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CLIMATE INFLUENCE ON OIL SARDINE AND INDIAN MACKEREL IN SOUTHEASTERN ARABIAN SEA

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ABSTRACT

The anomalies of sea surface temperature, coastal upwelling index, rainfall, multivariate ENSO index and chlorophyll *a* were analysed and correlated with catch rate anomalies of oil sardine and Indian mackerel exploited by purse seine along the coastal waters off Karnataka, India in South-Eastern Arabian Sea during period 1990–2014. The purse seines in Karnataka contributed on an average 75% and 65% catch of oil sardine and Indian mackerel respectively. The catch rate anomalies of oil sardine, showed a significant positive correlation with sea surface temperature and negative statistical correlation with multivariate ENSO index. Such significant relationship was not observed in the case of Indian mackerel. The relationship of those parameters to variations in catch distribution of oil sardine and Indian mackerel was explored with a generalized additive model. The GAM results indicated that for sardine, sea surface temperature (R–sq = 0.339) with 40.8% deviance and for mackerel, chlorophyll *a* (R–sq =0.419) with 58.9% deviance were better than other climatological factors and can be considered as a climatological predictor of catches in the region. The study also indicated a combination of sea surface temperature and multivariate ENSO index anomalies had better deviance of 56% for oil sardine.

INTRODUCTION

Fish catches are driven by fishing craft and gear efforts as well as climatological factors. Long–term natural variability in climate, oceanography and marine ecosystems leads to fluctuations in the abundance of exploited fish populations (Francis and Hare, 1994). The fishery of oil sardine (*Sardinella longiceps*, Clupeidae) and Indian mackerel (*Rastrelligerkanagurta,* Scombridae) which forms the major commercial marine fishery resources in southwest coast of India especially off waters of Kerala and Karnataka (Southeastern Arabian Sea) is also known to have wide fluctuations (Krishnakumar and Bhat, 2008; Jayaprakash and Pillai, 2000) dating back to last century (Hornell, 1910). According to Krishnakumar *et al.* (2008) the fluctuations observed in the fishery is due to some other independent factors rather than through overexploitation. Climate change has been recognised as one of the drivers of oil sardine distribution and abundance (Vivekanandan *et al.*, 2009). Studies on the relationship of pelagic fish to climatological parameters have been attempted by several earlier fishery researchers (Longhurst and Wooster, 1990; Madhuprathap *et al.*, 1994; Yohannan and Abdulrahiman, 1998; Krishnakumar and Bhat, 2008. Valavanis *et al.,* 2002b) has reported remarkable relation between species distributions and environmental anomalies with low SST/high chlorophyll concentration areas. A significant statistical relation was observed between the sea surface temperature and the sardine biomass (Garza–Gil *et al.*, 2015). With the introduction of purse seine in Karnataka in the mid–seventies the catch of oil sardine and Indian mackerel was reported to be 8, 837 t and 12, 247 t in 1977 respectively (Dhramaraja and Jacob, 1980) which has increased to 70, 229 t and 25, 781t in 2014 (CMFRI data repository) respectively. The purse seine fishery is carried throughout the year except during the fishing ban

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period of 60 days during the month of June and July. In this study the purse seine catch rates of oil sardine and Indian mackerel in the coastal waters off Karnataka in south-eastern Arabian Sea were investigated and the catch rate anomalies (CPUE) were correlated with anomalies of climatological parameters: sea surface temperature (SST), coastal upwelling index (UPI), rainfall, multivariate ENSO index (MEI) and chlorophyll *a* (Chl*a*) and rainfall.

MATERIALS AND METHODS

Catch and CPUE

The time series catch data of oil sardine and Indian mackerel for the year 1990–2014 was obtained from Central Marine Fisheries Research Institute (CMFRI) data repository, Kochi, India by employing the stratified multistage random sampling design (Srinath, 2003). The annual catch rate from purse seines was calculated as follows. The catches of oil sardine and Indian mackerel in tons were converted to kilograms and the calculated catch rate was expressed in units per effort.

Catch rate (CPUE) = Unit of biomass/ Unit of fishing effort

The Catch per Unit Effort (CPUE) or the catch rate is a standard tool among biologists to determine variations in fish stocks and among economists as an indicator for the efficiency of the fishing operation (Hoof and Salz, 2001).

Environmental data

Time series data and its analyses are the prerequisites for investigating long–term fluctuations in fish populations and the relationships between populations and environmental variables. The time series data of oceanographic parameters covering Karnataka waters, south-eastern Arabian Sea during 1990–2014 was procured from the following sites.

