

2015-16 ENSO contributed reduction in oil sardines along the Kerala coast,south-west India

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Abstract:

Fishery along the west coast of India largely depends on pelagic fish such as oil sardines which are dominant during the south-west monsoon. However, the response of sardine population to the warming caused by the climatic events such as El Niño/Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) is poorly studied. Here we hypothesize that the ENSO related changes in biogeochemistry can adversely affect the oil sardines. We have used biogeochemical data collected along the Kerala coast during September 2015 (ENSO year) and September 2017 (a normal year) supported with catch per unit effort (CPUE) and fishery landing data to show the ENSO-related bio-physical dynamics and its impact on the oil sardine population along the south-west coast of India. During the 2015 ENSO year, upwelling velocity decreased minimizing cooling of surface waters and resulted with an increase in sea surface temperature (SST) (~1.8°C). Consequent decrease in nutrient levels favoured nano-phytoplankton and pico-phytoplankton. On the other hand, during September 2017 when the ENSO effect was nullified, the decreased SST and availability of nutrients in the euphotic zone resulted in the dominance of micro-phytoplankton. The hydrographic conditions (reduction in upwelling intensity), and reduction in micro-phytoplankton abundance and zooplankton density in turn perhaps affected the fishery potential of the region. Oil sardines population (along the west coast) collapsed from 1.55 lakh tones (2014) to 0.46 lakh tones during 2015-2016 ENSO event, while in 2017 the conditions become favourable and their population was back to normal (1.27 lakh tones). Our results are in close agreement with our hypothesis and suggest that ENSO events could reduce phytoplankton productivity and disrupt the food chain, which in turn can affect the oil sardine population along the west coast of India.

Keywords Fishery; Kerala; plankton; oil sardine population; south-west coast of India

1. Introduction

Ocean warming is known to affect primary productivity (PP) through processes such as nutrient supply, stratification and acidification [Masotti et al., 2011]. Ocean warming is predicted to lower PP in low and middle-latitude coastal areas [Bakun et al., 2015]. Recently, Roxy et al. (2016) reported a 20% reduction in phytoplankton in the Indian Ocean as a response to warming. The El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) are the major climatic events affecting the tropical Indian Ocean [Murtugudde et al., 2000]. These processes can result in warming of the oceanic water column and can affect the biogeochemical processes. Such climatic events, apart from lowering the chlorophyll [Sarma 2006], also affect phytoplankton composition [Vidya and Kurian 2018]. However, its impact on biological components of coastal and marine ecosystems is poorly known.

The decreasing trends in PP over the upwelling areas can be detrimental to the marine food webs and the fishery potential of the region. Fishery production largely depends on the variability in phytoplankton biomass and primary productivity [Friedland et al. 2012]. Phytoplankton being the base of the food chain transfer energy to higher trophic levels thereby affecting fisheries and in turn the dependent human societies [Racault et al., 2017]. The Indian oil sardine (*Sardinella longiceps*) is one of the most important commercial fishes in India feeding on both phytoplankton (diatoms and dinoflagellates) and zooplankton (copepods) [Purusothaman et al., 2014]. In view of global warming and declining PP in the Indian Ocean, the response of oil sardines to these climatic changes needs to be explored further.

Studying how the processes such as ENSO and IOD affects phytoplankton via nutrient availability and in turn on fishery may help in predicting the impact of global warming on marine ecosystem [Racault et al., 2017]. IOD events are mostly triggered by ENSO events and frequently co-occur with them, however they also occur independently [Annamalai et al., 2003; Yamagata et al., 2004]. Sarma et al. [2006] showed a significant reduction in surface chlorophyll and also 30% decrease in photic zone integrated primary production in the Arabian Sea and was attributed to 1997 ENSO/IOD event. The reduction in chlorophyll was stronger during 1997

compared to 2006 ENSO/IOD year [Wiggert et al., 2009]. Their study showed that Arabian Sea experienced basin-wide primary production changes of -9% during 1997 and +15% during 2006 IOD/ENSO events. This indicates that each ENSO/IOD event behave differently; hence its biological impact as well. In 2015, the tropical Pacific experienced a strong El Niño event, which was one of the strongest El Niño events in the history. However, the tropical Indian Ocean did not show a strong positive IOD event in 2015, unlike 1997 [Liu et al., 2017]. The impact of ENSO and IOD on the physical structure of the Indian Ocean has been explored extensively, but its impacts on the biological production and associated fisheries received less attention. Based on hydrographic, biogeochemical and fisheries data from the south-west coast of India during September 2015 (strong ENSO) and September 2017 (normal year), the present study explores the impact of 2015-16 ENSO on phytoplankton, zooplankton and in turn on oil sardine population. Here we hypothesize that the 2015-16 ENSO adversely affected the oil sardines along the Kerala coast.

2. Material and Method

2.1 Sample collection

Water column measurements were carried out along the south-west coast of India, eastern Arabian Sea, during two oceanographic cruises onboard *RV Sindhu Sadhana* (SSD 14; September 2015 and SSD 41; September 2017). Sampling was carried out along a perpendicular transect off Kochi (Kots) where water depth ranged from 27 m to 1800m (Fig 1). Samples were taken from discrete depths using Niskin bottles mounted on a rosette frame fitted with a Sea-Bird Electronics conductivity-temperature-depth profiler (CTD).

2.2 Total Organic Carbon (TOC) and Total Nitrogen (TN)

Seawater was collected into acid-cleaned 30 mL glass vials and immediately frozen upright at -20 °C. A Shimadzu TOC-LCPH analyzer coupled with a Total N analyzer was used to determine TOC and TN concentrations (Dickson et al., 2007). Total Organic Carbon (TOC) was analyzed at 680°C following combustion catalytic oxidation method. TN was analyzed at 720°C following chemi-luminescence method, wherein the N oxidation product nitric oxide (NO) is quantified by reaction with ozone and detection of the resulting chemi-luminescence (Badr et al., 2003; Letscher et al., 2013). A 5-point calibration curve was generated before each batch. Triplicate

analysis was done for each sample. CRM (Deep Sea standard; 41–44 μM for TOC and 33 μM for TN) procured from University of Miami was run in each batch and the accuracy of the analysis was $\pm 1 \mu\text{M}$.

2.3 Phytoplankton pigment analysis

Phytoplankton pigments were extracted and analyzed by HPLC following the modified method of Van Heukelem [2002], as detailed in Kurian et al., [2012]. Calibration standards were procured from DHI, Denmark. Size fractionated contributions of phytoplankton (*fmicro*, *fnano*, and *fpico*) were calculated following Uitz et al. [2006]. In the present study, we used seven pigments (Fucoxanthin, Peridinin, Alloxanthin, 19'-Hexanoyloxyfucoxanthin (19'HF), 19' Butanoyloxyfucoxanthin (19'BF), Zeaxanthin and TChl*b* (Chl*b*+divinyl chlorophyll *b* (DivChl*b*)) as markers of phytoplankton taxa (diagnostic pigments; DP).

Size fractionated contributions of phytoplankton were calculated as follows:

$$f_{micro} = 100 \times (1.41[\text{Fuco}] + 1.41[\text{Per}]) / \Sigma\text{DP} \quad (>20 \mu\text{m})$$

$$f_{nano} = 100 \times (0.60[\text{Alloxanthin}] + 0.35[19'\text{BF}] + 1.27[19'\text{HF}]) / \Sigma\text{DP} \quad (2 \text{ to } 20 \mu\text{m})$$

$$f_{pico} = 100 \times (0.86[\text{Zea}] + 1.01[\text{TChl}b]) / \Sigma\text{DP} \quad (<2 \mu\text{m})$$

2.4 Zooplankton analysis

Mesozooplankton were collected using a Heron Tranternet (200 μm mesh size and mouth area of 0.25 m^2) equipped with a calibrated digital flowmeter (Hydrobios) to quantify the volume of filtered seawater. Vertical hauls were collected from the epi-pelagic realm (0-150 m) for the deeper stations, whereas the entire water column was sampled for the shallow stations. Samples were concentrated onboard through a 200 μm nylon mesh and split using a Folsom splitter to get a sub-sample (50%) containing ~ 300 individuals. These sub-samples were preserved in 4% buffered (sodium borate) formalin in seawater for further analysis. In the laboratory, an individual sample was placed in Bogorow's chamber and enumeration and morphological identification was done under a stereoscopic microscope (Olympus SZX 09). The sample was sorted to the group level, and the abundance of each group was calculated following standard procedure [Goswami, 2004]. All the samples were identified at broad taxonomic groups [Harris et al., 2000; Conway et al., 2003].

