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Influence of coastal upwelling on the fishery of small pelagics off Kerala, south-west coast of India

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ABSTRACT

In order to evaluate the impact of the interannual changes of upwelling on the small pelagics, the average chlorophyll *a* concentrations were compared with the fishery. The catch of small pelagics, especially that of the oilsardine increased from 1, 554 t in 1994 to 2,50, 469 t in 2007 in the Malabar upwelling zone off Kerala, India. The coastal upwelling index (CUI) during south-west monsoon increased by nearly 50% during the period 1998 to 2007. This substantial increase in coastal upwelling index elevated chlorophyll *a* concentration during monsoon which resulted in an increase of over 200% in annual average chlorophyll *a* concentration. The increasing coastal upwelling index and chlorophyll *a* during monsoon sustained an increasing catch of oilsardine during postmonsoon season. The responses of lesser sardine and Indian mackerel, which are midlevel carnivores, were different. The population increases of the oilsardine appear to replace decreases in the lesser sardines and Indian mackerel during the postmonsoon season.

Keywords: Chlorophyll, Coastal upwelling, Indian mackerel, Lesser sardines, Oilsardine

Introduction

The Malabar upwelling zone along Kerala coast (south-west coast of India) is one of the important upwelling systems of the world (Bakun *et al*., 1998) and contributes about 20% to the marine fish catch of India (Fig. 1).

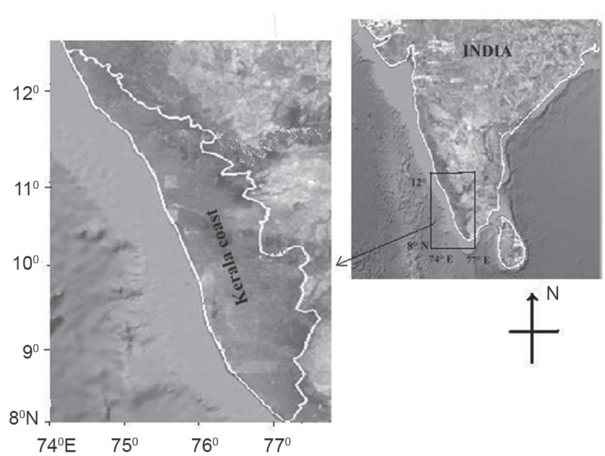

Fig. 1. Map of the study site off Kerala coast, India.

The striking feature of the Malabar upwelling zone is the predominance of pelagic resources such as oilsardine (*Sardinella longiceps*) and Indian mackerel (*Rastrelliger kanagurta*), which support the western Indian Ocean's largest coastal pelagic fishery (Vivekanandan *et al*., 2005). Though this upwelling is less in intensity when compared to the other upwelling regions of the Arabian Sea (like those at Somalia and Oman), it has profound impact on the coastal fisheries of India. While the west coast of India accounts for 70% fish yield of the total Arabian Sea production (Luis and Kawamura 2004)**,** the south-west coast alone accounts for 53% (Vivekanandan *et al*., 2009a). Historically, the fishery for these small pelagics has shown wide fluctuations (Krishnakumar and Bhat, 2008). In the last 100 years, there have been several periods of relatively high abundance, and several major population crashes of oilsardine (Krishnakumar *et al.*, 2008).

Ocean colour images of chlororphyll concentration and sea surface temperature (SST) have been the most commonly used remotely sensed products in fisheries research. From these images it is possible to identify particular features and processes known to influence the distribution and abundance of fish stocks, such as upwelling activity, frontal systems, and patterns of food abundance. To date, it is the distribution of fish populations and their planktonic life history stages, not their year-to-year fluctuations in abundance, which have received the greatest attention (Laurs, 1997). Another advantage of satellite image time series is their ability to provide detailed spatial representations of the physical state of marine systems through time, as opposed to just acting as high-resolution databases for environmental parameters. Satellite image time series clearly offer an important additional data source for studies into the effects of environmental variability on the behaviour of fish stocks and recruitment success.

Many researchers have tried to predict the availability of small pelagics in general, and oilsardine in particular, from the relationship between catches and climatic as well as oceanographic features such as seawater temperature, salinity, rainfall, upwelling and chlorophyll concentration along the south-west coast of India (Banse, 1959; Longhurst and Wooster, 1990; Madhupratap *et al.*, 1994; Yohannan and Abdulrahiman, 1998; Jayaprakash, 2002; Xu and Boyce, 2009). The studies were based mostly on the quarterly or annual landings. However, small pelagics are annual crops and there are monthly differences in growth, mortality and production. Hence, analysis of monthly catch data provides better projection on their relationship with oceanographic parameters.

