SEGREGATING THE IMPACT OF CLIMATE CHANGE *VIS-À-VIS* FISHING EFFORT ON INTER-ANNUAL VARIABILITY OF SELECTED SMALL PELAGIC FISHES USING NUMERICAL MODELS

by

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DECLARATION

I, POOJA A. S (2014-20-118) hereby declare that this thesis entitled **"Segregating the impact of climate change *vis-à-vis* fishing effort on inter-annual variability of selected small pelagic fishes using numerical models"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"Segregating the impact of climate change *vis-à-vis* fishing effort on inter-annual variability of selected small pelagic fishes using numerical models"** is a record of research work done independently by Ms. POOJA A. S, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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SYMBOLS AND ABBREVIATIONS

ACCER	Academy of Climate Change Education and Research
AIC	Akaike Information Criterion
AIM	Asia-pacific Integrated Model
APDRC	Asia-Pacific Data Research Center
AR5	Fifth-Assessment Report
ARIMA	Autoregressive integrated moving average
ASCAT	Advanced Scatterometer
AVISO	The Archiving, Validation, and Interpretation of Satellite Oceanographic
BOB	Bay of Bengal
CMAP	CPC Merged Analysis of Precipitation
Chl-*a*	Chlorophyll-*a* concentration
CCF	Cross Correlation Function
CMIP5	Coupled Model Inter-comparison Project 5
CMFRI	Central Marine Fisheries Research Institute
CPUE	Catch per Unit Effort
DDE	Dynamic Data Exchange
DMI	Dipole Mode Index
EAS	Eastern Arabian Sea
EAFM	Ecosystem Approach to fisheries management
EEZ	Exclusive Economic Zone
ENSO	El Niño-Southern Oscillation
ERS	European Remote Sensing Satellite
ESR	Earth Space Research
FAO	Food and Agriculture Organization
FRAD	Fishery Resources Assessment Division

GCAM	Global Change Assessment Model
GDP	Gross Domestic Product
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory Earth System Model Version 2M
IDE	Integrated Development Environment
iFREMER	French Research Institute for Exploitation of the Sea
IOD	Indian Ocean Dipole
iOS	iPhone Operating System
IOS	Indian Oil Sardine
IPCC	Intergovernmental Panel on Climate Change
JGCRI	Joint Global Change Research Institute
KAU	Kerala Agricultural University
KPSS	Kwiatkowski-Phillips-Schmidt-Shin
MacOS	Mac operating system
MERIS	MEdium Resolution Imaging Spectrometer
MGMS	Multi-Gear Mean Standardization Method
MLT	Mixed Layer Temperature
MODIS	Moderate Resolution Imaging Spectroradiometer
MPEDA	Marine Products Export Development Authority
MS	Microsoft
NetCDF	Network Common Data Form
NGO	Non-Governmental Organization,
NIES	National Institute for Environmental Studies
NMFDC	National Marine Fishery Resources Data Centre
NOAA	National Oceanic and Atmospheric Administration
OC-CCI	Ocean Colour Climate Change Initiative
OMZ	Oxygen Minimum Zone
OSCAR	Ocean Surface Currents Analyses Real-time

R Cran	R Comprehensive R Archive Network
Pr	Precipitation
QuikSCAT	Quik Scatterometer
RCP	Representative Concentration Pathway
SCPUE	Standardized Catch Per Unit Effort
SeaWiFS	Sea-Viewing Wide Field-of-View Sensor
SLA	Sea Level Anomaly
SODA	Simple Ocean Data Assimilation
SOI	Southern Oscillation Index
SPF	Small Pelagic Fishes
SSHA	Sea Surface Height Anomaly
SSH	Sea Surface Height
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
UI	Upwelling Index
UNFCC	United Nations Framework Convention on Climate Change
VBA	Visual Basic for Applications
VIIRS	Visible Infrared Imaging Radiometer Suite
VIF	Variance Inflation Factor
WCI	West Coast of India

INTRODUCTION

CHAPTER 1

INTRODUCTION

Climate change refers to a change in climate that is attributed directly or indirectly to human activity which alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods (UNFCC, 2011), it is a serious global environmental issue and it causes vast challenges in our ecosystem, biodiversity and human livelihood. Now scientists started to interchange the term global warming with climate change, as the temperature rise in different regions have different effects due to the characteristics of ocean currents hence some regions become cooler while some regions become hotter. The absence of the greenhouse effect will make the average temperature of the earth to be nearly 0°F (-18°C) instead of the much warmer 59°F (15°C) (Ma and Tipping, 1998). Hence, the greenhouse effect is essential for preventing the earth to become too cold. Unnatural level of increase of greenhouse effect is making variations in the distribution of earth's temperature, thus it is responsible for global warming.

Normally, climate change is happening around every 30 years and it may occur due to the natural or persistent anthropogenic changes in the composition of the atmosphere. Human influences the climate primarily through fossil-fuel, industrial, agricultural and other land-use emissions that alters the atmospheric composition. Emission of greenhouse gases, CO_2, CH_4, N_2O, tropospheric ozone and chlorofluorocarbons are the major sources for warming of the planet's surface globally. Rising of atmospheric greenhouse gas concentrations triggered increasing of global average temperatures by ~0.2°C per decade over the past 30 years (Hoegh-Guldberg and Bruno, 2010). As per the Intergovernmental Panel on Climate Change (IPCC AR5) synthesis report, in the northern hemisphere, the period from 1983 to 2012 was reported the likely warmest 30 years among the last 1400 years. The globally averaged combined land and sea surface temperature (SST) showed a warming of 0.85°C (0.65°C to 1.06°C) over the period 1880 to 2012. The upper 75 m of the world oceans showed a warming of 0.11°C which ranged from 0.09°C to 0.13°C per decade over the years from 1971 to 2010. They predicted that there could be a

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further temperature increase of at least 1.8°C during the 21st century and hence it high time for taking decisions for mitigation measures against climate change.

The earth system is itself an integrated system which subdivided into four main components including atmosphere (Air), hydrosphere (Water), lithosphere (Land) and biosphere (Living part). All the components are tightly interconnected and depend on each other. The vast majority of the energy in the earth system comes from the sun, it supplies energy through short wave radiation to the earth surface. The oceans and atmosphere interact in many different ways and the changes in the energy balance between them play a significant part in the planet's climate change. The concept of ocean-atmosphere coupling is one of the cornerstones of modern climate dynamics, originating in the pioneering work of Bjerknes (1972) and Wyrtki (1974). The ocean-atmosphere interactions are essential for explaining properties of quite a number of climate phenomena including El Niño-Southern Oscillation (ENSO) and decadal climate variability. In this extent, understanding of ocean-atmosphere coupling is critical for predicting climate variability, global changes in temperature patterns and global warming.

In earth's surface, 71% is occupied by ocean, have a dominant role in regulating climate. The marine ecosystems play an important part in the biology of the planet. The climate change is clearly and fundamentally altering the marine ecosystems, strongly influences marine productivity, altered food web dynamics, shifting species distributions, reduced abundance of habitat-forming species and increased incidence of disease outbreaks within marine ecosystems. Recent studies indicate that rapidly rising greenhouse gas concentrations are changing natural conditions of the ocean systems. One-third of the carbon dioxide produced by human activities is absorbed by open ocean. Rising of atmospheric CO_2 and the resulting increased oceanic CO_2 uptake are the predominant factors driving ocean acidification, induce a series of chemical changes such as reduced pH, carbonate ions and calcium carbonate saturation states (Dore *et al.*, 2009). During ocean acidification, ocean becomes more acidic, threatens for the survival of several marine organisms such as corals, molluscs, crustaceans, zooplankton and phytoplankton because they use calcite and aragonite for their making of shells and skeletal growth. Beyond a specific acidity threshold, calcite and aragonite become easily dissolved and it affects the entire food chain (Doney *et al*., 2011).

The influence of extreme weather events such as drought, flood, tsunami, storm surges and cyclones are crucial evidence for the climate change. There are multiple important climate and oceanic drivers that affect the marine environment. Significant environmental changes such as increasing sea surface temperature (SST), sea-level height, variations in chlorophyll-*a* (Chl-*a*), shifts in salinity, pH, fluctuations in rainfall and other oceanic conditions are expected to impact the marine ecosystems and associated fisheries (Salinger, *et al*., 2016).

One of the potential consequences of global warming is raising the SST and sea-level. The SST of the ocean is indicated by measurements taken at depths that range from 1 millimeter to 20 meters. Increasing SST causes melting of glaciers and continental ice caps, adding water to the ocean and further increasing sea-level. The major disruptions of marine ecosystems happening by extreme environmental conditions like El Niño/Southern Oscillation (ENSO), a large-scale climate drivers that can lead extremes of SST, challenging the biological tolerances of species, altering oceanic variables such as wind speed, salinity, thermocline depth and shift in stock productivity (Smith, 2011; Klaer *et al*., 2015). Similarly, different phases of ENSO and Pacific Decadal Oscillation also affect the distribution of regional climate (Holbrook *et al*., 2011) as it enhances temperature and sea-level which may have significant local effects on fishery-dependent communities.

India is a prominent marine fishing nation having seventh position among 25 world major producers in marine capture production (FAO, 2016). Indian coastal length is 8129 km which includes 1376 landing centers and our Exclusive Economic Zone (EEZ) is 2.02 million sq.km. According to the Marine Products Export Development Authority (MPEDA), the annual potential fish harvestable yield is about 4.414 million metric tons from its Exclusive Economic Zone (EEZ) which contributes 1.3 percent to total Gross Domestic Product (GDP). The Indian marine fisheries sector plays a vital role in our economy, supplementing protein food and nutritional security. Nearly 1.5 billion consumers rely on fish for more than 20% of their dietary animal protein hence, the concern over the ramification of climate change for the food security and livelihoods

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of fisherfolk is increasing. Due to the vast size and complex geography of India, climate change induces large spatial and temporal variations. Floods and droughts, monsoon depressions and cyclones, heat waves, cold waves, prolonged fog and snowfall are the important weather events affecting India whereas climate change itself is a primary factor undoubtedly influencing Indian marine fishery.

Mainly marine habitats are classified into pelagic and benthic. The pelagic zone is sometimes called the open-ocean zone and it is the entire water column of the ocean from the surface to the greatest depths. Almost all fishes spend the majority of their habitat in the pelagic zone. Marine pelagic fish species have five subcategories based on increasing water depth, include the epipelagic, mesopelagic, bathypelagic, abyssopelagic and hadopelagic zones. The pelagic fishes are contrasted with the benthic organisms they live in and on the bottom of the seafloor. Benthos include clams, corals, crabs, lobsters, sponges, worms and other tiny organisms that live in the greatest depths of the ocean. The fishes that dwell in the column waters below the pelagic zone are termed as demersal fishes.

Small pelagic fishes (SPF) are the primary energy channels of marine environment, they transfer the energy from lower trophic level to higher trophic levels, they feed plankton (Blaxter and Hunter, 1982; Cury *et al*., 2000), have short life span, highly mobile and have schooling behaviour. These fishes are the important food source for top predators such as large pelagic fishes, demersal fishes, marine birds and mammals. They exert major control on trophic dynamics of upwelling ecosystem (Cury *et al*., 2000). A third of global fisheries production is mainly from SPF which is used to produce the largest marine-based commodity. They have high economic value because of their human consumption, production of fish meal and fish oil. They have a significant role in global food security, particularly for the economy, diet and livelihood of communities in the developing world and for the well-being of villages in entire countries. SPF populations are more sensitive to the environmental variability than other fishes and substantial changes in their abundance over relatively short periods called "boom and bust" population dynamics. Their dynamics can also be balanced by a variety of external drivers include both anthropogenic and natural changes.

SPF often exhibit complex migration dynamics it is depending on their size and condition. Their spawning, metabolic activities and recruitment are modulated by environmental processes including upwelling and other oceanographic processes. Physical processes (Bakun, 1996) and food availability (Cushing, 1996) exert a remarkable role on larval survival which determines major changes in fish abundance (Cury and Roy, 1989; Larkin, 1996). Climate variability affects the reproductive potential, natural mortality, especially in early stages often imply large fluctuations in recruitment. Removal of million tonnes of small pelagic species upset the survival of demersal fishes, the entire food web of an ecosystem, income and employment-related to the small pelagic fishery (Brander, 2010). An increase in fishing pressure is one of the major reasons for changes in SPF. All these issues making challenges to fisheries management. The strong links between SPF with their environment and their significant roles as forage fish makes the strong candidates for an Ecosystem Approach to fisheries management (EAFM). Most importantly management practices need observation in the effects of environmental processes on stock productivity.

Indian Ocean is a potential area to study the impact of climate change and the Arabian Sea is a major ocean basin in the northern Indian Ocean. The Arabian Sea has a distinctive character when compared to other low latitude seas it is landlocked at the north by the Asian landmass. This trait of the Arabian Sea draws immense continental effect resulting in improved land-sea thermal gradient causing monsoon. South-west monsoon trigger the upwelling of nutrients along the west coast of India (WCI) results in higher productivity (Madhupratap *et al.*, 1994; Muraleedharan and Prasanna Kumar, 1996) hence the Arabian Sea is considered as one of the most productive marine ecosystems in the world. The Eastern Arabian Sea (EAS) has some pronounced economic importance as compared to the Western counterparts because the Eastern Arabian Sea contribute seventy percent of annual fishery production.

In India, pelagic fishery contributes around fifty-two percentage along the Indian coastline (CMFRI, 2017). Indian Oil Sardine (*Sardinella longiceps*) and Indian Mackerel (*Rastrelliger kanagurta*) are the major part of total pelagic fish catch. The landing statistics of Indian Oil Sardine and Indian Mackerel are highly fluctuating along the WCI since 1985. Climate change may strongly influence the abundance and

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distribution of fish populations and altering its breeding and migration patterns (Vivekanandan, 2010). Indian Ocean is subjected to different climatic phenomena and extreme events may influence the small pelagic resources of WCI.

For adapting to changing climate, need a close look at the links between future monitoring and research. It is responsible for flexible and reflexive management systems (Brander, 2010). We need an improvement in our skills for predicting climate variability and its impacts over the same period (*e.g.* El Niño status). Knowledge of the probability of future extreme events supports policy investment and resilience planning for reduce risks towards climate change. Information on environmental links and biomass also helps to enhance fisheries management.

In the view of previously stated evidence, the proposed study is focused on understanding the impact of climate change on Indian Oil Sardine fishery along the southwest coast of India.

The core objectives of the present study are, to separate the effect of major environmental variables and fishing effort on selected small pelagic fishes along the WCI, to study the influence of critical environmental variables on the abundance of small pelagic resources along the WCI and to predict the biomass of selected small pelagic resources based on identified critical environmental variables.

The proposed Regression model with Autoregressive integrated moving average (ARIMA) noise are beneficial to predict the future biomass of Indian Oil Sardine. Representative Concentration Pathways (RCPs) 4.5 and 6.0 scenarios of environmental variables were used to project the changes in the favorable habitat of Indian Oil Sardine. The results generated during the study will be able to come up with some useful recommendations or suggestions for suitable mitigation, adaptation strategies and policies in fisheries management practices for future. The study was done with a perceptive of helping fisherfolks and coastal communities impacted by climate change.

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REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

2.1 Attributes of Arabian Sea

2.1.1 Upwelling and Primary productivity

The Arabian Sea, a major tropical oceanic province in the northern Indian Ocean, is one of the most biologically productive ocean basins in the world ocean (Karl, 1987; Nair *et al.*, 1989; Smith *et al.*, 1991; Sathyendranath *et al.*, 1996; Madhupratap *et al.*, 1996; Prasanna Kumar *et al.*, 2002; Karati *et al.*, 2019). The high biological productivity of the Arabian Sea was triggered by seasonally changing physical processes in accordance with the semi-annual switching of atmospheric forcing. Upwelling, a significant phenomenon which contribute to the productivity of Arabian Sea, it is the slow and persistent rising of colder and nutrient-rich water from the deep ocean layers to the upper ocean layers occurs during the south-west monsoon months from May to September which enhance the primary productivity in the ocean (Prasanna Kumar *et al.*, 2002; Smitha *et al.*, 2008).

Sharma (1978) remarked that upwelling is one of the several oceanic processes, which crucially influence the distribution of pelagic fishes. Upwelling in the WCI, significantly affect their fishery through increasing the nutrient content in the euphotic zone thereby increasing the productivity of the region. Upwelling act as a first link of the food chain, leading to a bloom of phytoplankton and this is not a sudden process. Usually, phytoplankton blooms occur after lapse of some time because the algae in the water have to grow and multiply. In the case of the WCI, these blooms occur in July/August. He reported that upwelling commences from the deeper layers of the ocean in March. During May, upwelled water reaches the ocean surface. The process continues to occur vigorously till June. The intensity of upwelling reduces with increasing strength of southwest winds and finally ceases in July/August whereas the south-west monsoon has maximum strength. The reverse process, sinking occurs by September. The sea-level lowered with upwelling and increases in sea-level occurring in September corresponds to the onset of sinking.

According to Sverdrup *et al.* (1942), coastal upwelling describes wind-induced divergence caused by Ekman transport. Johanessen *et al.* (1987) claimed that wind is an important driving force. Upwelling is associated not only with local wind but also with large-scale south-west monsoon. The chemical and biological indications of upwelling is associated with the summer monsoon. Upwelling of the southwest coast of India is indicated by the rapid upward movement of isotherms, surface cooling and the associated sea-level falling. Chlorophyll maxima are recorded in June when the south-west monsoon winds are strongest at this period (Smitha *et al.*, 2008).

Many studies have explained the upwelling event along the southwest coast of India (Banse, 1968; Sharma, 1978; McCreary and Chao, 1985; Johannessen *et al.*, 1987; Shetye *et al.*, 1990; Shankar, 2005). Shah *et al.* (2015) reported that in the EAS, upwelling begins at the southern tip (8°N) during April, originate from south to north as the summer monsoon progresses and ends by September. On the other hand along the Northwest coast, the upwelling strengthened during August and continues until October. He claimed that the upwelling is not limited to the southwest coast of India from 8°N to 15°N. The southwest coast is also illustrated by downwelling from October to March. In the northwest coast, upwelling comes to an end by November and sinking occurs from December to March. Compared to the northwest coast, both upwelling and downwelling are stronger along the southwest coast of India.

Morrison *et al.* (1998) stated that well-developed oxygen minimum zone (OMZ) and high chlorophyll-*a* production are the distinctive character of the Arabian Sea during the south-west and north-east monsoon periods. Studies of Banse (1968) revealed that the upwelling which commences with the south-west monsoon triggered an uplift of the 20°C isotherm by 90-100 m. The cool and deoxygenated subsurface water withdraws from the shelf whereas the shelf waters are characterized by minimum oxygen distribution (<0.5 ml O^2/l). He remarked that the catch per unit effort of economically exploited fishes between Bombay and Karachi in November 1963 seems to be connected to the oxygen content of near-bottom water. Ramamirtham and Murty (1965) found that the continental shelf waters were plentiful in oxygen and the oxygen minimum layer beginning at the cap portion of the thermocline along the WCI.

The Bay of Bengal (BOB) is traditionally deemed to be a less productive oceanic regime is contrary to the Arabian Sea. Advection of nutrient-rich water into the euphotic zone formulates the Arabian Sea well productive this phenomenon is unlikely in the BOB because throughout the summer period, profuse rainfall and river water freshen the upper layers of the Bay by 3–7 psu. BOB gets plentiful fresh water from the hinterland rivers an imposing 1.6 x 10^{12} m^3 yr^{-1} compared to 0.3 x 10^{12} m^3 yr^{-1} in the Arabian Sea. Oceanic precipitation enabling its upper layers less saline (annual mean psu <34). Over the BOB, SST was warmer by 1.5-2°C than in the central Arabian Sea these results a strongly stratified surface layer. The weaker winds over the Bay are not able to erode the vigorously stratified surface layer thereby confining the turbulent wind-driven vertical mixing to a shallow depth of <20 m and restraining introduction of nutrients from below situated close to the mixed layer bottom into the upper layers (Prasanna Kumar *et al.*, 2002; Madhupratap *et al.*, 2003).

The Arabian Sea is distinguished by relatively low temperature, high nutrient content, greater salinity, more primary productivity, good biomass and maximum fish yield than those of the BOB (Ramasastry and Myrland, 1959; Sankaranarayanan and Qasim, 1968). The findings of Qasim (1977) declare that the column productivity of Arabian Sea is substantially higher than the BOB. Immensely productive areas of the EAS are enriched with the phosphate-phosphorous and nitrate-nitrogen nutrients. He also pointed out that the most productive regions of the EAS are indicated by upwelling.

2.1.2 Significance of Indian Monsoon

South-west (summer) monsoon and north-east (winter) monsoon are the two major monsoon periods of the Arabian Sea and these strongly influencing the physical, chemical and biological variations in the top layers of the seawater (Morrison *et al.*, 1998). The Arabian Sea becomes more productive during the peak summer monsoon (June-September) season by upwelling (Subrahmanyan 1959; Ramamirtham and Murthy, 1965; Qasim and Reddy 1967; Radhakrishna 1969; Ramamirtam and Rao, 1973; Nair *et al.*, 1989; Prasanna Kumar *et al.*, 2002).