- SST – daily mean sea surface temperature was obtained from International Comprehensive Ocean–Atmosphere data Set (ICOADS) website (http://dss.ucar.edu).
- Rainfall – monthly values of rainfall data was obtained from Indian meteorological Department (IMD)
- Chlorophyll *a* – monthly values of Chl*a* was obtained from from Sea–viewing Wide Field–of–view Sensor (Sea WiFS) satellite data {Lat (11.796, 15.509), Lon (69.300, 75.487)} through Giovanni.
- MEI – bimonthly multivariate ENSO index was obtained from the file path http://oceanview.pfeg.noaa.gov/thredds/dodsC/FNMOC/. The positive MEI values indicate warm (El Niño) and negative values indicate cold (La Niña) water conditions. The MEI is the weighted average of the main ENSO features of six variables such as sea–level pressure, the east–west and north south components of the surface wind, SST, surface air temperature and total amount of cloudiness (Wolter and Timlin, 1998).
- UPI – monthly values of upwelling (74.5E 13.0N coast angle 158 degrees) was obtained from Filename: wind_from_pressure.nc and file pathhttp://oceanview.pfeg.noaa.gov/thredds/dodsC/FNMOC/. Lag of six months was considered for analysing the effect of upwelling.

All month–wise oceanographic parameters were averaged on an annual basis and from the annual mean, anomalies were computed for further analysis. Anomalies, or the deviation from the mean, are created by subtracting climatological values from observed data. The quarterly values of CPUE and climatological parameters were annualized.

Statistical analysis

Bivariate Pearson's correlation was carried out using SPSS (ver.12) software to identify the oceanographic parameters that significantly correlated with oil sardine and Indian mackerel catches. Correlation analysis is a useful and widely applied tool for generating hypothesis about the effects of environmental or other variables on recruitment at various time scales. Generalized additive model (GAM) was used to relate the climatological parameters to variations in distribution of oil sardine and Indian mackerel. The advantage of this model is that the predictor variables have linear effects upon the response variable. GAMs were constructed in R studio, a component of R statistical programming software (vers. 3.2.2; R Development Core Team, 2015) using the gam function of the Mixed GAM Computation Vehicle (mgcv) package (Wood, 2006) with standardized CPUE as the response variable (dependent) and SST, UPI, Chl.*a*, MEI and rainfall as predictor variables (independent).

RESULTS

Catch and catch rate anomalies

In the decade 1990 to 1999, catches of mackerel by purse seine were invariably higher than that of oil sardines. However during the next decade and till 2014 oil sardine catches were higher than that of mackerel catch. Along the southwest coast of India, a similar inverse pattern in abundance of oil sardine and mackerel was observed from 1999. The increase in the oil sardine catch especially in the latter years is the result of higher catch in seines rather than in trawl or other mechanized or non mechanized gears. Quarterly analysis showed maximum landings of both Indian mackerel and oil sardine in the fourth quarter of the year (October to December). The percentage in the catch efforts varied from 2.8 to 5.3% with maximum in the year 2007 and minimum in the year 1995. The average catch rate (catch/unit effort) in purse seines were 657.6 kg and 480.3 kg per unit effort for oil sardine and Indian mackerel respectively. The catch rate anomalies showed a positive trend for oil sardines from 2000 (except in 2003 and 2004) reaching maximum in 2012 while the values were found to be inverse in most years for Indian mackerel. However no significant correlation was observed between the catch rate anomalies of both these species.

Climatological Parameter Anomalies

SST anomaly, in particular, is widely accepted as the proxy factor for a variety of oceanic and atmospheric–meteorological phenomena (Valavanis, 2003). The variation in anomaly values for the climatological parameters observed during 1990–2014 were SST: –0.44°C to 0.55°C highest in the year 2003 and lowest in 1996; rainfall: –653.84 to 913.08 mm, highest in 2013 and lowest in 2002; UPI: –304.71 to m^3s $^1/100m$ highest in 2013 and lowest in 2004; MEI: –0.15 to 1.5 being highest in 1997 and lowest in 2013 and Chl*a* (1998 – 2014): –0.18 to 0.5 mg/m^3, highest in 2000 and lowest in 2011. The anomalies in catch rates of oil sardine and Indian mackerel with anomalies of climatolgical parameters is represented in Figs.1–5.

