrain?var=1271>.
- Asia-Pacific Data Research Center, QuikSCAT, LAS8, 2020. [http://apdrc.soest.hawaii.edu/dods/public\\_data/satellite\\_product/QSCAT/qscat\\_clima](http://apdrc.soest.hawaii.edu/dods/public_data/satellite_product/QSCAT/qscat_clima).
- Asia-Pacific Data Research Center, Satellite Data, CCMP, CCMP monthly , v2, 2017. <http://apdrc.soest.hawaii.edu/las/v6/dataset?catitem=13037>.
- Asia-Pacific Data Research Center, SODA v3.3.1, 2018. <http://apdrc.soest.hawaii.edu/las/v6/dataset?catitem=4987>.
- Asia-Pacific Data Research Center, TRMM Microwave Imager (TMI) product: Monthly, 2018. <http://apdrc.soest.hawaii.edu/las/v6/constrain?var=13330>.
- Asokan, P. K., Krishnakumar, P. K. and Ghosh, S., 2009. Sea surface temperature changes and distribution shifts of Indian mackerel *Rastrelliger kanagurta*. In: Marine Ecosystems Challenges and Opportunities, Book of Abstracts (eds. Vivekanandan E., et al.), *J. Mar. Biol. Ass. India*, Cochin. 247- 248.
- Atlas, R., Hoffman, R. N., Ardizzone, J., Leidner, S. M., Jusem, J. C., Smith, D. K. and Gombos, D., 2011. A cross-calibrated, multiplatform ocean surface wind velocity product for meteorological and oceanographic applications. American Meteorological Society. pp. 157-174. 6.
- Australian Government, Bureau of Meteorology, 2018. <http://www.bom.gov.au/climate/current/soihtm1.shtml>.
- Australian Government, Bureau of Meteorology, 2018. <http://www.bom.gov.au/>
- AVISO, 2018. <https://www.aviso.altimetry.fr/en/home.html>.
- Babin, M., Bélanger, S., Ellingsen, I., Forest, A., Le Fouest, V., Lacour, T., Ardyna, M. and Slagstad D., 2015. Estimation of primary production in the Arctic Ocean using ocean colour remote sensing and coupled physical–biological models: Strengths, limitations and how they compare. *Progress Oceanog.*, 139: 197-220.
- Baeck, G. W., Park, J. M., Huh, S. H., Kim, H. J. and Jeong, J. M., 2014. Feeding habits of Kammal thryssa *Thryssa kammalensis* (Bleeker, 1849) in the coastal waters of Gadeok-do, Korea. *Anim. Cells. Syst.*, 18(2): 154-159.
- Bakun, A. 1990. Global climate change and intensification of coastal ocean upwelling. *Science*. 247(4939):198-201.
- Bakun, A. and Broad, K., 2003. Environmental ‘loopholes’ and fish population dynamics: comparative pattern recognition with focus on El Niño effects in the Pacific. *Fish. Oceanogr.* 12 (4/5): 458-473.

- Bakun, A., Field, D. B., Redondo-Rodriguez, A. and Weeks, S. J., 2010. Greenhouse gas, upwelling-favorable winds, and the future of coastal ocean upwelling ecosystems. *Global Change Biol.* 16: 1213-1228.
- Bakun, A., 1996. Patterns in the ocean: ocean processes and marine population dynamics. California Sea Grant, in cooperation with Centro de Investigaciones Biologicas del Noroeste, La Paz, Mexico. pp. 323.
- Bakun, A., Roy, C. and Lluch-Cota, S., 1998. Coastal upwelling and other processes regulating ecosystem productivity and fish production in the western Indian Ocean. *In: Large marine ecosystems of the Indian Ocean: Assessment, sustainability and management* (eds. Sherman, K., Okemwa, E. and Nitiba, M.). Massachusetts: Blackwell Sciences Inc., pp. 103-141.
- Bal, D. V. and Rao, K. V., 1984. Marine Fisheries of India Tata Mc Graw Hill Publishing Company Ltd. New Delhi. pp. 250.
- Bala, I. and Singh O. P., 2008. Relationship between Indian Ocean Dipole Mode and summer monsoon. *Mausam*, 59 (2): 167-172.
- Balakrishnan, V., 1957. Occurrence of larvae and young mackerel, *Rastrelliger canagurta* (Cuvier) off Vizhingam, near Trivandrum. *Curr. Sci. India*, 26: 57-58.
- Balan, V., 1964. Studies on the age and growth of the oil-sardine, *Sardinella longiceps* Valenciennes by means of scales. *Indian J. Fish.*, IIA (2): 663-696.
- Ban, S. S., Alidina, H. M., Okey, T. A., Gregg, R. M. and Ban, N. C., 2016. Identifying potential marine climate change refugia: A case study in Canada's Pacific marine ecosystems. *Global Ecol. Conserv.*, 8: 41-54.
- Banse, K., 1959. On upwelling and bottom-trawling off the southwest coast of India. *J. Mar. Biol. Ass. India*, 1 (1): 33-49.
- Barton, B. T., 2017. Beyond global warming: Putting the "climate" back into "climate change ecology. *Food Webs*, 13: 51-52.
- Beare, D. J., Burns, F., Greig, A., Jones, E. G., Peach, K., Kienzle, M., McKenzie, E. and Reid, D. G., 2004. Long-term increases in prevalence of North Sea fishes having southern biogeographic affinities. *Mar. Ecol. Prog. Ser.* 284: 269-278.
- Beaugrand, G., Reid, P. C., Ibanez, F. and *et al.*, 2002. Reorganisation of North Atlantic marine copepod biodiversity and climate. *Science*, 296: 1692-1694.
- Bebbington, J. and Larrinaga-Gonzalez, C., 2008. Carbon trading: Accounting and reporting issues. *Eur. Account Rev.*, 17(4): 697-717.
- Begg, G. A. and Waldman J. R., 1999. An holistic approach to fish stock identification. *Fish. Res.*, 43: 35-44.
- Behrenfeld, M. J., O'Malley, R. T., Siegel, D. A., McClain, C. R., Sarmiento, J. L., Feldman, G. C., Milligan, A. J., Falkowski, P. G., Letelier, R. M. and Boss, E. S., 2006. Climate-driven trends in contemporary ocean productivity. *Nature*, 444(7120): 752-755.

- Bélanger, S., Ehn, J. K. and Marcel, B., 2007. Impact of sea ice on the retrieval of water-leaving reflectance, chlorophyll a concentration and inherent optical properties from satellite ocean color data. *Remote Sensing Environ.*, 111 (1): 51-68.
- Bennet, P. S., 1967. On bomolochus Jonesi sp. Nov. Parasitic on the eye of the Indian mackerel *Rastrelliger kanagurta*. *J. Mar. biol. Ass. India*, 9 (1): 132-136.
- Bensam, P., 1970. On the fluctuations of the oil sardine fishery at Cannanore During 1961-1964. *Indian J. Fish.*, 17 (1&2): 132-148.
- Bera, S., 2017. Trend Analysis of Rainfall in Ganga Basin, India during 1901-2000. *Sci. Res.*, 6(1): <https://doi.org/10.4236/ajcc.2017.61007>.
- Bhimachar, B. S. and George, P. C., 1952. Observations on the food and feeding of the Indian mackerel *Rastrelliger kanagurta* (Cuvier). *Proc. Indian Acad. Sci.*, 36(3): 105-117.
- Boopendranath, M. R. and Hameed, M. S., 2012. Energy Analysis of the Ring Seine Operations, off Cochin, Kerala. *Fish. Technol.* 49:141-146.
- Brander, K. M., 2007. Global fish production and climate change. *PNAS*, 104 (5): 19709 -19714.
- Brander, K. M., 2010. Impacts of climate change on fisheries. *J. Mar. Sys.*, 79: 389-402.
- Buishand, T. A., 1982. Some methods for testing the homogeneity of rainfall records, *J. Hydrol.*, 58: 11-27.
- Caldwell, A. J., While, G. M., Beeton, N. J. and Wapstra, E., 2015. Potential for thermal tolerance to mediate climate change effects on three members of a cool temperate lizard genus, *Niveoscincus*. *J. Therm. Biol.*, 52: 14-23.
- Chacko, P. I. and Mathew, M. J., 1955. Programme of oil sardine research in Madras State Fisheries Department in 1954-55. Proceedings of the 43<sup>rd</sup> Indian Science Congress. 3: 309-310.
- Chan, E. Y., 2018. Climate change is the world's greatest threat – In Celsius or Fahrenheit?. *J. Environ. Psychol.*, 60: 21-26.
- Chao, Q. and Feng, A., 2018. Scientific basis of climate change and its response. *Global Energy Interconnection.*, 1: 420-427.
- Chavez, F. P., Ryan, J., Lluch-Cota, S. E. and Niquen, C. M., 2003. From Anchovies to Sardines and Back: Multidecadal Change in the Pacific Ocean. *Science*, 299: 217-221.
- Chelton, D. B., Esbensen, S. K., Schlax, M. G., Thum, N., Freilich, M. H., Wentz, F. J., Gentemann, C. L., Mcphaden, M. L. and Schopf, P. S., 2001. Observations of Coupling between Surface Wind Stress and Sea Surface Temperature in the Eastern Tropical Pacific. *J. Climate*, 14: 1479-1498.

- Chen, I. C., Hill, J. K., Ohlemuller, R., Roy, D. B. and Thomas, C. D., 2011. Rapid range shifts of species associated with high levels of climate warming. *Science*, 333: 1024-1026.
- Chen, I. C., Lee, P. F. and Tzeng, W. N., 2005. Distribution of albacore (*Thunnus alalunga*) in the Indian Ocean and its relation to environmental factors. *Fish. Ocean.*, 14: 71-80.
- Cheung, W. W. L., Watson, R. and Pauly, D., 2013. Signature of ocean warming in global fisheries catch. *Nature*, 497: 365-368.
- Cheung, W. W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R., Zeller, D. and Pauly, D., 2010. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biol.*, 16: 24-35.
- Chidambaram, K., Krishnamurty, C. G., Venkataraman, R. and Chari, S. T., 1952. Studies on mackerel: fat variations and certain biological aspects. *Proc. Indian Acad. Sci.*, 35B (2): 43-68.
- Chidambaram, K., 1950. Studies on length frequency of the oil sardine, *Sardinella longiceps* Cuv. and on certain factors influencing their appearance on the Calicut coast of Madras Presidency. *Proc. Indian Acad. Sci.*, 31B (5): 252-286.
- Chidambaram, K. and Menon, M. D., 1945. The correlation of the West Coast (Malabar and South Kanara) fisheries with plankton and certain oceanographical features. *Proc. Indian Acad. Sci.*, 22 (B): 355-367.
- Chidambaram, K., 1944. Food of the Indian mackerel (*Rastrelliger kanagurta*, Russell) of the west coast of the Madras Presidency. *Curr. Sci. India*, 13: 214-215.
- Clark, C. O., Webster, P. J. and Cole, J. E., 2003. Interdecadal variability of the relationship between the Indian Ocean zonal mode and East African coastal rainfall anomalies. *J. Climate*, 16: 548-554.
- CMFRI, 2016. Annual Report 2015-14. Central Marine Fisheries Research Institute, Kochi. pp. 296.
- CMFRI, 2017. Annual Report 2016-17. Central Marine Fisheries Research Institute, Kochi. pp. 292.
- CMFRI, 2018. Annual Report 2017-18. Central Marine Fisheries Research Institute, Kochi. pp. 304.
- Cochrane, K. and Japp, D., 2015. Pelagic Fisheries: A retrospective analysis of their status in the Southwest Indian Ocean, *In: Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. Van der Elst R.P. and Everett B.I.). Oceanographic Research Institute, Special Publication, 10. pp. 448.
- Collette, B. B. and Nauen, C. E., 1983. FAO Species Catalogue. Scombrids of the World. An annotated and illustrated catalogue of Tunas, Mackerels, bonitos and related species known to date. Rome FAO Fish Synop., 125 (2): 137.