Longhurst *et al.* (1995) mentioned that 50% of the global primary production provided by photosynthetic phytoplankton and it acts as the foundation of the ocean food chain. Intense monsoon triggers the upwelling and increasing chlorophyll-*a* production along the southwest coast of India (Joseph *et al*., 2007). Peculiar hydrographical environment and related prevailing south-west monsoon are helpful for the rate of replenishment of nutrients such as phosphate and a rich crop of phytoplankton (Jayaraman and Seshappa, 1957). Rainfall has a crucial control on primary productivity especially at the onset of monsoon. Upwelling throughout the summer monsoon enhances the primary productivity and abundance of planktivorous fishes along the EAS. During winter season, sinking occurs and related productivity prefers the population of demersal fishes along the north-west coast (Banse and McClain, 1986; Bhattathiri *et al*., 1996).

Chidambaram and Menon (1945) found a positive correlation within the plankton and the pelagic fisheries. 0.32-1.12 mg/m^3 was the surface chlorophyll-*a* concentration in the Arabian Sea (Prasanna Kumar *et al*., 2002). The peak values for phytoplankton primary blooms concurrent with the monsoon time (George, 1953; Subrahmanyan, 1959). However, fluctuations in the primary production leads to decadal trend in fishery along the coastal zones (Vivekanadan *et al*., 2005).

2.2 Fluctuations in fish landings along the Eastern Arabian Sea

At the time of 2015, total marine fish landings of India was evaluated as 3.40 million tonnes registering 5.3% decrease compared to 3.59 million tonnes in 2014. Indian Oil Sardine is one of the main small pelagic fisheries along the Indian coast experienced a severe decline in its landings, comparable to prior year catch (CMFRI, 2016).

The Indian Oil Sardine showed a declining trend and shifted to 2nd position in the marine fish landings rankings in 2016. 3.63 million tonnes was the marine fish landings in India for 2016 whereas 6.6% increase occurred compared to 2015. The Indian Mackerel became the major contributor in 2016 with 2.49 lakh tonnes. For the first time since 1999, Indian Oil Sardine was not ranked as a leading species in terms of catch and it fell below the Indian Mackerel. Since 2013, Indian Oil Sardine landings persisted to show a reduction trend with an estimate of 2.45 lakh tonnes in the year 2016 (CMFRI, 2017).

During 2017, Marine fish landings in India registered 5.6% increases to reach 3.83 million tonnes. A significant come back for Indian Oil Sardine which peaked

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the resource list with 3.37 lakh tonnes. The western coastal states entrained in the maximum production of Indian Oil Sardine here Kerala registered 1.25 lakh tonnes. The east coast observed a reduction in Indian Oil Sardine landing with 83% and 36% in the Andhra Pradesh and in Tamil Nadu respectively. Considering fish production of the Kerala show a 12% increase with 5.85 lakh tonnes, owing to the recovery of Indian Oil Sardine fishery whereas Indian Oil Sardine landings achieved nearly 3 times hike. Ockhi cyclone was affected the fishing days in the coastal states of Kerala, Tamil Nadu and Karnataka. The pelagic finfishes predominated in the marine fish landings contributing 54% of the landings. 60% of the pelagic fish landings in 2017 was contributed by Indian Oil Sardine, Indian Mackerel, ribbon fish, lesser sardines and Bombay-duck whereas the Indian Oil Sardine alone contribute 16.3% (CMFRI, 2018).

India have 6th position in marine fish production after China, Indonesia, USA, Russia and Peru with a 4.5% contribution (FAO, 2018). Our marine fisheries sector imparts employment to nearly two million fishermen. Total marine fish landings along the Indian coast for the year 2018 was calculated at 3.49 million tonnes to indicate a trend of decline about 3.47 lakh tonnes (9%) compared to 3.83 million tonnes in 2017 whereas 1.86 million tonnes contributed by pelagic resources. Indian Oil Sardine falling to 9th position in 2018 from its first position in 2017 with massive reduction (54%) in its landings that is to 1.55 lakh tonnes from 3.37 lakh tonnes in 2017. The Indian Mackerel became the principal resource with a contribution of 2.84 lakh tonnes towards the total landings (8.1%) though the landings of this resource reduced by 1.4% compared to its landings in 2017 (CMFRI, 2019).

2.3 Environmental influence on biological features of small pelagic fishery along the southwest coast of India

As reported by Jayaprakash and Pillai (2000), 2 to 33% of the annual marine fish production of India contributed by the Indian Oil Sardine which is distributed all along the Indian coast. These species sustain a commercial fishery with high magnitude along the coasts of Kerala, Karnataka, Goa and the southern part of Maharashtra. SPF population exist in intermediate trophic levels of marine ecosystem, support transfer of biomass and energy from lower (e.g. plankton) to higher (e.g. predators) trophic levels (Cury *et al*., 2000; Ghofar, 2004).

SPF have short life spans and they are sensitive to climate variations (Cury and Roy 1989; Palomera *et al*., 2007; Brander., 2010). The fluctuations noticed in the fishery is due to some other independent factors rather than through overexploitation (Krishnakumar *et al*., 2008). (Kawasaki *et al*., 1991; Francis and Hare, 1994; Krishnakumar and Bhat, 2008) argued that the deviations in the physical, chemical and biological oceanographic environs have a greater influence on biological features of small pelagic fishery along the southwest coast of India.

Changes in the ecosystem conditions can reduce foraging, growth, fecundity, migratory behaviour, alters metamorphosis and affects endocrine homeostasis of organisms (Portner *et al*., 2001). Brander (2010) explained that climate change influenced on fishes due to different types of direct and indirect effects of several physical and chemical factors which include temperature, wind, vertical mixing, salinity, oxygen, pH and others. The direct effects act on many factors like the physiological characteristics, growth and development rates, reproductive capacity, behaviour and survival rate of individuals. Indirect effects control the ecosystem practices and amendments in the production of food or abundance of competitors, predators and pathogens. Vivekanandan *et al.* (2009) specified that the changing climate has been identified as one of the drivers of Indian Oil Sardine abundance and distribution.

According to Mukundan (1967), peak landing for Indian Oil Sardine appears to be within this temperature range of 26.5°C to 28.5°C. Indian Oil Sardine shows a pattern of variation in abundance equivalent to the fluctuations in total plankton, salinity and temperature. Chidambaram (1950) pointed out that the 26 to 28°C is the favourable range of temperature for the inshore migration of the juveniles of Indian Oil Sardine and increases within this range or when above 29°C, they disappear to deeper waters. He also commented that the changes in the hydrological conditions largely controlled the movement of Indian Oil Sardine shoals in inshore waters. Climate change-induced abnormalities in the oceanic ecosystem such as higher SST affected the Indian mackerel and Indian Oil Sardine stocks which leads to the

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northward extension of their distribution ranges (Asokan *et al.*, 2009). At the time of annual temperature deviations, fish stocks may shift locations for retaining optimum temperature range (Mountain and Murawski, 1992; Overholtz *et al.*, 2011) and outside of the distinct range of environmental conditions could be stressful or fatal for the fishes (Barton *et al.*, 2002;Neuheimer *et al.*, 2011). Yá˜nez *et al.* (2001) explained that the changes in the abundance of the pelagic fishes of the north area off Chile in the period 1950-1998 were related to SST changes.

Raja (1972) and Kumaran *et al.* (1992) examined the impact of rainfall on Indian Oil Sardine. Qasim (1973) analysed that the peak spawning of fishes largely seems to occur during the pre-monsoon months and along the west coast during the monsoon and post-monsoon months. Landings of pelagic fishes seem to occur maximum during monsoon months followed by post-monsoon months. The intensive spawning period of the Indian Oil Sardine coexist with the monsoon season (Qasim, 1973; Rajagopalan *et al.*, 1992). May-June is the peak spawning period of Indian mackerel observed along the southwest coast (Pradhan and Palekar, 1956; Noble, 1974; Yohannan and Abdurahiman, 1998). Rainfall significantly control the spawning process of SPF. The failure or even unequal distribution of monsoon during the spawning time adversely affect the spawning potential of the fishes and if this continues in all the major spawning months of June to August the overall egg production is diminished. The survival rate of eggs and larvae may reduce and also suffer as they would be out of phase with the required natural environment for growth and development (Raja, 1972). South-west monsoon has a critical importance in the production of phyto and zooplankton, especially in the inshore upwelling areas. The period 1987-88 was observed as a weak monsoon period consequently, there has been a marked decline in the catch of pelagic fish especially the Indian Oil Sardine (Rajagopalan *et al.*, 1992). The low rainfall might be affecting the fecundity, recruitment success and food availability for SPF (Jayaprakas, 2002).

The *Sardinella longiceps* is a voracious feeder, particularly in the adolescent stages at which they enter the inshore waters and feed the plankton. The preceding studies from different centers though mostly from commercial catches obtained from inshore areas specify the Indian Oil Sardine is a plankton feeder (Chidambaram, 1950; Nair, 1952; Venkataraman, 1960; Dhulkhed, 1962; Kagwade, 1964; Noble, 1965). The presence of plankton as food is essential for a good fishery, food availability and the environmental conditions are most beneficial to ensure fast growth and survival of their larvae (Mukundan. 1967; Renjima *et al.*, 2016). The phytoplankton production and its peak identified during the south-west monsoon (June-September) along the WCI (Subrahmanyan, 1959; Qasim and Reddy 1967; Radhakrishna; 1969). At the time of the post-monsoon period, we can observe a positive correlation between the plankton and pelagic fishes (Chidambaram and Menon, 1945). The climate change is affecting the composition of plankton causes SPF population changes (Brosset *et al.*, 2015; Saraux *et al.*, 2019).

Mukundan. (1967) stated that the temperature-salinity factors are highly influencing the entry of fishes into the inshore areas. The landings of Indian Oil sardine and Indian Mackerel are exhibit a pattern of variations in abundance corresponding to the fluctuations in total plankton, salinity and temperature. The peak landings for both species appear to be within the range 28.5 ‰ to 33.5 ‰ of salinity.

The global annual seawater temperature and sea-level would rise by 0.8 to 2.5°C and 8 to 25 cm respectively during 2050 (IPCC, 2007). Increases in temperature create a host of additional change such as rising sea-level. Small pelagic fishery landings are related to environmental factors such as precipitation, sea-level and upwelling. The earlier studies found that, in the period of upwelling, fall in sea-level is happened along the WCI due to the divergence of upper currents along the coast (Sharma, 1978; Shankar *et al.*, 2002). Upwelling areas are characterized by ascending motion of isotherms, lowering of sea-level, cooling of the sea surface and high biological productivity (Banse, 1959; Darbyshire, 1967).

A significant increase of sea-level was observed along the WCI during the north-east monsoon due to the well-known downwelling process and convergence of upper currents along the coast in the time of November to February (Shankar *et al.*, 2002). Sea-level contractions/expansions related to SST, warming of the upper layers of the ocean also triggering stratification of the water column, curtailing

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mixing in the ocean and subsequently affecting nutrient availability and primary production. These changes have enhanced the size of the nutrient-poor "ocean deserts" of the Pacific and Atlantic by 6.6 million km^2 or 15% over the period 1998 to 2006 (Hoegh-Guldberg and Bruno, 2010).

2.4 Consequences of extreme climatic events

El Niño events negatively affect the reproductive processes or development of eggs and larvae of pelagic clupeoids (Bernal *et al.*, 1983; Santander and Flores, 1983). El Niño makes horizontal and vertical migration in the fishery resources and the more intensive events upset reproduction and survival rate of fishes (Sharp and McLain, 1993; Tarazona and Castillo, 1999) which create strong socio-economic impacts (Glantz, 1998).

The eastern boundary of the Chile-Peru current system accounts one of the most biologically productive ecoregions in the world due to the better coastal upwelling and the horizontal advection of nutrients. Environmental regime changes at the starting of the 1970s. The onset of the 1972-1973 El Niño marking a major decline in the anchovy fishery (Yáñez *et al.*, 2008). From 1997 to 1998 El Niño events, Chilean and Peruvian pelagic marine landings decreased by about 50% results a huge drop in fishmeal export values by about US$8.2 billion generated negative economic effects (Sumaila *et al.*, 2011). Martínez *et al.* (1986) found that extreme environmental conditions that related to the El Niño phenomenon make drastic alterations in the peak spawning of resources off northern Chile. The El Niño related warming affects the upwelling dynamics and productivity causes a decline in Peruvian anchoveta (*Engraulis ringens*, *Engraulidae*) while sardines (*Sardinops sagax, Clupeidae*) tend to increase (Chavez *et al.*, 2003).

El Niño events reduce anchovy catches, affecting the fecundity, egg viability, survival of larvae, post-larvae and juveniles. These events decreases recruitment and stock biomass. Anchovy mortality increases at the first stages due to the variations in the quality of food caused by less effective upwelling happened in this period (Chavez *et al.*, 2003).

2.5 Relevance of Representative Concentration Pathways

The Representative Concentration Pathways (RCPs) are, set of greenhouse gas concentration and emissions pathways intended to help research on climate change impacts and related potential policy responses (Moss *et al.*, 2010; Van Vuuren *et al.*, 2011). The RCP 4.5 is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100 without overshooting the long-run radiative forcing target level. It was developed by the GCAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI) in the United States (Smith and Wigley 2006; Clarke *et al.*, 2007; Wise *et al.*, 2009).

RCP 6.0, is another stabilization scenario in which total radiative forcing is stabilized shortly after 2100 without overshoot by the application of a range of technologies and strategies for lowering greenhouse gas emissions. This scenario was developed by the AIM modeling team at the National Institute for Environmental Studies (NIES) in Japan (Fujino *et al.*, 2006; Hijioka *et al.*, 2008).

As reported by Van Vuuren *et al.* (2011), RCPs, a set of four new pathways established for the climate modeling community as a basis for long-term and near-term modeling experiments. They make significant improvements in climate research and ensure a potential foundation for further research and assessment including emissions mitigation and impact analysis. The RCPs applied in a wide range of policy-experiments. At the same time, they were suitable in climate research which contribute essential information for decision-making, promote research on the mitigation action and socio-economic conditions that would be consistent with a given concentration pathways.

The RCPs are allowed a unique set of data, particularly for comprehensiveness, specify detail and given information of spatial scale for climate model projections. The RCP scenarios are expected to provide a consistent analytical thread in climate change research extensively used by scientists, policymakers, NGOs and commentators for effective communication and exchanging of ideas. A wide number of experiments have been suggested based on the RCPs (Hibbard *et al.*, 2007; Taylor *et al.*, 2011). Climate projections in the IPCC fifth assessment report (AR5) are made using the newly developed RCPs under the Coupled Model Inter-comparison Project 5 (CMIP5) (Chaturvedi *et al.*, 2012; Rogelj *et al.*, 2012).

2.6 Impact of climate change and the role of fisheries management strategies

Overfishing, pollution and habitat degradation are the major reasons for the poor performing of the global marine fisheries sector. Observations, experiments and simulation models prove that climate change makes variations in primary productivity, shift the distribution and alters the potential yields of exploited marine species which reflects on the economics of fisheries worldwide. Plentiful scientific information underlines the need for implementation of mitigation, adaptation practices and policies for reducing the impacts of climate change on fisheries (Sumaila *et al.*, 2011).

According to Brander (2010), downscaling and regional modeling of ocean and climate change will help to upgrade our forecasting ability and to study likely consequences for ecosystems and fisheries. He pointed out that, our existing knowledge is insufficient in many respects and does not provide a proper basis for improved management of fisheries and marine ecosystems for adapting to climate change.

More effective management of fisheries and marine ecosystems can seriously play a major role in adapting to the impacts of climate change. To adapt the variations in climate, future monitoring and research in the fisheries sector must be closely linked to responsive, flexible and reflexive management systems. The understanding how climate change may affect decadal and shorter time scale variability is necessary for predicting future climate change impacts on marine ecosystems and fisheries. Without stresses due to other factors, such as overfishing and pollution, the fish stocks will be more resilient to climate change impacts (Sumaila *et al.*, 2011). Little attention wanted for preventing the alterations in fisheries ecosystem and its effects on people, especially for the millions of small-scale fisherfolk (fishers, fish processors, traders and ancillary workers) in the developing world who are among the most vulnerable to climate change (Sadovy, 2005; McClanahan *et al.*, 2008).

The influence of climate change and related disruptions occurred in the fisheries sector affect the large numbers of poor people and the options for future economic growth in those countries for which fisheries are a main source of food, employment and export revenues (Allison *et al.*, 2009). The investigation of the economic impacts of climate change on fisheries can help considerably in the planning strategies for adaptation or mitigation (Hanneson, 2007).

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

3.1 STUDY AREA

The current study was carried out along the WCI and the location of the study region lies between 8^0N-16^0N and 72.5^0E-76^0E (Figure 1) whereas Kerala, Karnataka and Goa are the major maritime states mainly concerned for the study. Indian Oil Sardine was the major small pelagic fish contribute a large portion to pelagic fishery landings of selected coastal areas.

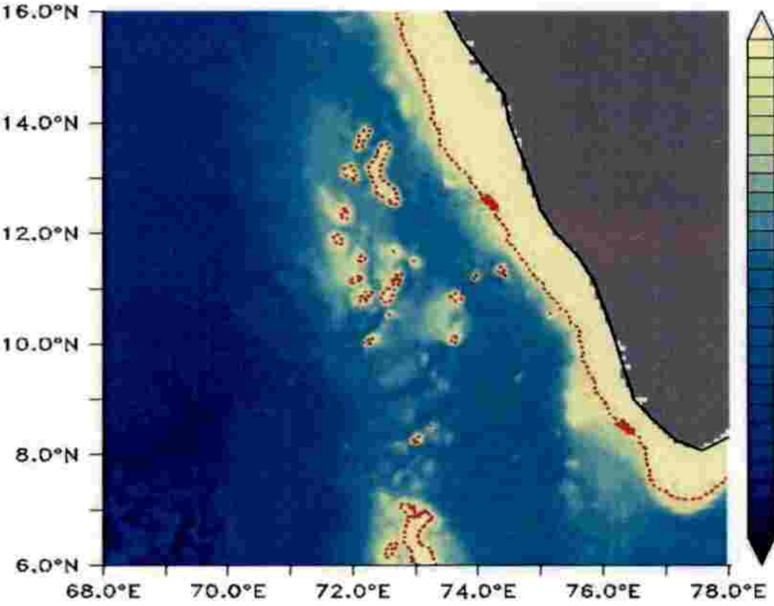

Figure 1: Location map. The area between represents the study area (Redrawn from Akash, 2018)

3.2 STUDY SPECIES

3.2.1 Indian Oil Sardine *(Sardinella longiceps)*

Indian Oil Sardine was the most important and abundant clupeoid in Indian waters and have a large commercial and economical value particularly in the southern states of India. They are herbivorous and feed primarily on phytoplankton (especially diatoms), both as juveniles and adults, but also on zooplankton (especially copepods by the juveniles). Sub-cylindrical elongate body and rounded belly are the diagnostic features.

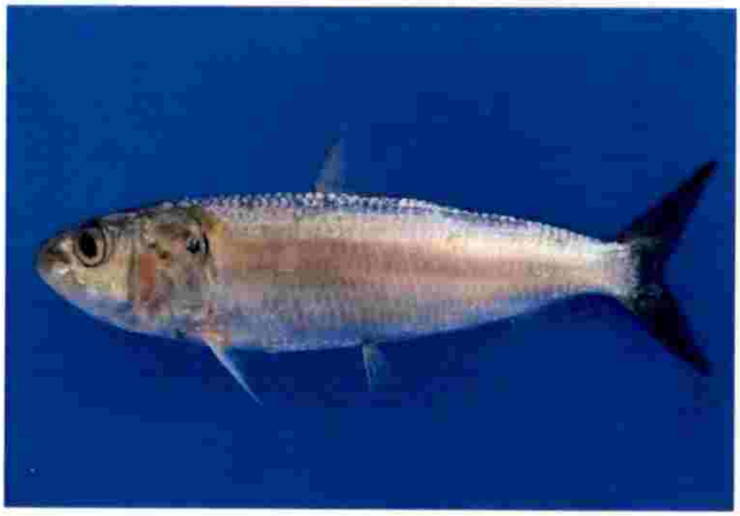

Figure 2: Indian Oil Sardine (*Sardinella longiceps*)

They breed once a year. On the WCI the spawners of Indian Oil Sardine arriving in June-July it is the period of south-west monsoon months whereas temperature and salinity decreases. Sometimes their spawning season was extended and show intensive spawning in August-September. Pelagic in nature, mostly found up to 50 m depth, schooling behaviour, strongly migratory. 3-4 years is the maximum lifespan of this species and 26-28°C is the most reported favourable temperature range (Chidambaram, 1950).

Local Names: Mathi (Malayalam), Boothai (Kannada), Taralai, Haid (Marathi).

Geographical Distribution: Indian Ocean (northern and western parts only, Gulf of Aden, Gulf of Oman, not available in Red Sea or Persian Gulf, eastward to southern part of India, on eastern coast to Andhra; possibly to Andamans) (Whitehead, 1985).

3.3 DATA AND MATERIALS

The data sets used for the present study are summarised in the following tables (Table 1, 2, 3, 4).