2.5 Physical parameters

2.5a Sea Surface Temperature (SST)

The daily averaged Optimally Interpolated (OI) SST with spatial resolution 0.25 degree was taken from NOAA National Climatic Data Centre (<https://www.ncdc.noaa.gov/oisst>).

2.5b Ekman Pumping Velocity (EPV)

The daily wind speed with 25 km resolution was obtained from ASCAT (<http://manati.star.nesdis.noaa.gov/products/ASCAT.php>). Using the above data Ekman pumping velocity (EPV) was calculated following Smith (1968).

$$EPV = \frac{1}{\rho f} \nabla \times \tau$$

where $\nabla \times \tau$ is the curl of the daily wind stress vector, ρ is the density of the sea water and f is the coriolis parameter. EPV (ms^{-1}), is used as an index for upwelling in the ocean with the positive values indicate upwelling and negative values indicate downwelling.

2.5c Niño3.4 and DMI index

To characterize the ENSO variability, we used the Niño3.4 index, whereas DMI index was used to characterize the IOD, and both were obtained from <http://stateoftheocean.osmc.noaa.gov/sur/ind/>.

2.6 Statistical analysis

Spearman rank correlation was performed between Niño3.4 index, DMI index and oil sardine landing data. The correlation was also performed between oil sardine CPUE and landing data.

2.7 Fishery data

The oil sardine standardized data (CPUE) has been used from Kripa et al. [2018], while the landing data has been used from Prathiba et al. [2018] and FRAD, CMFRI [2015, 2016, 2017, 2018]. The details of methodology, gears and boats are detailed in Kripa et al. [2018]

3. Results and Discussion

The biogeochemical properties in the south-west coast of India during the September 2015 and 2017 were measured, in which the former year (September 2015) is a strong ENSO year

accompanied with weak IOD; while the latter (September 2017) year is the weak IOD event. Both the years (2015 and 2017) showed similar positive Dipole Mode Index (DMI) (Figure 2a) while the Niño3.4 index was distinctly different (strong ENSO event during September 2015 compared to 2017). Hence, we assume that the major variability during 2015 might be contributed by the ENSO rather than IOD. The Niño 3.4 index was 2.1 and -0.5 during September 2015 and 2017 (Fig 2a) respectively. This indicates that September 2015 is a strong ENSO year, while 2017 is a normal year. This seems to have affected the Chl *a* distribution showing low phytoplankton biomass during ENSO year (Fig 2b). The average surface Chl *a* concentrations were 619 and 887 ngL⁻¹ during ENSO and normal year, respectively. The 2015-16 ENSO is one of the strongest on record, comparable to the 1982-83 and 1997-98 events that triggered widespread ecosystem changes in the northeast Pacific [Jacox et al., 2016]. These events also resulted in a warming of surface waters and depressed Chl *a* concentrations across a broad region of the California Current System [McClatchie et al., 2016]. Few studies have already reported coral bleaching in the Indo-Pacific [Normile 2016], along the Great Barrier Reef [Hughes et al., 2017] and also widespread bleaching in global waters [DeCarlo et al., 2017] associated with 2015-16 ENSO. Recently DeCarlo et al. [2017] showed an increase in SST by 2°C in the South China Sea during June 2015 associated with ENSO. Similarly, our measurements during 2015 and 2017 along the Kerala coast show a considerable increase in SST (1.8°C) and sea surface salinity (SSS; 0.61) during the former year. The average SST and SSS were 29.3°C and 34.65 during September 2015 (ENSO) and 27.5°C and 34.03 during September 2017 (normal year). During 2015, the upper 30m water column showed average temperature ~28.5°C (Fig. 3a), whereas it was much cooler (~24.4°C) during 2017 (Fig. 3b). The salinity in the upper 30 m was higher during 2015 compared to 2017 (Fig. 3b & c). This we attribute to the less rainfall over the region during the ElNiño year (Kumar et al., 2006). In addition, the intrusion of Arabian Sea high-salinity (ASHSW) water is also more at subsurface depth during the ENSO year (Fig. S1a) compared to the normal year (Fig. S1b). The weak open ocean circulation in the Arabian Sea during the ENSO event, allows more transport of ASHSW [Prasanna Kumar and Prasad, 1999].

We also compared our *insitu* measurements with satellite-derived SST for the region. During September 2015, the satellite-derived average SST was 29.2°C while it reduced to 27.5°C in September 2017 (Fig. 1 a-b). Consistent with *insitu* measurements, satellite derived SST also showed a significant reduction in its value (~1.7°C reduction) during the normal year (2017) compared to ENSO year (2015). In order to understand the reason for comparatively lower SST during 2017, we have computed the Ekman Pumping Velocity (EPV) over the region. During September 2015, the study region showed negative (close to zero) EPV values indicating downwelling (ENSO driven), whereas positive values during 2017 supported intense upwelling over the region (Fig. 1 c-d). As nutrient concentrations in the oceans generally increase with depth, even the mild difference in the magnitude of the upwelling intensity can cause significant effect on the biological production. Earlier, Gomez et al. [2012] reported similar observations from the eastern tropical pacific, wherein they observed inhibition of upwelling during ENSO.

In the present study, we tried to understand the impact of 2015 ENSO (resultant increased temperature of 1.8°C) on the phytoplankton biomass and higher trophic levels. Here we used photosynthetic marker pigments to characterize the phytoplankton communities. Fucoxanthin is generally used as a marker pigment for diatoms (though it is present in some haptophytes and chrysophytes), and peridinin for dinoflagellates, both representing micro-phytoplankton. 19'-hexanoylfucoxanthin (19'HF) represent haptophytes (nano-phytoplankton), whereas zeaxanthin represents cyanobacteria (*Synechococcus*) and divinyl Chl *a* is a marker for *Prochlorococcus*, both representing pico-phytoplankton. The marker pigments of micro-phytoplankton showed contrasting trends to that of nano-phytoplankton and pico- phytoplankton (Fig.4). Fucoxanthin and peridinin concentrations in the upper 50 m were very low during ENSO year, while 19'HF, zeaxanthin and div Chl *a* were low during the normal year (Fig 4). Size fractionated analysis of phytoplankton showed an average of only 30% contribution by micro-phytoplankton (f_{micro}) in ENSO year which increased to 78% during the normal year (Fig 5). This indicates that micro-phytoplankton (mainly diatoms, and to some extent dinoflagellates) doubled once the ENSO effect was nullified. In contrast, nano-phytoplankton and pico-phytoplankton contribution to the total phytoplankton (f_{nano} & f_{pico}) reduced from 24% and 46% in ENSO year to 8% and 14% during the normal year (Fig 5). Recently, Vidya and Kurian [2018] reported 50% reduction in micro-phytoplankton abundance in the north-eastern Arabian Sea during the 2015-16 ENSO

event. Similar to our results, Moye and Borrego [1985] reported higher nano-phytoplankton abundance in the warmer waters off south Mexico during the summer of the El Niño year 1983, whereas nutrients, Chl *a*, diatom and dinoflagellate abundance were lower than those reported for previous summers with no El Niño events. Cota and Borrego [1988] also reported similar changes along with the abundance of cyanobacteria during the 1983 El Niño. Earlier, Lenz [1992] reported that small cells of phytoplankton with a high surface to volume ratio grow more rapidly at higher temperatures.

High micro-phytoplankton counts during normal year resulted in higher organic carbon production (TOC: 129 μM) as compared to ENSO year (90 μM ; Fig. 6 a,b). The increase in diatom abundance during the normal year could be due to high nutrient availability as seen from the higher TN concentration (Fig 6c, d). Variation in the size fractions of phytoplankton may be a consequence of variation in nitrogen availability during both the years. TN concentrations were low (<15 μM in top 20 m) during ENSO year as compared to the normal year (>30 μM in top 20 m). During the ENSO year, the down-welling reduced the nutrient availability in the surface waters. Apart from the reduced vertical fluxes, the fresh water influx was also low with limited horizontal fluxes of nitrogen as it was a drought year.