- Costanza, R., d'Arge, R., de Groot, R., Farberk, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., P. and van den Belt, M., 2013. The value of the world's ecosystem services and natural capital. *Nature*, 387: 253-260.
- Cox, P. M., Betts, R. A., Jones, C. D., Spall, S. A. and Totterdell I. J., 2000. Acceleration in global warming due carbon-cycle feedbacks in a coupled climate model. *Nature*, 408: 184-187.
- Cury, P., Bakun, A., Crawford, R. J. M., Jarre, A., Quinones, R. A., Shannon, L. J. and Verheye H. M., 2000. Small pelagics in upwelling systems: patterns of interaction and structural changes in "wasp-waist" ecosystems. *ICES J. Mar. Sci.*, 57: 603-618.
- Cuvier, 1817. FAO identification of species, volume 4.
- Dabuleviciene, T., Kozlov, I. E., Vaiciute, D. and Dailidienė, I., 2018. Remote Sensing of Coastal Upwelling in the South-Eastern Baltic Sea: Statistical Properties and Implications for the Coastal Environment. *Remote Sens.*, 1752, doi:10.3390/rs10111752.
- Dahanukar, N., Raut, R. and Bhat, A., 2004. Distribution, endemism and threat status of freshwater fishes in the Western Ghats of India. *J. Biogeography*, 31: 123-136.
- Das, I., Hazra, S., Bhattacharya, S. B., Das, S. and Giri, S., 2016. A study on seasonal change in feeding habit, health status and reproductive biology of Indian Mackerel (*Rastrelliger kanagurta*, Cuvier) in coastal water of West Bengal. *Indian J. Geo-Mar. Sci.* 45(2): 254-260.
- Dash, S. K., Jenamani, R. K., Kalsi, S. R. and S. K. Panda, 2007. Some evidence of climate change in twentieth-century India. *Climatic Change*, 85: 299-321.
- Day, F., 1889. The fauna of British India Including Ceylon and Burma. Fishes : 1 London. pp. 548.
- de Moel, H., Ganssen, G. M., Peeters, F. J. C., Jung, S. J. A., Kroon, D., Brummer, G. J. A. and Zeebe, R. E., 2009. Planktonic foraminiferal shell thinning in the Arabian Sea due to anthropogenic ocean acidification? *Biogeosciences*, 6: 1917-1925.
- Desai, P. S., Honne Gowda H. and Kasturirangan, K., 2000. Ocean research in India: Perspective from space. *Curr. Sci. India*, 78(3): 268-278.
- Deshmukh, A. V., Kovale, S. R., Sawant, M. S., Shirdhankar M. M. and Funde, A. B., 2010. Reproductive biology of *Sardinella longiceps* along Ratnagiri coast off Maharashtra. *Indian J. Mar. Sci.*, 39(2): 274-279.
- Deshmukh, A. V., Sumod, K. S., Aneesh Kumar, K. V., Smitha, B. R. and Yadav, S. K., 2016. Some aspect of spawning season and biology of Indian Oil Sardine *Sardinella longiceps* along, Goa- Karwar Sector of Southwest coast of India, *Indian J. Mar. Sci.* 45(11): 1481-1486.

- Devadoss, P., 1973. On the occurrence of juvenile oil sardine, *Sardinella longiceps* Val. In the inshore waters of Bombay. *Indian J. Fish.*, 20 (1): 234-236.
- Devanesan, D. W. and Chidambaram, K., 1948. Common food fishes of the Madras Presidency, Government Press, Madras, 32-34.
- Devanesan, D. W. and John, V., 1940. On the natural history of *Rastrelliger kanagurta* with special reference to its spawning season and eggs. *Curr. Sci. India*, 9 (10): 462-464.
- Devanesan, D. W., 1943. A brief investigation into the causes of the fluctuation of the annual fishery of the oil-sardine of Malabar, *Sardinella longiceps* Cuv. & Val., determination of its age and an account of the discovery of its eggs and spawning grounds, Madras Fish, Bull., 28(l): 1-38.
- Devaraj, M., Kurup, K. N., Pillai, N. G. K., Balan, K., Vivekanandan, E. and Sathiadas, R., 1997. Status, prospects and management of small pelagic fisheries of India. In : Small Pelagic resources and their Fisheries in the Asia-Pacific region. Proc. of the APFIC working Party on Marine Fisheries. Bangkok, Thailand. RAP Publ. 1997/31, pp. 91-181.
- Diamond, H. J., Lorrey, A. M., Knapp K. R. and Levinson D. H., 2012. Development of an enhanced tropical cyclone tracks database for the southwest Pacific from 1840 to 2010. *Int. J. Climatol.*, 32: 2240-2250.
- Dhulkhed, M. H., 1964. Observations on the spawning behaviour of the Indian oil sardine, *Sardinella longiceps* Valenciennes, determined by ova diameter studies. *Indian J. Fish.*, 11 A (1): 371-376.
- Dhulkhed, M. H., 1973. Sex ratio in oil sardine. *Indian J. Fish.*, 20 (1): 236-239.
- Doney, S. C., Ruckelshaus, M., Duffy, J. E., Barry, J. P., Chan, F., English, C. A., Galindo, H. M., Grebmeier, J. M., Hollowed, A. B., Knowlton, N., Polovina, J., Rabalais, N. N., Sydeman, W. J. and Talley, L. D., 2012. Climate Change Impacts on marine ecosystems. *Ann. Rev. Mar. Sci.*, 4: 11-37.
- Dulvy, N. K., Baum, J. K., Clarke, S., Compagno, L. J. V., Cortes, E., Domingo, A., Fordham, S., Fowler, S., Francis, M. P., Gibson, C., Martinez, J., Musick, J. A., Soldo, A., Stevens, J. D. and Valenti, S., 2008. You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. *Aquatic Conserv: Mar. Freshw. Ecosyst.* DOI: 10.1002/aqc.975.
- Dwivedi, S., 2012. Forecasting the peak anomalies of dominant intrinsic modes of Indian Ocean Dipole. *Deep-Sea Res. PT. I*, 70: 73-82.
- Edwards, M. and Richardson, A. J., 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. *Nature*, 430: 881-884.
- Elizbarashvili, E. Sh., Elizbarashvili, M. E., Kutaladze, N. B., Elizbarashvili, Sh. E. and Chelidze, N. Z., 2017. Long-term changes in the number and temperature of hot days in Georgia under global warming. *Russ. Meteorol. Hydrol.*, 42 (10): 665-670.

- Fasullo, J. T. and Gent, P. R., 2017. On the Relationship between Regional Ocean Heat Content and Sea Surface Height. *J. Climate*, 30: 9195-9211.
- Feely, R. A., Doney, S.C. and Cooley, S. R., 2009. Ocean acidification: present conditions and future changes in a high-CO<sub>2</sub> world. *Oceanography*, 22: 36-47.
- Fortunato, H., 2015. Bryozoans in climate and ocean acidification research: A reappraisal of an under-used tool. *Reg. Stud. Mar. Sci.*, 2: 32-44.
- Fotedar, R. K. and Savaria, Y. D., 1988. Unusual fishery for oil sardines along the West Saurashtra Coast. *Mar. Fish. Info. Ser., Tech. Ext. Ser.*, 80: 26-27.
- Francis, R. C. and Hare, S., 1994. Decadal-scale regime shifts in the large marine ecosystems of the North-east Pacific: a case for historical science. *Fish. Oceanogr.* 3(4): 279-291.
- Froese, R. and Pauly, D., 2011. FishBase version (02/2011). World Wide Web electronic publication. [www.fishbase.org](http://www.fishbase.org).
- Froese, R. and Pauly, D., 2017. FishBase, version (January, 2017). World Wide Web electronic publication. Retrieved from <https://www.fishbase.org>.
- FSI, 2014 . Annual Report for the year 2013-14. Fishery Survey of India, Government of India.
- Ganga, U., 2000. Oil Sardine Fishery at Karwar - an Update. *J. Mar. Biol. Ass. India*. 42 (1&2): 112-123.
- Ganga, U., 2010. Investigations on the biology of Indian Mackerel *Rastrelliger kanagurta* (Cuvier) along the Central Kerala coast with special reference to maturation, feeding and lipid dynamics. Doctoral thesis, Central Marine Fisheries Research Institute. pp.159.
- Gattuso, J. P., Magnan, A., Billé, R., Cheung, W. W., Howes, E. L., Joos, F., Allemand, D., Bopp, L., Cooley, S. R., Eakin, C. M., Hoegh-Guldberg, O., Kelly, R. P., Pörtner, H. O., Rogers, A. D., Baxter, J. M., Laffoley, D., Osborn, D., Rankovic, A., Rochette, J., Sumaila, U. R., Treyer, S. and Turley, C., 2015. Contrasting futures for ocean and society from different anthropogenic CO<sub>2</sub> emissions scenarios. *Science*. 3;349(6243):aac4722. doi: 10.1126/science.aac4722.
- Gazeau, F., Quiblier, C., Jansen, J. M., Gattuso, J. P., Middelburg, J. J., Heip, C. H. R., 2007. Impact of elevated CO<sub>2</sub> on shellfish calcification. *Geophys. Res. Lett.* 34: 7603.
- Genner, M. J., Sims, D. W., Southward, A. J., Budd, G. C., Masterson, P., Mchugh, M., Rendle, P., Southall, E. J., Wearmouth, V. J. and Hawkins, S. J., 2010. Body size-dependent responses of a marine fish assemblage to climate change and fishing over a century-long scale. *Global Change Biol.* 16: 517-527.
- George, J. V., Nuncio, M., Chacko, R., Anilkumar, N., Noronha, S. B., Patil, S. M., Pavithran, S., Alappattu, D. P., Krishnan, K. P. and Achuthankutty, C. T., 2013. Role of physical processes in chlorophyll distribution in the western tropical Indian Ocean. *J. Marine Syst.* 113-114: 1-12.