Table 1: The oceanographic datasets used for the study

Variable	Data Observations	Source	Temporal resolution / Period	Spatial resolution
Temperature	SST (Potential Temperature)	SODA v2.2.4 (APDRC)	Quarterly 1998 to 2015	0.5°x 0.5°
Precipitation	Precipitation	CMAP	Quarterly 1998 to 2015	2.5° x 2.5°
Chlorophyll-*a*	chlorophyll-*a*	OC-CCI	Quarterly 1998 to 2015	0.04° x 0.04°
SSHA	SSHA	AVISO, (L4)	Quarterly Oct 1998 to Feb 2015	0.33° x 0.33°
Wind	u and v wind component	ERS2 (APDRC)	Quarterly Aug 1998 to May 1999	1° x 1°
	u and v wind component	QuickSCAT (APDRC)	Quarterly Jan 2000 to Dec 2008	0.25° x 0.25°
	u and v wind component	ASCAT (APDRC)	Quarterly Jan 2009 to Dec 2015	0.25 °x 0.25°
Dipole Mode Index	Dipole Mode Index	Bureau of Meteorology, Australian Government	Quarterly 1998 to 2015	NIL
Southern Oscillation Index	Southern Oscillation Index	Bureau of Meteorology, Australian Government	Quarterly 1998 to 2015	NIL

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Table 2: The fishery datasets used for the study

Data	Source	Period
Gear-wise Indian Oil Sardine landing data	CMFRI, (NMFDC), FRAD	Quarterly 1998-2015
Effort in Unit operations	CMFRI, (NMFDC), FRAD	Quarterly 1998-2015

Table 3: The IPCC – RCP datasets used for the study

Variable	CMIP5 Model	Period	Oceanic grid resolution
Sea Surface Temperature (SST) RCP-4.5, 6.0	GFDL-ESM2M	Monthly 2015, 2030, 2050, 2080	1.0° x 1.0°
Precipitation (Pr) RCP-4.5, 6.0	GFDL-ESM2M	Monthly 2015,2030, 2050,2080	1.0° x 1.0°
Chlorophyll-*a* concentration (Chl-*a*) RCP-4.5, 6.0	GFDL-ESM2M	Monthly 2015,2030, 2050,2080	1.0° x 1.0°
Sea Surface Salinity (SSS) RCP-4.5, 6.0	GFDL-ESM2M	Monthly 2015,2030, 2050,2080	1.0° x 1.0°
Sea Surface Height (SSH) RCP-4.5, 6.0	GFDL-ESM2M	Monthly 2015,2030, 2050,2080	1.0° x 1.0°
pH RCP-4.5, 6.0	GFDL-ESM2M	Monthly 2015,2030, 2050,2080	1.0° x 1.0°

Table 4: Observed extreme climatic events during 1998 to 2015
(Source: www.bom.gov.au)

El Niño	La Niña	Positive IOD	Negative IOD
1997-1998	1998-2001	2006	1998
2002-2003	2007-2008	2012	2010
2006-2007	2008-2009	2015	2014
2009-2010	2010-2012		
2015-2016			

3.3.1 Temperature

Simple Ocean Data Assimilation (SODA v2.2.4) Model: The temperature data at 5-50 m depth for the study period from January 1998 to December 2015 was freely available from Asia-Pacific Data Research Center (APDRC) website (http://apdrc.soest.hawaii.edu/). Simple Ocean Data Assimilation (SODA) are assimilated reanalysis oceanographic data sets they given level 4 (L4) data. SODA provided gridded reanalysed data for different variables for global ocean. 0.5^0x 0.5^0 was the spatial resolution of SST data and unit is degree Celsius (°C), downloaded in the format of a Network Common Data Form (NetCDF) (Giese and Ray, 2011).

3.3.2 Rainfall

CMAP (CPC MERGED ANALYSIS OF PRECIPITATION): CMAP refers to a collection of precipitation data sets, 2.5°x2.5° was the spatial resolution. This data set was constructed from an analysis of gauge data and satellite-derived precipitation estimates. Precipitation data for the study period were collected from an open access source https://climatedataguide.ucar.edu in NETCDF format and milligram per meter cube (mg/m^3) was the unit.

3.3.3. Chlorophyll-*a* concentration (Chl-*a*)

The Ocean Color Climate Change Initiative (OC-CCI) chlorophyll product was an admixed form of MODIS-Aqua, SeaWiFS, VIIRS and MERIS data sets. The data for chlorophyll-*a* concentration was collected from the OC-CCI website http://www.esa-oceancolour-cci.org/. It was a level 2 (L2) data with 0.04° x 0.04° spatial resolution, milligram per meter cube (mg/m^3) was the unit and downloaded in NetCDF format (Sathyendranath *et al.*, 2016).

3.3.4 Sea Surface Height Anomaly (SSHA)

Archiving, Validation and Interpretation of Satellite Oceanographic (AVISO) was an open source, the data for SSHA was downloaded from https://www.aviso.altimetry.fr/en/home.html website in NetCDF format. The spatial resolution of the data was 0.33° x 0.33° and unit was cm.

3.3.5 Wind

The magnitude of wind speed was calculated by using the following formulae.

$$W=\sqrt{U^2+V^2} \text{ ------------(1)}$$

Where U and V are the zonal and meridional components of wind speed and W was the magnitude of wind speed.

The zonal and meridional components of surface wind along the EAS are collected from several sources are outlined below.

3.3.5 a. European Remote Sensing Satellite (ERS 2)

APDRC was a suitable open source for European Remote Sensing Satellite generation 2 (ERS 2), It was a microwave scatterometer data and collected from the website of APDRC. The data for the study period from 1998 to 1999 was extracted from ERS 2. The spatial resolution of ERS 2 data was 1° x 1°, unit was meter per second (m/s) and data were obtained in the format of NetCDF.

3.3.5 b. QuikSCAT

Monthly gridded Quik Scatterometer (QuikSCAT) satellite surface wind data for the study period January 2000 to December 2008 were obtained from APDRC. QuikSCAT satellite included a specialized microwave radar that measures sea surface wind in all weather conditions. 0.25^0x 0.25^0 was the spatial resolution, meter per second (m/s) was the unit and NetCDF was the data received format.

3.3.5 c. Advanced Scatterometer (ASCAT)

Monthly gridded Advanced Scatterometer (ASCAT) surface wind data from January 2009 to December 2015 were collected from APDRC. ASCAT given level 3 data of surface wind with 0.25° x 0.25° spatial resolution and the unit was meter per second (m/s) (Bentamy and Fillon, 2012). The collected format of the data was NetCDF.

3.3.6 Dipole Mode Index

SST anomaly between the western equatorial Indian Ocean (50E-70E and 10S-10N) and the south-eastern equatorial Indian Ocean (90E-110E and 10S-0N) was indicated the strength of the Indian Ocean Dipole (IOD). The Dipole Mode Index (DMI) can be positive or negative. When the DMI was positive then, the phenomenon was referred to as positive IOD and when it was negative, it was negative IOD. The data were collected from Australian Bureau of Meteorology, National Climate Centre.

3.3.7 Southern Oscillation Index

The Southern Oscillation Index (SOI) was the pressure differences between the Central Pacific ocean (Tahiti Island, French Polynesia) and Eastern Pacific ocean (Darwin, Australia), SOI was a measure of the intensity of El Niño and La Niña events. The data was obtained from the Australian Bureau of Meteorology, National Climate Centre and SOI can be calculated as follows;

$$\mathrm{SOI} = 10 \times \frac{(\mathrm{Pdiff}-\mathrm{Pdiffav})}{\mathrm{SD(Pdiff)}} \text{ ------------------- } (2)$$

Where;

Pdiff = (average Tahiti MSLP for the month) − (average Darwin MSLP for the month)

Pdiffav = long-term average of Pdiff for the month in question

SD (Pdiff) = long-term standard deviation of Pdiff for the month in question.

The SOI ranges calculated by multiplying with 10, the given ranges from about -35 to +35 and thus the value of SOI will become as a whole number. The negative values below −7 of the SOI indicated the El Niño event. The positive values above +7 denoted the La Niña event. All the values between +7 and −7 stated the neutral conditions.

3.3.8 Upwelling Index (UI)

Ekman mass transport was computed from the alongshore component of wind was used as an index for measuring the intensity of upwelling along the EAS. Estimation of Ekman Mass Transport was done by the method of Shah *et al.*, 2015.

$$M_v = \tau_y / f \text{ ----------- } (3)$$

Where, M_v was the Ekman mass transport, τ_y was the wind stress due to the alongshore component of wind and f was the Coriolis parameter ($2\Omega\sin\varphi$); Ω was the angular velocity of earth and φ was the latitude.

3.3.9 RCP data

RCP datasets for environmental variables such as SST (°C), precipitation (mm/day), chlorophyll-*a* concentration (mg/m^3), sea surface salinity (psu), sea surface height (cm) and pH (unit) were downloaded from open source https://esgf-node.llnl.gov/search/esgf-llnl/. The RCP 4.5 and 6.0 are the intermediate scenarios used in modeling studies and the variables selected from NOAA-

Geophysical Fluid Dynamics Laboratory Earth System Model Version 2M (GFDL-ESM2M). It was a Coupled Model Intercomparison Project Phase5 (CMIP5) model. 1.0° x 1.0° was the oceanic grid resolution and r1i1p1 was the ensemble of GFDL-ESM2M. The data for each variables in the given years 2015, 2030, 2050 and 2080 respectively collected in the format of NetCDF and unit was watts per square meter (w/m^2).

3.4 SOFTWARE USED

3.4.1 Ferret v6.93

Ferret was ultimately designed to meet the needs of oceanographers and meteorologists. It was quite flexible to use in Linux-based operating systems, which will be helpful to manage, visualize and analyse large and complex datasets. In ferret, we can able to define new variables and mathematical expressions, which can create high-quality images for publication purposes like line plots, scatter plots, line contours, filled contours, raster output, vector output, polygons, 3D wireframes and wide variety of map projections.

3.4.2 R v3.6.0, RStudio v1.1.442, CRAN

R runs on a wide variety of Linux-based platforms, MacOS and Windows. It was an extensively used free software environment and language for statistical computing and graphics, useful in wide range of statistical and graphical techniques: statistical tests, linear and nonlinear modelling, time series analysis, classification, clustering, etc.

RStudio was support to work with R interactively and user-friendly, it was a freely accessible Integrated Development Environment (IDE) for R, useful for making publication-quality graphs.

CRAN store the identical, up-to-date, versions of code and documentation for R and it was a network of ftp and web servers around the world.

3.4.3 Excel 2013

Microsoft Excel (MS Excel) was utilized in various calculations, statistical analysis, graphing, charting etc. Excel able to access the data from external sources via Microsoft's Dynamic Data Exchange (DDE). MS Excel is a largely adopted spreadsheet developed by Microsoft and it compatible with Windows, MacOS, Android and iOS.

3.5 METHODOLOGY

3.5.1 a. Multi-Gear Mean Standardization Method (MGMS)

The quarter-wise fish landing data of Indian Oil Sardine and corresponding gear-wise effort from 1998 to 2015 was collected from the National Marine Fishery Resources Data Centre (NMFDC), Central Marine Fisheries Research Institute (CMFRI) and used for the study. The CPUE was derived by using landing data and gear-wise fishing effort.

CPUE was standardized by using the MGMS methodology proposed by Gibson-Reinemer *et al.*, 2016. The main steps of the standardization procedure are;

i. Calculating CPUE

$$c_{ij} = TCj\ /e \text{ ----------------- } (4)$$

where;

c_{ij} - CPUE of species 'i' in observation 'j'

TCj - Total catch of all 'i' species in each observation 'j'

e - Effort of the gear

ii. Calculating the mean standardized catch

$$MSC_{ij} = (c_{ij}\ /e)\ /\ TC\ mean\ /e \text{ ----------------- } (5)$$

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where;

MSC_{ij} - Mean standardized catch of species 'i' in observation 'j'

c_{ij}/e - CPUE of species 'i' in observation 'j'

To standardize the data for each gear, the CPUE of species 'i' in observation 'j' (c_{ij}/e) was divided by the mean/average of total CPUE across all observations. The statistical procedures for standardization was done by using the statistical computing environment R, Comprehensive R Archive Network (CRAN) and Microsoft Excel.

3.5.1 b. Models for predicting the Indian Oil Sardine biomass

The standardized CPUE (SCPUE) was used as a proxy for biomass of Indian Oil Sardine. SCPUE which spans from 1998 to 2013 was used for building the model and data pertaining to the 2014 and 2015 was used for model validation. The variables such as chlorophyll-*a*, upwelling index, SST, precipitation, SLA and wind speed were used as explanatory variables. A regression model with ARIMA noise are used for modeling the SCPUE time series of Indian Oil Sardine. ARIMA modeling was one of the most popular traditional method, fitted to abundance time series and useful in forecasting (Zhang, 2003; Zuur and Pierce, 2004). The development of ARIMA models are based on the Box-Jenkins methodology (1976).

The multicollinearity of time series data were tested by using the Variance Inflation Factor (VIF). In the presence of multicollinearity, the effect of a single explanatory variable cannot be identified. If one variable exhibited the highest VIF value it had high multicollinearity. A maximum VIF value above 10, it affected the least square estimates (Kutner *et al.*, 2005).

Stationarity was an essential condition in the ARIMA model building. For a stationary time series, its statistical characteristics such as the mean and the autocorrelation structure are constant over time. The data used were examined for the presence of trend and heteroscedasticity. The differencing was done for removing the trend and stabilize the variance of non-stationary series (Zhang, 2003). The Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test by Kwiatkowski *et al.*, (1992) was used to determine the stationarity. In the relationship between two-time series (y_t and x_t), the series y_t may related to the past lags of the x-series. The cross-correlation function (CCF) was help to identify the lags of the x variable that might be useful predictors of y_t. The relationship between two-time series was determined by using CCF.

3.5.2 Regression model with ARIMA noise

A regression model with explanatory or independent variables defined as

$$Y_t = \beta_0 + \beta_1 X_{1,t} + \beta_2 X_{2,t} + \beta_3 X_{3,t} + \beta_4 X_{4,t} + \beta_5 X_{5,t} + N_t \text{ ----------(6)}$$

Where Y_t was a linear function of the five predictor variables ($X_{1,t},\ldots,X_{5,t}$) and N_t was usually assumed to be an uncorrelated error term (white noise).

When error terms are autocorrelated, it can be appropriately defined by an ARMA (1,1) process. The error series N_t was assumed to follow an ARIMA model. If N_t follows an ARIMA(1,1,1) model, expressed in the following form

$$Y_t = \beta_0 + \beta_1 X_{1,t} + \beta_2 X_{2,t} + \beta_3 X_{3,t} + \beta_4 X_{4,t} + \beta_5 X_{5,t} + N_t \text{ ----------(7)}$$

Where

$$(1-\varphi_1 B-\varphi_2 B^2-\varphi_3 B^3-\varphi_4 B^4 - \varphi_5 B^5)\, N_t = (1-\theta_1 B-\theta_2 B^2 - \theta_3 B^3- \theta_4 B^4 - \theta_5 B^5)\, a_t \text{ -------(8)}$$

Where a_t was assumed to be white noise.

When substituting the error term into the regression equation given

$$Y_t = \beta_0+\beta_1 X_{1,t}+\beta_2 X_{2,t}+\beta_3 X_{3,t}+\beta_4 X_{4,t}+\beta_5 X_{5,t} + \frac{(1-\theta_1 B-\theta_2 B^2-\theta_3 B^3-\theta_4 B^4-\theta_5 B^5)a_t}{(1-\varphi_1 B-\varphi_2 B^2-\varphi_3 B^3-\varphi_4 B^4-\varphi_5 B^5)} \text{-----(9)}$$

The model had two error terms, the error from the regression model (N_t) and the error from the ARIMA model (a_t). Only the ARIMA model errors are assumed to be white noise.

The Akaike Information Criterion (AIC) values are estimated for the models and AIC values are used to determine the best predictors. The procedure was repeated for all subsets of predictors and the model with the lowest AIC value had the best goodness of fit. Until chose the best model with the lowest AIC value used for the prediction.

3.5.3 ARIMA Modeling

ARMA model was built on differenced data stated an ARIMA model, where "*I*' indicated the differencing. The ARIMA modeling approach declared a variable as a weighted average of its past values. The model was a combination of an autoregressive (AR) part and a moving average (MA) part. If a variable N_t was modeled as an autoregressive process, AR(p) where N_t can be defined as

$$N_t = C+\varphi_1 N_{t-1} + \varphi_2 N_{t-2} + \ldots .. + \varphi_p N_{t-p} + at \text{ -------(10)}$$

Where C was a constant term, $\varphi\ i$ (i = 1, …, p) are the weights for the autoregressive terms and a_t was a new random term, which was assumed to be normally distributed "white noise".

Used a backshift operator B_i on N_t, can be written as in the following form

$B_i N_t = N_{t-i}$ (i =1,2,…….), this process can be described as

$$N_t = C+\varphi_1 B N_t + \varphi_2 B^2 N_t + \ldots\ldots + \varphi_p B^p N_t + at, \text{ or -------(11)}$$

$$(1-\varphi_1 B-\varphi_2 B^2-\ldots-\varphi_p B^p) N_t = C+at. \text{ -------(12)}$$

The series N_t can also be stated in terms of the random errors of its past values which was a moving average MA(q) model that defined as

$$N_t = C + a_t - \theta_1 a_{t-1} - \theta_2 a_{t-2} - \ldots - \theta_q a_{t-q} \text{ ---------(13)}$$

Where θ_j (j=1,…,q) are the weights for the moving average terms.

Used the backshift operator, this equals

$$N_t = C-\theta_1 Ba_t - \theta_2 B^2 a_t - \ldots - \theta_q B^q a_t + a_t \text{ , or ---------(14)}$$

$$N_t = C+(1-\theta_1 B-\theta_2 B^2-\ldots-\theta_q B^q) a_t. \text{ ---------(15)}$$

It was possible to composed the autoregressive and moving average terms in one equation, leading to an ARMA(p, q) model that expressed as

$$(1-\varphi_1 B-\varphi_2 B^2-\ldots-\varphi_p B^p) N_t = C+(1-\theta_1 B-\theta_2 B^2-\ldots-\theta_q B^q) a_t \text{ -------(16)}$$

Where a_t was assumed to be "white noise".

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RCP Projections for Environmental Variables

4.1.1 Sea Surface Temperature (RCP 4.5)

In order to study the climate change impact in any marine ecosystem, it was relevant to look upon SST as a major oceanographic parameter influenced the marine habitat. We have considered the RCP 4.5 and 6.0 to project SST scenarios to come up with pragmatic values on changes in the south-west coast of India during 2015, 2030, 2050 and 2080. We took the year 2015 as a reference year to compare the observed values and train the model based on validations done.

In each of the three-time slices in comparison with 2015 as a benchmark, SST for RCP 4.5 indicated a minor change in SST. 27.8°C, 28°C, 28.17°C and 29.25°C are the projected mean SST for RCP 4.5 scenario during 2015, 2030, 2050 and 2080 respectively. An increasing trend was observed with a natural gradient during projected years 2030, 2050 and 2080 respectively (Figures 3 and 4). During 2030 and 2050, SST for RCP 4.5 scenario projected a slight increase (0.2°C and 0.37°C) as compared to 2015 whereas an increase of 1.45°C was observed in projections of 2080 relative to the reference year 2015. The observed highest and lowest values for SST are given in Table 5. Table 6 represented the projected values of SST during the peak south-west monsoon (July-August) and north-east monsoon (November-December) for the selected years 2015, 2030, 2050 and 2080 respectively. As compared to 2015, the projected mean SST for the peak south-west monsoon indicated an increase of SST by 0.5°C, 0.7°C and 1.8°C during 2030, 2050 and 2080 respectively. During the north-east monsoon, SST increased by 1.5°C, 0.8°C and 1.75°C in 2030, 2050 and 2080 respectively. In the future, high temperature subsequently can create unfavourable monsoon which may impact the spawning process of one or more related species and induced failure of the associated fishery (Figures 3 and 4).