Table 1. Pearson correlation between anomalies of oil sardine and Indian mackerel catch rates and anomalies of climatological parameters off Karnataka waters (1990-2014)

	Oil sardine	Indian mackerel	SST	Rainfall	MEI	UPI	Chl a
Oil sardine	1						
Indian mackerel	–.349	1					
SST	.457*	–.352	1				
Rainfall	.133	.197	.091	1			
MEI	–.472*	–.007	–.065	–.233	1		
UPI	–.136	.145	–.161	.291	.186	1	
Chl.*a*	–.257	.008	–.248	–.153	–.058	.322	1

* indicates significant relationship (>.05, two tailed)

Fig. 1. Catch rate anomalies with SST anomaly

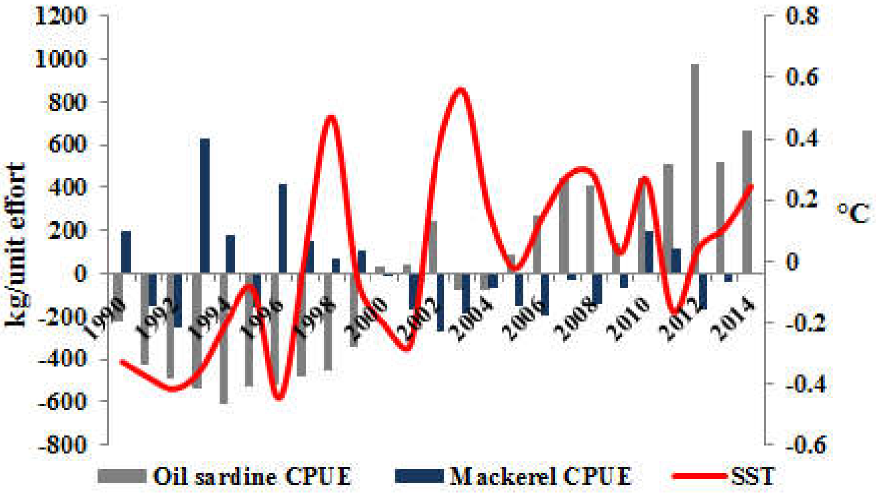

Fig.1. Catch rate anomalies with SST anomaly

Statistical analysis

The catch rate anomalies of oil sardine have shown statistically significant positive correlation with SST and negative correlation with MEI. No such significance was observed between and within the anomalies of climatological parameters. However analysis of quarterly data did show significant negative correlation of chlorophyll with rainfall, SST and oil sardine catch rate; in the case of Indian mackerel significant negative correlation was observed for MEI with rainfall and Indian mackerel catch rate.

The correlation between and within anomalies of climatological parameters and anomalies of catch rate of oil sardine and Indian mackerel is shown in Table 1. GAM results indicated good fit with mackerel catch rate anomaly and chlorophyll anomaly while for sardine good fit was observed with SST anomaly. R plot showed SST and Chl.*a* to be predicting factor for good distribution of oil sardine and Indian mackerel respectively. A temperature anomaly range of 0.1 to 0.3 indicating temperature of 28.1 °C to 28.38°C (Fig. 6) seems to be favorable for sardine distribution and chlorophyll concentration of 0.50 to 0.59 mg/m^3 for mackerel catch distribution (Fig. 7). Fig. 6a and Fig. 7a indicates the GAM output for oil sardine and Indian mackerel respectively.

DISCUSSION

Oil sardine and mackerel fishery along Indian coast is postulated to have an inverse relationship (Devaraj and Vivekanandan, 1999) and even showed a ten year cyclic pattern in their abundance to sun spot activity (Srinath, 1998). But lack of such correlation has been observed by other studies (Longhurst and Wooster, 1990; Madhupratap *et al.*, 1994; Krishnakumar *et al.*, 2008). The present analysis showed negative correlation, but statistically significant correlation between the catch rate anomalies of these two fisheries has been ruled out. However positive and highly significant correlation (< 0.01 level) was observed when analyzed on quarterly basis (second quarter to fourth quarter). SST anomaly showed a positive and significant influence on catch rate anomalies of oil sardine.