- George, G., Meenakumari, B., Raman, M., Kumar, S., Vethamony, P., Babu, M. T. and Verlecar, X., 2012. Remotely sensed chlorophyll: a putative trophic link for explaining variability in Indian oil sardine stocks. *J. Coast. Res.*, 28: 105-113.
- George, K. C. and Banerji, S. K. 1964. *Age and growth studies on the Indian mackerel Rastrelliger kanagurta (Cuvier) with special reference to length-frequency data collected at Cochin. Indian J. Fish.*, 11 A (2): 621-638.
- George, P. C, Dhulkhed, M. H. and Rao, V. R., 1959. Observations on the mackerel fishery of the Netravati Estuary, West Coast, South India. *Bombay Nat. Hist. Soc*, 56 (1): 32-38.
- George, P. C. and Annigeri G. G., 1960. On the occurrence of small sized mackerels *Rastrelliger kanagurta* (Cuvieri) of Rantangiri coast. *Curr. Sci. India* 29: 316-320.
- Ghani, I. M. M. and Ahmad, S., 2010. Stepwise Multiple Regression Method to Forecast Fish Landing. *Procd. Soc. Behv.* 8: 549-554.
- Ghosh, S, Rao, M. V. H., Mahesh, V. U., Kumar, M. S. and Rohit, P., 2016. Fishery, reproductive biology and stock status of the Indian mackerel *Rastrelliger kanagurta* (Cuvier, 1817), landed along the north-east coast of India. *Indian J. Fish.*, 63 (2): 33-41.
- Ghoshal , T., Sil S. and Chakraborty, A., 2014. An inter comparison of daily and monthly in situ, satellite derived and reanalyzed sea surface temperature climatology fields over the Bay of Bengal. *Mar. Geod.*, 37(1): 65-76.
- Gireeshkumar, T. R., Mathew, D., Pratihary, A. K., Naik. H., Narvekar. K. U., Araujo, J., Balachandran, K. K., Muraleedharan, K. R., Thorat, B., Nair, M. and Naqvi S. W. A., 2017. Influence of upwelling induced near shore hypoxia on the Alappuzha mud banks, South West Coast of India, *Cont. Shelf Res.*, 139: 1-8.
- Goela, P. C., Cordeiro, C., Danchenko, S., Icely, J., Cristina, S. and Newton, A., 2016. Time series analysis of data for sea surface temperature and upwelling components from the southwest coast of Portugal. *J. Marine Syst.*, 163: 12-22.
- Gonzalez-Nuevo, G., Gago, J. and Cabanas J. M., 2014. Upwelling index: a powerful tool for marine research in the NW Iberian upwelling system, *J. Oper. Oceanogr.*, 7(1): 47-57.
- Gopakumar, G. N., Pillai G. and Omana T. A., 1991. The fishery characteristics and biology of mackerel at Vizhinjam. *J. mar. biol. Ass. India*, 33 (1&2): 107-114.
- Gopakumar, G., Pillai, N.G.K., 2000. Whitebaits. *In: Central Marine Fisheries Research and Management* (eds. Pillai, V. N. and Menon, N. G.). CMFRI Kochi, pp. 296-308.
- Gopal, C. and Savaria, Y. D., 1991. Minor fishery for the Indian oil sardine (*Sardinella longiceps*) along Saurashtra coast. *Indian J. Fish.* 38 (1): 39-41.
- Gopinathan, C. P., Rodrigo, J. X., Kasim, M. H. and Rajagopalan M. S., 1994. Phytoplankton pigments in relation to primary production and nutrients in the

inshore waters of Tuticorin, South East coast of India. *Indian J. Mar. Sci.*, 23: 209-212.

- Gordon, H., Du, T. and Zhang, T., 1997. Remote sensing of ocean color and aerosol properties: Resolving the issue of aerosol absorption. *Appl. Optics*, 36: 8670-8684.
- Grantham, B. A., Chan, F., Nielsen, K. J., Fox, D. S., Barth, J. A., Huyer, A., Lubchenco, J., Menge, B. A., 2004. Upwelling-driven nearshore hypoxia signals ecosystem and oceanographic changes in the northeast Pacific. *Nature*, 429, 749–754.
- Hand, R., Keenlyside, N., Omrani, N., Bader, J. and Greatbatch, R. J., 2018. The role of local sea surface temperature pattern changes in shaping climate change in the North Atlantic sector. *Clim. Dynam.* DOI: 10.1007/s00382-018-4151-1.
- Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D.W. and Medina-Elizade, M., 2006. Global temperature change. *PNAS*, 103: 14288-14293.
- Hardenberg, J. D. F., 1956. A review on the current knowledge of Rastrelliger. I.P.F.C. Rastrelliger Sub-Committee Session, Penang, Malaysia.
- Hare, J. A., Alexander, M. A., Fogarty, M. J., Williams, E. H. and Scott, J. D., 2010. Forecasting the dynamics of a coastal fishery species using a coupled climate-population model. *Ecol. Appl.*, 20(2): 452–464.
- Harou, A. P., Laoie, R. F., Kniveton, D. R. and Frogley, M. R., 2006. The influence of the Indian Ocean dipole mode on precipitation over the Seychelles. *Int. J. Climatol.*, 26: 45-54.
- Haryanto, Y. D., 2018. Propagation of upwelling on Western-Coast Sumatera during MJO event. *J. Ecol. Eng.* 19(1): 122-128.
- Hausfather, Z., Cowtan, K., Clarke, D. C., Jacobs, P., Richardson, M. and Rohde R., 2017. Assessing recent warming using instrumentally homogeneous sea surface temperature records. *Sci. Adv.* 3(1): e1601207 DOI: 10.1126/sciadv.1601207.
- Hays, G. C., Anthony, J., Richardson, A. J. and Robinson, C., 2005. Climate change and marine plankton. *Trends Ecol. Evol.* 20 (6): 337- 344.
- Heck, B. and Rummel, R., 1990. Strategies for Solving the Vertical Datum Problem Using Terrestrial and Satellite Geodetic Data. *In: Sea Surface Topography and the Geoid: Edinburgh, Scotland* (eds. Sünkel, H. and Baker, T.), August 10–11, 1989, Springer, New York.
- Henson, S. A., Sarmiento, J. L., Dunne, J. P., Bopp, L., Lima, I., Doney, J. John, S. C. and Beaulieu, C., 2009. Is global warming already changing ocean productivity? *Biogeosci. Discuss.*, 6: 10311-10354.
- Ho, C. -R., Zheng, Q., Soong, Y. S., Kuo, N. -J. and Hu, J. -H., 2000. Seasonal variability of sea surface height in the South China Sea observed with TOPEX/POSEIDON altimeter data. *J. Geophys. Res.*, 105: 13981-13990.

- Hoegh-Guldberg, O. and Bruno, J. F., 2010. The Impact of Climate Change on the World's Marine Ecosystems. *Science*, 328 (5985): 1523-1528.
- Hood, R. R., Beckley, L. E. and Wiggert, J. D., 2017. Biogeochemical and ecological impacts of boundary currents in the Indian Ocean. *Prog. Oceanogr.* 156: 290-325.
- Hood, P. B. and Johnson A. K., 2000. Age, growth, mortality, and reproduction of red porgy, *Pagruspagrus*, from the eastern Gulf of Mexico. *Fisheries Bulletin*, 98: 723-735.
- Hornell, J. and Nayudu, M. R., 1924. A contribution to the life-history of the Indian oil sardine, with notes on the plankton of the Malabar coast. *Madras Fish. Bull.*, 17: 129-97.
- Hornell, J., 1910. Report on the results of a fishery cruise along the Malabar Coast and to the Laccadive islands in 1908. *Madras Fish. Bull.*, 4: 71-126.
- Houghton, J., 2004. Global Warming: The Complete Briefing. New York: Cambridge UP. 3<sup>rd</sup> ed. pp.351
- Hsieh, C. H., Reiss, C. S., Hunter, J. R., Beddington, J. R., May, R. M. and Sugihara, G., 2006. Fishing elevates variability in the abundance of exploited species. *Nature*. 443 (7113): 859-862.
- Hulkoti, S. H., Shivaprakash, S. M., Anjanayappa, H. N., Somashekara, S. R., Benakappa, S., Kumar Naik, A. S., Ganesh Prasad, L., Panda, K., Kumar, J., 2013. Breeding Biology of Indian Mackerel, *Rastrelliger kanagartha* (Cuvier) from Mangalore Region. *Environ. Ecol.*, 31 (2A): 683-688.
- Hunter, J. R., 1981. Feeding ecology and predation in marine fish larvae. In: Marine fish larvae (eds. Lasker, R.). Seattle: University of Washington Press, pp. 34-59.
- IOCCG, 2010. Atmospheric correction for remotely-sensed ocean-colour products. Reports of the International Ocean-Colour Coordinating Group 10.
- IPCC, 2000. Special report on emission scenarios. *In*: Intergovernmental Panel on Climate Change (IPCC) (ed. Nakicenovic, N. and Swart, R.). Cambridge University Press, Cambridge, UK.
- IPCC, 2007a. Climate change 2007: The physical science basis. *In*: Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. and Miller, H. L.). Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, New York.
- IPCC, 2007b. Climate change 2007: Impacts, adaptation and vulnerability. *In*: Contribution of working group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J. and Hansson C. E.). Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, New York.

- IPCC, 2013. Climate change 2013: The physical science basis. In: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change., In: Intergovernmental Panel on Climate Change, Working Group I Contribution to the IPCC Fifth Assessment Report (AR5) (eds. Stocker, T. F., Qin, D., Plattner, G. -K. Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley P. M.). Intergovernmental Panel on Climate Change, New York, pp. 1535.
- IPCC, 2014. Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.
- Ishii, M., Shouji, A., Sugimoto, S. and Matsumoto, T., 2005. Objective analyses of sea-surface temperature and marine meteorological variables for the 20th century using ICOADS and the Kobe collection. *Int. J. Climat.*, 25, 865-879.
- Jackett, D. R., McDougall, T. J., Feistel, R., Wright, D. G. and Griffies, S. M., 2006. Algorithms for density, potential temperature, conservative temperature and the freezing temperature of seawater. *J. Atmos. Ocean. Technol.*, 23: 1709-1728.
- Jadhav, R. N., Narain P., Nair, P. V. R., Pillai, V. K., Ponnaiah, A. G., Balachandran, V. K. and *et al.*, 1989. Oceanographic parameters and their relationship to fish catch estimation: a case study in coastal waters north of Cochin during 1981. In Proc. Seminar on Remote Sensing in Marine Resources, Central Marine Fisheries Research Institute, Cochin. 17-18:1-12.
- Jaiswal, R. K., Lohani, A. K. and Tiwari, H. L., 2015. Statistical analysis for change detection and trend assessment in climatological parameters, *Environ. Process.*, 2: 729-749.
- James, P. S. B. R. and Santha, J. P., 1976. An instance of unusual feeding behaviour of the Indian mackerel, *Rastrelliger kanagurta* (Cuvier) off Mangalore. *J. Bombay Nat. Hist. Soc.*, 73(3): 538-539.
- Jayaprakash, A. A. and Pillai, N. G. K., 2000. The Indian oil sardine. In: Marine Research and Management (eds. Pillai, V. N. and Menon, N. G.), Central Marine Fisheries Research Institute (Indian Council of Agricultural Research) Tatapuram P.O., Cochin-682 014 Kerala, India, 259-281.
- Jayaprakash, A. A. 2002. Long term trends in rainfall, sea level and solar periodicity. A case study for forecast of Malabar sole and oil sardine fishery. *J. Mar. Biol. Assoc. India*, 44: 163-75.
- Jayaprakash, A. A., 2003. Whitebaits. In: Status of Exploited Marine Fishery Resources of India (eds. Joseph, M. M. and Jayaprakash, A. A.). Central Marine Fisheries Research Institute, Kochi, India, pp. 30-39.
- Jayaram, C. and Dinesh Kumar P. K., 2018. Spatio-temporal variability of upwelling along the southwest coast of Indiabased on satellite observations. *Cont. Shelf. Res.*, 156: 33-42.