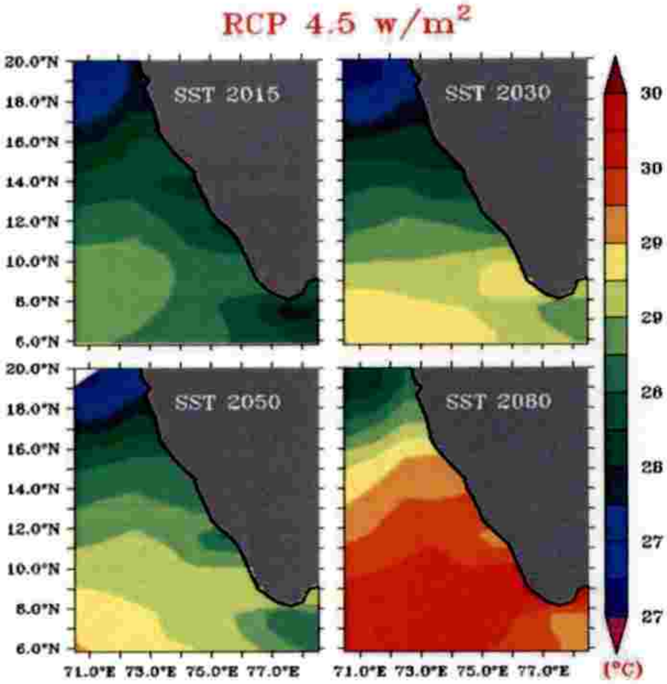

Figure 3: Sea surface temperature spatial projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

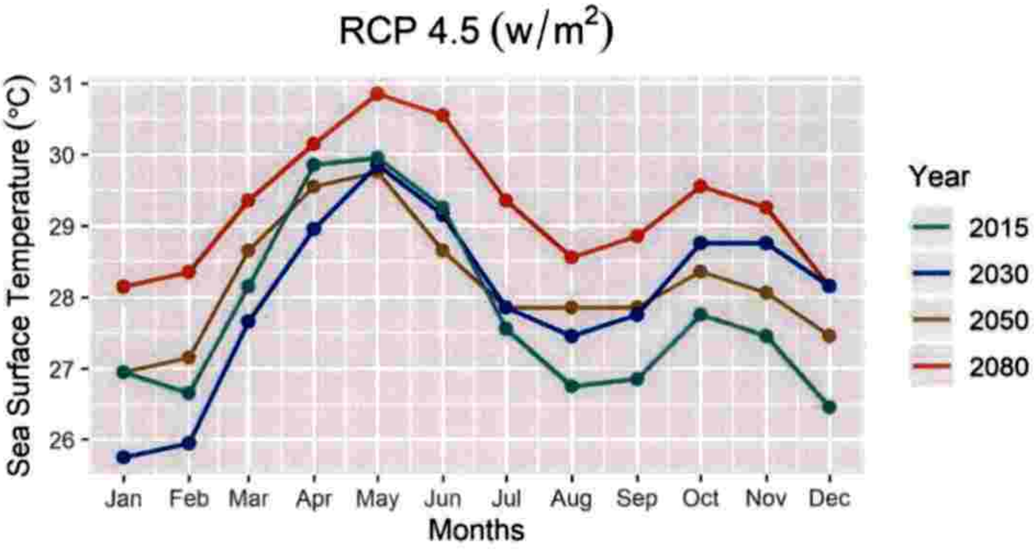

Figure 4: Sea surface temperature projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

Observed mean SST for 2080 was 29.25°C, which significantly exhibited the highest SST projections than the threshold temperature needed for small pelagic fishes. In 2080, the highest projected SST identified in May (30.85°C) may create threatening to natural spawning behaviour.

Table 5: Projected Environmental Variables of RCP 4.5 scenario for 2015, 2030, 2050 and 2080 along the southwest coast of India

		RCP 4.5 Environmental Variables											
		Sea Surface Temperature (°C)		Precipitation (mm/day)		Chlorophyll (mg/m³)		Sea Surface Salinity (psu)		Sea Surface Height (cm)		pH (unit)	
No	Year	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1	2015	May (29.95)	December (26.45)	August (17.30)	February (0.024)	August (0.38)	May (0.14)	May (36.38)	October (35.66)	April (80.35)	October (56.28)	Aug, Sep (8.08)	April (8.04)
2	2030	May(29.85)	January (25.75)	Jun (10.47)	February (0.009)	January (0.36)	May (0.15)	May (36.2)	October (35.62)	May (83.49)	October (64.9)	Feb, Aug (8.04)	May (8.01)
3	2050	May (29.75)	January (26.95)	August (10.82)	December (0.16)	January (0.30)	May (0.16)	March (35.93)	September (35.39)	April (88.86)	October (61.57)	January (8.01)	April, May (7.98)
4	2080	May (30.85)	Jan, Dec (28.15)	July (12.55)	January (0.03)	August (0.26)	May (0.12)	May (36.22)	October (35.39)	May (84.72)	October (68.48)	Aug, Dec (7.97)	May (7.94)

Table 6: Projected Environmental Variables of RCP 4.5 scenario for 2015, 2030, 2050 and 2080 during south-west monsoon and north-east monsoon along the southwest coast of India

		Peak summer monsoon				Peak north east monsoon			
No	RCP 4.5 Environmental Variables	2015	2030	2050	2080	2015	2030	2050	2080
1	Sea Surface Temperature (°C)	27.15	27.65	27.85	28.95	26.95	28.45	27.75	28.7
2	Precipitation (mm/day)	14.44	6.41	10.64	10.11	0.04	0.43	0.21	1.03
3	Chlorophyll (mg/m³)	0.33	0.25	0.27	0.24	0.25	0.17	0.27	0.19
4	Sea Surface Salinity (psu)	36.08	35.92	35.52	35.96	36.03	35.94	35.71	35.72
5	Sea Surface Height (cm)	67.35	71.04	73.77	75.34	68.44	70.74	70.01	75.47
6	pH (unit)	8.07	8.04	8.01	7.97	8.07	8.03	8	7.97

4.1.2 Sea Surface Temperature (RCP 6.0)

Figures 5 and 6 are represented the SST projections for RCP 6.0 during 2030, 2050 and 2080 in comparison with benchmark estimates made for 2015. 27.56°C, 27.76°C, 28.49°C and 29.20°C are the projected SST values during 2015, 2030, 2050 and 2080 respectively. Mean SST during the year 2015 was 27.56°C. Mean SST increased with a magnitude of 0.2°C, 0.92°C and 1.64°C in 2030, 2050 and 2080 respectively as compared to 2015. The projected maximum and minimum values of mean SST for each years are given in Table 7. During the peak south-west monsoon, as compared to the reference year 2015, SST increased by 1.05°C and 1.9°C in 2050 and 2080 respectively. During the peak north-east monsoon, SST increased by 0.65°C, 1.35°C and 2.4°C in 2030, 2050 and 2080 respectively concerning the reference year 2015 (Table 8).

The monthly projections of RCP 4.5 and RCP 6.0 scenarios for SST provided the possible inferences related to temperature variability that occurs along the southwest coast of India. Year 2015 was taken as a benchmark which could be validated with the real-time satellite data and compared to the model-based RCP projections for the future years 2030, 2050 and 2080 respectively (Figures 3, 4, 5 and 6).

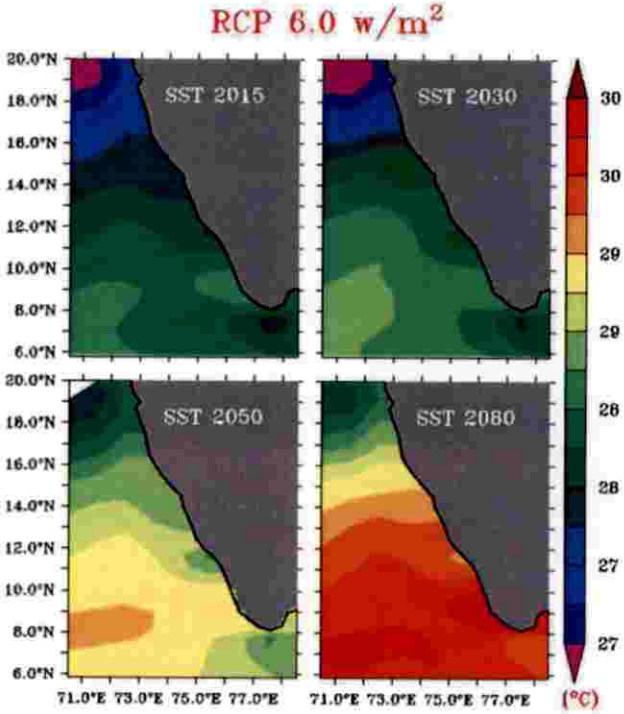

Figure 5: Sea surface temperature spatial projection for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

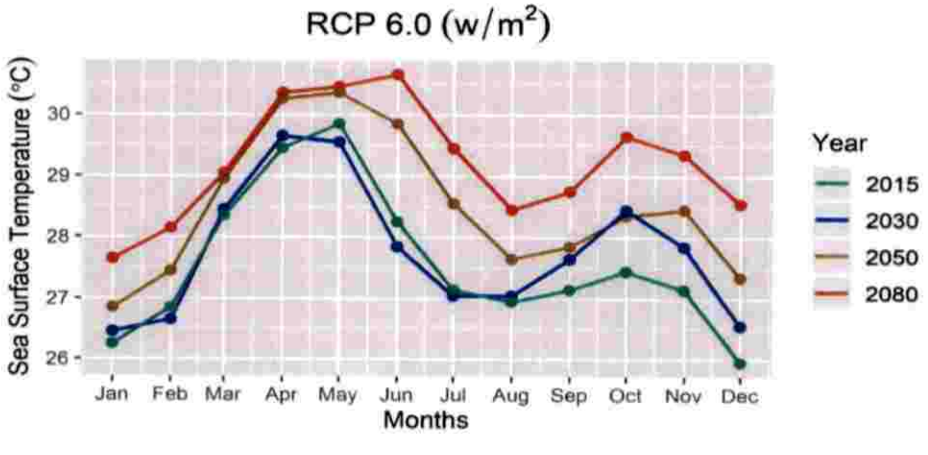

Figure 6: Sea surface temperature projection for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

Table 7: Projected Environmental Variables of RCP 6.0 scenario for 2015, 2030, 2050 and 2080 along the southwest coast of India

		RCP 6.0 Environmental Variables											
		Sea Surface Temperature (°C)		**Precipitation (mm/day)**		**Chlorophyll (mg/m³)**		**Sea Surface Salinity (psu)**		**Sea Surface Height (cm)**		**pH (unit)**	
No	Year	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1	2015	May (29.85)	December (25.95)	Jun (13.01)	February (0.00)	December (0.32)	May (0.14)	April (36.27)	September (35.59)	April (85.87)	October (57.6)	Aug, Sep (8.07)	May (8.04)
2	2030	April (29.65)	January (26.45)	October (11.86)	December (0.03)	December (0.34)	April (0.16)	May (35.3)	October (34.76)	April (93.91)	October (64.6)	January (8.05)	April (8.01)
3	2050	May (30.35)	January (26.85)	August (13.59)	February (0.00)	August (0.33)	May (0.14)	May (35.92)	October (35.34)	Apri (87.53)	October (62.52)	August (8.01)	April (7.98)
4	2080	Jun (30.65)	January (27.65)	September (11.64)	February (0.00)	September (0.28)	May (0.13)	May (36.19)	November (35.38)	February (80.25)	November (66.09)	January (7.94)	April (7.92)

Table 8: Projected Environmental Variables of RCP 6.0 scenario for 2015, 2030, 2050 and 2080 during south-west monsoon and north-east monsoon along the southwest coast of India

No		**Peak summer monsoon**				**Peak north east monsoon**			
	RCP 6.0 Environmental Variables								
1		**2015**	**2030**	**2050**	**2080**	**2015**	**2030**	**2050**	**2080**
2	Sea Surface Temperature (°C)	27.05	27.05	28.1	28.95	26.55	27.2	27.9	28.95
3	Precipitation (mm/day)	8.71	6.7	12.35	8.89	0.12	0.43	0.67	4.38
4	Chlorophyll (mg/m³)	0.3	0.33	0.29	0.24	0.29	0.31	0.25	0.24
5	Sea Surface Salinity (psu)	35.9	35.15	35.67	35.96	35.88	35.02	35.55	35.54
6	Sea Surface Height (cm)	67.39	70.56	72.89	75.84	69.27	72.15	68.19	69.19
	pH (unit)	8.07	8.04	8.01	7.94	8.07	8.04	8.01	7.94

In climate change studies, precipitation was considered as a major variable influenced the marine ecosystem along with SST.

4.1.3 Precipitation (RCP 4.5)

The projections for RCP 4.5 (Figures 7 and 8) indicated expected average precipitation for future years which are 3.48 mm/day, 3.86 mm/day and 4.35 mm/day during 2030, 2050 and 2080 respectively as compared to the reference year 2015 (3.94 mm/day). The precipitation shows a decrease of 0.45 mm/day and 0.07 mm/day in 2030 and 2050 respectively whereas an increase of 0.41 mm/day observed during 2080 as compared to 2015. The highest and lowest precipitation months were given in Table 5. As compared to 2015, the projected mean precipitation values for the south-west monsoon decreased by 8.02 mm/day, 3.80 mm/day and 4.32 mm/day during 2030, 2050 and 2080 respectively. But average precipitation for the peak north-east monsoon increased by 0.39 mm/day, 0.16

mm/day and 0.99 mm/day during 2030, 2050 and 2080 respectively (Table 6). Hence compared to 2015, the projected values of the RCP 4.5 scenario given an increase in predicted north-east monsoon precipitation and a decrease in south-west monsoon during 2030, 2050 and 2080. A regular trend of increases or decreases in precipitation was not observed from 2015 to 2080.

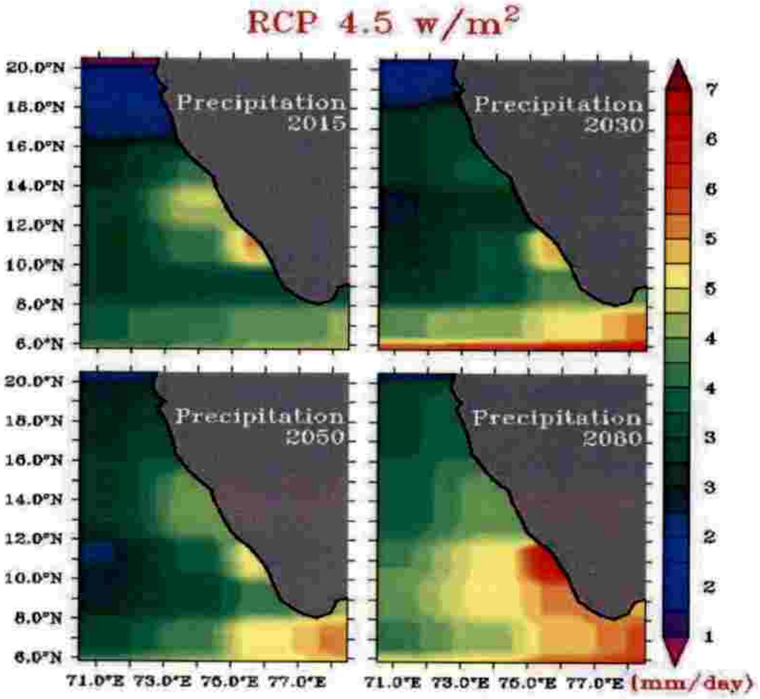

Figure 7: Precipitation spatial projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

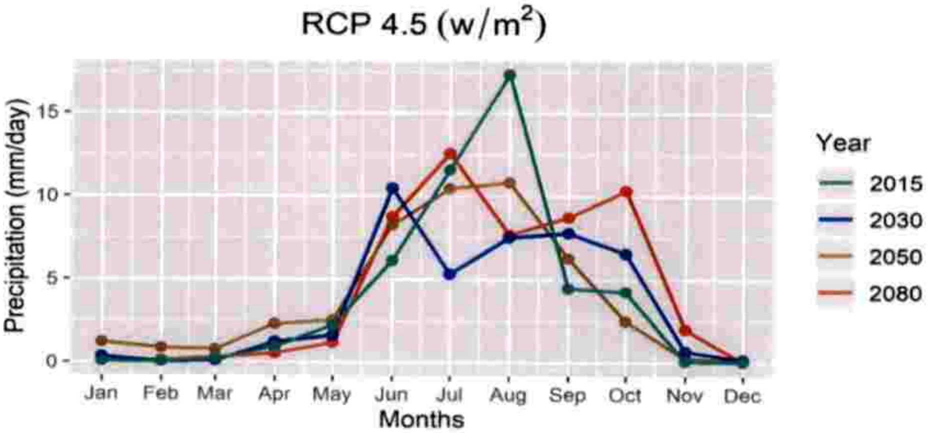

Figure 8: Precipitation projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

4.1.4 Precipitation (RCP 6.0)

4.05 mm/day, 3.73 mm/day, 3.97 mm/day and 4.46 mm/day are the projected mean precipitation values for 2015, 2030, 2050 and 2080 respectively (Figures 9 and 10). The mean precipitation for RCP 6.0 shows a decrease of 0.32 mm/day and 0.07 mm/day during 2030 and 2050 respectively whereas, it showed a slight increase of 0.41 mm/day in 2080. Considering the peak south-west monsoon, mean precipitation values showed a decrease of 2.01 mm/day for 2030, an increase of 3.63 mm/day and 0.17 mm/day in 2050 and 2080 respectively as compared to 2015. The highest and lowest values of precipitation are given in Table 7. During the north-east monsoon, the precipitation values showed an increase of 0.31 mm/day, 0.55 mm/day and 4.26 mm/day in 2030, 2050 and 2080 respectively (Table 8, Figure 10). The spawning of fishes largely seems to occur along the west coast of India during the summer monsoon and post-monsoon months, variations in SST will undoubtedly affect the monsoon. Figures 7, 8, 9 and 10 are given the changes in the monthly projections of precipitation that may affect the spawning potential, survival rate of eggs, larvae and SPF populations in future years.

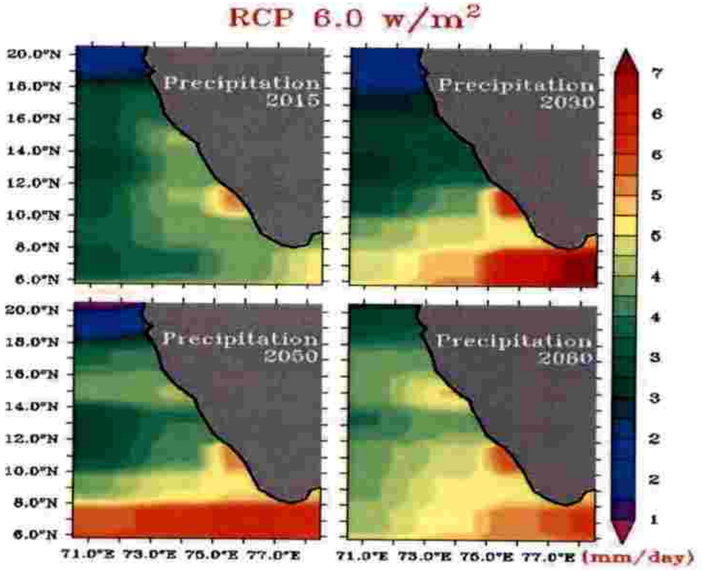

Figure 9: Precipitation spatial projection for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

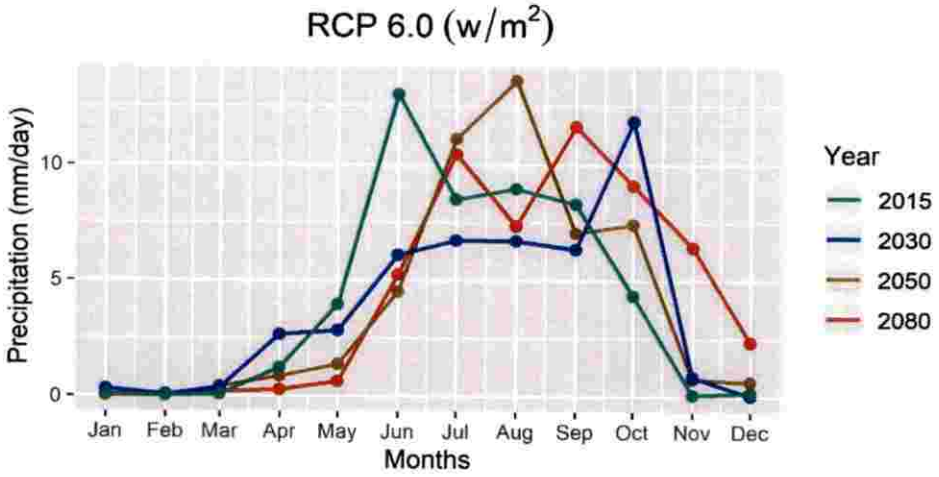

Figure 10: Precipitation projection for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

4.1.5 Chlorophyll-*a* (RCP 4.5)

The projected mean chlorophyll-*a* concentration along the southwest coast of India, for future years 0.23 mg/m^3, 0.24 mg/m^3 and 0.18 mg/m^3 during 2030, 2050 and 2080 respectively as compared to the reference year 2015 (0.24 mg/m^3). The highest and lowest values of chlorophyll-*a* are given in Table 5. The projected values of chlorophyll-*a* for RCP 4.5 are decreased by 0.01 mg/m^3 and 0.05 mg/m^3 during 2030 and 2080 respectively as compared to 2015. During 2050, chlorophyll-*a* slightly increased by 0.003 mg/m^3. (Figures 11 and 12). During peak south-west monsoon, primary production indicated a decrease of 0.08 mg/m^3, 0.05 mg/m^3 and 0.08 mg/m^3 in 2030, 2050 and 2080 respectively. During north-east monsoon, observed a falling trend by 0.07 mg/m^3 and 0.05 mg/m^3 in 2030 and 2080 respectively. A slight increase was observed by 0.01 mg/m^3 in 2050 as compared to 2015 (Table 6).