Further a temperature anomaly between 0.2 to 0.3°C seemed to be quite favorable for constant catches. This was observed during 2007, 2008 and 2010. In all these years the average SST value was found to be 28.32°C. This consistency in the catch may also be due to the combined favorable influences of UPI and La Niña events. Studies by Nagasawa (2001) showed increased production of Pacific herrings in Japanese waters during

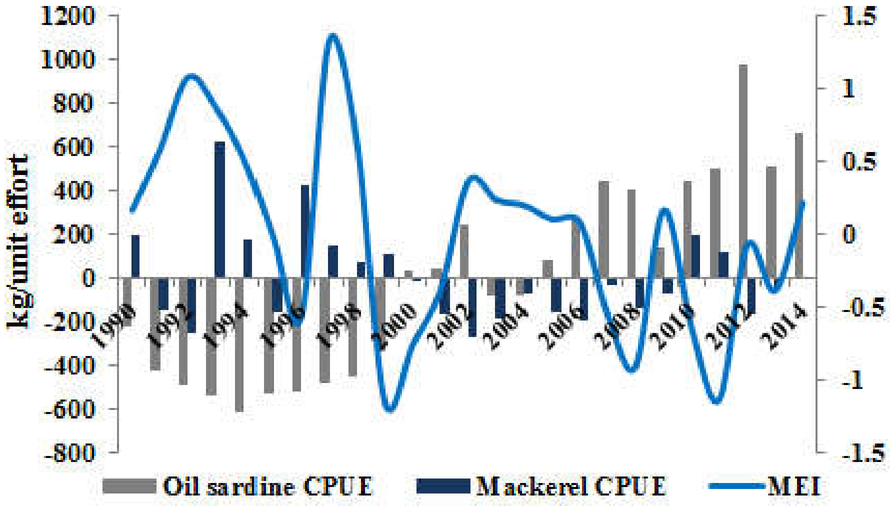

Fig.2. Catch rateanomalies with MEI anomaly

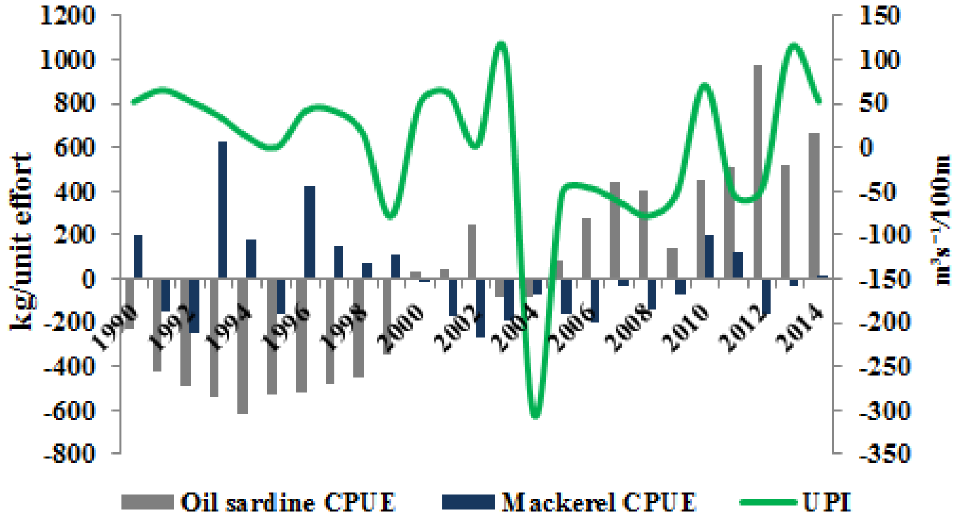

Fig.3. Catch rate anomalies with UPI anomaly

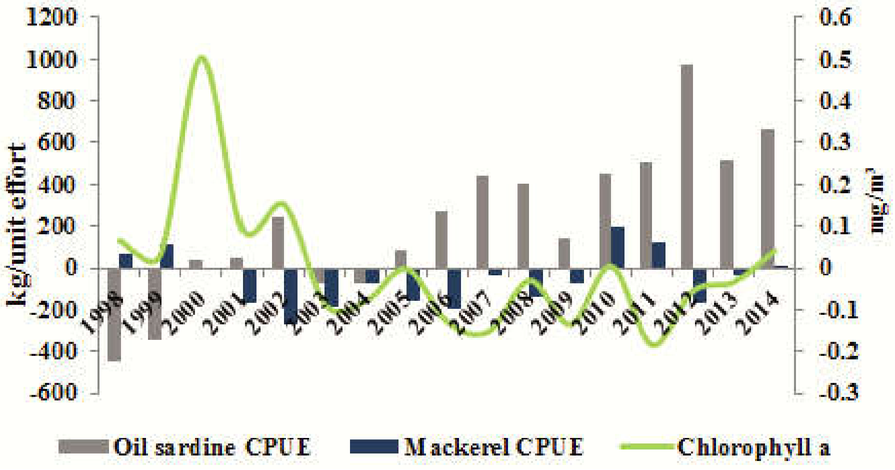

Fig.4. Catchrate anomalies with chlorophyll *a*anomaly

low to near–average SST periods whereas catches were poor during high SST periods. Selvin and Lipton (2012) reported SST to have a positive but insignificant correlation with oil sardine catch. Catch rate anomaly of oil sardine showed negative correlation with upwelling index which is in concurrence with earlier study carried out by Krishnakumar *et al.* (2008) without anomalies. The UPI anomaly was maximum in 2003 and minimum in 2004 but the catch rate of oil sardine slumped down thus indicating intense upwelling and down welling is not favorable for its fishery.

The catch rate of both oil sardine and Indian mackerel has shown a negative correlation with MEI but found to be significant with oil sardine catch rate. El Niño and La Niña events cause physical changes across wide regions of the Pacific and Indian Oceans that affect the abundance and spatial distribution of several commercially important fish stocks (Miller, 2007).

The El Niño was strongest in 1997–98 and affected the climate in many parts of the world (McPhaden, 1999). The maximum catch rates of oil sardines was recorded during a weak El Niño year (1632 kg/unit effort in 2012) and during a weak La Niña year (1173 kg/unit effort in 2013) and the SST during that period varied from 28.1 to 28.2°C. The study showed decrease in catch rate in oil sardine during El Niño events and the spurt in catch rate in 2000–2001 can be attributed to La Niña event which occurred soon after strong El Niño event in 1998–99 (Fig. 3). During this revival year of oil sardine the anomalies of SST and MEI were negatively very high while the anomalies of UPI and Chl.*a* were positively very high. The La Niña events also seem to favor Indian mackerel catch rate but with less intensity than that of oil sardine. Krishnakumar and Bhat (1998) have reported the collapse of mackerel fishery (1999–2000) along the southwest coast of India and Yamashiro *et al.* (1998) on the decrease in squid catch rates in Peru waters due to La