- Jayaram, C., Bansal, S., Krishnaveni, A. S., Chacko, N., Chowdary, V. M., Dutta, D., Rao, K. H., Dutt, C. B. S., Sharma, J. R. and Dadhwal, V. K., 2016. Evaluation of SARAL / AltiKa Measured Significant Wave Height and Wind Speed in the Indian Ocean Region. *J. Indian Soc. Remote*, 44 (2): 225-231.
- Johannessen, O. M., Subbaraju G. and Blindheim J. 1981. Seasonal variation of the oceanographic conditions off the southwestern coast of India during 1971-75. *Fisk Dir. Skr. Ser. HavUnders.*, 18, 247-261.
- Jha, P. N., Chinnadurai, S., Renjith, R. K., Madhu, V. R. and Soni, J., 2019. A Preliminary Study on Trawl Geometry: Effect of Speed and Warp Length on Mouth Opening. *Fish. Technol.*, 56: 302-305.
- John, C. C. and Menon, M. A. S., 1942. Food and feeding habits of the oil sardine and mackerel. *Curr. Sci. India*, 11: 243-244.
- Joseph, G., 1996. Imaging sensors for remote sensing. *Remote Sensing Reviews*, 13:3-4, 257-342.
- Jugnu, R. and Kripa V., 2009. Effect of *Chattonella marina* [(Subrahmanyam) Hara et Chihara 1982] bloom on the coastal fishery resources along Kerala coast, India. *Indian J. Mar. Sci.*, 38(1): 77-88
- Jump, A. S., Matyas, C. and Penuelas, J., 2009. The altitude-for-latitude disparity in the range 745 retractions of woody species. *Trends Ecol. Evol.*, 24: 694-701.
- Kaddo, J. R., 2016. Climate Change: Causes, Effects, and Solutions. A with Honors Projects. 164. <https://spark.parkland.edu/ah/164>.
- Kamble, S., Kazi, T. G., Chaudhari, K. J., Shirdhankar, M. M. and Dhaker, H. S., 2017. Catch composition of purse-seine fishing along Ratnagiri coast of Maharashtra state, India. *J. Exp. Zool. India* 20 (1): 431-434.
- Kämpf, J. and Kavi, A., 2018. SST variability in the eastern intertropical Indian Ocean -On the search for trigger mechanisms of IOD events. *Deep Sea. Res. PT II* (in press). <https://doi.org/10.1016/j.dsr2.2018.11.010>.
- Kang, H. M. and Yusof, F., 2012. Homogeneity Tests on Daily Rainfall Series in Peninsular Malaysia. *Int. J. Contemp. Math. Sci.*, 7: 9-22.
- Kanuri, V.V., Gijjapu, D. R. , Munnooru, K., Sura A., Patra S., Vinjamuri R. R., Karri R., 2017. Scales and drivers of seasonal pCO<sub>2</sub> dynamics and net ecosystem exchange along the coastal waters of southeastern Arabian Sea. *Mar. Pollut. Bull.*, 121: 372-380.
- Karl, T. R, Knight, R. W., Easterling, D. R. and Quayle, R. G. 1995. Indices of climate change for the United States. *B. AM. Meteorol. Soc.*, 77: 279-292.
- Karna, S. K., 2017. Length–weight and length–length relationship of *Thyssa purava* (Hamilton, 1822), *Thyssa polybranchialis* Wongratana, 1983 and *Thyssa mystax* (Bloch & Schneider, 1801) from Chilika lagoon, India. *Appl. Ichthyol.*, 33:1284-1286.

- Keeling, R. F., Körtzinger, A. and Gruber, N., 2010. Ocean Deoxygenation in a Warming World. *Annu. Rev. Mar. Sci.*, 2:199-229.
- Kevin, E. and Trenberth K. E., 2011. Changes in precipitation with climate change. *Clim. Res.*, 47: 123-138.
- Klemas, V. 2013. Fisheries applications of remote sensing: An overview. *Fish. Res.*, 148: 124-136.
- Klyashtorin, L. B., 1997. Global climate cycles and Pacific forage fish stock fluctuations. In: Forage Fishes in marine Ecosystems. Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program Report no 97-01. University of Alaska Fairbanks. pp. 545-557.
- Knutti, R., Rogelj, J. and Sedlacek, J., 2016. A scientific critique of the two-degree climate change target. *Nat. Geosci.*, 9 (1): 13-18.
- Kramer, D. 1960. Development of eggs and larvae of the Pacific mackerel and distribution and abundance of larvae 1952-1956. 17.5. Department of Interior, Fish Wildl. Serv. *Fish. Bull.*, 174, 60:393-438.
- Kripa, V., Mohamed K. S., Said Koya, K. P, Jeyabaskaran, R., Prema, D., Padua, S., Kuriakose, S., Anilkumar, P. S., Nair, P. G., Ambrose, T. V., Dhanya, A. M., Abhilash, K. S., Bose, J., Divya, N. D., Shara, A. S. and Vishnu, P. G., 2018. Overfishing and Climate Drives Changes in Biology and Recruitment of the Indian Oil Sardine *Sardinella longiceps* in Southeastern Arabian Sea. *Front. Mar. Sci.*, 5:1-20. <https://doi.org/10.3389/fmars.2018.00443>.
- Kripa, V., Prema, D., Jeyabaskaran, R., Khambadkar, L. R., Nandakumar, A., Anilkumar P. S., Ambrose, T. V., Bose, J., Nair, P. G. and Pillai V. N., 2015. Inter-annual variations of selected oceanographic parameters and its relation to fishery of small pelagics off Kochi, southwest coast of India. *J. Mar. Biol. Ass. India*, 57 (2): 52-57.
- Krishnakumar P. K. and Bhat G. S., 2008. Seasonal and interannual variations of oceanographic conditions off Mangalore coast (Karnataka, India) in the Malabar upwelling system during 1995–2004 and their influences on the pelagic fishery. *Fish. Oceanogr.*, 17:1, 45-60.
- Krishnakumar, P. K., Mohamed, K. S., Asokan, P. K., Sathianandan, T. V., Zacharia, P. U., Abdurahiman, K. P., Shettigar, V. and Durgekar, R. N., 2008. How environmental parameters influenced fluctuations in oil sardine and mackerel fishery during 1926-2005 along the south-west coast of India? *Mar. Fish. Infor. Serv. Tech. and Ext. Ser.*, 198: 1-5.
- Krishnakumar, P. K., Prathibha, R., Nayak, H. and Rajagopalan, M., 2006. Assessing the impacts of climate change on marine fisheries of Karnataka and identifying regime shifts. In: Proceedings of the International Workshop on Improved Sustainability of Fish Production Systems and Appropriate Technologies for Utilization (eds. Kurup B. M.) Cochin, India: School of Industrial Fisheries, Cochin University of Science & Technology, pp. 63-70.

- Kuffner, I. B., Andersson, A. J., Jokiel, P. L., Rodgers, K. S. and Mackenzie, F. T., 2008. Decreased abundance of crustose coralline algae due to ocean acidification. *Nat. Geosci.*, 1: 114-117.
- Kumar, K. and Balasubramanian, K., 1987. Fishery and biology of oil sardine *Sardinella longiceps* (Valenciennes) from coastal waters of Parangipettai. CMFRI Bull. in National Symposium on Research and Development in Marine Fisheries I & II 1987, 44: 42-45.
- Kumar, M. A., Padmavati, G., and Venu, S., 2015. Food and Feeding Dynamics of *Stolephorus commersonii* (Lacepede, 1803) (Family: Engraulidae) from South Andaman. *J. Mar Biol.*, <http://dx.doi.org/10.1155/2015/870919>.
- Kumaran, M., Rao, K. V. N., Annigeri, G. G., Mohan, M., Nair, P. N. R., Puthran, P. and *et al.* 1992. Present Status of Exploitation of Fish and Shellfish Resources: Oil sardine. *Bull. Centr. Mar. Fish. Res. Inst.*, 45:92-110.
- Kumaran, M., Yohannan, T. M. and Khan, F., 1988. Marine Fish Calendar-Calicut. *Mar. Fish. Infor. Serv. Tech. and Ext. Ser.*, 81: 9.
- Kuriakose, S., Mini, K. G., Srinivasan, J., Ammini, P. L., Seynudeen, M. B., George, K. P. and Sindhu A. K., 2012. Marine fisheries of the south-west coast of India during 2009-2010. *Mar. Fish. Infor. Serv.; Tech. and Ext. Ser.*, 214: 4-6.
- Kuriakose, S., Srinivasan, J., Ammini, P. L., Haja Najeemudeen, S., George, K. P., Beena, M. R., Seynudeen, M. B., Subbaraman, G. and Sindhu A. K., 2010. Marine fisheries of the south-west coast of India during 2008. *Mar. Fish. Infor. Serv.; Tech. and Ext. Ser.*, 205: 3-5.
- Kuthalingam, M. D. K., 1960. Observations on the life history and feeding habits of the Indian sardine *Sardinella longiceps* (Cuv. & Val.), *Treubia*, 25: 202.
- Kuthalingam, M. D. K., 1956. Observations on the food and feeding habits of the Indian mackerel *Rastrelliger kanagurta*. *Zool. Soc. India*, 8: 99-106.
- Kutty, M. N. 1962. Observations on the Indian mackerel, *Rastrelliger canagurta* (Cuvier) from the trawl catches along the Bombay coast. *Indian J. Fish.*, 9A (2): 590-603.
- Lam, T. J., 1983. Environmental influences on gonadal activity in fish. In *Fish Physiology Vol. IX (B) Reproduction* (ed: Hoar W. S., Randall D. J. and Donaldson E. M.), Academic Press, pp. 65-116.
- Lasker, R., 1975. Field criteria for survival of anchovy larvae: the relationship between inshore chlorophyll maximum layers and successful first feeding. *U.S. Fisheries Bulletin*, 73: 453-462.
- Lasker, R., 1981. The role of a stable ocean in larval fish survival and subsequent recruitment. *In: Marine fish larvae* (eds. Lasker, R.). Seattle: University of Washington Press, pp. 80-85.
- Le Quéré, C., Raupach, M. R., Canadell, J. G., Marland, G., Bopp, L., Ciais, P., Conway, T. J., Doney, S. C., Feely, R. A., Foster, P., Friedlingstein, P., Gurney, K., Houghton, R. A., House, J. I., Huntingford, C., Levy, P. E., Lomas,

- M. R., Majkut, J., Metz, N., Ometto, J. P., Peters, G. P., Prentice, I. C., Randerson, J. T., Running, S. W., Sarmiento, J. L., Schuster, U., Sitch, S., Takahashi, T., Viovy, N., van der Werf, G. R. and Woodward, F. I., 2009. Trends in the sources and sinks of carbon dioxide. *Nat. Geosci.*, 2: 831-836.
- Lehodey, P., Alheit, J., Barange, M., Baumgartner, T., Beaugrand, G., Drinkwater, K., Fromentin, J. -M., Hare, S. R., Ottersen, G., Perry, R. I., Roy, C. and van der Lingen, C. D., 2006. Climate Variability, Fish, and Fisheries. *J. Climate*, 19: 5009-3030.
- Levitus, S., Antonov, J. I., Boyer, T. P., Locarnini, R. A., Garcia, H. E. and Mishonov A. V., 2009. Global ocean heat content 1955–2008 in light of recently revealed instrumentation problems. *Geophys. Res. Lett.*, 36: L07608, doi:10.1029/2008GL037155.
- Lewandowska, A. M., Boyce, D. G., Hofmann, M., Matthiessen, B., Sommer, U. and Worm, B. 2014. Effects of sea surface warming on marine plankton, *Ecol. Lett.*, 7: 614-623.
- Li, J. and Clarke, A. J., 2007. Interannual Sea Level Variations in the South Pacific from 5° to 28°S. *J. Phys. Oceanogr.*, 37: 2882-2894.
- Liang, C., Xian, W. and Pauly, D., 2018. Impacts of Ocean Warming on China's Fisheries Catches: An Application of “Mean Temperature of the Catch” Concept. *Front. Mar. Sci.*, doi.org/10.3389/fmars.2018.00026.
- Lima, F. P. and Wethey, D. S., 2012. Three decades of high-resolution coastal sea surface temperatures reveal more than warming. *Nature Commun.*, 3: 704, DOI: 10.1038/ncomms1713.
- Lluch-Belda, D., Crawford, R. J. M., Kawasaki, T., MacCall, A. D., Parrish, R. H., Schwartzlose, R. A. and Smith, P. E., 1989. World-wide fluctuations of sardine and anchovy stocks: the regime problem *S. Afr. J. Mar. Sci.*, 8: 195-205.
- Loarie, S. R., Duffy, P. B., Hamilton, H., Asner, G. P., Field, C. B., Ackerly, D. D., 2009. The velocity of climate change. *Nature*, 462: 1052-1055. doi:10.1038/nature08649.
- Longhurst, A. R. and Pauly, D., 1987. Ecology of tropical ocean. Academic press, San Diego. pp. 407.
- Longhurst A. R. and Wooster W. S., 1990. Abundance of oil sardine (*Sardinella longiceps*) and upwelling on the south west coast of India. *Can. J. Fish. Aquat. Sci.*, 47: 2407- 2419.
- Lumban-Gaol, J., Leben, R. R., Vignudelli, S., Mahapatra, K., Okada, Y., Nababan, B., Mei-Ling, M., Amri, K., Arhatin, R. E. and Syahdan, M., 2015. Variability of satellite-derived sea surface height anomaly, and its relationship with Bigeye tuna (*Thunnus obesus*) catch in the Eastern Indian Ocean. *Eur. J. Remote. Sens.*, 48: 465-477.
- Luther, G., Rao, K. V. N., Gopakumar, G., Muthiah, C., Pillai, N. G., Rohit, P., Kurup, K. N., Reuben, S., Devadoss, P., Rao, G. S., Bennet, P. S. and Radhakrishnan