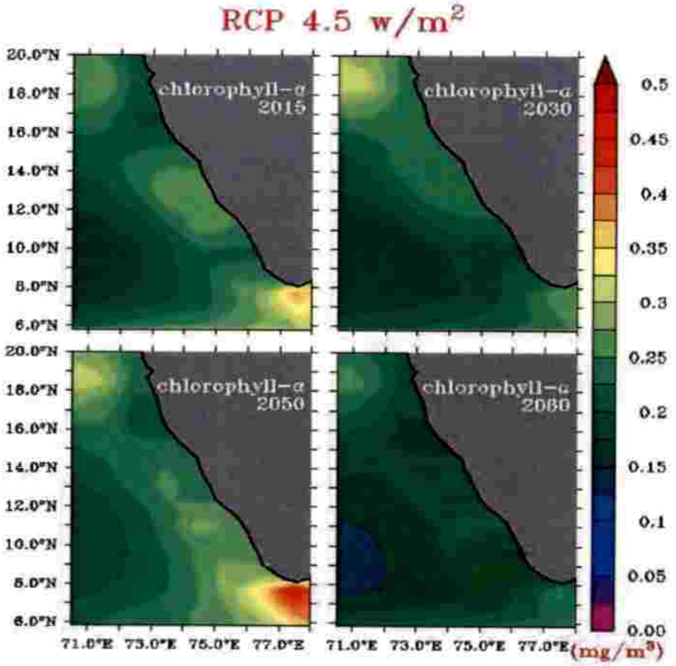

Figure 11: Chlorophyll-*a* concentration spatial projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

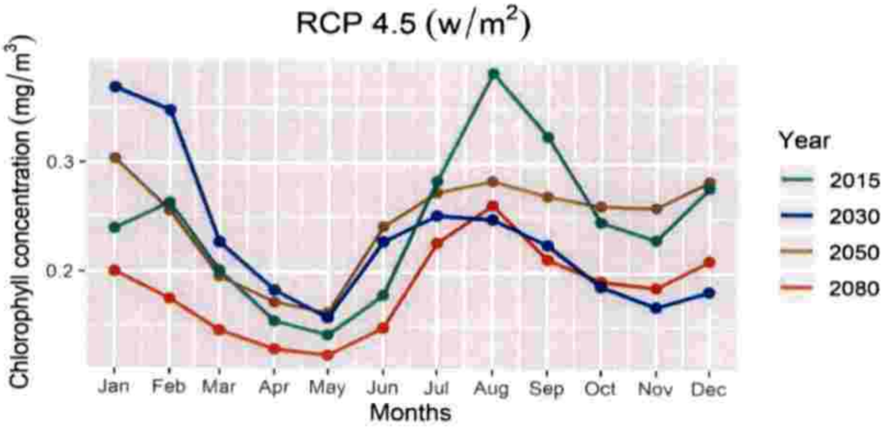

Figure 12: Chlorophyll-*a* projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

4.1.6 Chlorophyll-*a* (RCP 6.0)

Figures 13 and 14 are represented the annual mean chlorophyll-*a* production difference in future years and given the distinction with 2015. 0.25 mg/m^3 was the obtained mean chlorophyll-*a* production in 2015. For future years projected values are, 0.27 mg/m^3, 0.23 mg/m^3 and 0.20 mg/m^3 during 2030, 2050 and 2080 respectively. At the time of south-west monsoon, as compared to 2015 chlorophyll-*a* values showed a decreasing trend by 0.05 mg/m^3 in 2080 whereas a slight increase occurred by 0.03 mg/m^3 in 2030. The projected maximum and minimum values for chlorophyll-*a* was given in Table 7. During north-east monsoon, as compared to 2015 chlorophyll-*a* values are reduced by 0.04 mg/m^3 and 0.05 mg/m^3 in 2050 and 2080 respectively. However, 0.01 mg/m^3 increase takes place in 2030 (Table 8). RCP 6.0 scenario provided generally a decreasing trend in future chlorophyll-*a* concentration by 0.02 mg/m^3 and 0.04 mg/m^3 in 2050 and 2080 respectively. The year 2030 would have a small increase in chlorophyll-*a* by 0.01 mg/m^3 than 2015. Monthly projections of both RCP 4.5 and RCP 6.0 scenarios for chlorophyll-*a* concentration (Figures 11, 12, 13 and 14) conveyed the changes for future years that may influence the migration of small pelagic fishes and their population shifts.

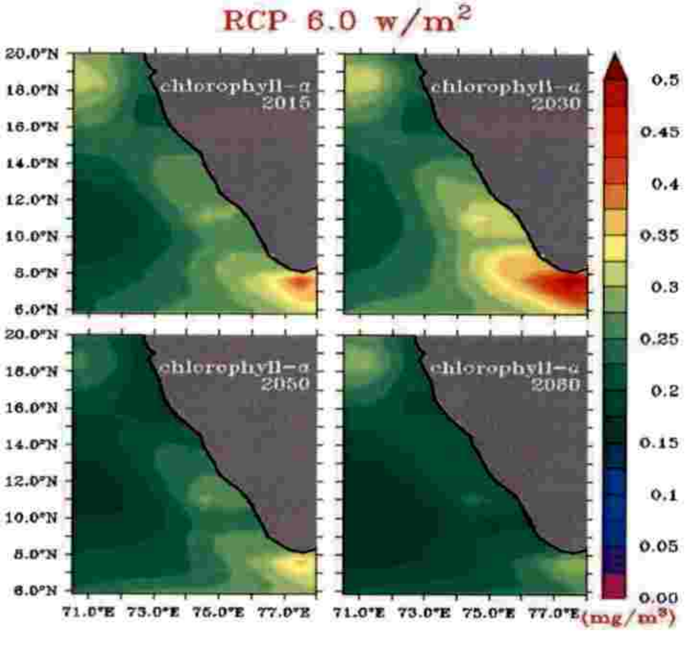

Figure 13: Chlorophyll-*a* spatial projection for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

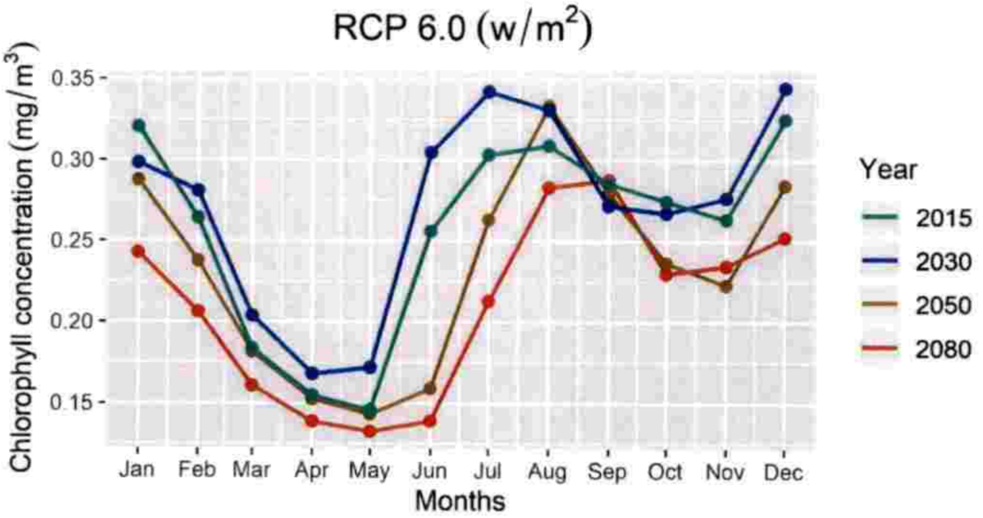

Figure 14: Chlorophyll-*a* projection for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

4.1.7 Sea Surface Salinity (RCP 4.5)

Future projections of SSS for RCP 4.5 scenarios are given in figures 15 and 16 they showed an overall reduction trend of SSS. Projected SSS are 36.12 psu, 35.97 psu, 35.69 psu and 35.95 psu during 2015, 2030, 2050 and 2080 respectively. Projected values of SSS decreased by 0.14 psu, 0.42 psu and 0.16 psu during 2030, 2050 and 2080 respectively as compared to 2015.

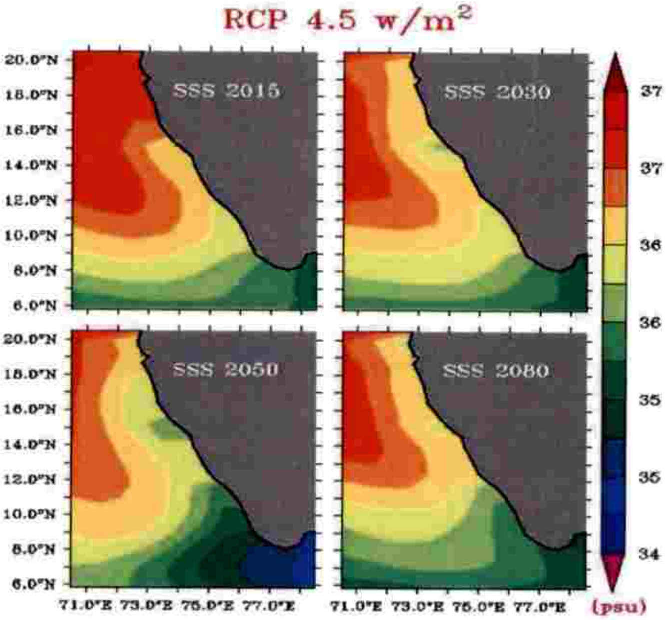

Figure 15: Sea surface salinity spatial projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

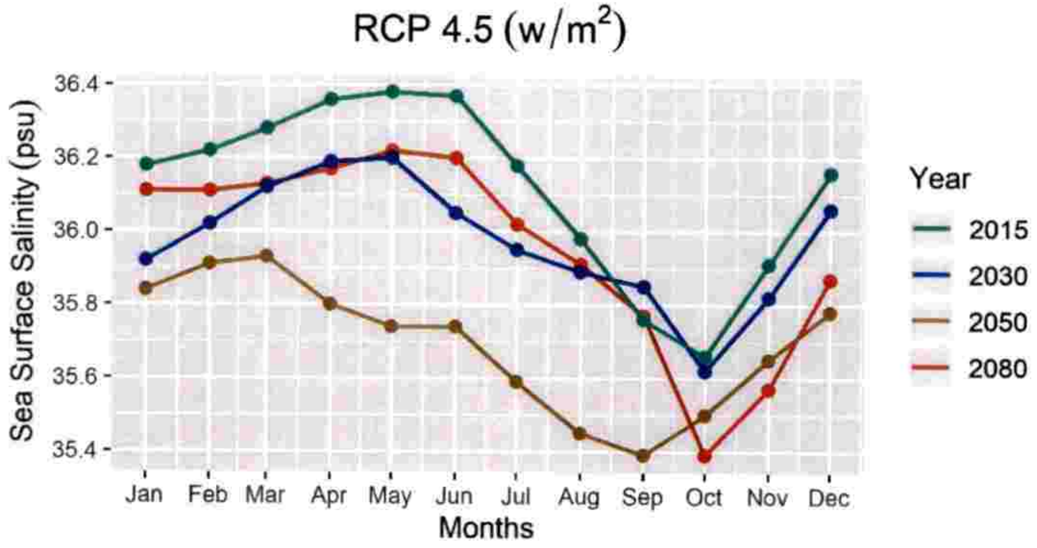

Figure 16: Sea surface salinity projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

The projected values of SSS along the southwest coast of India for RCP 4.5 are given in Table 5. During the south-west monsoon, mean SSS decreased by 0.16 psu, 0.56 psu and 0.11 psu during 2030, 2050 and 2080 respectively as compared to 2015. In the case of north-east monsoon, observed a decreasing trend of mean SSS by 0.09 psu, 0.32 psu and 0.31 psu during 2030, 2050, and 2080 respectively as compared to 2015 (Table 6).

4.1.8 Sea Surface Salinity (RCP 6.0)

Figures 17 and 18 are represented the projections of SSS for RCP 6.0, it was decreased by 0.84 psu, 0.30 psu and 0.09 psu during 2030, 2050 and 2080 respectively as compared to 2015. 35.97 psu, 35.12 psu, 35.67 psu and 35.87 psu are the projected values of mean SSS for the years 2015, 2030, 2050 and 2080 respectively. During the south-west monsoon, mean SSS values are decreased by 0.75 psu and 0.23 psu in 2030 and 2050 respectively. SSS increased by 0.06 cm in 2080 as compared to 2015. The observed maximum and minimum values for SSS RCP 6.0 scenario given in Table 7. During the north-east monsoon, SSS values are decreased by 0.86 psu, 0.33 psu and 0.34 psu during 2030, 2050 and 2080 respectively as compared to mean SSS values of 2015 (Table 8). In this study, the average SSS values are decreased subsequently with 2015 that may create failure of small pelagic fishery (Figures 15, 16, 17 and 18).

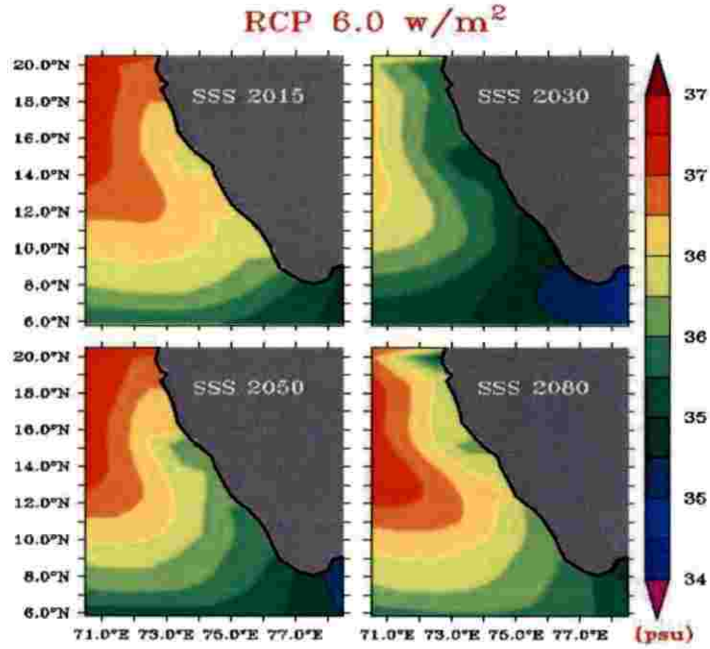

Figure 17: Sea surface salinity spatial projection for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

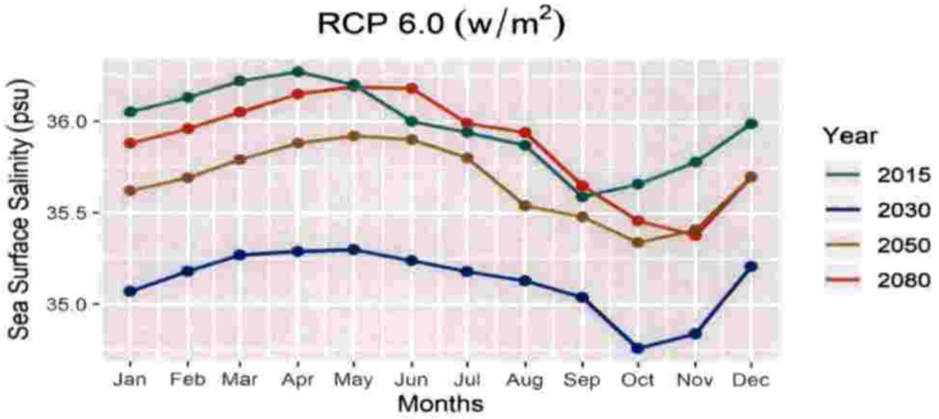

Figure 18: Sea surface salinity projection for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

4.1.9 Sea Surface Height RCP 4.5

Figures 19 and 20 are represented the mean SSH for RCP 4.5 scenario showed an increasing trend of SSH. The projected SSH values are 70.84 cm, 74.70 cm, 75.60 cm and 77.99 cm during 2015, 2030, 2050 and 2080 respectively.

The SSH increased by 3.86 cm, 4.75 cm and 7.14 cm during 2030, 2050 and 2080 respectively as compared to 2015. The projected values for RCP 4.5 scenario given in Table 5. During the south-west monsoon, mean SSH increased by 3.69 cm, 6.41 cm and 7.99 cm during 2030, 2050 and 2080 with respect to 2015. During the north-east monsoon, mean SSH values increased by 2.29 cm, 1.56 cm, 7.03 cm during 2030, 2050 and 2080 as compared to 2015 (Table 6).

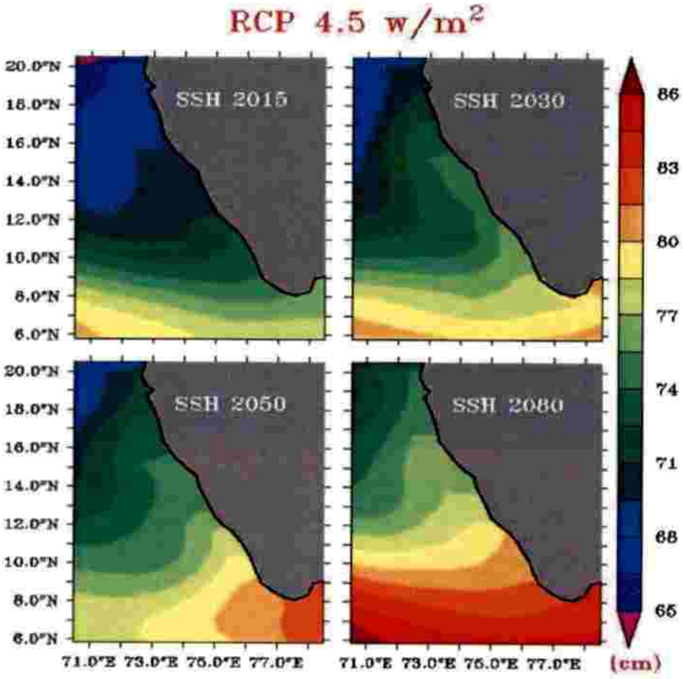

Figure 19: Sea surface height spatial projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

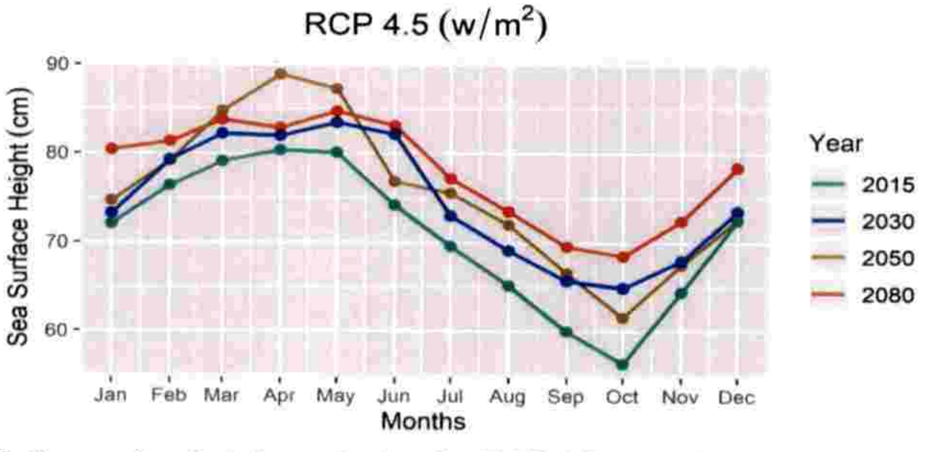

Figure 20: Sea surface height projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

4.1.10 Sea Surface Height (RCP 6.0)

The projected mean SSH values for the RCP 6.0 scenario are 73.25 cm, 78.52 cm, 75.69 cm and 74.89 cm obtained during 2015, 2030, 2050 and 2080 respectively. As compared to 2015, mean SSH values increased by 5.27 cm, 2.44 cm and 1.64 cm during 2030, 2050 and 2080 respectively (Figure 22). The observed highest and the lowest SSH values are given in Table 7. During the south-west monsoon, projected values of SSH are given an increase of 3.16 cm, 5.5 cm and 8.45 cm during 2030, 2050 and 2080 respectively as compared to 2015. Considering the north-east monsoon, mean SSH values showed an increase of 2.88 cm during 2030. The mean SSH decreased by 1.08 cm and 0.08 cm during 2050 and 2080 respectively (Table 8). The present study points out the variation of SSH for 2030, 2050 and 2080 that may influence the SPF production (Figures 19, 20, 21 and 22).