ENSO driven variations in both horizontal and vertical input of nutrient-rich water can affect micro-phytoplankton abundance, and in-turn the zooplankton and larval fish productivity [McGowan et al., 1998]. Zooplankton of the eastern Arabian Sea is typically characterized by the abundance of copepods that support rapid growth and survival of commercially valued fishes such as sardines. Zooplankton abundance during the ENSO year was also low as compared to the normal year (Fig 7), indicating the response of zooplankton to the warm waters. Few studies from the Alaskan Gyre and the California Current [Fulton and Le Brasseur, 1985; García and Gutiérrez 1996] have reported structural changes in the composition of the zooplankton as a consequence of ENSO.

As the micro-phytoplankton and zooplankton being at the base of the food chain/web, it can directly/indirectly affect the organisms that are dependent on it including fishes. Recently, Shankar et al. [2019] suggested that the south eastern Arabian Sea has stronger upwelling that

leads to microplankton that can be directly fed by fish such as the oil sardine. Thomas et al. [2016] suggest that zooplankton such as copepod plays an important role in the distribution of pelagic fishes along the southeastern Arabian Sea. As sardines are known to feed on micro-phytoplankton (especially diatoms) and zooplankton (copepods), we believe that the decline in the micro-phytoplankton and zooplankton during the ENSO year reduced the oil sardine population. In order to differentiate between the effect of ENSO and IOD, we did spearman rank correlation (2014 to 2017) between the Niño3.4 index, DMI and the oil sardine landings. Niño3.4 index showed moderate negative correlation ($r = -0.43$) with oil sardines, whereas DMI showed very weak positive relation ($r = 0.19$). This indicates that the oil sardine populations are mainly influenced by ENSO rather than IOD. The oil sardine CPUE [Kripa et al., 2018] and the oil sardine landing [Pratibha et al., 2018] shows a very strong positive correlation with $r = 0.85$ for fishing boats with mechanized units using ring seines (MRS) and $r = 0.99$ for fishing boats with outboard engines using ring seines (OBRS) for the period 2011 to 2015. CPUE for MRS reduced from 312 kg/hour during 2014 to 159 kg/hour during 2015 [Kripa et al., 2018]. The fish landing data also followed similar trend as CPUE and reduced from 1.55 lakh tonnes in 2014 to 0.68 lakh tonnes in 2015 and 0.45 lakh tonnes in 2016 [FRAD, CMFRI (2015, 2016, 2017 2018)](Fig 8). In fact oil sardines catch percentage during 2015 was only ~16% of that during 2012 [Kripa et al., 2018]. Such a drop of fish landings was also reported in the Pacific Ocean after the 1958 to 1960 El Niño and the 1983 to 1984 El Niño [McGowan et al. 1998]. While in 2017, when the ENSO effects were nullified and the micro-phytoplankton dominated along the Kerala coast, the zooplankton abundance increased and in turn the oil sardines population increased to 1.27 lakh tonnes (Fig 8). In fact, during 2017 oil sardines were the most dominant species in marine fish landings throughout India with 8.8% contribution (3.37 lakh tonnes) [FRAD, CMFRI (2018)]. Oil sardine landings recorded an increase of 38% in 2017 mainly due to the recovery of sardine fishery along the south-west coast of India [FRAD, CMFRI, 2018] (Fig 8).

From figure 8 it is clearly seen that the decline in the oil sardine along the Kerala coast is not compensated by an increase along the east coast or towards the northern states of the west coast. Comparing the landings data between 2014 and 2015, although there is a slight increase in Tamil Nadu and Andhra Pradesh (+0.2 lakh tonnes), it's minimal when compared to the drop in oil sardines in Kerala alone (-0.87 lakh tonnes). Other states along the west coast (Gujarat,

Maharashtra, Karnataka and Goa) also do not show any increase during 2015. This indicates that only a small fraction (~23%) of the total sardine population might have migrated to the east coast during the ENSO year. While majority of the drop in number could be due to scarcity of food and the extra energy being utilized to find the food especially during the juvenile and first year stages. Considering that the 0-year class forms a major component of the sardines [Kripa et al., 2018], hence the effects of the ENSO on the oil sardines were more rapid.

The recruitment and growth of the fishes depend on the oceanic environment in which water column temperature is the most easily determined environmental factor which can be used as an indicator of the changing ecological conditions. Warmer temperatures are known to affect fish abundance through phenological changes [Kuczynski et al., 2017]. Recently, Kripa et al. [2018] reported that ENSO driven rise in temperature negatively impacted maturation process. Although, ENSO driven rise in temperature is expected to increase larval production [Niquen and Bouchen 2004], more importantly it can also affect the food availability [Thara 2011]. She reported that primary production is less in the eastern Arabian Sea during ENSO years as compared to LaNiña years, and this negatively affects the oil sardine populations. Kripa et al. [2018] also highlighted the possible role of jelly fishes in the recruitment failure since they predate on zooplankton and fish larvae.

The present study highlights the impact of ENSO on the water masses, nutrient availability, phytoplankton, zooplankton and in-turn on fish (oil sardine) population along the Kerala coast. The warmer temperature and decrease in food availability (mainly diatoms) during ENSO year might have adversely affected the oil sardine population. In view of climate change scenario, understanding of such impacts on the fishery potential will help in better utilizing our fishery resources in the future.

4. Conclusion

The present study investigated the impact of 2015-16 ENSO on the water masses, nutrient availability, primary and secondary producers and in turn on the oil sardine population. The 2015-16 ENSO lowered the Chl *a* biomass across the Kerala coast mainly due to reduced nutrient supply. The high temperatures and low nutrients during the ENSO year favored the

smaller plankton such as pico-phytoplankton and nano-phytoplankton, which in turn might have decreased the abundance of zooplankton, principally copepods. The reduced abundance of both micro-phytoplankton and zooplankton during the ENSO year consecutively affected the oil sardine population. While during the normal year with the intrusion of more nutrients from the upwelling and the fresh water influx, the micro-phytoplankton, zooplankton and oil sardine population increased. These results are consistent with our hypothesis that the 2015-16 ENSO might have affected the oil sardine population. Considering that oil sardines are the most dominant species in marine fish landings in India, this study attains great importance. These results could also be considered as an assessment of global warming effect on oil sardines in future warming scenarios.

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[AUTHOR'S CONTRIBUTIONS]:

Suhas Shetye has written the manuscript with the inputs received from other co-authors. TOC and TN analyses were done by SS, phytoplankton pigments data were generated by SK, zooplankton data by MG, whereas PJV supported physical oceanographic data.

References

1. Gómez AR., Salmerón O., Álvarez R. 2012 Satellite observations of the effect of Enso on the Tehuantepec and Papagayo upwellings. *Interciencia* **37**, 828-832.
2. Annamalai H, Murtugudde R, Potemra J, Xie SP, Liu P, Wang B. 2003 Coupled dynamics over the Indian Ocean: spring initiation of the Zonal Mode, *Deep-Sea Res. Pt. II*, **50**, 2305–2330.
3. Badr EA., Achterberg EP., Tappin AD., Hill SJ., Braungardt CB. 2003. Determination of dissolved organic nitrogen in natural waters using high-temperature catalytic oxidation. *Trends Anal. Chem.* **22**(11), 819-827.