- N. S., 1992. Resource characteristics and stock assessment of whitebaits. *Indian J. Fish.*, 39 (3-4): 152-168.
- Luther, G., 1979. Anchovy fishery of southwest coast of India with Notes on characteristics of the resources. *Indian J. Fish.*, 26 (1&2): 23-36.
- Luther, G., 1972. Whitebait resources of the south-west coast of India. Symposium on Pelagic Fishery Resources of the Seas around India, 11-13.
- Luther, G., 1990. Biology of whitebait anchovies of Indian waters. *In: Tuna baitfish in the Indo-Pacific region* (eds. Blaber, S. J. M. and Copland, J. E.), pp. 75-82.
- Luther, G., 1995. Fishery and resource characteristics of mackerel of Visakhapatnam coast. *Mar. Fish. Infor. Serv. Tech and Ext. Ser.*, 138: 1-5.
- Madhupratap, M., Haridas, P., Ramiah, N. and Achuthankutty C., 1992. *In: Oceanography of the Indian Ocean* (eds. Desai, B.N.), Oxford and IBH, New Delhi. pp. 99-212.
- Madhupratap, M., Shetye, S. R., Nair, K. N. V. and Nair, S. R. S., 1994. Oil sardine and Indian mackerel: their fishery, problems and coastal oceanography. *Curr. Sci. India*, 66(5): 340-348.
- Mahesh Kumar, U., Swain, D., Sasamal, S. K., Reddy, N. N. and Ramanjappa, T., 2015. Validation of SARAL/AltiKa significant wave height and wind speed observations over the North Indian Ocean. *J. Atmos. Sol-Terr. Phys.*, 135: 174-180.
- Manjusha, U., Jayasankar, J., Remya, R., Ambrose, T. V. and Vivekanandan, E., 2013. Influence of coastal upwelling on the fishery of small pelagic off Kerala, south-west coast of India. *Indian J. Fish.*, 60(2): 37-42.
- Marra, J. and Barber, R. T., 2005. Primary productivity in the Arabian Sea: A synthesis of JGOFS data. *Prog. Oceanogr.*, 65(2-4): 159-175.
- Martin, R.E., 1995. Cyclic and secular variation in microfossil biomineralization-clues to the biogeochemical evolution of the Phanerozoic oceans. *Glob. Planet. Change* 11: 1-23.
- Martino, J. C., Fowler, A. J., Doubleday, Z. A., Grammer, G. L. and Gillanders, B. M., 2019. Using otolith chronologies to understand long-term trends and extrinsic drivers of growth in fisheries. *Ecosphere*, 10(1): e02553. 10.1002/ecs2.2553.
- Menon, M. D. and George K. C. 1975. White-bait resources of the southwest coast of India. *Seafood export J.*, 7(1): 1-14.
- Menon, N. N., Sankar, S., Smitha, A., George, G., Shalin, S., Sathyendranath, S. and Platt, T., 2019. Satellite chlorophyll concentration as an aid to understanding the dynamics of Indian oil sardine in the southeastern Arabian. *Sea. Mar. Ecol. Prog. Ser.*, 617-618: 137-147.
- Miller, A. J., Song, H. and Subramanian, A. C., 2015. The physical oceanographic environment during the CCE-LTER Years: Changes in climate and concepts. *Deep-Sea Res.-II*, 112: 6-17.

- Mimura N., 2013. Sea-level rise caused by climate change and its implications for society. *Proc. Jpn. Acad. Ser. B. Phys. Biol. Sci.*, 89(7): 281-301.
- Mishra, A. K. and Rafiq, M., 2019. Rainfall estimation techniques over India and adjoining oceanic regions. *Curr. Sci. India*, 116 (1): 56-68.
- Mishra, A. K., Nagaraju, V., Rafiq, M. and Chandra, S., 2018. Evidence of links between regional climate change and precipitation extremes over India. *Weather*, <https://doi.org/10.1002/wea.3259>.
- Mukhopadhyay, A., Giri, S., Hazra, S., Das, S. and Chanda, A., 2019. Influence of Oceanographic Variability on the Life Cycle and Spawning Period of *Sardinella fimbriata* in the Northern Part of Bay of Bengal. *Proc Zool Soc.*, <https://doi.org/10.1007/s12595-019-00314-5>.
- Muni Krishna, K., 2016. Observational study of upper ocean cooling due to Phet super cyclone in the Arabian Sea. *Adv. Space Res.*, 57(10): 2016: 2115-2120.
- Murty, A. V. S., 1974. The wind drifts off the west coast of India and their influence on the oil sardine fishery. *J. Mar. Biol. Assoc. India.*, 16(2): 520-522.
- Murty, A. V. S. and Edelman M. S., 1970. On the relation between the intensity of the south west monsoon and the oil sardine fishery of India. *Indian. J. Fish.*, 13(1&2): 142-49.
- Nair, P. G., 2015. Studies on major small pelagic fishes along the kerala coast with respect to the potential fishery zone (pfz) advisories. Doctor of Philosophy in Biosciences, Mangalore University. pp183.
- Nair, P. G., Joseph, S., Kripa, V., Remya, R. and Pillai, V. N., 2016. Growth and maturity of Indian oil sardine *Sardinella longiceps* (Valenciennes, 1847) along southwest coast of India. *J. Mar. Biol. Ass. India*, 58 (1): 64-68.
- Nair, P. G., Joseph, S. and Pillai, V. N., 2015. Length-weight relationship and relative condition factor of *Stolephorus commersonii* (Lacepede, 1803) exploited along Kerala coast. *J. Mar. Biol. Ass. India*, 57 (2): doi: 10.6024/jmbai.2015.57.2.01856-04.
- Nair, R. V. and Chidambaram, K., 1951. A review of the Indian oil sardine fishery. *Proc. Nat. Instit. Sci India.*, 17(1):71-85.
- Nair, R. V. and Subrahmanyam, R. V., 1955. The diatom, *Fragilaria oceanica* Cleve, an indicator of abundance of the Indian oil sardine *Sardinella longiceps* Cuv. & Val. *Curr. Sci. India*, 24(2): 41-42.
- Nair, R. V., 1959. Notes on the spawning habits and early life history of the oil sardine, *Sardinella longiceps* (Cuv. & Val.) *Indian J. Fish.*, 6(6): 342-359
- Nair, R. V., 1953. Studies on the revival of the Indian oil sardine fishery. *Proc. Indo-Pac. Fish. Coun.*, 115-129.
- Nair, R. V., 1958. The sardines. In: Fisheries of the west coast of India (ed. Jones. S.), CMFRI, Kochi, pp. 31-37.

- Nair, R. V., 1960. Synopsis on the biology and fishery of the Indian sardines. Species synopsis No. 11, FAO Fisheries Biology Synopsis No. 16 (2): 329-414.
- Nath, S. R., Beraki, T., Abraha, A., Abraham, K. and Berhane Y., 2015. Gut Content Analysis of Indian Mackerel (*Rastrelliger kanagurta*). *J. Aquac. Mar. Biol.*, 3(10): 00052. DOI: 10.15406/jamb.2015.03.00052.
- Nath, P., Sahu, R., Kabita, Sk. and Bhattacharya, D., 2007. Vitellogenesis with special emphasis on Indian fishes. *Fish Physiol Biochem.*, 33: 359-366.
- Navalgund, R. R., Jayaraman, V. and Roy, P. S., 2007. Remote sensing applications: An overview. *Curr. Sci. India*, 93 (12): 1747-1766.
- Ningsih, N. S., Hadi S., Utami, M. D., Rudiawan, A. P., 2011. Modelling of storm tide flooding along the southern coast of java, Indonesia. *Adv. Geosci.*, 24, 87-103.
- Noble, A., 1974. Fishery and Biology of The Mackerel, *Rastrelliger Kanagurta* (Cuvier) At Cochin. *J. mar. biol Ass. India*, 16 (3): 816-819.
- Noble, A., 1962. Food and feeding habits of the Indian mackerel, *Rastrelliger kanagurta* (Cuvier) at Karwar. *Indian J. Fish.*, 9A (2): 701-713.
- Noble, A. and Geetha, P., 1992. The Indian mackerel *Rastrelliger kanagurta* (Cuvier) an annotated bibliography. *CMFRI spl. Publ.*, No. 52, pp.126.
- NOAA Physical Sciences Laboratory, 2018. [https://psl.noaa.gov/gcos\\_wgsp/Timeseries/Data/dmi.had.long.data](https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/dmi.had.long.data).
- Nwankwoala, H. N. L, 2015. Causes of Climate and Environmental Changes: The need for Environmental-Friendly Education Policy in Nigeria. *J. Educat. Pract.*, 6 (30): 224-234.
- Ober, G. T., Thornber, C., Grear, J. and Kolbe, J. J., 2016. Ecological differences influence the thermal sensitivity of swimming performance in two cooccurring mysid shrimp species with climate change implications. *J. Ther. Bio.*, <http://dx.doi.org/10.1016/j.jtherbio.2016.11.012>.
- Ocean Color Climate Change Initiative (OC-CCI), 2017. [ftp://oc-cci-data:ELaiWai8ae@oceancolour.org/occci-4.2/geographic/netcdf/monthly/chlor\\_a/](ftp://oc-cci-data:ELaiWai8ae@oceancolour.org/occci-4.2/geographic/netcdf/monthly/chlor_a/)
- Pörtner, H. O. and Peck, M. A., 2010. Climate change effects on fishes and fisheries: towards a cause-and-effect understanding. *J. Fish Biol.*, 77: 1745-1779.
- Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., Dasgupta, P., Dubash, N. K., Edenhofer, O., Elgizouli, I., Field, C. B., Forster, P., Friedlingstein, P., Fuglestedt, J., Gomez-Echeverri, L., Hallegatte, S., Hegerl, G., Howden, M., Jiang, K., Jimenez Cisneroz, B., Kattsov, V., Lee, H., Mach, K. J., Marotzke, J., Mastrandrea, M. D., Meyer, L., Minx, J., Mulugetta, Y., O'Brien, K., Oppenheimer, M., Pereira, J. J., Pichs-Madruga, R., Plattner, G. -K., Pörtner, H. -O., Power, S. B., Preston, B., Ravindranath, N. H., Reisinger, A., Riahi, K., Rusticucci, M., Scholes, R., Seyboth, K., Sokona, Y., Stavins, R., Stocker, T. F., Tschakert, P., van Vuuren, D., van Ypserle, J. P., 2014. Climate Change