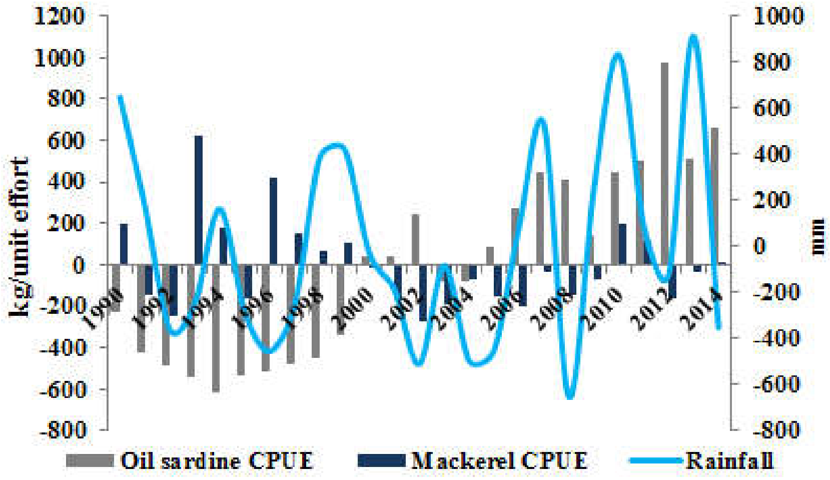

Fig.5. Catch rateanomalies with rainfall anomaly

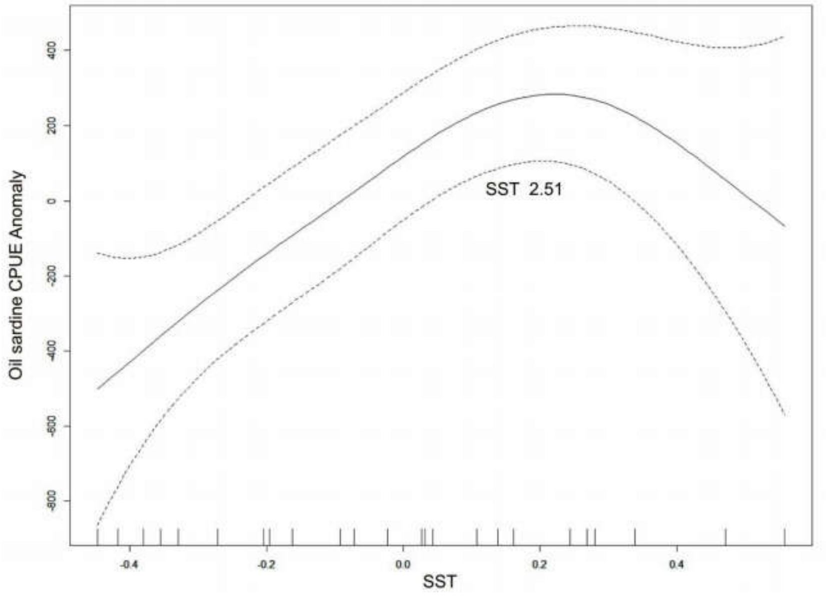

Fig. 6. Modeled (GAM) effect of SST anomaly on oil sardine catch rate anomaly. The x–axis shows the values of the explanatory variables, and the y–axis shows the results of smoothing the fitted values. The tick marks on the horizontal axis represent the values of the observed data points. The solid line shows the fitted GAM function and the black–dotted line indicates 95 % confidence intervals

Niña event which preceded the 1997–1998 El Niño events. Chl.*a* has a close direct relationship with the primary production (Gopinathan *et al*., 1994). The catch rate anomalies of oil sardine was observed to be negative with Chl.*a* while mackerel showed a positive relationship with Chl. *a*. The quarterly data analysis however showed chl.*a* anomaly to be positive with catch rate anomaly of oil sardine and SST during the second (April to June) and third quarter (July to September), statistically significant negative correlation was observed even with SST during the fourth quarter (October to December) the positivity thus being nullified when analyzed annually. Selvinand Lipton (2012) in their study during 2008 – 2010 recorded Chl.*a* to be positively correlated with SST and negatively correlated with oil sardine catch. Though the catch of oil sardine and Indian mackerel was highest during the fourth quarter, the catch rates of these two species were highest during the second quarter when SST was high (29.1°C) and Chl. *a* content low (0.27 mg/m³) but in the following third quarter (July to September) the chlorophyll content was highest with 1.04 mg/m³, the result of which may be due to high SST observed in the second quarter that has favored the full bloom of phytoplankton in the waters.