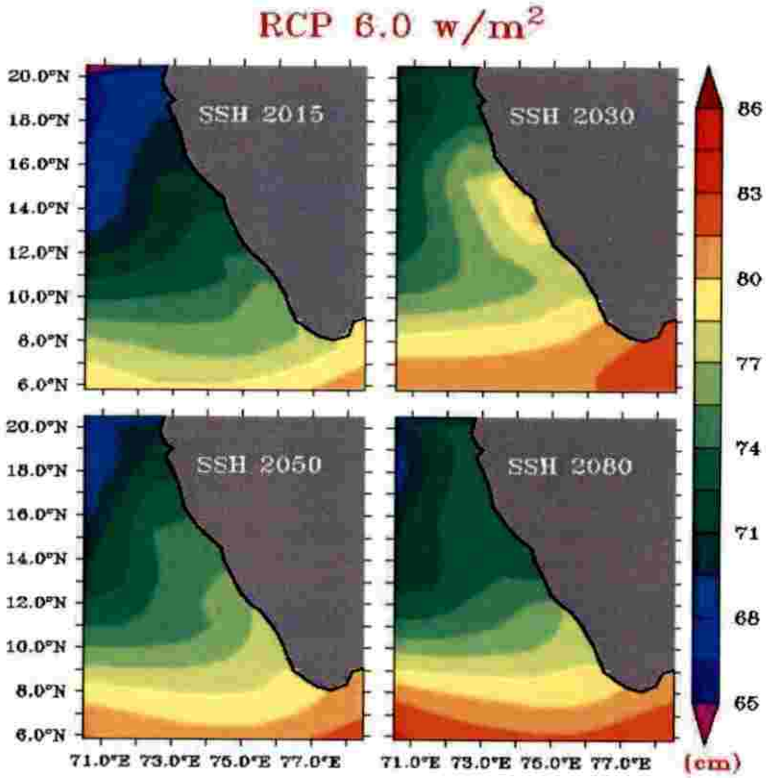

Figure 21: Sea surface height spatial projection for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

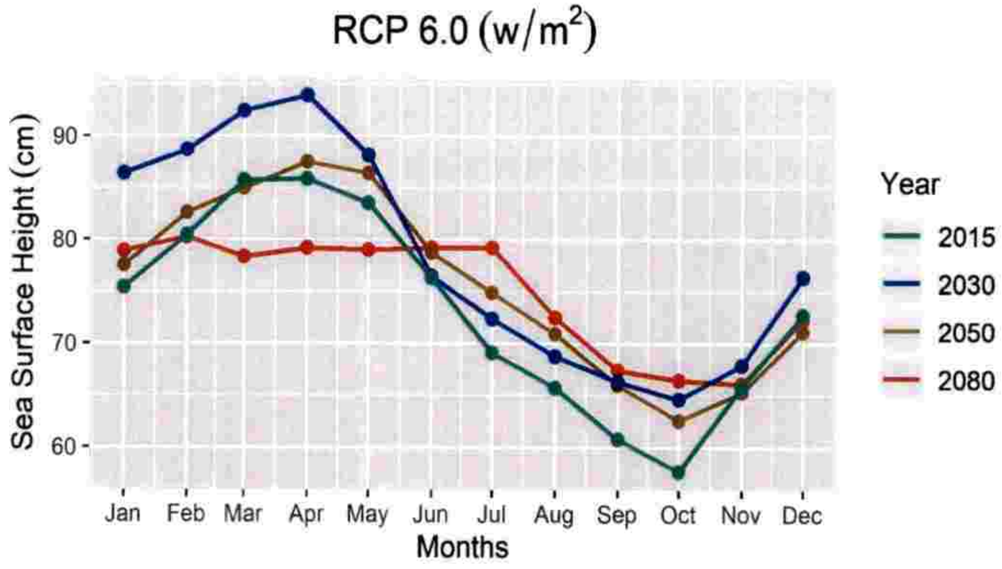

Figure 22: Sea surface height for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

4.1.11 pH (RCP 4.5)

8.06 unit, 8.03 unit, 8.00 unit and 7.96 unit are the projected mean pH values for RCP 4.5 during 2015, 2030, 2050 and 2080 respectively. The mean pH values are given a decrease of 0.03 unit, 0.06 unit and 0.09 unit during 2030, 2050 and 2080 respectively as compared to 2015 (Figures 23 and 24). The projected values for RCP 4.5 are given in Table 5. During the south-west monsoon, projected values are given a decrease of 0.03 unit, 0.06 unit and 0.10 unit during 2030, 2050 and 2080 respectively as compared to the reference year 2015. The projected mean pH values for the north-east monsoon decreased by 0.03 unit, 0.06 unit and 0.10 unit during 2030, 2050 and 2080 respectively (Table 6).

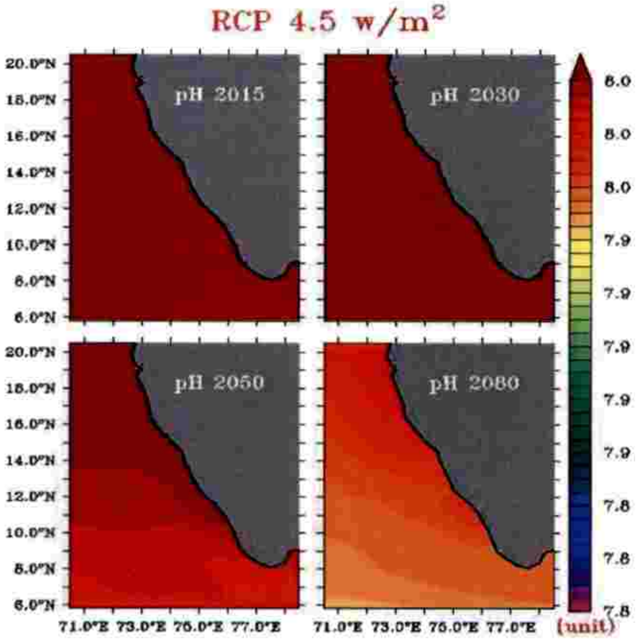

Figure 23: pH spatial projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

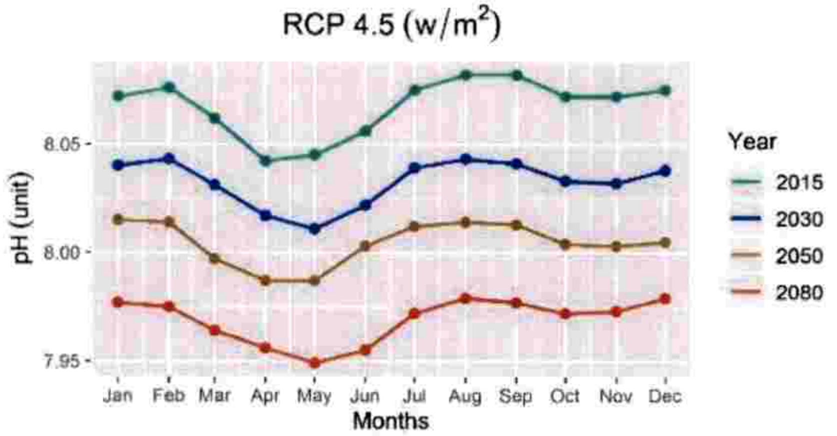

Figure 24: pH projection for RCP 4.5 scenario over the EAS during 2015, 2030, 2050 and 2080

4.1.12 pH (RCP 6.0)

Figures 25 and 26 are represented the pH projections for RCP 6.0. 8.06 unit, 8.03 unit, 8.00 unit and 7.93 unit are the projected values during 2015, 2030, 2050 and 2080 respectively. The mean pH values decreased by 0.02 unit, 0.06 unit and 0.13 unit during 2030, 2050 and 2080 respectively. The projected highest and lowest values of pH are given in Table 7. At the time of south-west monsoon, the projected values of pH are given a decreasing of 0.02 unit, 0.06 unit, and 0.13

unit during 2030, 2050 and 2080 respectively as compared to the reference year 2015. At the time of north-east monsoon, projected values of pH decreased by 0.03 unit, 0.05 unit and 0.13 unit during 2030, 2050 and 2080 respectively (Table 8). The study projected a decreasing trend of pH (Figures 23, 24, 25 and 26) indicated a strengthening of ocean acidification. Low pH may influenced the abundance of small pelagic fishes.

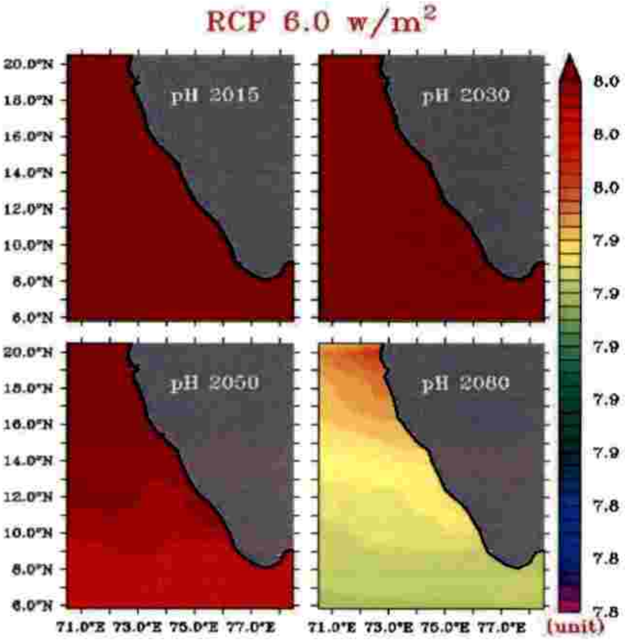

Figure 25: pH projection for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

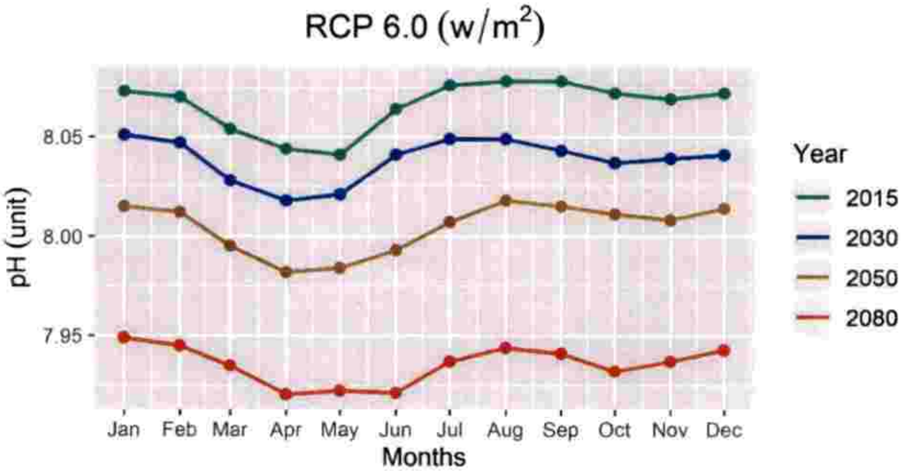

Figure 26: pH spatial projection for RCP 6.0 scenario over the EAS during 2015, 2030, 2050 and 2080

4.2 Time Series Analysis

Based on previous studies (Chidambaram and Menon 1945; Mukundan, 1967; Qasim and Reddy 1967; Sharma 1978; Madhupratap *et al.*, 1996; Yáñez *et al.*, 2008; Vivekanandan *et al.*, 2009), it is evident that the oceanography was influenced the population and abundance of pelagic fishes along the southwest coast region. Seasonal wind circulation patterns and reversal of prevailing winds are making the Arabian Sea an exceptional oceanic region from other oceanic regimes. From May to September, south-westerly winds dominant on the Arabian Sea brings in the south-west monsoon. While during November to February north-easterly winds starts and brings in north-east monsoon.

Climate change played a significant role in biology (feeding, life cycle, reproduction etc.) and physics (migration patterns, behavioural changes etc.) related to fishes and fish catch. The environmental variables such as chlorophyll-*a*, upwelling, SST, precipitation, SLA and wind speed etc. had a crucial influence on the Indian Oil Sardine fishery.

The small pelagic fishes are very small in size, plankton feeders and dwells up to 50 m depth. They are highly vulnerable to the surface and subsurface water column changes due to environmental forcing and climate variability. Indian Oil Sardine was an important species from the west coast region, especially along the southwest coast.

Upwelling was an important phenomenon that made the Arabian Sea more productive. Upwelling brings nutrient-rich cold water from the subsurface to the surface and that region becomes the major accumulation point for fishes. Seasonal occurrence of coastal upwelling and downwelling phenomena are the major reasons for the biological productivity in the coastal regions. Upwelling attains maximum intensity during the south-west monsoon and it can enhance the chlorophyll-*a* productivity. Usually, chlorophyll-*a* concentration had a direct relationship with upwelling intensity and an inverse relationship with SST. Generally, the production of chlorophyll-*a* concentration was higher during the south-west monsoon.

The ocean surface absorbed the radiation from the sun, it heated up and the resultant SST driven various air-sea interactions. The SST anomaly implies an adiabatic cooling and warming atmosphere, changed the climate or weather pattern of the respective region (Shankar *et al.*, 2016). The coupled action of ocean and atmosphere had a great influence on the Indian Oil Sardine fishery. SST was the most important environmental variable that influenced the fish behaviour and biological processes (Chidambaram 1950; Mukundan, 1967). Each species preferred the specific temperature limit for living and reproduction. The temperature above or below of that specific limit would affect the fishery of that region by affecting their spawning time. It was the major reason for the migration of SPF to other suitable region with optimum environmental conditions. The spawning time selection of fishes depended on the effects of bimodal temperature variability. The primary phase of the bimodal temperature variability occurred just before the initiation of spawning season (February to May) that temperature should have some influence on the ready-to-spawn fishes and thus on the annual fishery.

Several previous studies stated that the extreme climatic events such as Indian Ocean Dipole (IOD) and El Niño-Southern Oscillation (ENSO) had a specific influence on marine climate and distribution of fishes (Sharp and McLain, 1993; Yáñez *et al.*, 2008; Sumaila *et al.*, 2011). The temperature of the southwest coast region was modulated by IOD and ENSO. Highest SST coincided with the positive IOD or El Niño or co-occurrence of these events. During La Niña, negative IOD years and co-occurrence of these events the temperature was reduced significantly.

The wind speed was an environmental variable that modulated the larval mortality and distribution of larvae. The upwelling along the southwest coast of India occurred mainly because of the Ekman transport due to the strong equatorward alongshore wind during the south-west monsoon. Wind speed was higher during the south-west monsoon.

4.2.1 Time series analysis of SCPUE of Indian Oil Sardine

The highest SCPUE of Indian Oil Sardine was observed during the 4th quarter of 2013 (84.75) while the lowest SCPUE was obtained in the 3rd quarter of 1998 (0.88) (Table 9). Generally, after 1999 the trend showed an increasing pattern up to 2003. A decreasing of SCPUE occurred during the 3rd quarters of 2013, 2014 and 2015 whereas 4.02, 7.14 and 1.82 are the observed SCPUE values respectively (Figure 27).

The years 1997-1998 were strong El Niño years and the co-occurrence of strong El Niño and negative IOD events are observed in the year 1998 (figure 28). The impact of strong El Niño adversely affected the fishery, this is the major reason for the significant decrease of SCPUE during 1998.

Analysis of the time series of upwelling intensity revealed that the 3rd quarter of 2013 obtained highest upwelling intensity (-781.66 kg/m/s) that caused the highest SCPUE during the 4th quarter of 2013, but in the 2nd quarter (primary peak period of bimodal variability) of 1998 showed low upwelling intensity (-329.66 kg/m/s) because it was a strong El Niño year. The impact of strong El Niño influenced the upwelling intensity and chlorophyll-*a* concentration which causes the lowest SCPUE in the 3rd quarter of 1998 (Figures 31and 32).

Analysis of the time series of chlorophyll-*a* given that the 3rd quarter (peak summer monsoon) of 2013 obtained higher chlorophyll-*a* concentration (1.21 mg/m^3) that might be the cause for the highest SCPUE during the 4th quarter of 2013 but in the 2nd quarter of 1998 obtained low chlorophyll-*a* concentration (0.55 mg/m^3) due to the strong El Niño and that could be the reason for lowest SCPUE in the 3rd quarter of 1998 (Figures 29 and 30).

Similarly, the favorable precipitation (11.41 mm/day) and SST (27.01°C) are observed in the 3rd quarter of 2013 resulted highest SCPUE in the 4th quarter of 2013. On the other hand lowest precipitation (7.51 mm/day) and highest SST (29.59°C) are obtained in the 2nd quarter of 1998 made the lowest biomass of Indian Oil Sardine in the 3rd quarter of 1998 (Figures 33, 34, 35 and 36).

The impact of extreme climatic events and related fluctuations in the SCPUE values were also studied. El Niño, La Niña, positive IOD and negative IOD are the major extreme climatic events occurred during the period 1998-2015. The co-occurrence of climatic events are also observed in this period (Table 4, figure 28). A strong El Niño was observed in the years 1997-1998, this is the major reason for the lowest SCPUE (37.10) in the 1998. The co-occurrence of strong El Niño and negative IOD events are also observed in the year 1998. Similarly, co-occurrence of extreme climatic events influenced the SCPUE values of the years 2006, 2010, 2012 and 2015.

During 2006, co-occurrence of weak El Niño and positive IOD events are influenced the Indian Oil Sardine production whereas low SCPUE value (42.29) was obtained. The co-occurrence of strong La Niña and negative IOD events are provide favourable production, they are observed during 2010 whereas 47.27 was the SCPUE value. During 2012, co-occurrence of strong La Niña and positive IOD events are observed and corresponding high SCPUE value was 67.80, whereas the influence of strong La Niña episode during 2010-2012 was more reflected in the SCPUE value than the influence of positive IOD. A massive reduction for SCPUE of Indian Oil Sardine (31.09) was noticed during 2015 due to the co-occurrence of strong El Niño and positive IOD events. The observed maximum and minimum values of environmental variables and SCPUE are represented in Table 9.

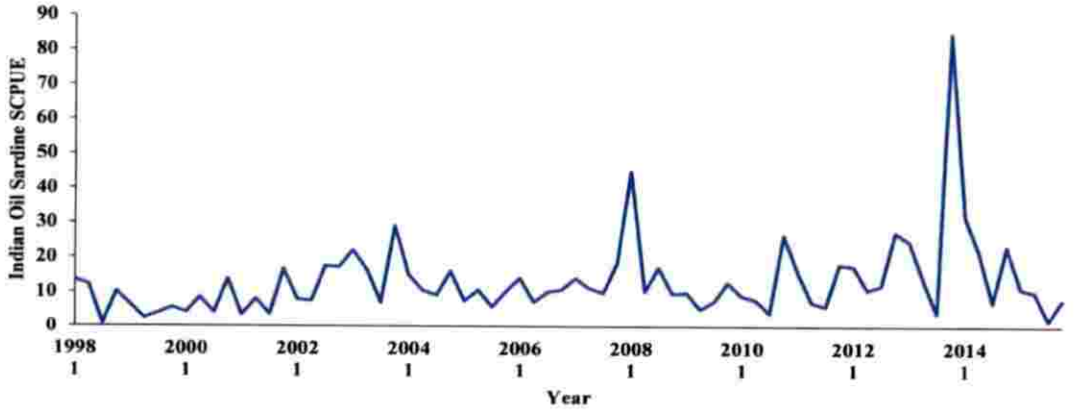

Figure 27: Interannual variability (for the first Quarter) of SCPUE of Indian Oil Sardine along the southwest coast of India

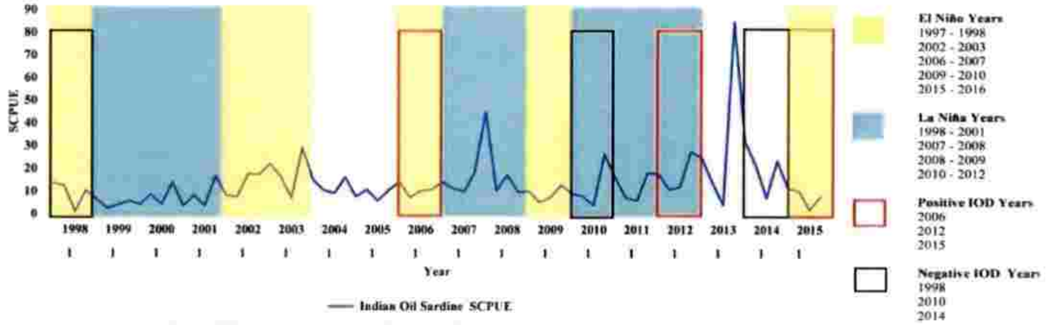

Figure: 28 Impact of extreme events on SCPUE of Indian Oil Sardine along the southwest coast of India

Table 9: Observations of SCPUE and Environmental Variables. 'High' and 'Law' indicate maximum and minimum values in the data.

SCPUE		Environmental Variables											
		Chlorophyll-a (mg/m³)		Upwelling (Kg/m/s)		Sea Surface Temperature (°C)		Precipitation (mm/day)		Sea Level Anomaly (cm)		Wind speed (m/s)	
High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
84.75 (2013, Q_4)	0.88 (1998, Q_3)	2.5 (2004, Q_3)	0.36 (2015, Q_2)	-1055.6 (2005, Q_3)	260 (2003, Q_1)	29.59 (1998, Q_2)	24.24 (2000, Q_3)	14.55 (2007, Q_3)	0.08 (1998,Q_1)	20.4 (2015,Q_1)	2002, Q_3(11.8)	7.4 (2007,Q_1)	1.45 (1999Q_4)

4.2.2 Time series analysis of Chlorophyll-*a* concentration

The highest chlorophyll-*a* concentration was observed in the 3rd quarter of 2004 (2.51 mg/m^3) and the lowest was in the 2nd quarter of 2015 (0.36 mg/m^3). The co-occurrence of strong El Niño and positive IOD events are observed in the year 2015 which is increased the SST and reduced the primary production (Figures 29 and 30, Table 9). From the analysis of time series data of SST and upwelling index, 3rd quarter of 2004 was a period of lowest SST (26.86°C) and highest upwelling (-960.33 kg/m/s), it could trigger the primary production of the period. During the 2nd quarter of 2015, had very strong SST (29.43°C) and lowest upwelling (-211.66 kg/m/s) they lead to the reduction of chlorophyll-*a* concentration during the 2nd quarter of 2015 (Figures 31, 32, 33 and 34). Hence it was understood that the chlorophyll-*a* concentration had a direct relationship with upwelling and inverse relationship with SST.