- 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.
- Pal, I. and Al-Tabbaa, A., 2009. Trends in seasonal precipitation extremes - An indicator of 'climate change' in Kerala, India. *J. Hydrol.*, 367 (1-2): 62-69.
- Palipane, E., Lu, J., Staten, P., Chen, G. and Schneider, E. K., 2017. Investigating the zonal wind response to SST warming using transient ensemble AGCM experiments. *Clim. Dynam.*, 48 (1-2): 523-540.
- Panikkar, N. K., 1952. Fisheries research in India. Part 1. *J. Bombay Nat. Hist. Soc.*, 50(4): 764-765.
- Panikkar, N. K., 1949. *Survey of the pelagic fisheries of the world Part II: The Biology of Pelagic Fishes. Proc. Indo Pacific Fish. Council*, 2: 123-132.
- Pankhurst, N. W. and Munday, P. L., 2011. Effects of climate change on fish reproduction and early life history stages. *Mar. Freshwater Res.*, 62, 1015-1026.
- Pante, E. and Simon-Bouhet, B., 2013. marmap: A Package for Importing, Plotting and Analyzing Bathymetric and Topographic Data in R. *PLoS ONE*, 8(9): e73051. <https://doi.org/10.1371/journal.pone.0073051>
- Parnesan, C. and Yohe, G., 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, 421(6918): 37-42.
- Parnesan, C., 2006. Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst.*, 37: 637-669.
- Parthasarathy, A., Srinivasan, S., Appleby, A. J. and Martin, C. R., 1992. Temperature-dependence of the electrode-kinetics of oxygen reduction at the platinum Nafion(R) interface - a microelectrode investigation. *J. Electrochem. Soc.*, 139 (9): 2530-2537.
- Patadiya, D. S., Jawahar, P., Jayakumar, N. and Pereira, J. J., 2018. Length: weight relationship and relative condition factor of Indian anchovy *Stolephorus indicus* (van Hasselt, 1823) from Thoothukudi coastal waters. *J. Entomol. Zool. Stud.*, 6(2): 279-282.
- Pawase, S. V., Nirmale, V. H., Pawar, R. A., Sawant, M. S., Metar, S. Y. and Bhosale, B. P., 2018. Study on Growth and Mortality of *Thryssa dussumieri* (Valenciennes, 1848) along the Coast of Ratnagiri. *Adv. Agr. Res. Technol. J.*, 2(1): 48-52.
- PBL, 2009. News in climate science and exploring boundaries: A policy brief on developments since the IPCC AR4 report in 2007. Netherlands Environmental Assessment Agency (PBL), Bilthoven/The Hague.
- Perrette, M., Yool, A., Quartly, G. D. and Popova, E. E., 2011. Near-ubiquity of ice-edge blooms in the Arctic. *Biogeosciences*, 8: 515-524.

- Perry, A. L., Low, P. J., Ellis, J. R. and Reynolds, J. D., 2005. Climate change and distribution shifts in marine fishes. *Science*, 308 (5730): 1912-1915.
- Peter, R. E. and Yu, K. L., 1997. Neuroendocrine regulation of ovulation in fishes: basic and applied aspects. *Rev. Fish Biol. Fish.*, 7: 173-197.
- Pettitt A. N., 1979. A non-parametric approach to the change point problem, *J. Royal Statist. Soc.*, 28: 126-135.
- Pillai N. G. K., 2011. Handbook of fisheries and aquaculture, Indian Council of Agricultural Research, New Delhi, pp. 1116.
- Pillai V. N. 1991. Salinity and thermal characteristics of the coastal waters off southwest coast of India and their relation to major pelagic fisheries of the region. *J. mar. biol. Ass. India*, 1991, 33 (1 & 2): 115-133.
- Piontkovski, S. A. and Al-Jufaili, S., 2013. Coastal upwellings and Mesoscale Eddies of the Western Arabian Sea: Some Biological Implications. *Int. J. Oceans Oceanogr.*, 7(2): 93-115.
- Pitcher, T. J. and Cheung, W. W. L., 2013. Fisheries: Hope or despair? *Mar. Pollut. Bull.*, 74: 506-516.
- Pohlert, T. 2018. Non-Parametric Trend Tests and Change-Point Detection. pp.18.
- Poloczanska, E. S., Brown, C. J., Sydeman, W. J., Kiessling, W., Schoeman, D. S., Moore, P. J., Brander, K., Bruno, J. F., Buckley, L. B., Burrows, M. T., Duarte, C. M., Halpern, B. S., Holding, J., Kappel, C. V., O'Connor, M. I., Pandolfi, J. M., Parmesan, C., Schwing, F., Thompson, S. A. and Richardson, A. J., 2013. Global imprint of climate change on marine life. *Nat. Clim. Change*, 3: 919-925.
- Pörtner, H. -O. and Knust, R., 2007. Climate Change Affects Marine Fishes Through the Oxygen Limitation of Thermal Tolerance. *Science*, 315(5808): 95-97.
- Pörtner, H. -O. and Farrell, A. P. 2008. Ecology physiology and climate change. *Science*, 322(5902): 690-692.
- Potts, J. C. and Manooch, C. S., 2001. Differences in the age and growth of white grunt from North Carolina and South Carolina versus southern Florida. *Bull. Mar. Sci.*, 68:1-12.
- Pour, M. S., Malekian, N., Khayatizadeh, J. and Kamali I., 2014. Reproductive cycle of the female Indian mackerel, *Rastrelliger kanagurta* in the northern Persian Gulf and Oman Sea (Histological and Biometrical studies). *SG. Res.*, 5 (4): 150-157.
- Prabhu, M. S. and Dhulkhed, M. H., 1967. On the occurrence of small-sized oil sardine, *Sardinella longiceps* Val. *Curr. Sci. India*, 36 (15): 410-411.
- Pradhan, L. B., 1956. Mackerel fishery of Karwar. *Indian J. Fish.*, 1956; 3(1): 141-85.
- Pradhan, L. B. and Reddy C. V. G., 1962. Fluctuations in the mackerel landings at Calicut in relation to hydrographical factors. *Indian J. Fish.*, 9(I)A: 100-109.

- Prasanna Kumar, S., Raj, P., Roshin, R., P., Narvekar, J., Dinesh Kumar, P.K. and Vivekanandan, E., 2009. Response of the Arabian Sea to global warming and associated regional climate shift. *Mar. Environ. Res.*, 68: 217-222.
- Purcell, J. E., Uye, S. and Lo W. -T., 2007. Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. *Mar. Ecol. Prog. Ser.*, 350: 153-174.
- Purcell, J. E., 2012. Jellyfish and ctenophore blooms coincide with human proliferations and environmental perturbations. *Annu. Rev. Mar. Sci.*, 4: 209-235.
- Purcell, J. E. and Arai, M. N., 2001. Interactions of pelagic cnidarians and ctenophores with fishes: a review. *Hydrobiologia*, 451: 27-44.
- Qasim, S. Z., 1973. An appraisal of the studies on maturation and spawning in marine teleosts from the Indian waters. *Indian J. Fish.*, 20: 166-181.
- R. Core Team, 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <http://www.R-project.org>.
- Rabindranath, P., 1966. Biology and Seasonal Distribution of the, Pelagic Food Fishes of Trivandnim Coast. Kerala Univ. Publ., pp. 1-14.
- Radhakrishnan, N., 1962. Observations on the maturity and spawning of Indian mackerel, *Rastrelliger canagurta* (Cuvier) at Karwar. *Indian J. Fish.*, 9A (2): 512-524.
- Radhakrishnan, N., 1965. Oil sardine investigation at Karwar. *Indian J. Fish.*, 12A (1): 99-117.
- Radhakrishnan, N., 1964. *Age and rate of growth of the Indian mackerel, Rastrelliger canagurta (Cuvier) with notes on its fishery at Karwar. Indian J. Fisheries*, 11A (1): 187-216.
- Rajagopalan, M. S., Thomas, P. A., Mathew, K. J., Selvaraj, G. S. D., Rani Mary, G., Mathew, C. V., Naomi, T. S., Kaladharan, P., Balachandran, V. K. and Geetha, A. 1992. Productivity of the Arabian Sea along the southwest coast of India. *CMFRI Bulletin*, 45: 9-37.
- Ramamirtham, C. P. and Patil, M. R. 1964. Hydrography of the west coast of India during the pre-monsoon period of the year 1962-Part 2: In and offshore waters of the Konkan and Malabar coasts. *J. mar. biol. Ass. India*, 7: 150-168.
- Ramamirtham, C. P. and Rao, D. S., 1973. On upwelling along the west coast of India. *J. Mar. Biol. Ass. India*, 15 (1): 306-317.
- Ramesh, N., James, R. A. and Oremus, K. L., 2019. The small world of global marine fisheries: the cross-boundary consequences of larval dispersal. *Science*, 364 (6446): 1192-1196.

- Rao, A. S., Behera, S. K., Masumoto, Y. and Yamagata, T., 2002. Interannual variability in the subsurface tropical Indian Ocean. *Deep-Sea Res. II*, 49: 1549-1572.
- Rao, K. V. N. and Rao, K. P., 1957. Differences in the food of the young and the adult Indian mackerel, *Rastrelliger kanagurta* (Cuv.). *Nature*, 180. 711-712.
- Rao, K. V. N., 1962. Observations on the bionomics of the Indian mackerel, *Rastrelliger kanagurta* (C.) caught in the Lawson's bay, near Waltair, Andhra Coast. *Proc. Symp. Scombroid Fishes.*, 2: 574-585
- Rao, R. B., 2013. Mini purseseine operation recorded for oil sardine catch at Jiwna and Bharadhkhol-Divegar landing centres in Raigad region of Maharashtra. *Mar. Fish. Infor. Ser. Tech. Ext. Ser.*, 216: 4-5.
- Rao, G. S., 1988a. Biology of *Stolephorus devisi* (Whitley) from Mangalore area, Dakshina Kannada. *J. Mar. Biol. Ass. India*, 30 (1&2): 28-37.
- Rao, G. S., 1988b. Some aspects of biology of *Stolephorus bataviensis* (Hardenberg) from Mangalore area, Dakshina Kannada. *J. Mar. Biol. Ass. India*, 30 (1&2): 107-113.
- Rao, G. S., 2011. Climate Change and Marine Fisheries Management. In: Climate Change-Impact on Environment and human health Proceedings of National Seminar. Gayatri Vidya Parishad Degree College, Visakhapatnam, pp. 3-15.
- Rao, K. V. N., 1962. Food of the Indian mackerel, *Rastrelliger kanagurta* (Cuvier) taken by drift-nets in the Arabian sea off Vizhingam, South Kerala. *Indian J. Fish.*, 9A (2): 530-541.
- Rao, K. V. N., 1964. Proc. Symp. Scombroid Fish. *Mar. biol. Ass. India*, 1: 469-482.
- Rao, K. V. N., 1965. Food of the Indian mackerel *Rastrelliger kanagurta* (Cuvier) taken by drift nets in the Arabian sea off Vizhinjam, south Kerala. *Indian J. Fish.*, 9 (2) A: 530-541.
- Rao, V. R., 1967. Spawning behaviour and fecundity of the indian mackerel, *Rastrelliger kanagurta* (Cuvier), at Mangalore. *Indian J. Fish.*, 14 (1&2):171-186.
- Rashmi, R., Polnikov, V., Pogarskii, F., Gomorev, I., Samiksha, V. and Vethamony, P., 2016. Long-Term Variability of the Wind Field over the Indian Ocean Based on ERA-Interim Reanalysis. *Atmos. Ocean*, 54 (5): 505-518.
- Rasmusson, E. M. and Wallace, J. M., 1983. Meteorological Aspects of the El Niño/Southern Oscillation. *Science*, 222(4629): 1195-1202.
- Raybaud, V., Bacha, M., Amara, R. and Beaugrand, G., 2017. Forecasting climate-driven changes in the geographical range of the European anchovy (*Engraulis encrasicolus*). *ICES J. Mar. Sci.*, 74 (5): 1288-1299.
- Reid, P. C., Edward S. M., Hunt H. G. and *et al.*, 1998. Phytoplankton change in the North Atlantic. *Nature*, 391: 546.