Recent investigations on the impact of seawater warming on *S. longiceps* have shown an extension of northern and eastern boundaries of distribution of the fish along the Indian coast in the last two decades (Vivekanandan *et al*., 2009b). It was also shown that the catches of the fish along Kerala coast have increased, indicating that changing climatic factors are advantageous to distribution and abundance of the oilsardine. This is evident from the increase in the oilsardine catch from 1,554 t in 1994 to 2,50, 469 t in 2007. In order to elucidate the climatic mechanism that helped to increase the abundance and catches, we examined relationships between upwelling intensity and chlorophyll *a* concentration and catches of small pelagics, namely oilsardine, lesser sardines and Indian mackerel which together contribute nearly 50 % to the total catches along Kerala coast.

Materials and methods

Data collection

To quantify seasonal and inter-annual changes in the upwelling and its relationship between chlorophyll *a* and small pelagics, monthly average data on mean coastal upwelling index (CUI) was downloaded from the Global Upwelling Index data group of NOAA's PFEG Live Access Server (http://las.pfeg.noaa.gov) for the Kerala coast (lat 8º 12.5' N; long 77º - 74' E), having 140° and 133° coast angle for the years 1967–2007. Data on chlorophyll (Chl *a*) concentration were collected (for the years 1998-2007) from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS.R009). The data were gathered for three to five nearshore locations in the southern, central and northern parts off Kerala, averaged, and plotted to find the annual and seasonal (pre monsoon: February to May; monsoon: June to September; post- monsoon: October to January) trends. The seasonality was calculated by averaging monthly values. The monthly estimated landings data for oilsardine, lesser sardines (*Sardinella gibossa, Sardinella fimbriata*, *Sardinella albella* and *Sardinella sirm*) and Indian mackerel along Kerala coast during 1967-2007 were taken from Central Marine Fisheries Research Institute (CMFRI) database.

Statistical analysis

Pair-wise quantitative relationship between climatic variables and recourses was studied by Pearson correlation analysis using SPSS version 16. Correlation analysis is a useful and widely applied tool for generating hypothesis about the effects of environmental or other variables on recruitment on various time scales.

As the resources as well as the environmental parameters are multiple, whose impact are better studied in a combined way rather than individually, canonical correlation analysis was also performed between the set of resources and environmental parameters using SAS version 9.2. Canonical correlation analysis (CCA) is a technique for analysing relationships between two sets of variables. Each set can contain several variables, and CCA calculates a linear from each set, called a canonical variable, such that the correlation between two canonical variables is maximised (Lebart *et al*., 1984).

To understand the mechanism of influence of climatic factors upon the resources, the data was also analysed treating each variable as a time series. Once the data sets were treated as a time series, enormous leverage was obtained by way of calculation of auto correlation at various lags and lagged cross correlation between pairs of variables.

Results and discussion

The coastal upwelling index (CUI) was substantially higher during the monsoon season (711 m^3 s^{-1}) than the pre-monsoon and post-monsoon seasons (Table 1).

During south-west monsoon, low sea level indicates remote forcing of upwelling, rather than the wind-driven upwelling. The annual trend in CUI showed reduction from 505 to 150 $m^3 s^{-1}$ (Fig. 2) during 1967-2007. Contrary to the annual decreasing trend, the monsoonal CUI increased by more than 100% from 301.25 to 713 m^3 s^{-1} during 1998 -2007 (Fig. 2).

During the summer monsoon (south-west monsoon), an intense low-level wind jet (Findlater Jet) blows diagonally across the Arabian Sea producing coastal upwelling along Somalia, Oman and the south-west coast of India (Wyrtki, 1973). This substantial increase in CUI elevated the chlorophyll *a* concentration from 4.81 mg m^{-3} (1998) to 11.69 mg m^{-3} (2007) during monsoon (Fig. 3). The Chl *a* concentration was three to four times higher

Table 1. Seasonal settings of coastal upwelling index (CUI) off Kerala (the values are average for the years 1967 – 2007 for chlorophyll *a* concentration for catches of oilsardine, lesser sardine and Indian mackerel the values are average for the years 1998 – 2007)

Parameter	Pre - monsoon (Feb-May)	Monsoon (June-Sep)	Post-monsoon (Oct-Jan)
CUI (m^3s^{-1} along 100 m coastline)	380.11	710.82	-111.21
Chl *a* ($mg\ m^{-3}$)	2.25	8.49	3.47
Oilsardine (t)	49 364	67 412	85 602
Lesser sardine (t)	3 853	1 093	6 825
Indian mackerel (t)	8 967	20 753	17 753