The primary production related to the south-west monsoon and the highest precipitation increased the production of chlorophyll-*a* concentration. The highest precipitation was obtained during the 3rd quarter of 2004. The lowest precipitation was obtained during the 2nd quarter of 2015 due to the co-occurrence of strong El Niño and positive IOD events. 8.75 mm/day and 6.98 mm/day are the observed precipitation values in the 2004 (3rd quarter) and 2015 (2nd quarter) respectively (Figures 35 and 36). Figure 30 represented the fluctuations in the chlorophyll-*a* concentration and related variations in the SCPUE of Indian Oil Sardine. In the figure 30, significant changes in chlorophyll-*a* concentration and SCPUE values are observed during the period of occurrence and co-occurrence of extreme events. The lowest chlorophyll-*a* concentration and SCPUE was noticed in the 2015 due to the co-occurrence of strong El Niño and positive IOD events.

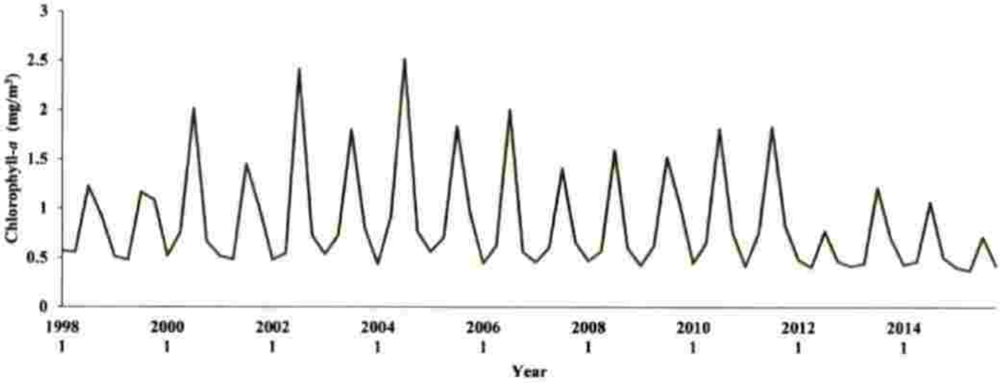

Figure 29: Interannual variability (for the first Quarter) of Chlorophyll-*a* along the southwest coast of India

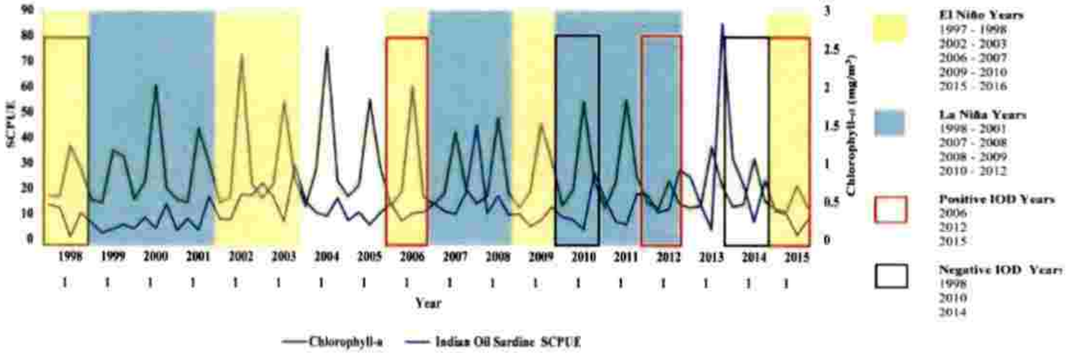

Figure 30: Impact of extreme events on Chlorophyll-*a* variability and its reflection on SCPUE of Indian Oil Sardine along the southwest coast of India

4.2.3 Time series analysis of Upwelling Index

Figure 31 shows an inter-annual variability of upwelling index along the southwest coast of India. The highest upwelling index was observed during the 3rd quarter of the year 2005 (-1055.66 kg/m/s) while the lowest was observed during the 1st quarter of 2003 (260 kg/m/s) (Table 9). On the other hand, the wind speed was high during the 3rd quarter of 2005 (7.28 m/s) and the lowest was obtained during the 1st quarter of 2003 (3.52 m/s) (Figures 39 and 40).

In the time series of chlorophyll-*a* concentration, the 3rd quarter of 2005 had high chlorophyll-*a* concentration (1.83 mg/m^3) and the 1st quarter of 2003 (weak El Niño year) obtained low chlorophyll-*a* concentration (0.53 mg/m^3) (figures 29 and 30).

The time series of SLA showed low SLA values (-10.18 cm) during the 3rd quarter of 2005 and high SLA (9.95 cm) was observed during the 1st quarter of 2003 (Figures 37 and 38) hence, it was clear that upwelling had a direct relationship with the wind speed, chlorophyll-*a* concentration and an inverse relationship observed with the SLA. The variations in the upwelling index affected the SCPUE. Upwelling was influenced by the different extreme climatic events and co-occurrence of extreme events which induced the changes of SCPUE along the southwest coast of India. The impact of different extreme events in the upwelling index and SCPUE variability are given in figure 32.

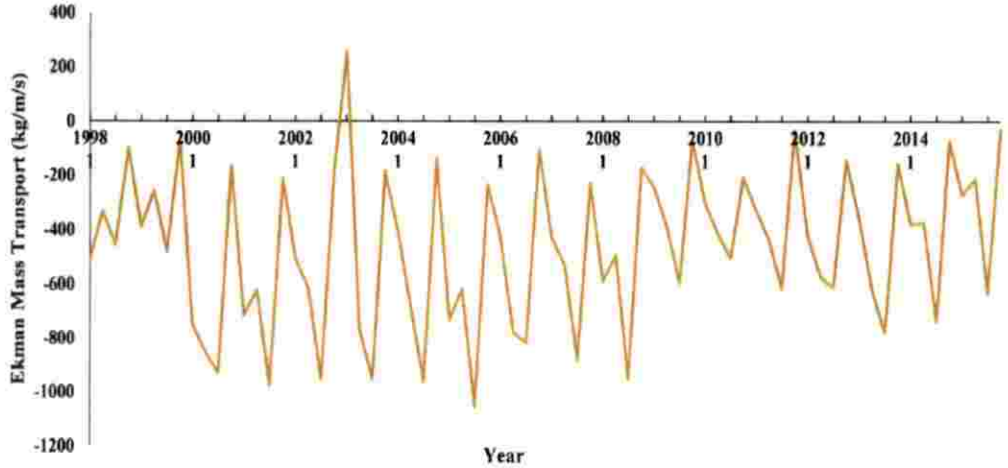

Figure 31: Interannual variability (for the first quarter) of upwelling index along the southwest coast of India

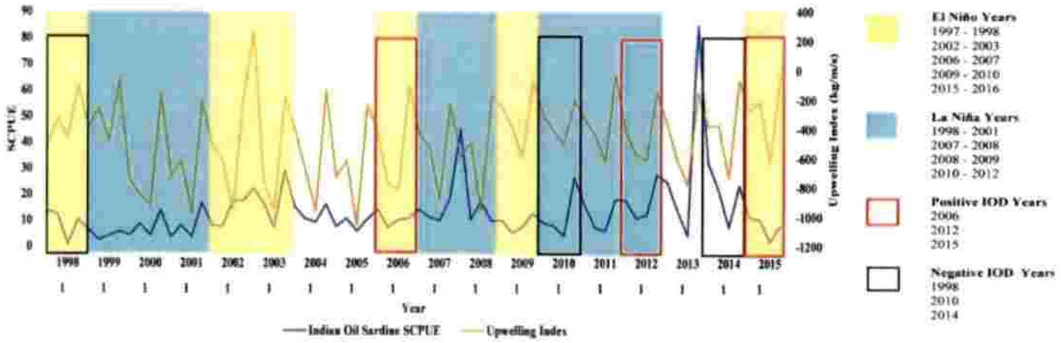

Figure 32: Impact of extreme events on upwelling index variability and its reflection on SCPUE of Indian Oil Sardine along the southwest coast of India

4.2.4 Time series analysis of Sea Surface Temperature

The time series analysis of SST showed that the strong SST (29.59°C) was obtained during the 2nd quarter of 1998 and lowest (24.24°C) was observed during the 3rd quarter of 2000 (figures 33 and 34, Table 9). From the time series analysis of upwelling index and chlorophyll-*a* concentration, it was observed that the 2nd quarter of 1998 had low upwelling intensity (-329.66 kg/m/s) and low chlorophyll-*a* concentration (0.55 mg/m^3) due to the strong El Niño. The year 2000 was a moderate La Niña year whereas 3rd quarter had a high intensity of upwelling (-927.66 kg/m/s) and high chlorophyll-*a* concentration (2.01 mg/m^3) due to the low SST (Figures 29, 30, 31 and 32). During the time series analysis of precipitation, the 2nd quarter of 1998 was given low precipitation (7.51 mm/day) whereas 3rd quarter of 2000 had high precipitation (9.24 mm/day) (Figures 35 and 36).

The years 1997-1998 and 2015 are strong El Niño years; hence the highest SST was obtained which adversely affected the fish production. 1998-2001 are moderate La Niña years and the lowest SST was observed during 1998-2001. The SST had an inverse relationship with upwelling intensity and chlorophyll-*a* concentration. The impact of extreme events or co-occurrence of climatic events in the SST variability are given in figure 34. The significant reduction of SCPUE value was observed during 1998 due to the occurrence of strong El Niño event. The co-occurrence of strong El Niño and negative IOD events are also observed during 1998. Similarly, the co-occurrence of strong El Niño and positive IOD events increased the SST and reduced the SCPUE in the 2015.

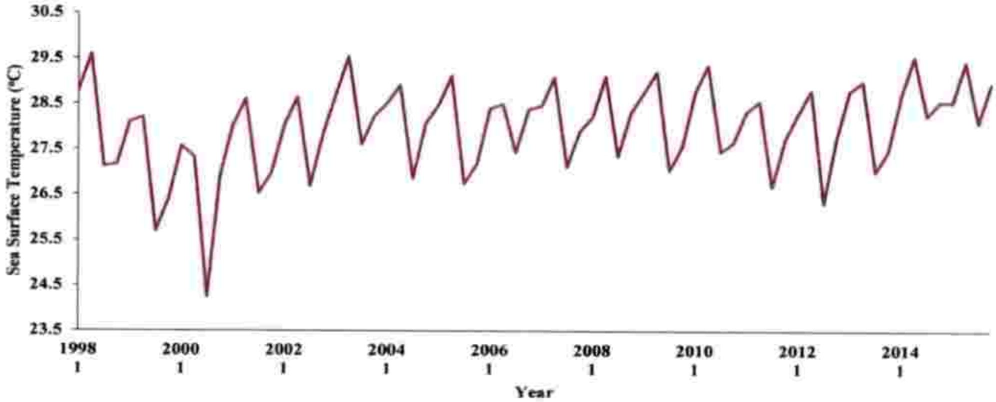

Figure 33: Interannual variability (for the first Quarter) of sea surface temperature along the southwest coast of India

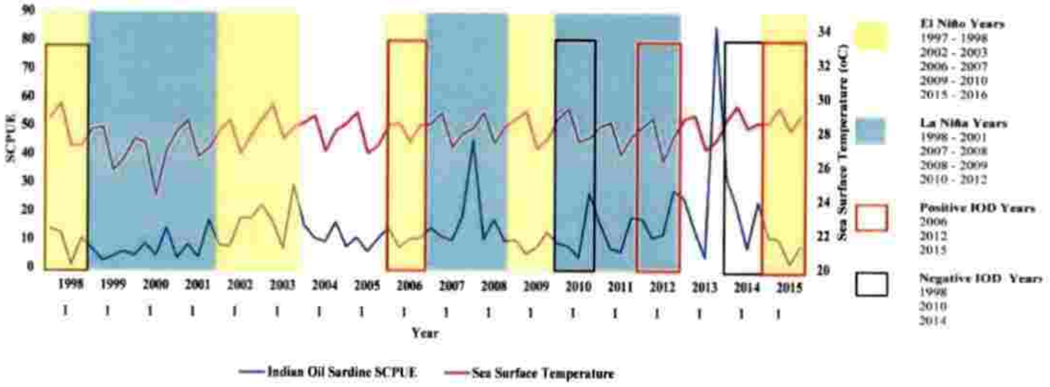

Figure 34: Impact of extreme events on sea surface temperature variability and its reflection on SCPUE of Indian Oil Sardine along the southwest coast of India

4.2.5 Time series analysis of Precipitation

The maximum precipitation of 14.55 mm/day was obtained during the 3rd quarter of 2007 and the lowest of 0.08 mm/day observed during the 1st quarter of 1998 (Figures 35 and 36, Table 9). The impact of extreme events and variations in the precipitation and SCPUE are given in figure 36. When analysing the time series of SST, the highest SST was observed during the 1st quarter of 1998 (28.77°C) due to the occurrence of strong El Niño event. The co-occurrence of extreme events such as strong El Niño and negative IOD are observed during 1998. The lowest SST was obtained during the 3rd quarter of 2007 (27.11°C) it was a weak to moderate La Niña year (Figures 33 and 34). Time series analysis of chlorophyll-*a* was revealed that, during the 3rd quarter of 2007, highest chlorophyll-*a* concentration (1.40 mg/m^3) obtained while lowest chlorophyll-*a* concentration (0.57 mg/m^3) observed during the 1st quarter of 1998 (Figures 29 and 30). The precipitation had an inverse relationship with the SST and a direct relationship with the chlorophyll-*a* concentration whereas fluctuations in precipitation causes the variations in the SCPUE values. The impact of strong El Niño influence the SCPUE values during 1998.

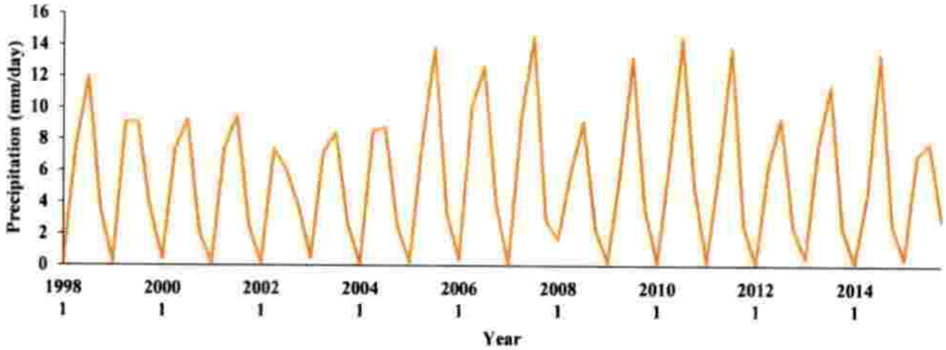

Figure 35: Interannual variability (for the first Quarter) of precipitation along the southwest coast of India

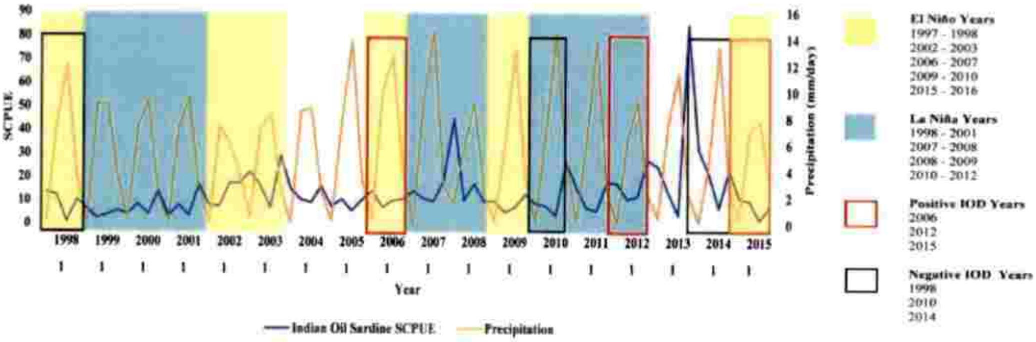

Figure 36: Impact of extreme events on precipitation variability and its reflection on SCPUE of Indian Oil Sardine along the southwest coast of India

4.2.6 Time series analysis of Sea-Level Anomaly

The highest SLA (20.4 cm) was observed during the 1st quarter of 2015 due to the co-occurrence of Strong El Niño and positive IOD which increased the SST (28.54°C). The lowest SST (26.69°C) and SLA (-11.82 cm) were obtained during the 3rd quarter of 2002 (weak El Niño year) (Figures 33, 34, 37, 38 and Table 9). When analysing the time series of upwelling index, it was clear that in the 1st quarter of 2015, the lowest upwelling intensity (-271.33 kg/m/s) occurred whereas highest upwelling (-950.66 kg/m/s) observed during the 3rd quarter of 2002 (Figures 31 and 32). The SLA had an inverse relationship with the upwelling index. The effect of extreme events in the SLA variability and changes of SCPUE of Indian Oil Sardine are given in figure 38. The year 2002 given highest SCPUE than 2015 due to the weak El Niño effect. During 2015, a lowest SCPUE was obtained because co-occurrence of El Niño and positive IOD events are influenced the SCPUE.

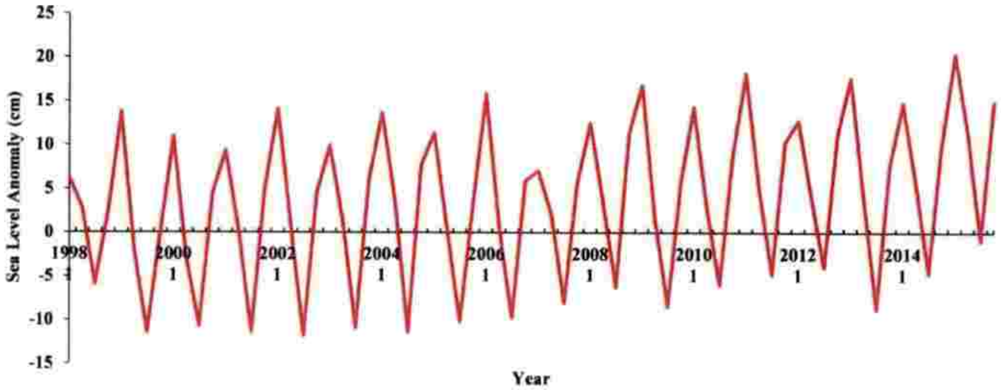

Figure 37: Interannual variability (for the first Quarter) of sea-level anomaly along the southwest coast of India

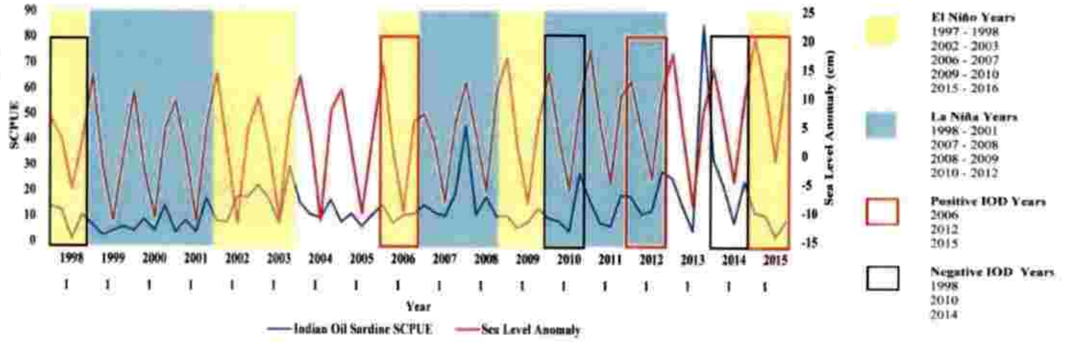

Figure 38: Impact of extreme events on sea-level anomaly variability and its reflection on SCPUE of Indian Oil Sardine along the southwest coast of India

4.2.7 Time series analysis of wind speed

The highest wind speed (7.49 m/s) was obtained during the 3rd quarter of 2007 and the lowest (1.45 m/s) was observed during the 4th quarter of 1999 (Figures 39 and 40, Table 9). When analysing the time series of upwelling index, chlorophyll-*a* concentration, SST, SLA and precipitation were found that, in the

3rd quarter of 2007, low SST (27.11°C) and low SLA (-8.05 cm) observed while high precipitation (14.55 mm/day), high chlorophyll-*a* concentration (1.40 mg/m^3) and high upwelling index (-879.33 kg/m/s) are obtained whereas 2007 was a weak to moderate La Niña year. The year 1999 was a moderate La Niña year, during the 4th quarter of 1999, low SLA (0.09 cm) and SST (26.4°C) were observed whereas weak precipitation (3.58 mm/day), chlorophyll-*a* (1.08 mg/m^3) and upwelling intensity (-65.56 kg/m/s) are obtained (Figures 29, 30, 31, 32, 33, 34, 35, 36, 37 and 38). High SST, SLA and low chlorophyll-*a* concentration are observed along the southwest coast of India due to the downwelling occurred in the winter monsoon. The fluctuations in the wind speed and SCPUE values are observed during the period of co-occurrence of extreme events (figure 40).