- Richardson, A. J. and Schoeman, D. S., 2004. Climate Impact on Planktonb Ecosystems in the Northeast Atlantic. *Science*, 305: 1609-1612.
- Richardson, A. J., Bakun, A., Hays, G. C. and Gibbons, M. J., 2009. The jellyfish joyride: causes, consequences and management responses to a more gelatinous future. *Trends Eco. Evol.*, 24 (6): 312-322.
- Riebesell, U., Zondervan, I., Rost, B., Tortell, P.D., Zeebe, R. E. and Morel, F. M. M., 2000. Reduced calcification in marine plankton in response to increased atmospheric CO<sub>2</sub>. *Nature*, 407: 634-637.
- Roemmich, D., Gilson, J., Davis, R., Sutton, P., Wijffels S. and Riser, S., 2007. Decadal spin-up of the South Pacific subtropical gyre. *J. Phys. Oceanogr* 37(2): 162-173.
- Rohit, P. and Gupta, A. C., 2008. Whitebait fishery of Mangalore - Malpe, Karnataka during 1997-2002. *Indian J. Fish.*, 55(3): 211-214.
- Rohit, P. and Gupta. C. A., 2004. Fishery, biology and stock of the Indian mackerel *Rastrelliger kanagurta* off Mangalore-Malpe in Karnataka, India. *J. Mar. Biol. Ass. India*, 46(2): 185-191.
- Rohit, P. and S.U. Bhat. 2003. Sardine fishery with notes on the biology and stock assessment of oil sardine off Mangalore-Malpe. *J. Mar. Biol. Ass. India*, 45 (1): 63-71.
- Roul, S. K., Rethesh, T. B., Prakasan, D., Abdussamad, E. M. and Rohit, P., 2017. Length-weight relationship of *Thryssa malabarica* (Bloch, 1795) and *Thryssa dayi* Wongratana, 1983 from Kerala, southwest coast of India. *J. Appl. Ichthyol.*, 1-2. DOI: 10.1111/jai.13441.
- Ruckstuhl, A. F., Jacobson, M. P., Field R. W. and Dodd, J. A., 2001. Baseline subtraction using robust local regression estimation. *J. Quant. Spectrosc. Ra.*, 68: 179-193.
- Rykaczewski, R. R. and Checkley, D. M. Jr., 2008. Influence of ocean winds on the pelagic ecosystem in upwelling regions. *Proc Natl Acad Sci USA*, 105(6):1965-1970.
- Ryther J. H., 1969. Photosynthesis and Fish Production in the Sea. *Science*, 166 (3901): 72-76.
- Sahadevan, P. 2017. On the reported inverse relationship of oil sardine (*Sardinella longiceps*) and mackerel (*Rastrelliger kanagurta*) landings in India. *Int. J. Fish. Aquatic Stud.*, 5(1): 397-402.
- Saji, N. H. and Yamagata, T., 2003. Possible impacts of Indian Ocean Dipole mode events on global climate. *Clim. Res.*, 25: 151-169.
- Sajna, V. H., Zacharia, P. U., Liya, V. B., Rojith, G., Somy, K., Joseph, D. and George, G., 2019. Effect of Climatic Variability on the Fishery of Indian Oil Sardine along Kerala Coast. *J. Coastal Res.*, 86: 184-192.

- Sathaye, J., Shukla, P. R. and Ravindranath, N. H., 2006. Climate change, sustainable development and India: Global and national concerns, *Curr. Sci. India*, 90(3), 314-325.
- Sathyendranath, S., Groom, S., Grant, M., Brewin, R. J. W., Thompson, A., Chuprin, A., Horseman, A., Jackson, T., Martinez Vicente, V., Platt, T. and *et al.*, 2016. ESA Ocean Colour Climate Change Initiative (Ocean\_Colour\_cci): Version 2.0 Data, Centre for Environmental Data Analysis, 2016, doi:10.5285/b0d6b9c5-14ba-499f-87c9-66416cd9a1dc.
- Schneider, N., Di Lorenzo, E. and Niiler, P., 2005. Salinity variations in the Southern California current. *J. Phys. Oceanogr.*, 35: 1421-1436.
- Sekharan, K. V. and Dhulkhed, M. H., 1963. On the oil sardine fishery of the Mangalore zone during the years 1957-1963. *Indian J. Fisheries*, 10A (2): 601-626.
- Sekharan, K. V., 1958. On the South Kanara coastal fishery for mackerel, *Rastrelliger kanagurta* (Cuvier) together with notes on the biology of the fish. *Indian J. Fish.*, 5(1): 31-35.
- Sekharan, K. V., 1965. On the oil sardine fishery of the Calicut area during the years 1955-56 to 1958-59. *Indian J. Fish.*, 9A (2): 679-700.
- Seneviratne, S. I., Donat, M. G., Pitman, A. J. and *et al.*, 2016. Allowable CO<sub>2</sub> emissions based on regional and impact-related climate targets. *Nature*, 529 (7587): 477-483.
- Shah, P., Sajeev, R., Thara, K. J., George, G., Shafeeque, M., Akash, S. and Platt, T., 2019. A Holistic Approach to Upwelling and Downwelling along the SouthWest Coast of India. *Mar. Geod.*, 42:1, 64-84.
- Shah, P., Sajeev, R. and Gopika, N., 2015. Study of Upwelling along the West Coast of India - A Climatological Approach. *J. Coastal Res.*, 31(5): 1151-1158.
- Shah, R. and Srivastava, R., 2019. Effect of climate change on cloud properties over Arabian Sea and Central India. *Pure App. Geophys.*, 176: 2729-2738.
- Silas, E. G., 1974. Larvae of the Indian mackerel, *Rastrelliger kanagurta* (Cuvier) from the west coast of India. *Indian J. Fish.*, 21 (1): 233-253.
- Silva, C., Yáñez E., Barbieri M. A., Bernal C. and Aranís A., 2015. Forecasts of swordfish (*Xiphias gladius*) and common sardine (*Strangomera bentincki*) off Chile under the A2 IPCC climate change scenario. *Prog. Oceanogr.*, 134: 343-355.
- Sims, D. W., Wearmouth, V. J., Genner, M. J., Southward, A. J. and Hawkins, S. J., 2004. Low-temperature-driven early spawning migration of a temperate marine fish. *J. Anim. Ecol.*, 73: 333-341.
- Siriskar, D. A., Khedkar, G. D. and Lior, D., 2013. Production of salted and pressed anchovies (*stolephorus* sp.) and its quality evaluation during storage. *J. Food Sci. Technol.* 50(6): 1172-1178.

- Sivadas, M. P., Nair, R., Balasubramanian, K. K. and Bhaskaran M. M. 2006. Length weight relationship, relative condition, size at first maturity and sex ratio of Indian mackerel *Rastrelliger kanagurta* from Calicut. *J. Mar. Biol. Ass. India*, 48 (2): 274- 277.
- Sivadas, M. and Bhaskaran, M. M., 2009. A note on the stomach content analysis of the Indian mackerel *Rastrelliger kanagurta* (Cuvier) from Calicut, Kerala. *Indian J. Fish.*, 56(2): 143-146.
- Smith, S. L. and Madhupratap M., 2005. Mesozooplankton of the Arabian Sea: Patterns influenced by seasons, upwelling, and oxygen concentrations. *Prog. Oceanogr.* 65(2-4): 214-239.
- Smitha, A., Joseph, K. A., Jayaram, C. and Balachand, A. N., 2014. Upwelling in the southeastern Arabian Sea as evidenced by Ekman Mass transport using wind observation from OCEANSAT-II Scatterometer. *Indian J. Geo-Mar. Sci.*, 43: 111-116.
- Smitha, B. R., Sanjeevan, V. N., Vimalkumar, K. G. and Revichandran, C., 2008. On the upwelling off the southern tip and along the west coast of India. *J. Coastal Res.*, 24 (4C): 95-102.
- Somero, G. N., 2012. The physiology of global change: linking patterns to mechanisms. *Ann. Rev. Mar. Sci.* 4: 39-61.
- Sparre, P. and Venema, S. C., 1992. Introduction to tropical fish stock assessment. Food and agriculture organization of the United Nations, Rome, 306/1 pp. 376.
- Srinath, M., 1998. Exploratory analysis on the predicability of oil sardine landings in Kerala. *Indian J. Fish.*, 45(4): 363-374.
- Srinath, M., Kuriakose, S., Mini, K. G., Beena, M. R. and Sindhu, A. K., 2003. Trends in Landings. *In: Status of Exploited Marine Fishery Resources of India* (eds. Joseph M. M. and Jayaprakash A. A.). pp 255.
- Srinath, M., Kuriakose, S. and Mini K. G., 2005. Methodology for the Estimation of Marine Fish Landings in India, *CMFRI Special Publication*, 86: pp. 57.
- Stamatopoulos, C. and Abdallah, M., 2015. Standardization of Fishing Effort in Qatar Fisheries: Methodology and Case Studies. *J. Marine Sci. Res. Dev.*, 5(3): DOI; 10.4172/2155-9910.1000170.
- Stouffer, J. Y., Yin, J., Gregory, J. M., Dixon, K. W., Spelman, M. J., Hurlin, W., Weaver, A. J., Eby, M., Flato, G. M., Hasumi, H., Hu, A., Jungclaus, J. H., Kamenkovich, I. V., Levermann, A., Montoya, M., Murakami, S., Nawrath, S., Oka, A., Peltier, W. R., Robitaille, D. Y., Sokolov, A., Vettoretti, G. and Weber, S. L., 2006. Investigating the causes of the response of the thermohaline circulation to past and future climate changes. *J. Clim.*, 19: 1365-1387.
- Sudarsan, D., Sivaprakasam, T. E., Somvanshi, V. S., John, M. E., Nair, K. N. V. and Joseph, A. 1988. An appraisal of the marine fishery resources of the Indian Exclusive Economic Zone. *FSI Bulletin*, 18: pp. 85.