4. Bakun A, Black BA, Bograd SJ, García-Reyes M, Miller AJ, Rykaczewski RR, Sydeman WJ. 2015 Anticipated effects of climate change on coastal upwelling ecosystems. *Curr Clim Change Rep* **1**, 85.
5. Conway, D.V.P., White, R.G., Hugues-Dit-Ciles, J., Gallienne, C.P., Robins, D.B., 2003. Guide to the Coastal And Surface Zooplankton Of The South-western Indian Ocean. Occasional Publications. Marine Biological Association of the United Kingdom, Plymouth, UK (354p).
6. Cota SS. and Borrego SA. 1988 The ‘ El Nifio ’ Effect on the Phytoplankton of a North-western Baja California Coastal Lagoon. *Estuar. Coast Shelf Sci.* **27**,109-115.
7. DeCarlo T M, Cohen AL, Wong GTF, Davis K, Lohmann P, Soong K. 2017 Mass coral mortality under local amplification of 2 °C ocean warming. *Scientific Reports* **7**, 44586.
8. Dickson AG, Sabine CL, Christian JR, (Eds.). 2007 Guide to best practices for ocean CO₂ measurements. *PICES Special Publication* **3**, 191.
9. FRAD, CMFRI, 2015 Marine Fish Landings in India 2014, Technical Report, CMFRI, Kochi.
10. FRAD, CMFRI, 2016 Marine Fish Landings in India 2015, Technical Report, CMFRI, Kochi.
11. FRAD, CMFRI, 2017 Marine Fish Landings in India 2016, Technical Report, CMFRI, Kochi.
12. FRAD, CMFRI, 2018 Marine Fish Landings in India 2017, Technical Report, CMFRI, Kochi.
13. Friedland KD, Stock C, Drinkwater KF, Link JS, Leaf RT, Shank BV, JM Rose, Pilskaln CH, Fogarty MJ. 2012 Pathways between primary production and fisheries yields of large marine ecosystem. *PLoS ONE* **7**(1), e28945.
14. Fulton JD. and LeBrasseur RJ. 1985. Interannual shifting of the subarctic boundary and some of the biotic effects on juvenile salmonids. p.: 237-252. In: W.S. Wooster & D.L. Fluharty (Eds.) El Niño North. Washington Sea Grant Program, University of Washington, Seattle, U.S.A.
15. García P.R. and Gutiérrez G.J. 1996. Copepod community structure at Bahia Magdalena, Mexico during El Niño 1983-1984. *Est. Coast. Shelf Sci.* **43**, 583-595.
16. Goswami, S.C., 2004. Zooplankton methodology, collection and identification – a field manual. National Institute of Oceanography, Dona Paula, Goa (26 pp).
17. Harris, R., Wiebe, P., Lenz, J., Skjoldal, H.R., Huntley, M. (Eds.), 2000. ICES Ooplankton Methodology Manual. Academic Press.

- Hughes et al. 2017 Global warming and recurrent mass bleaching of corals. *Nature* **543**, 373-377.
18. Jacox MG, Hazen E L, Zaba KD, Rudnick DL, Edwards CA, Moore AM, Bograd SJ. 2016 Impacts of the 2015–2016 El Niño on the California Current System: Early assessment and comparison to past events. *Geophys. Res. Lett.*, **43**, 7072–7080.
19. Kripa V, Mohamed KS, Koya KPS, Jeyabaskaran R, Prema D, Padua S, Kuriakose S, Anilkumar PS, Nair PG, Ambrose TV, Dhanya AM, Abhilash KS, Bose J, Divya ND, Shara AS and Vishnu PG (2018). Overfishing and Climate Drives Changes in Biology and Recruitment of the Indian Oil Sardine *Sardinella longiceps* in Southeastern Arabian Sea. *Front. Mar. Sci.* 5:443.
20. Kuczynski L, Chevalier M, Laffaille P, Legrand M, Grenouillet G. 2017 Indirect effect of temperature on fish population abundances through phenological changes. *PLoS One* **12**(4), e0175735.
21. Kumar KK., Rajagopalan B., Hoerling M., Bates G., Cane M. 2006 Unraveling the Mystery of Indian Monsoon Failure During El Niño. *Science* **314**, 115-119.
22. Kurian S., Roy R., Repeta D.J., Gauns M., Shenoy D.M., Suresh T., Sarkar A., Narvenkar G., Johnso, C.G., Naqvi S.W.A., 2012. Seasonal occurrence of anoxygenic photosynthesis in Tillari and Selaulim reservoirs, Western India. *Biogeosciences* **9**, 2485-2495.
23. Lenz J. 1992. Microbial loop, microbial food web and classical food chain: their significance in pelagic marine ecosystems. *Arch. Hydrobiol. Beih.* 37: 265-278.
24. Letscher RT, Hansell DA, Kadko D, Bates, N.R. 2013 Dissolved organic nitrogen dynamics in the Arctic Ocean. *Mar. Chem.* **148**, 1-9.
25. Liu L, Yang G, Zhao X, Feng Han G, WuY, Yu W. 2017 Why Was the Indian Ocean Dipole Weak in the Context of the Extreme El Niño in 2015?. *J Climate* **30**, 4755-4761.
26. Masotti I, Moulin C, Alvain S, Bopp L, Tagliabue A, Antoine D. 2011 Large-scale shifts in phytoplankton groups in the Equatorial Pacific during ENSO cycles. *Biogeosciences* **8**, 539–550.
27. McGowan, J.A., Cayan D.R. and Dorman L.M. 1998. Climate-ocean variability and ecosystem response in the Northeast Pacific. *Science* **281**, 210-217.
28. McClatchie S. et al., 2016. State of the California Current 2015-16: Comparisons with the 1997-98 El Niño. *CalCOFI Reports*, **57**, 1-57.

29. Murtugudde R., McCreary J.P. and Busalacchi A.J. 2000. Oceanic processes associated with anomalous events in Indian Ocean with relevance to 1997-1998, *J. Geophys. Res.*, **105**, 3295-3306.
30. Niquen M, Bouchon M. 2004 Impact of El Niño events on pelagic fisheries in Peruvian waters. *Deep Sea Res. II* **51**,563-574
31. Normile D. 2016 El Niño's warmth devastating reefs worldwide. *Science* **352**, 15-16.

32. Prasanna Kumar., Prasad TG., 1999. Formation and spreading of Arabian Sea high salinity water mass. *Journal of Geophysical Research* 104, 1455-1464.

33. Prathibha R., Sivadas, M., Abdussamad, EM., Rethinam, A.M.M., Said Koya K.P., Ganga U., Ghosh S., Rajesh K.M., Koya M K., Chellappan, A., Mini K.G., George G., Roul S.K., Surya S., Sukumaran S., Vivekanandan E., Retheesh T. B., Prakasan D., Kumar S.M., Mohan S., Vasu R., Suprabha V. 2018. The Enigmatic Indian Oil Sardine: An Insight. CMFRI Special publication No. 130 p. 156
34. Purusothaman S., Silambarasan, A., Jayaprabha N, Murugesan P. 2014 Feeding Strategies and Diet Composition of Oil Sardine *Sardinella longiceps Valenciennes 1847* in the Trawl Bycatches off Parangipettai, Southeast Coast of India. *Asian Fisheries Science* **27**, 137-148.
35. Racault MF, Sathyendranath S, Brewin RJW, Raitsos DE, Thomas J, Trevor P. 2017 Impact of El Niño Variability on Oceanic Phytoplankton. *Front. Mar. Sci.* **4**,133.
36. Roxy MK, Modi A, Murtugudde R, Valsala V, Panickal S, Kumar P, Ravichandran M, Vichi M, Lévy M. 2016 A reduction in marine primary productivity driven by rapid warming over the tropical Indian Ocean. *Geophys. Res. Lett.*, **43**, 826–833.
37. Sarma VVSS. 2006 The influence of Indian Ocean Dipole (IOD) on biogeochemistry of carbon in the Arabian Sea during 1997–1998. *J. Earth Syst. Sci.*, **115**(4), 433–450.
38. Shankar D., Remya R., Anil A.C., Vijith V. 2019. Role of physical processes in determining the nature of fisheries in the eastern Arabian Sea. *Progress in Oceanography* 172, 124–158.
39. Smith RL. 1968 Upwelling. *Oceanogr. Mar. Biol. Ann. Rev.*, **6**, 11–46.
40. Thara KJ, 2011. "Response of Eastern Arabian sea to extreme climatic events with special reference to selected pelagic fishes," Ph.D. dissertation, *Dept. Phys. Ocean., School Marine Sci., Cochin Univ. Sci. Technol.*, Kochi, India.