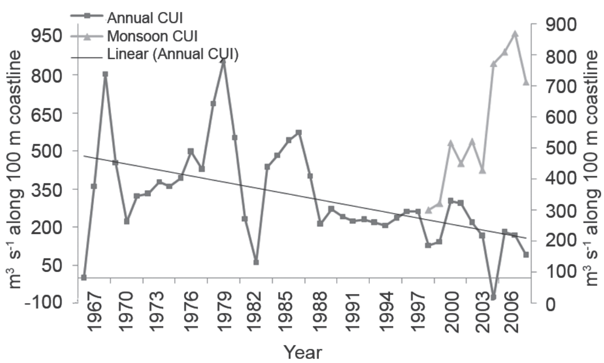

Fig. 2. Annual average of CUI and monsoon CUI

during monsoon (8.49 mg m^{-3}) than during the other two seasons (2.25 – 3.47 mg m^{-3}) as shown in Table 1. The high concentration and increasing trend of Chl *a* during monsoon resulted in nearly 200% increase in annual average Chl *a* concentration from 3.23 mg m^{-3} in 1998 to 6.58 mg m^{-3} in 2007 (Fig. 3). Increase in Chl *a* concentration coinciding with upwelling during monsoon season has been reported along the south-west coast of India by several authors (Banse, 1959; Ramamirtham and Rao, 1973; Muraleedharan and Prasannakumar, 1996; Madhuprathap *et al.*, 2001; Krishnakumar and Bhat, 2008).

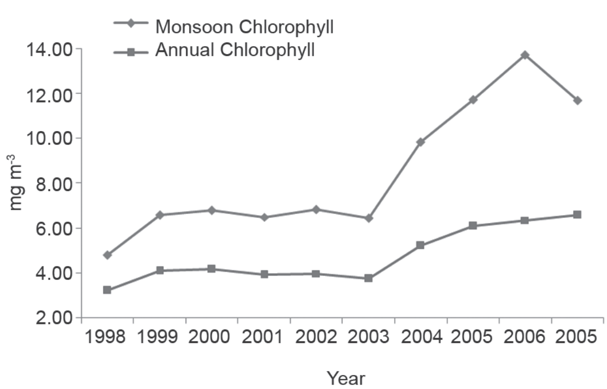

Fig. 3. Annual and monsoon seasonal average of chlorophyll *a*

The annual oilsardine catch along Kerala coast fluctuated widely during the 41 year period. The catch decreased from 2,35, 410 t in 1967-68 to 40, 613 t in 1986 and further decreased to 1, 554 t in 1994. Since then the catch has substantially increased in the last 13 years reaching 2,50, 469 t in 2007 (Fig. 4).

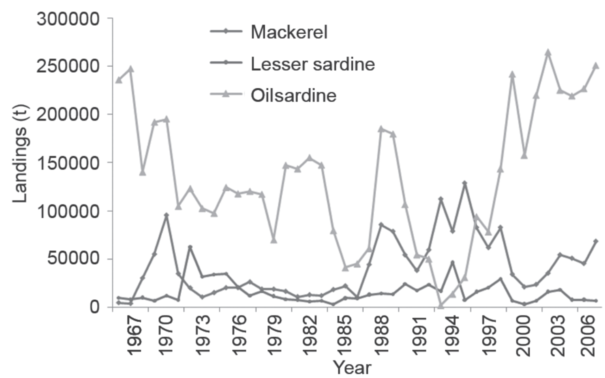

Fig. 4. Annual landings of oilsardine, lesser sardine and Indian mackerel

The highest oilsardine landing was in the postmonsoon season (Table 1). Usually, the peak pelagic fish production from the Malabar coast is recorded during August–December, during or immediately after the upwelling season (Banse, 1959; FAO, 1980; Johannessen *et al.*, 1981; Yohannan and Abdulrahiman, 1998; Prathibha and Bhat, 2003; Prathibha and Gupta, 2004). A positive correlation was evident between CUI and Chl *a* concentration during monsoon ($r = 0.941$, $p<0.05$); and between monsoon CUI and postmonsoon oilsardine catches ($r = 0.628$, $p<0.05$) during 1997- 2007. The peak spawning activity of oilsardine is during the south-west monsoon (Nair, 1960). Egg development and growth of post-larvae are rapid, and the fish reach 100 mm length in about three months (Raja, 1972). Thus the individuals spawned during south-west monsoon are recruited to the fishery during post-monsoon period. It may be concluded that the increasing CUI has induced higher Chl *a* concentration during south-west monsoon, which has resulted in increasing recruitment and catches of oilsardine during post south-west monsoon season along the Kerala coast. This is confirmed by the cross correlation analysis (Fig. 5).