- Sumaila, U. R., Cheung, W. W. L., Lam, V. W. Y., Pauly, D. and Herrick, S., 2011. Climate change impacts on the biophysics and economics of world fisheries. *Nat. Clim. Change*, 1: 449-456.
- Sundararaj, B. I., 1981. Reproductive physiology of teleost fishes: a review of present knowledge and needs for further research. Aquaculture development and co-ordination Programme, FAO, U.N., ADCP/REP/16, Rome, pp. 1-82.
- Sunday, J. M., Pecl, G. T., Frusher, S., Hobday, A. J., Hill, N., Holbrook, N. J., Edgar, G. J., Stuart-Smith, R., Barrett, N., Wernberg, T. and et al., 2015. Species traits and climate velocity explain geographic range shifts in an ocean-warming hotspot. *Ecol. Lett.*, 18: 944-953.
- Supraba, V., Dineshbabu, A. P., Thomas, S., Rohit, P., Rajesh, K. M. and Zacharia P. U., 2016. Shift in diet composition of Indian mackerel *Rastrelliger kanagurta* - an analysis in relation to climate change. *Indian J. Fish.*, 63(2): 42-46.
- Supraba, V., Dineshbabu, A. P., Thomas, S., Rohit, P. and Rajesh, K. M., 2013. An instance of unusual feeding habit of the Indian Mackerel, *Rastrelliger kanagurta* from the Mangalore Fishing Harbour. *Mar. Fish. Infor. Serv., Tech. Ext. Ser.*, 218: 21.
- Suzuki, T. and Ishii, M., 2011. Long-term regional sea level changes due to variations in water mass density during the period 1981–2007. *Geophys. Res. Lett.*, 38, L21604, doi:10.1029/2011GL049326.
- Timm, O., Timmermann, A. and DeCarlo S.H., 2009. User-friendly data portal provides access to a transient paleoclimate simulation covering the last 21 kyr. *Pages News*, 17(1): 4-5.
- Thara, K. J., 2011. Response of Eastern Arabian Sea to extreme climatic events with special reference to selected pelagic fishes. PhD thesis. Cochin University of Science and Technolog. pp 163.
- Tomczak, M. and Godfrey, J. S., 1994. Regional Oceanography: An Introduction. Pergamon Press, Oxford. pp. 422.
- Trenberth, K. E, Fasullo, J. T. and Kiehl, J. T., 2009. Earth's global energy budget. *Bull. Amer. Meteor. Soc.*, 90: 311-323.
- Trenberth, K. E., Fasullo, J. and Smith, L., 2005. Trends and Variability in Column-Integrated Atmospheric Water Vapor. *Clim. Dynam.*, 24: 741-758.
- Valenciennes, M. A. 1847. Histoire naturelle des poisson, Paris, 20, pp 472.
- van Rijn, I., Buba, Y., DeLong, J., Kiflawi, M. and Belmaker, J., 2017. Large but uneven reduction in fish size across species in relation to changing sea temperatures. *Glob Change Biol.*, 23: 3667-3674.
- Varghese, E., Sathianandan, T. V., Jayasankar, J., Kuriakose, S., Mini, K. G. and Muktha, M., 2020. Bayesian state-space implementation of Schaefer production model for assessment of stock status for multi-gear fishery. *J. Indian Society Agri. Statistics*, 74(1): 35-42.

- Varela, R, Santos, F., Gómez-Gesteira, M., Álvarez, I., Costoya, X. and Díaz, J. M., 2016. Influence of Coastal Upwelling on SST Trends along the South Coast of Java. *Plos One*, 11(9): e0162122.
- Venkataraman, G., 1960. Studies on the food and feeding relationship of the inshore fishes of Calicut on the Malabar coast. *Indian J. Fish.*, 7: 275-306.
- Venkataraman, G., 1970. The Indian Mackerel: IV. Bionomics and life history. *CMFRI Bulletin* 24:17-40.
- Venkataraman, G. and Mukundan, C., 1971. A note on the food of young mackerel. *J. Mar. Biol. Ass. India*, 12(1&2): 230-232.
- Venketaraman, G., 1961. Studies on the food and feeding relationships of the inshore fishes off Calicut on the Malabar coast. *Indian J. Fish.*, 7(2): 275-306.
- Vijayaraghavan, P., 1962. *Some observations on the spawning behaviour of mackerel.* *Indian J Fisheries*, 9A (2): 647-652.
- Vivekanandan, E., Gomathy, S., Thirumilu, P., Meiyappan, M. M. and Balakumar, S. K., 2009. Trophic level of fishes occurring along the Indian coast. *J. Mar. Biol. Ass. India*, 51 (1): 44-51.
- Vivekanandan, E., 2006. Impact of climate change on marine fisheries. *CMFRI Newsletter*, 112: 1-4.
- Vivekanandan, E., 2010. Impact of Climate Change on Indian Marine Fisheries and Options for Adaptation. *Souvenir: Lobster Research in India*. 65-71.
- Vivekanandan, E., 2011. Marine Fisheries Policy Brief-3; Climate change and Indian Marine Fisheries. *CMFRI Special Publication*, 105: 1-97.
- Vivekanandan, E. and Krishnakumar, P. K., 2010. Spatial and temporal differences in the coastal fisheries along the east coast of India. *Indian J. Mar. Sci.*, 39 (3): 380-387.
- Vivekanandan, E., Srinath, M., Pillai, V. N., Immanuel S. and Kurup K. N., 2003. Marine fisheries along the southwest coast of India, *In: Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries* (eds. Silvestre, G., Garces, L., Stobutzki, I., Luna, C., Ahmad, M., Valmonte-Santos, R. A., Lachica-Aliño, L., Munro, P., Christensen V. and Pauly D.). *WorldFish Center Conference Proceedings* 67: pp. 120.
- Vivekanandan, E., Gomathy, S., Thirumilu, P., Meiyappan, M. M. and Balakumar S. K., 2009. Trophic level of fishes occurring along the Indian coast. *J. Mar. Biol. Ass. India*, 51 (1): 44-51.
- Vivekanandan, E., Srinath, M. and Kuriakose, S., 2005. Fishing the marine food web along the Indian coast. *Fish. Res.*, 72: 241-252.
- Wabnitz, C. C. C., Lam, V. W. Y., Reygondeau, G., The, L. C. L., Al-Abdulrazzak, D., Khalfallah, M., Pauly, D., Palomares, M. L. D., Zeller, D. and Cheung, W. W. L., 2018. Climate change impacts on marine biodiversity, fisheries and society

- in the Arabian Gulf. *Plos One*, 13(5): e0194537. <https://doi.org/10.1371/journal.pone.0194537>.
- Wang, S., Cao, L. and Li, N., 2014. Responses of the ocean carbon cycle to climate change: Results from an earth system climate model simulation. *Adv. Clim. Change Res.*, 5 (3): 123-130.
- Weber, W. 1974. The influence of hydrographical factors on the spawning time of tropical fish. In: Proc. International Seminar on Fisheries Resources and their management in South east Asia (ed. K. Tiews), Berlin 19 November - 6 December, pp. 269-281.
- Widdicombe, C. E., Eloire, D., Harbour, D., Harris, R. P. and Sommerfield, P. J., 2010. Long term phytoplankton community dynamics in the Western English Channel. *J. Plankton Res.*, 32 (5): 643-655.
- Wilson, C, 2001. Correlations between surface chlorophyll and sea surface height in the tropical Pacific during the 1997–1999 El Niño–Southern Oscillation event. *J. Geophys. Res.*, 106 (12): 31175–31188.
- Wyrtki, K., 1973. An equatorial jet in the Indian Ocean. *Science*, 181: 262-264.
- Xie, S. –P., Deser, C., Vecchi, G. A., Ma, J., Teng, H. and Wittenberg, A. T., 2010. Global Warming Pattern Formation: Sea Surface Temperature and Rainfall. *J. Climate*, 23: 966-986.
- Xie, S. -P., 2004. Satellite observations of cool ocean–atmosphere interaction. *Bull. Amer. Meteor. Soc.*, 85: 195-208.
- Xu, X., Qiu, Z. and Chen, H., 1982. The general descriptions of the horizontal circulation in the South China Sea. In Proc. Symp. Chin. Soc. Mar. Hydrol. Meteorol., Science Press, Beijing, 119-127.
- Yan, X., Konopka, P., Ploeger, F., Tao, M., Müller, R., Santee, M. L., Bian, J. and Riese M., 2018. El Niño Southern Oscillation influence on the Asian summer monsoon anticyclone. *Atmos. Chem. Phys.*, 18: 8079-8096.
- Yáñez, E., Plaza, F., Sánchez, F., Silva, C., Barbieri, M. A. and Boh, G., 2017. Modelling climate change impacts on anchovy and sardinelandingsin northern Chile using ANNs. *Lat. Am. J. Aquat. Res.*, 45(4): 675-689.
- Yohannan, T. M. and Abdurahiman, U. C., 1998. Environmental influence on the behaviour of Indian mackerel and their availability to fishing gear along the Malabar coast. *Indian J. Fish.*, 45(3): 239-247.
- Yohannan, T. M., 1977. Studies on the mackerel fishery of Mangalore area during 1969-73. *Indian J. Fish.*, 24 (1&2): 113-123.
- Yohannan, T. M. and Nair, P. N. R., 2002. The resources of Indian mackerel – characteristics, exploitation and future prospects. In : Management of Scombroid Fisheries, Central Marine Fisheries Research Institute, Kochi (eds. Pillai, N. G. K., Menon, N. G., Pillai, P. P. and Ganga, U.), pp. 24-32.

- Yu, J. and Lau, K. M., 2005. Contrasting Indian Ocean SST variability with and without ENSO influence: A coupled atmosphere-ocean GCM study. *Meteorol. Atmos. Phys.*, 90 (3-4): 179-191.
- Zaki, S., Jayabalan, N., Al-Kiyumi, F., Al-Kharusi, L. and Al-Habsi, S., 2012. Maturation and spawning of the Indian oil sardine *Sardinella longiceps* Val. from the Sohar coast, Sultanate of Oman. *J. Mar. Biol. Ass. India*, 54 (1): 100-107.
- Zeebe, R. E., 2012. History of Seawater Carbonate Chemistry, Atmospheric CO<sub>2</sub>, and Ocean Acidification. *Annu. Rev. Earth Planet Sci.*, 40: 141-165.
- Zhang, C. I. K., Lee, J. B., Kim, S. and Oh, J., 2000. Climatic regime shifts and their impacts on marine ecosystem and fisheries resources in Korean waters. *Prog. Oceanogr.*, 47 (2-4): 171-190.
- Zhang, X, Li, T., F. Weng, F., Wu, C.-C. and Xu, L., 2007. Reanalysis of western Pacific typhoons in 2004 with multi-satellite observations. *Meteorol. Atmos. Phys.*, 97: 3-18.

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# APPENDICES

## Abbreviation

\$	Dollar
%	Percentage
/	Per
°C	Degree in Celsius
µg/l	Microgram per liter
µMol/m <sup>2</sup> /s	Micro mol per meter square per second
µS/cm	Microsiemens per centimetre
‰	Part per thousand
'0' year	Zero year
CDOM	Colored Dissolved Organic Matter
CH <sub>4</sub>	Methane
Cm	Centimeter
CO <sub>2</sub>	Carbon-di-Oxide
Dbar	Decibar
DO	Dissolved oxygen
E	East
G	Gram
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
Kg/ hour	Kilogram per hour
kg/m <sup>3</sup>	Kilogram per meter cube

Km	Kilometer
M	Meter
m/s	Meter per second
ml/l	Milliliter per liter
Mm	Millimeter
mS/cm	Millisiemens per centimetre
MTN	Mechanized trawl net
MPS	Mechanized purse seine
MRS	Mechanized ring seine
NM	Non-mechanized gears
N	North
N <sub>2</sub> O	Nitrous oxide
NOAA	National Oceanic and Atmospheric Administration
NTU	Nephelometric Turbidity Units
O <sub>2</sub>	Oxygen
OBRS	Outboard ring seine
OBGN	Outboard gillnet
OBTN	Outboard trawl net
PAR	Photosynthetically Active Radiation
Ppb	Part per billion
PPM	Part per million
PSU	Practical Salinity Unit
RCP	Representative Concentration Pathway
S	South
yr <sup>-1</sup>	Per year

$\rho$

Rho

$\Omega$

Omega

$\Theta$

Theta

$\Phi$

Phi