41. Thomas S, Dineshababu AP, Rajesh KM, Rohit P, Nataraja GD, Mishal P. 2016 Environmental influence on the secondary productivity and fish abundance in coastal fishing grounds off mangalore, south-eastern Arabian Sea. *Indian J. Fish.*, **63**(3), 24-32.
42. Torres-Moye G. and Alvarez-Borrego S. 1985 The 1983 'El Nino' effects on nutrients and summer phytoplankton of western Baja California coastal waters. *Ciencias Marinas* **11**,107-113.
43. Uitz J, Claustre H, Morel A, Hooker SB. 2006 Vertical distribution of phytoplankton communities in open ocean: an assessment based on surface chlorophyll. *J. Geophys. Res.* **11**, C0800.33.
44. Van Heukelem., 2002 HPLC phytoplankton pigments: Sampling, laboratory methods, and quality assurance procedures. In: Mueller, J., and Fargion, G., (Eds.), Ocean Optics Protocols for Satellite Ocean Color Sensor, Revision 3, Volume 2, Chapter 16, NASA Technical Memorandum 2002-2004, pp.258-268.
45. Vidya PJ, Kurian S. 2018 Impact of 2015–2016 ENSO on the winter bloom and associated phytoplankton community shift in the northeastern Arabian Sea. *J. Marine Syst.*, **186**, 96–104.
46. Wiggert JD, Vialard J, Behrenfeld MJ. 2009 Basin wide modification of dynamical and biogeochemical processes by the positive phase of the Indian Ocean Dipole during the SeaWiFS era, in: Indian Ocean Biogeochemical Processes and Ecological Variability, vol. 185, edited by: J. D. Wiggert, R. R. Hood, S. Wajih, A. Naqvi, K. H. Brink, and S. L. Smith, p. 350.
47. Yamagata T, Behera SK, Luo JJ, Masson S, Jury MR, Rao SA. 2004 Coupled ocean-atmosphere variability in the tropical Indian Ocean. *Geoph. Monog. Series*, **147**, 189–211.

Figure Legends

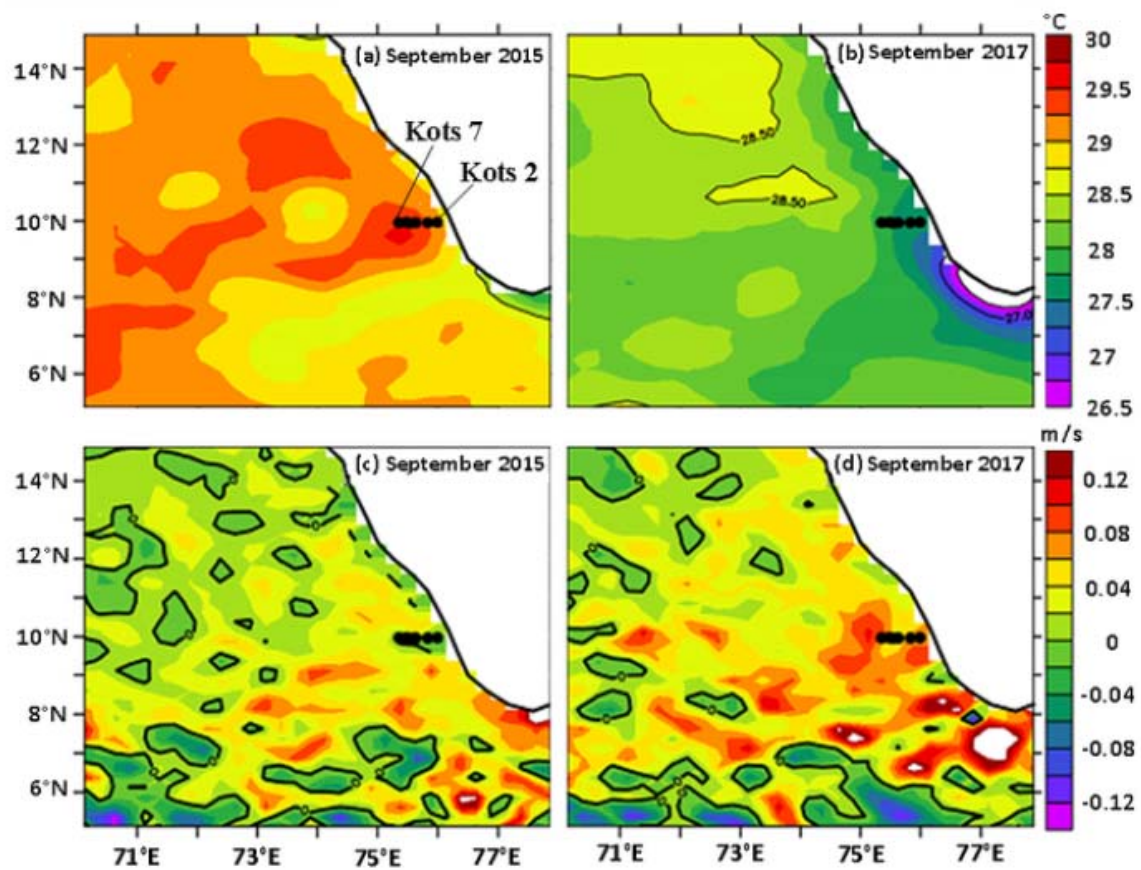


Figure 1: Satellite derived images of SST during September 2015 and 2017 (a and b), Ekman Pumping velocity computed from wind stress during September 2015 and 2017(c and d).

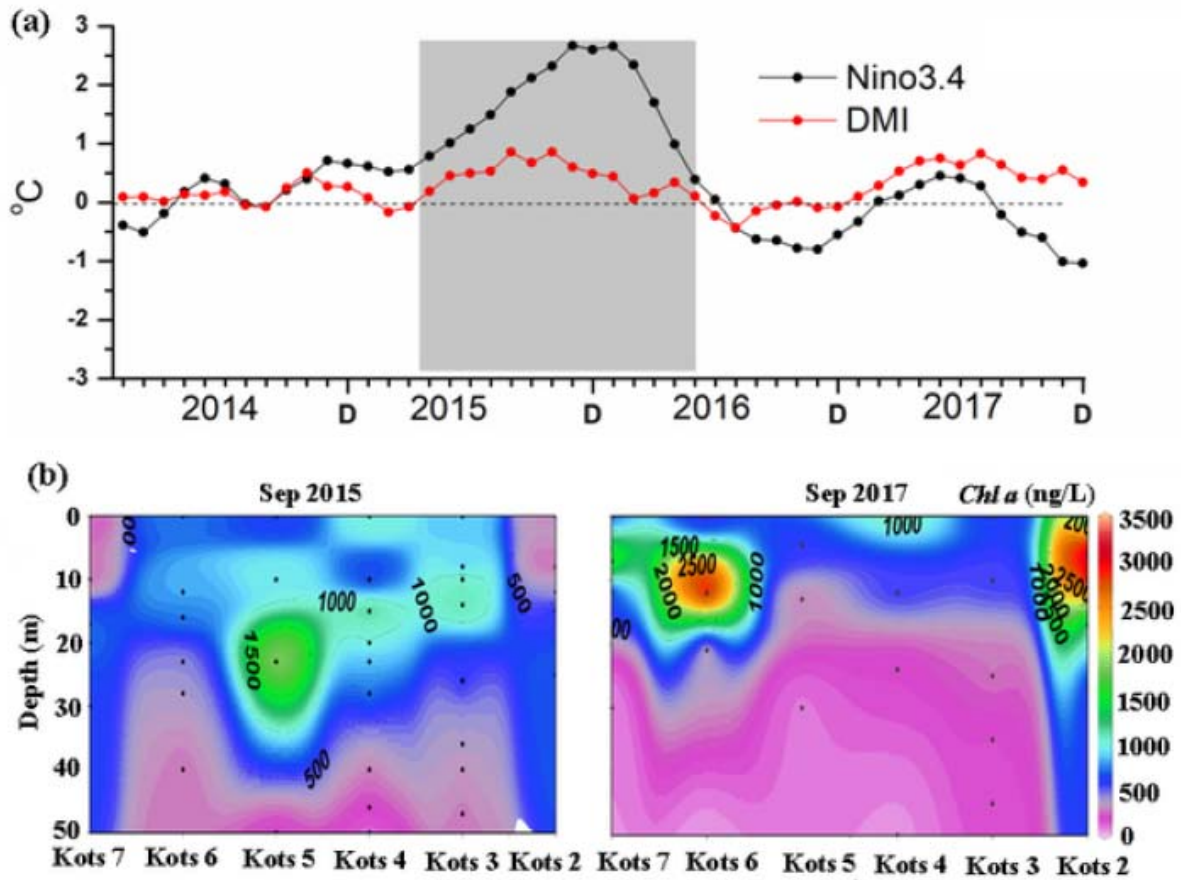


Figure 2: (a) Time series of Niño 3.4 index (black line) and dipole mode index (red line); Vertical structure of Chl *a* during (b) September 2015 and (c) September 2017.