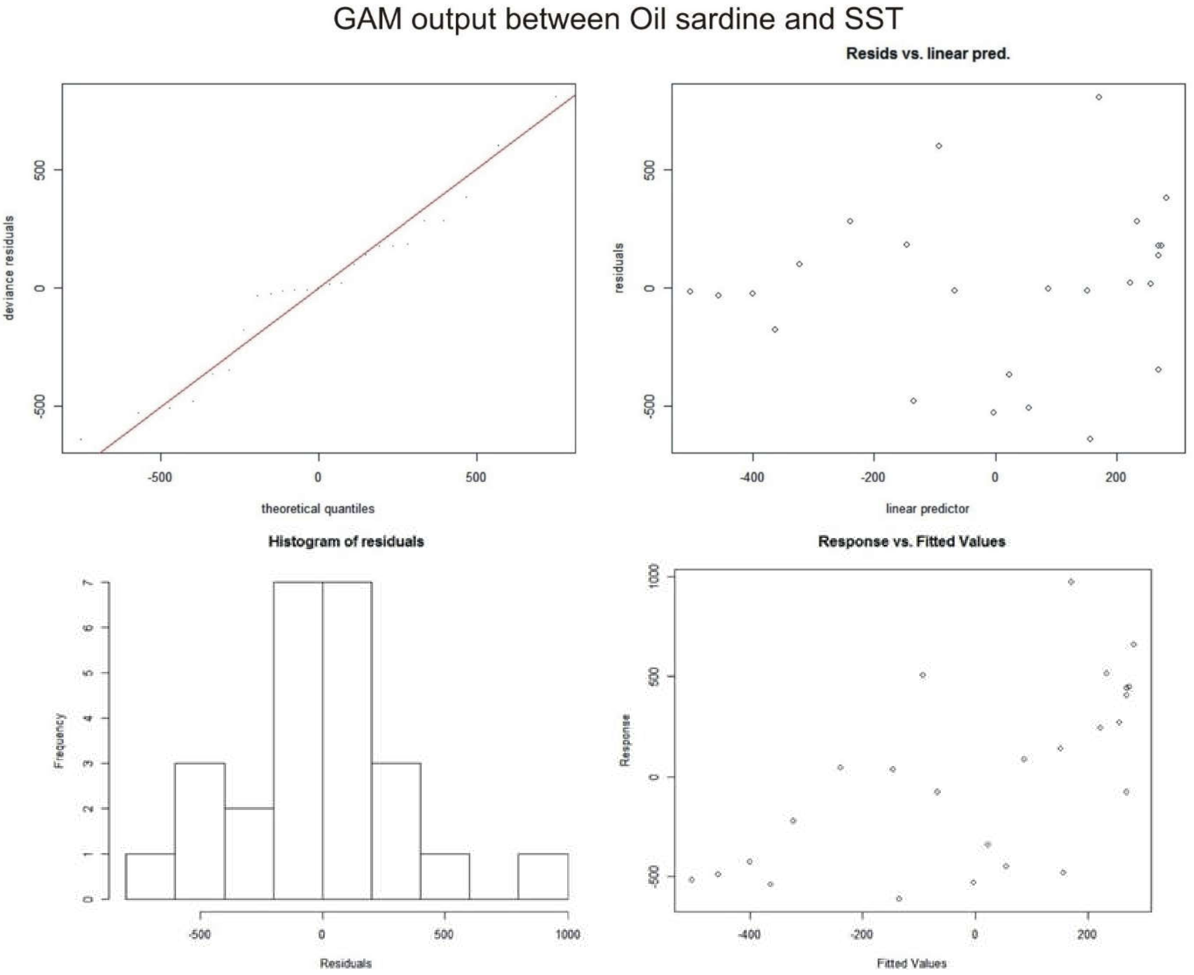

Fig. 6a. GAM output between anomalies of catch rate of oil sardine and SST

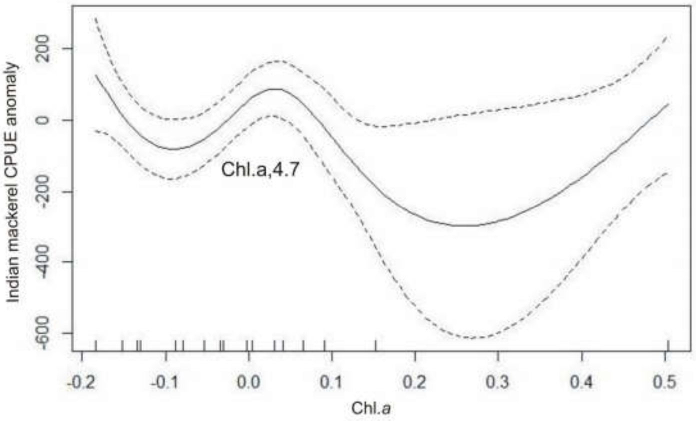

Fig. 7. Modeled (GAM) effect of chlorophyll *a* anomaly on Indian mackerel catch rate anomaly. The x–axis shows the values of the explanatory variables, and the y–axis shows the results of smoothing the fitted values. The tick marks on the horizontal axis represent the values of the observed data points. The solid line shows the fitted GAM function and the black–dotted line indicates 95 % confidence intervals

But this bloom of phytoplankton may not be a favorable food for oil sardine thus showing catch rate to be low during the third quarter. Vinayachandran *et al*. (2004) observed the bloom fully developed during June to July.