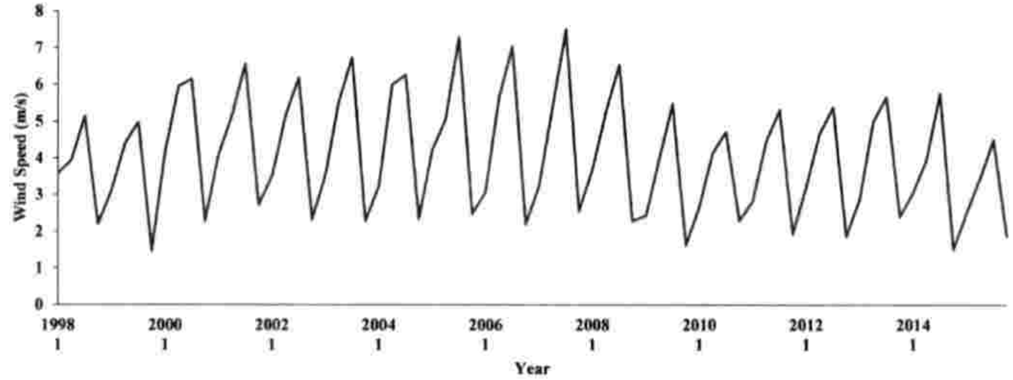

Figure 39: Interannual variability (for the first Quarter) of wind speed along the southwest coast of India

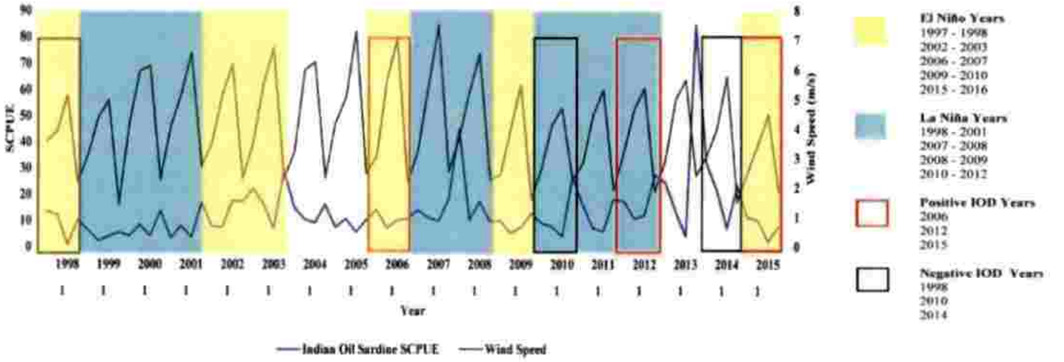

Figure 40: Impact of extreme events on wind variability and its reflection on SCPUE of Indian Oil Sardine along the southwest coast of India

4.3 Model based prediction of Indian Oil Sardine

The results of modeling exercises are dealt in this session. There was no multicollinearity between the environmental variables except for the wind speed. A seasonal pattern was observed in the data and the differencing was done. Cross-correlation was computed for the SCPUE with each explanatory variable. SCPUE series was influenced by the 3 lagged values of upwelling series as well as 2 values of precipitation series. The model with the least AIC value was chosen for the predicting the biomass of Indian Oil Sardine. The computed AIC values are given in Table 10, from this it could be inferred that the combination of SLA and chlorophyll-*a* concentration generated the least AIC value (394.13) and the best fit. The observed and predicted SCPUE values are given in figure 41 whereas substantial differences between the actual and predicted SCPUE values are observed in the different years which may be due to the influences of other environmental variables other than SLA and chlorophyll-*a* concentration.

During the 3rd quarter of 2000, a poor SCPUE value (4.23) was observed because the changes in environmental variables may affected the SCPUE. But the model prediction (15.07) was completely different from the observed. The year 2000 was a moderate La Niña period whereas the impact of La Niña and related changes of environmental variables affected the SCPUE values. A low chlorophyll-*a* concentration (0.75 mg/m^3) of the 2nd quarter of 2000 might have decreased the observed SCPUE values of the 3rd quarter of 2000.

The model given poor prediction (9.57) in the 1st quarter of 2003 and the predicted SCPUE value was less than half of the observed value (21.54). The occurrences of weak El Niño events are observed during the years 2002-2003 and these events were affected the environmental variables. Suitable SST (26.69°C), upwelling (-950.66 kg/m/s) and chlorophyll-*a* concentration (2.41 mg/m^3) of the 3rd quarter of 2002 were influenced the SCPUE value of 1st quarter of 2003 and it may be the major reason for the highest observed SCPUE value in the 1st quarter of 2003.

The peak SCPUE value (48.15) was observed in the 1st quarter of 2008 as a result of favourable environmental conditions occurred in the previous year 2007, but the model prediction (20.83) was poor for this quarter with a value less than half of the observed. The climatic events affected the environmental variables and SCPUE of Indian Oil Sardine. The occurrence of weak to moderate La Niña was observed in the years 2007 and 2008 might have affected the environmental factors. The significant influence of environmental variables in the 3rd quarter of 2007 such as SST (27.11°C), precipitation (14.55 mm/day), upwelling (-879.33 kg/m/s) and chlorophyll-*a* concentration (1.40 mg/m^3) may be the major instigates for the highest SCPUE of 2008.

During the 4th quarter of 2010, predicted SCPUE value (13.80) was less than half of the observed SCPUE value (32.32). The model prediction was poor for this quarter due to the influence of other environmental variables. The effect of environmental variables of previous quarters causing the highest SCPUE in the 4th quarter of 2010. The co-occurrence of strong La Niña and negative IOD events are observed during the year 2010. The impact of co-occurrence of climatic events affected the natural habitat of Indian Oil Sardine and the changes in environmental variables influenced the SCPUE values. The favourable precipitation (14.44 mm/day) was obtained in the 3rd quarter of 2010 whereas suitable SST conditions (27.45°C), upwelling index (-502.33 kg/m/s) and chlorophyll-*a* concentration (1.80 mg/m^3) may cause the highest SCPUE of Indian Oil Sardine in the 4th quarter of 2010.

A highest SCPUE (29.61) was observed during the 4th quarter of 2012, but the model prediction (14.57) was less than half of the observed value. The co-occurrence of strong La Niña and positive IOD events are observed in the 2012. The impact of co-occurrence of extreme events changed the environmental variables. The optimum temperature condition (26.31°C) and upwelling (-611.66 kg/m/s) are obtained in the 3rd quarter of 2012 they may give the highest SCPUE during the 4th quarter of 2012 (figure 41).

The residuals were tested with the Ljung-Box test proposed by McLeod and Li (1983) which showed that the residuals had no remaining autocorrelations and accepted as white noise.

Table 10: Observed AIC values for models

Sl.No.	Variables included in the Models	AIC Value
1	Sea Level Anomaly, Chlorophyll-*a*	394.13
2	Precipitation, Sea Level Anomaly, Chlorophyll-*a*	395.55
3	Sea Surface Temperature, Sea Level Anomaly, Chlorophyll-*a*	396.44
4	Upwelling, Sea level Anomaly, Chlorophyll-*a*	396.6

4.3.1 Prediction

The SCPUE of Indian Oil Sardine for 2014 and 2015 are predicted by using the combination of environmental variables such as SLA and chlorophyll-*a* concentration. The predicted and observed SCPUE values of 2014 and 2015 are given in figure 42 whereas the model captured the patterns of increase or decrease of observed SCPUE values except in some data points. The model exhibit almost near prediction in the 2nd and 3rd quarters of 2014. During the 2nd quarter of 2014, model prediction (18.59) was almost equal to the observed SCPUE value (21.61). Similarly in the 3rd quarter, the model prediction (10.94) was almost near to the observed SCPUE (7.14), but the model exhibit significant difference in SCPUE prediction for 1st and 4th quarters of 2014. During the 1st quarter of 2014, model prediction (14.99) was less than half of the actual SCPUE (31.99). Similarly in the 4th quarter, model prediction (15.53) was completely different from observed SCPUE (23.34).

The suitable environmental variables in the 3rd quarter of 2013 such as precipitation (11.41 mm/day), upwelling (-781.66 kg/m/s), chlorophyll-*a* concentration (1.21 mg/m^3) and SST (27.01°C) may be caused the highest SCPUE

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value of 1st quarter of 2014. Similarly, favourable environmental conditions are obtained during the 3rd quarter of 2014 they affected the SCPUE values of 4th quarter. 2014 was a negative IOD year might have influenced the environmental factors whereas Precipitation (13.42 mm/day), upwelling (-737.33 kg/m/s) and chlorophyll-*a* concentration (1.06 mg/m^3) are the major environmental variables trigger the SCPUE of 4th quarter of 2014.

The year 2015 had a significant importance in the production of Indian Oil Sardine. The co-occurrence of strong El Niño and positive IOD events are observed in the year 2015 they are adversely affected the environmental variables related to the growth of Indian Oil Sardine and a low SCPUE was obtained in this year. During the 1st quarter of 2015, the model prediction (15.87) was almost equal to the observed (11.25). Similarly in the 2nd quarter of 2015, model given almost near prediction (13.03) to the actual SCPUE (10.14).

A remarkable difference was obtained in the prediction of SCPUE values in the remaining quarters (3rd and 4th). During the 3rd quarter of 2015, a meager SCPUE value was observed (1.82) due to the changes in environmental variables. The highest SST (29.43°C), low precipitation (6.98 mm/day), upwelling (-211.66 kg/m/s) and chlorophyll-*a* concentration (0.36 mg/m^3) of 2nd quarter of 2015 were caused the low observed SCPUE value in the 3rd quarter of 2015. But the model prediction (11.13) was totally different from the observed SCPUE. Similarly in the 4th quarter, a low SCPUE value (7.87) was obtained. The effect of low precipitation (7.78 mm/day) and chlorophyll-*a* concentration (0.71 mg/m^3) in the 3rd quarter of 2015 were influenced the SCPUE value of 4th quarter and a poor SCPUE value was obtained but the model given completely different prediction (14.90) of SCPUE value.

In this study, the SCPUE of Indian Oil Sardine was predicted with the time series of six environmental variables. The best model combination of SLA and chlorophyll-*a* concentration was provided the prediction which can be used for decision support tools in the climate change related research and beneficial for preparing effective adaption measures in the management practices of Indian Oil

Sardine. More numbers of environmental variables can be include in the model and they can give better prediction.

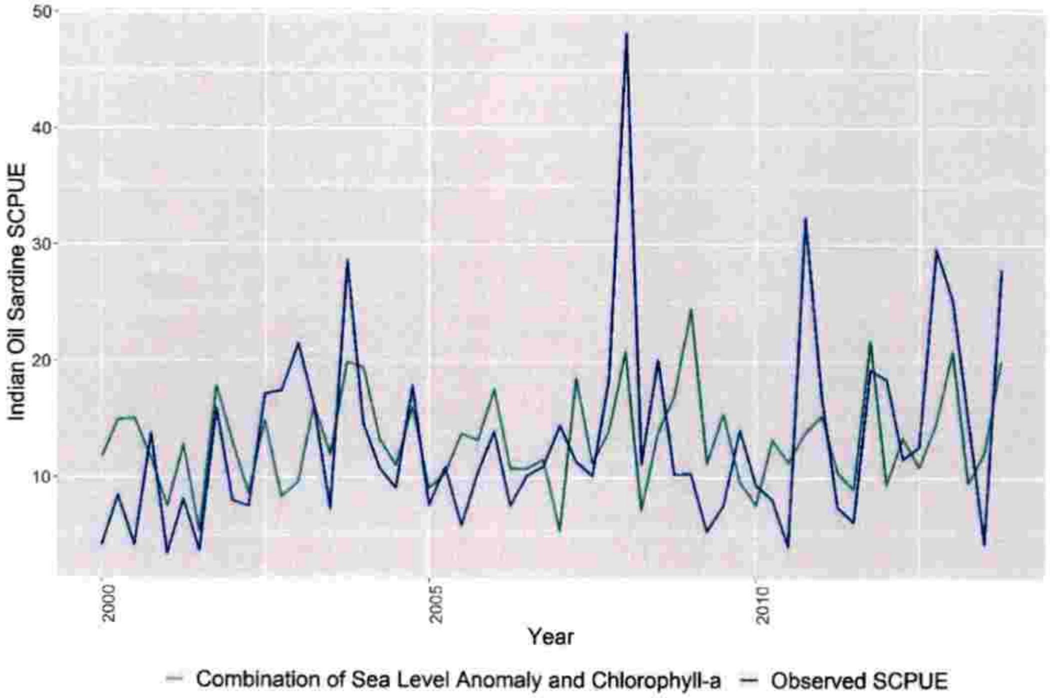

Figure 41: Observed and predicted SCPUE values of Indian Oil Sardine

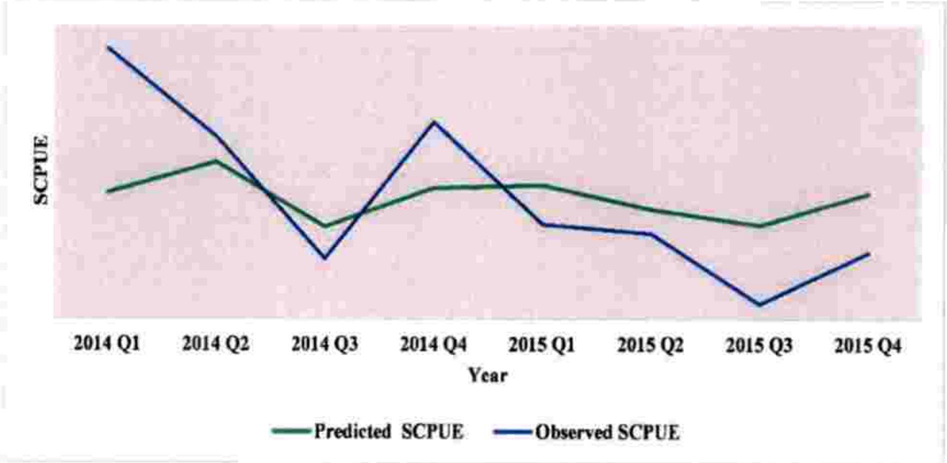

Figure 42: Prediction of SCPUE values for 2014 and 2015

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SUMMARY AND CONCLUSIONS

CHAPTER 5

SUMMARY AND CONCLUSIONS

In this study, we have attempted to find a solution for forecasting the biomass change in Indian Oil Sardine after getting rid of the variability possible due to change in effort. We were able to standardize the fish landing data of Indian Oil Sardine following published protocols and estimate the standardized catch per unit effort (SCPUE) for Indian Oil Sardine. The possible environmental variables affecting Indian Oil Sardine were identified and data sets were estimated using IPCC approved models for RCP 4.5 and 6.0. The variables estimated in RCP were sea surface temperature (SST), precipitation (Pr), chlorophyll-*a* concentration (Chl-*a*), sea surface salinity (SSS), sea surface height (SSH) and pH. A detailed description of the trends in the variables are discussed in each section in the chapter dealing with results and discussion.

Further, we tried to develop a model using the SCPUE of Indian Oil Sardine and various combinations of environmental variables in regression model with Autoregressive integrated moving average (ARIMA) noise. The time-series data before analysis were checked for the lead/ lag which can be there in the marine conditions for conversion into the fish biomass, Cross-correlation function (CCF) is used to estimate this. Finally, the 31 model combinations for all these variables was compared using the Akaike Information Criterion (AIC) values generated as part of the model simulation exercise. The variables tried in modeling were sea surface temperature, precipitation, chlorophyll-*a* concentration, upwelling, sea-level anomaly and wind speed. The model combinations with least AIC value (394.13) and giving a good fit were identified for forecasting the Indian Oil Sardine biomass. The model selected was with a combination involving sea-level anomaly and chlorophyll-*a* concentration. The forecasts were realistic and the catch/ abundance were in tune with the changes observed in these environmental variables during the study. The study could provide us insights to the use of existing statistical tools for segregating the fishing effort based changes generate scenarios for various environmental variables affecting fisheries. Finally, come up with a model to forecast the Indian Oil Sardine biomass in a realistic scenario and validate it. The variables influencing the fishery is projected in RCP 4.5 and 6.0 scenarios for the years 2015, 2030, 2050 and 2080. The study indicated the relevance of environmental variables in assessing the abundance of fishery resources in a changing climatic regime.

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LIST OF PUBLICATIONS

1. **Pooja A. S,** Mini K. G, Akash S, Deepthi A, Alphonsa Joseph, Sreepriya V, Phiros Shah, Muhammad Shafeeque, Sathianandan T. V, Nameer P. O and Grinson George*. 2019. **Modeling the biomass of Indian Oil Sardine along the south west coast of India using Regression model with ARIMA noise.** *J. Mar. Biol. Assoc. India*. (Under review)

2. Akash S, Phiros Shah, Muhammad Shafeeque, **Pooja A. S**, Zacharia P. U, Ajith Joseph K, Vivekanand Bharti, Sathianandan T. V and Grinson George*. 2019. **Observed links between oceanography and Indian Oil Sardine (*Sardinella longiceps*) fishery along the southwest coast of India.** *Acta Oceanologica Sinica* (Springer). (Under review)

3. **Pooja A. S**, Mini K. G, Phiros Shah, Muhammad Shafeeque, Akash S, Sathianandan T. V, Nameer P. O and Grinson George*. 2019. Book of Abstracts. **Climate change impact and predicting variabilities in the environmental health of maricultural practices in the Eastern Arabian Sea**. *Asian-pacific aquaculture,2019* Tamil Nadu Fisheries University Chennai Trade Centre Tamil Nadu, India.

4. **Pooja A. S**, Phiros Shah, Muhammad Shafeeque, Akash S, Mini K. G, Sathianandan T. V, Nameer P. O. and Grinson George,*.2019. Book of Abstracts. **Climate change impact and forecasting the vagaries of primary production in the Eastern Arabian Sea.** *National Conference on Integrating Biogeochemistry and Ecosystems in a Changing Oceanic Environment*, Kerala University of Fisheries and Ocean Studies (KUFOS) Panangad, Ernakulam, Kerala, India. pp. 21.

5. **Pooja A. S**, Mini K. G, Akash S, Deepthi A, Alphonsa Joseph, Sreepriya V, Phiros Shah, Muhammad Shafeeque, Sathianandan T. V, Nameer P. O and

Grinson George*. 2020. Book of Abstracts. **Modeling the biomass of Indian Oil Sardine along the southwest coast of India using Regression model with ARIMA noise.** *Third International Symposium on Marine Ecosystems Challenges and Opportunities (MECOS3)2020,* ICAR-Central Marine Fisheries Research Institute, Kochi, India. pp. 355.

6. **Pooja A. S**, Mini K. G, Akash S, Phiros Shah, Muhammad Shafeeque, Sathianandan T. V, Nameer P. O and Grinson George*. Book of Abstracts. 2020. **Explaining inter-annual fluctuations in Indian Oil Sardine using environmental variables related to climate change**. *National seminar on Agrometeorological Interventions for Enhancing Farmers Income (AGMET-2020).* Kerala Agricultural University (K.A.U) Thrissur, 680 656, India. pp. 286.

7. Phiros Shah, Muhammad Shafeeque, Trevor Platt, Shubha Sathyendranath, Neethu V.G, **Pooja A. S**, Akash S and Grinson George*. Book of Abstracts. 2019. **Unravelling the productivity fluctuations in the coastal environment – causes and effects** *Asian-pacific aquaculture,2019* Tamil Nadu Fisheries University Chennai Trade Centre Tamil Nadu, India.

SEGREGATING THE IMPACT OF CLIMATE CHANGE *VIS-À-VIS* FISHING EFFORT ON INTER-ANNUAL VARIABILITY OF SELECTED SMALL PELAGIC FISHES USING NUMERICAL MODELS

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THESIS ABSTRACT

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ABSTRACT

Marine capture fisheries are subjected to anthropogenic pressures and impact from climate change. These two factors result in the inter-annual variability of marine fish species. In this study, we have tried to nullify the anthropogenic effect in the form of fishing effort by subjecting the fish catch data to a standardization procedure which provided us with the standardized catch per unit effort (SCPUE). The candidate species selected is Indian Oil Sardine which is the dominant and most commercially harvested species. SCPUE of Indian Oil Sardine data and six major climate variables viz., sea surface temperature, precipitation, chlorophyll-*a* concentration, upwelling, sea-level anomaly and wind speed were subjected to a simulation analysis using regression model with Autoregressive integrated moving average (ARIMA) noise. The lead/lag duration for different climate-related variables used in forecasting the fish biomass was estimated using a Cross-correlation function (CCF) and the model enabled forecast was made for the year 2014 and 2015. The suitable model for the best Akaike Information Criterion (394.13) enabled with a good fit for the output was used for the prediction. On the basis of AIC values and best fit obtained during the study we have arrived at the best combination of variables among the 31 models tested. The variables used in this study was predicted using the approved IPCC models and RCP 4.5 and 6.0 scenarios. Thus we could achieve (i) standardization of fishing effort which segregated the variability in inter-annual fluctuations in Indian Oil Sardine due to effort changes (ii) Scenarios generated for the variables relevant to model studies and predicting them for different RCPs and (iii) Model for forecasting the Indian Oil Sardine biomass using the predicted variables. The study calls upon the need for integrating climatic variables into biomass forecasting with more refined protocols to ascertain the future of Indian marine fisheries in a climate change scenario.

Keywords: ARIMA, simulation, climate variables, inter-annual variability, fisheries, Indian Oil sardine