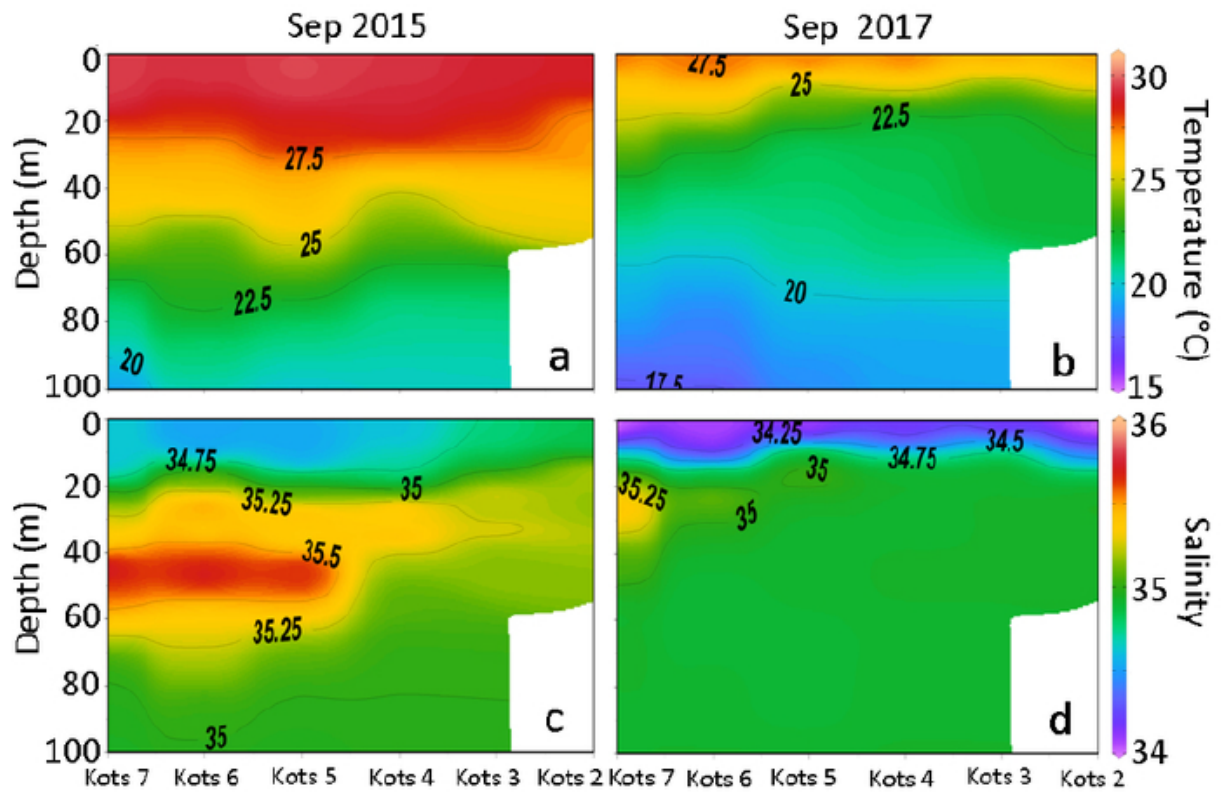


Figure 3: Vertical structure of temperature (a and b) and salinity (c and d) along the Kots transect during September 2015 and 2017.

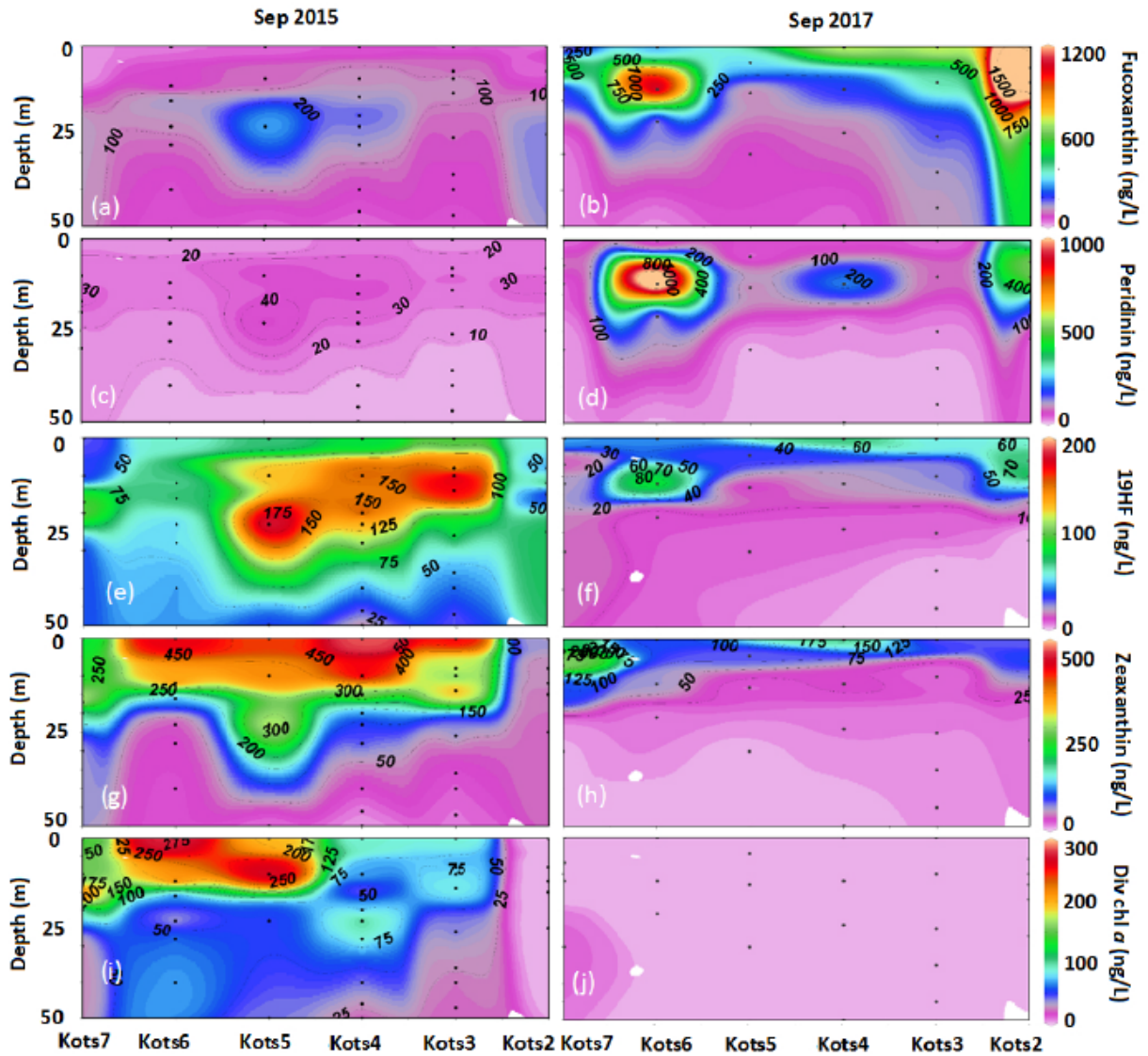


Figure 4: Vertical cross shelf variations in fucoxanthin, peridinin, 19'HF, zeaxanthin and divinyl Chl *a* during El Niño year (2015) and normal year (2017) along the Kerala coast.