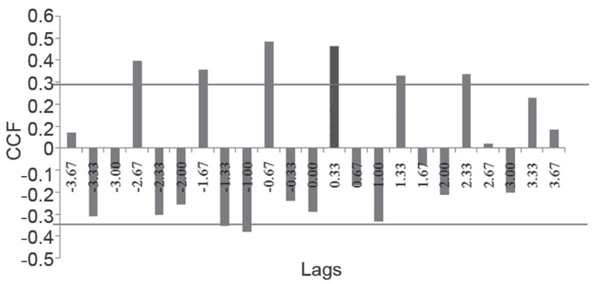

Fig. 5. Cross correlation between CUI and oilsardine

As it can be seen, lag 1 lines are very significant (0.467) indicating a correlation between CUI and oilsardine with lag one season. The increasing catch extended to the pre-monsoon season too, but at a lower magnitude (Fig. 6).

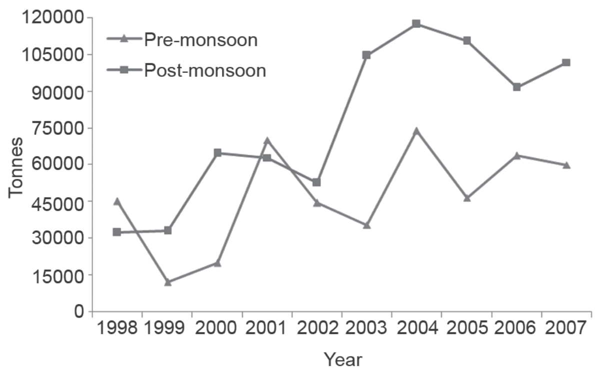

Fig. 6. Oilsardine landings during pre-monsoon and post- monsoon season

The lesser sardine catches, but for annual spurt in 1973 and 1995, remained almost unchanged during the 41 year period (Fig. 4). The highest lesser sardine landings were in the post-monsoon season. A strong negative correlation was evident between post-monsoon lesser sardine catch and monsoon CUI ($r = -0.718$, $p<0.05$) and Chl *a* ($r = -0.556$, $p<0.05$)**.** This relationship is confirmed by a negative correlation between oilsardine and lesser sardine catches during the post-monsoon season ($r = -0.354$, $p<0.05$). It is possible that the oilsardine, which is primarily a herbivore feeding on phytoplankton (trophic level: 2.50), has proliferated during post-monsoon and replaced lesser sardines, which are midlevel carnivores (trophic level: 3.15) (Vivekanandan *et al.*, 2009c). This kind of seasonal species succession in relation to climatic and oceanographic factors is common among fish populations.

The Indian mackerel catch increased from 4, 500 t in 1967 to 1,28, 411 t in 1996 and reduced to 20, 798 t in 2001; the catch recovered to 68, 062 t in 2007 (Fig. 4). The highest mackerel landing was during the monsoon. There is no relationship between monsoon CUI and Chl *a* and post-monsoon mackerel (trophic level: 3.40) catches. The dominance of oilsardine is further confirmed by a negative correlation between oilsardine and mackerel during monsoon season ($r = -0.639$, $p<0.05$). Being a low trophic level species, the oilsardine has the capacity for population explosions and dominates other fish species in terms of abundance if they are exposed to favourable conditions such as phytoplankton abundance. Thus the three major small pelagics responded in different ways to the prevailing environmental conditions.

Our analysis based on satellite–derived data on coastal upwelling over the Kerala coast (south-eastern Arabian sea) shows enhanced upwelling by nearly 50% and an increase of Chl *a* concentration by over 200% during south-west monsoon. This indicates that the current warming trend is beneficial to herbivorous small pelagics which is in conformity with the canonical correlation analysis performed between the resource group (oilsardine, lesser sardine and Indian mackerel) and oceanographic variables (CUI and Chl *a*). The first and second canonical variables of both oceanographic factors and resources positively correlated (CC1= 0.791; F = 5.04; df = 58.56; p= 0.0001 and CC2= 0.565; F = 2.87; df = 50; p= 0.0324) (Table 2.) Similar findings for the western as well as the central Arabian Sea (Goes *et al.*, 2005) support the potential for more widespread blooms of phytoplankton if the warming trend continues. This will have an important bearing on regional fisheries.

Table 2. Canonical correlation coefficients, together with their significance values for the canonical resource variables and the canonical climatic variables

CanCorr1	0.791* (0.0001)
CanCorr 2	0.580 * (0.0324)
CanCorr 3	0.036 (0.854)

* Correlation is significant at the 0.01 level

The significant value under the column headings indicates the global significance of the comparison provided by the most conservative among a panel of tests, namely Wilks' Lamda, Pillai's trace, Hotelling-Lawley and Roy's Greatest Root (suggested by Rao, 1973) for the multivariate linear regression. As for the significance of single regressors, the estimate is based on Rao's modified approximate F statistic (Rao, 1973).

Fish catches are driven by fishing effort and climatic factors. The three species/group investigated here are caught mainly by ring seines and gillnets. As the type and effort of fishing craft and gear are almost the same for the three fish groups, the differences in the catches could be attributed to climatic and oceanographic factors.

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