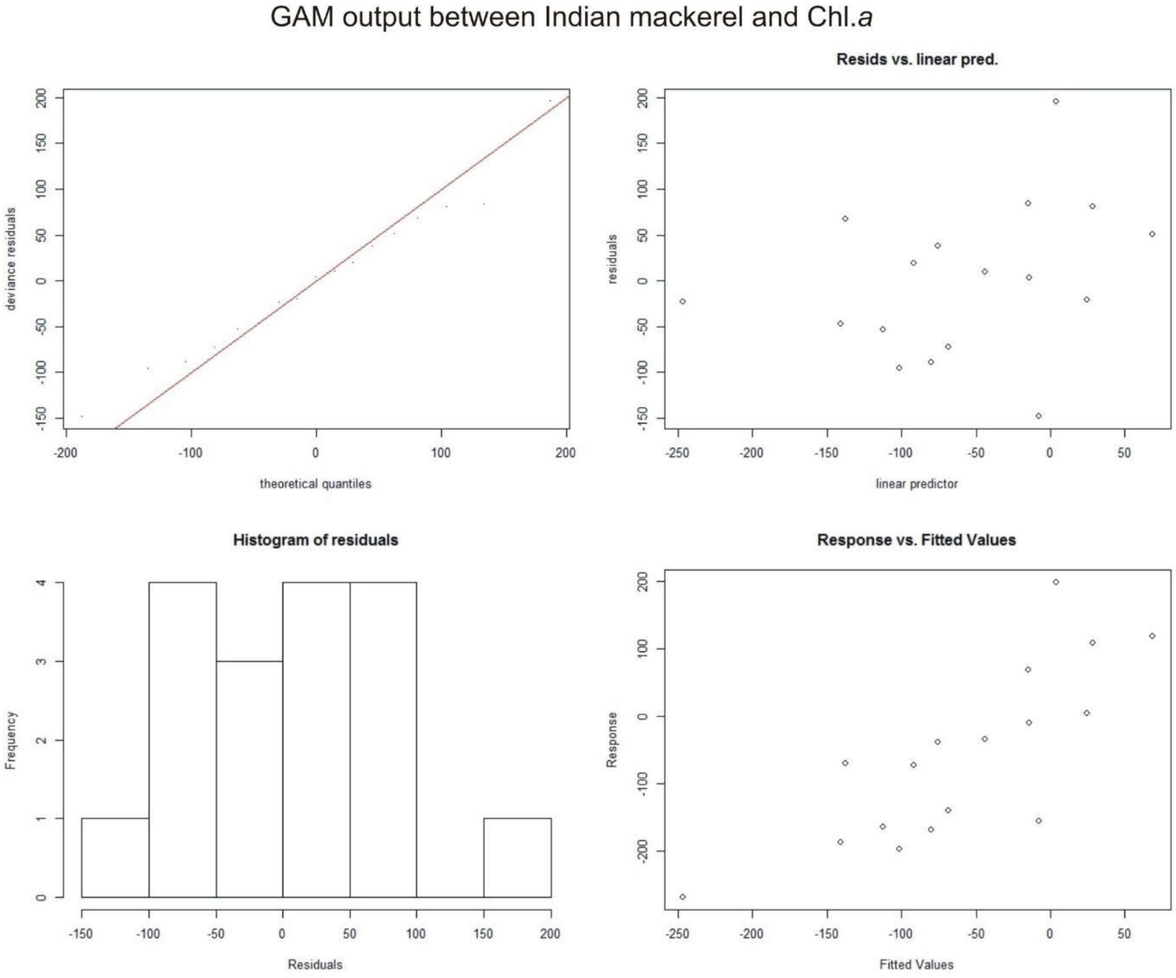

Fig. 7a. GAM output between anomalies of catch rate of Indian mackerel and Chlorophyll

Valvanis *et al*. (2002a) reported that low SST/high Chl.*a* areas indicate offshore feeding grounds for many commercially important species, especially small pelagic fish (sardine and anchovy) and pelagic squids. With rainfall anomaly, the catch rate anomalies of oil sardine and Indian mackerel was observed to have positive correlation even though insignificant. The rainfall was found to be very high during the third quarter which would have caused the increase in catch during the fourth quarter but the anomalies of both were highest during the second quarter. The catch rate anomaly was observed to be highest (2012) and lowest (1994) when the rain fall anomaly was in the least negative value (–120.4 mm) and positive value (162.4 mm) respectively.

According to Kumaran *et al*. (1992) there does not seem to be any direct relationship between oil sardine landings and the total rainfall on annual basis. To conclude, significant inverse relationships were not observed between the catch rate anomalies of oil sardine and mackerel on annual basis even though a positive and significant relationship was observed seasonally. Pearson's correlation showed climatological anomalies especially SST and MEI to have significant relationship with catch rates of oil sardine while in Indian mackerel the results were insignificant. Usually there exists inverse relationship between the two.

Graphically, a SST anomaly of 0.2°C seems to indicate oil sardine catches to be more or less constant. A weak La Niña event and a weak El Niño anomaly event showed maximum catch rates in oil sardine. The revival of oil sardine during 2001–2002 may be attributed to combination of high negative anomaly values of SST and MEI and high positive anomaly values of Chl.*a* and UPI. GAM results indicated SST anomaly range of 0.1 to 0.3°C (28.1°C to 28.38°C) and Chl.*a* anomaly of 0.00 to 0.05 mg/m³ (0.50 to 0.54 mg/m³ Chl.*a* concentration) as predictors of catches in the region for oil sardine and Indian mackerel respectively.

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