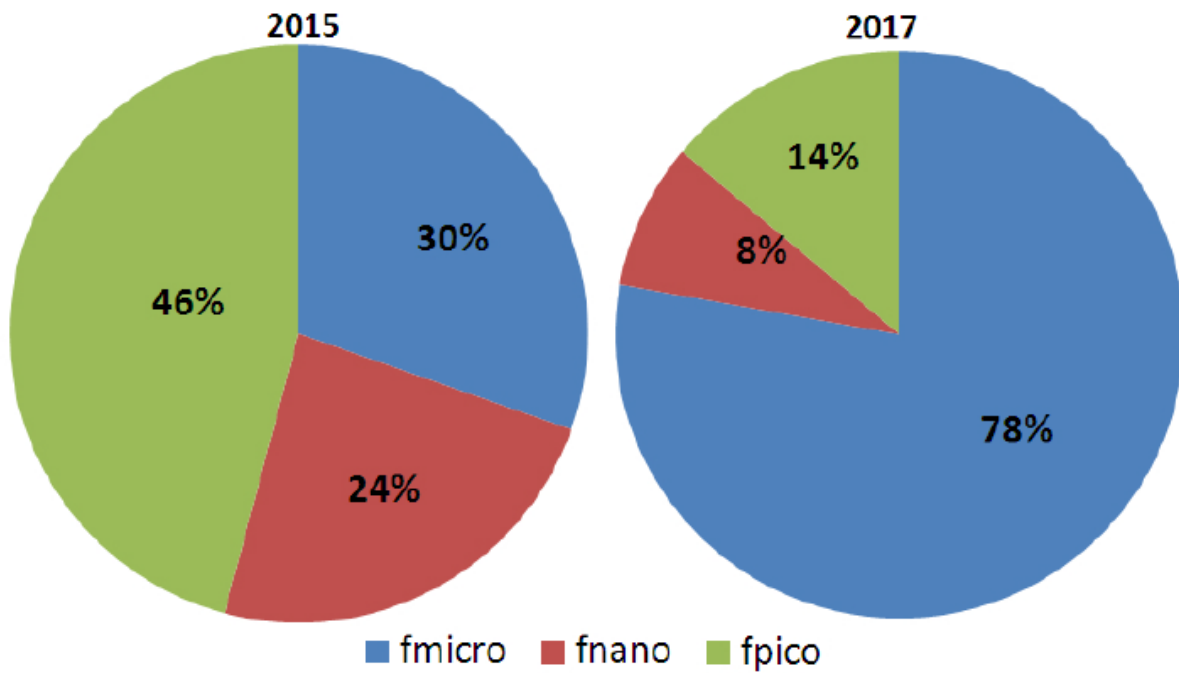


Figure 5: Percentage contribution of micro-phytoplankton, nano-phytoplankton and pico-phytoplankton during September 2015 and 2017 along the Kerala coast.

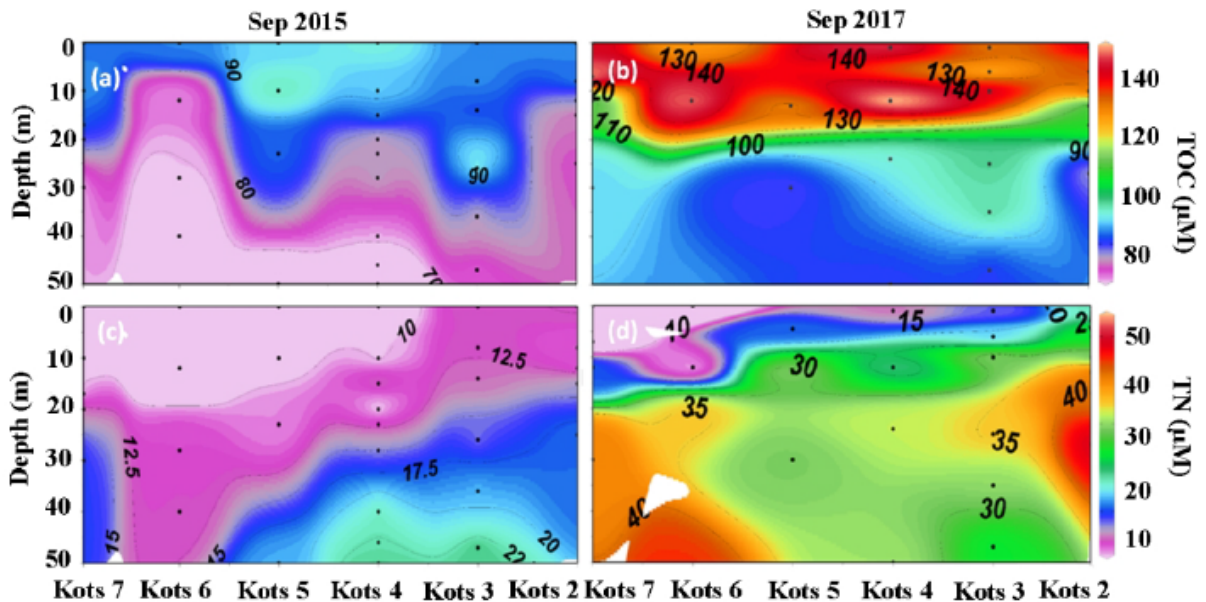


Figure 6: Vertical cross shelf variations in TOC and TN during El Niño year (2015) and normal year (2017) along the Kerala coast.

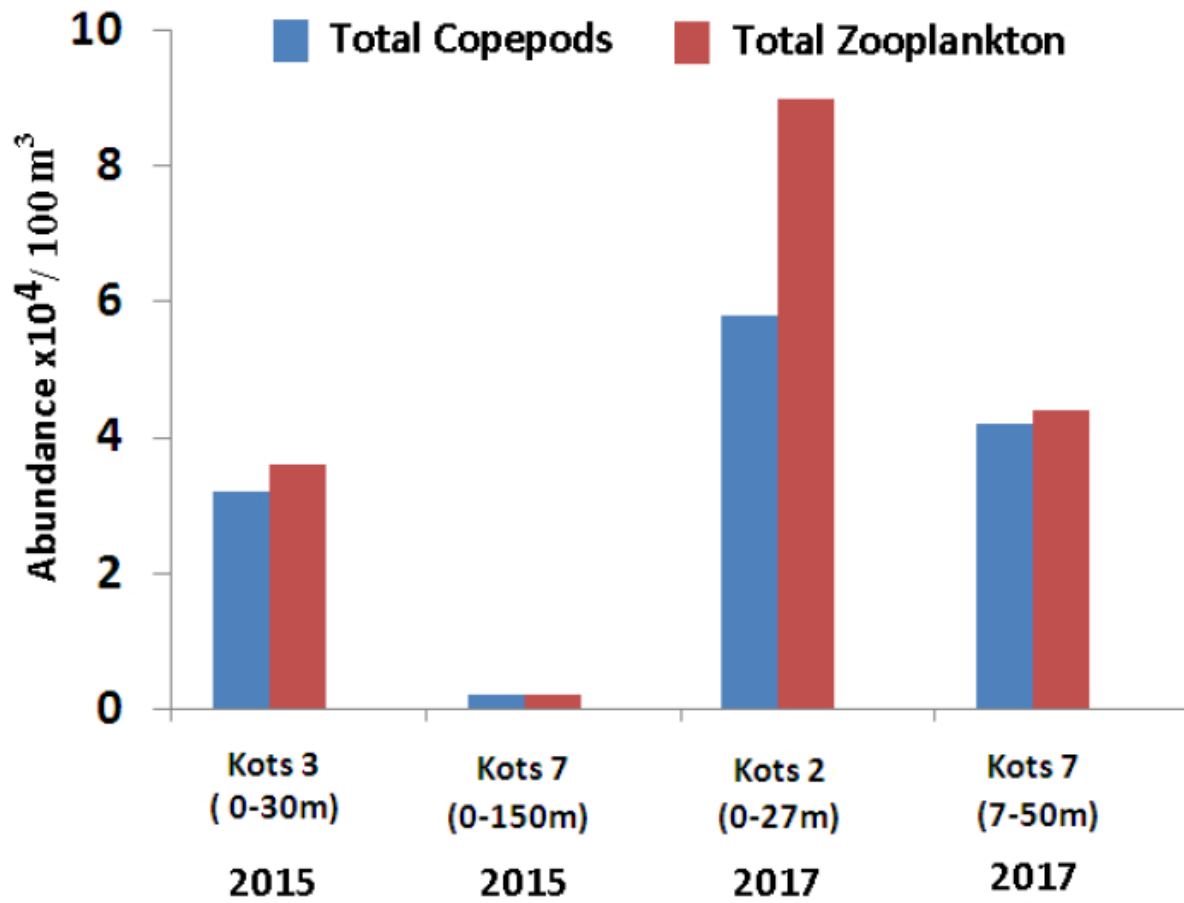


Figure 7: Zooplankton abundance during September 2015 and 2017 along the Kots transect.

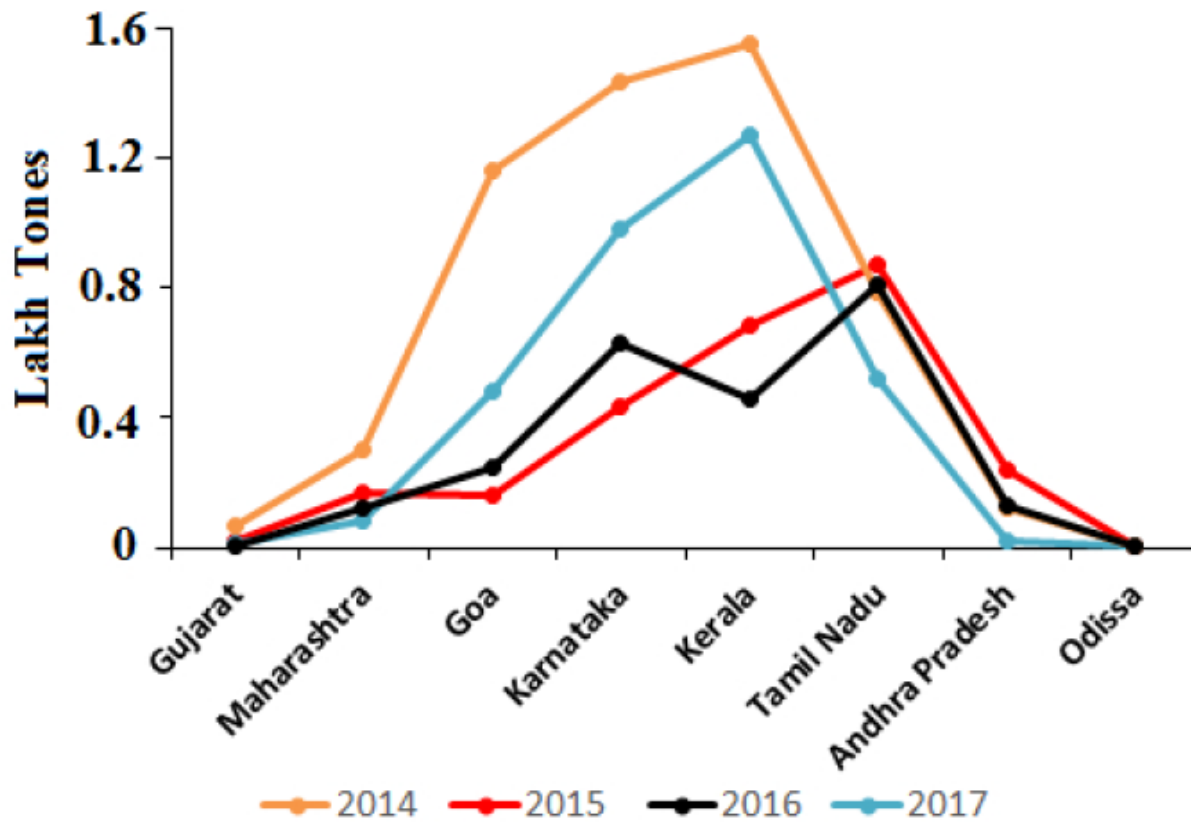
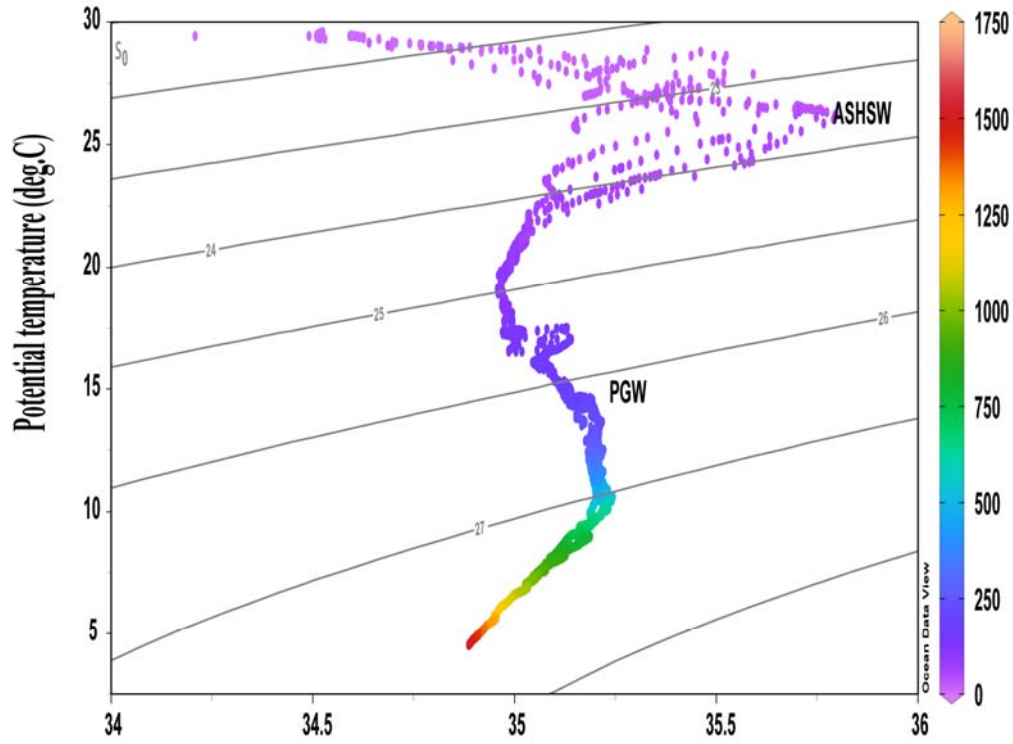


Figure 8: Fisheries data of oil sardine landings along the west and east coasts of India

(a) September 2015 (SSD 14)



(b) September 2017 (SSD 41)

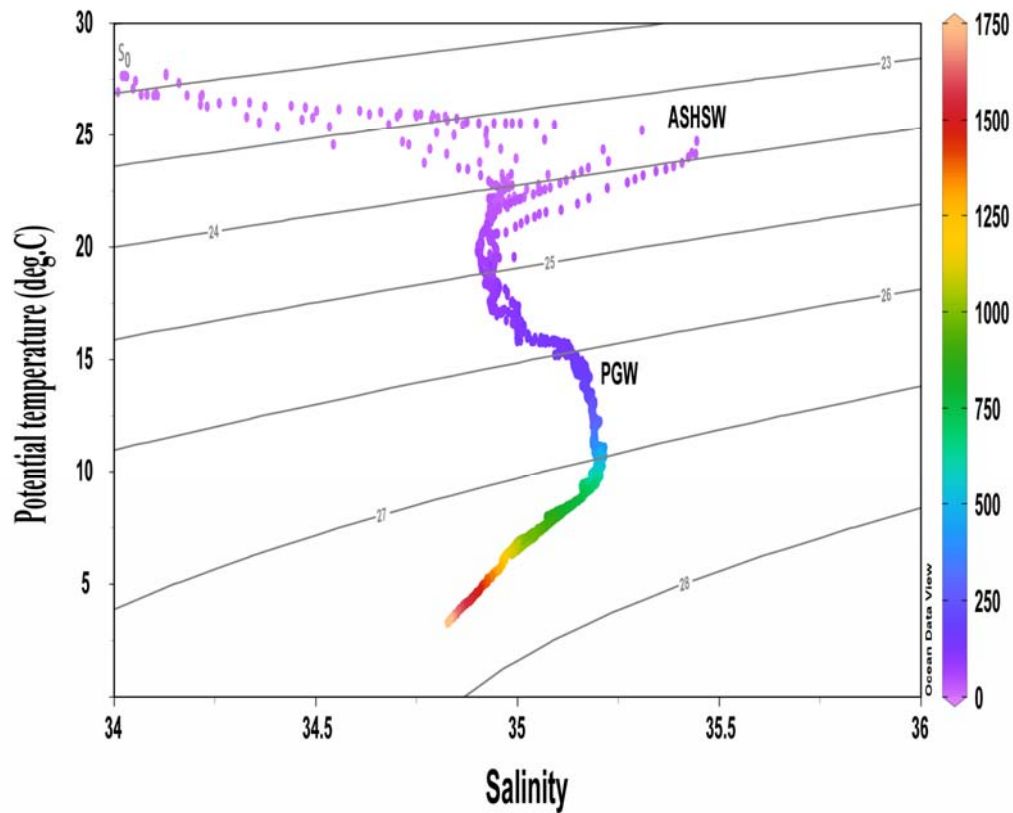


Fig: S1: Watermasses at the KOTS transect during the (a) ENSO year and (b) normal year