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 2,504,469 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 saridines and Indian mackerel during the postmonsoon season.

Keywords: Chlorophyll, Coastal upwelling, Indian mackerel, Lesser saridines, 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 chlorophyll 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 (Laur, 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 8° 12.5’ N; long 77° - 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 gibbosa, Sardinella fimбриa, 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 resources 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 m³ 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 m³ 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 m³ 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.
and further decreased to 1,554 t in 1994. Since then the catch has substantially increased in the last 13 years reaching 2,504,699 t in 2007 (Fig. 4).

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)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre - monsoon (Feb-May)</th>
<th>Monsoon (June-Sep)</th>
<th>Post-monsoon (Oct-Jan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUI (m³/s along 100 m coastline)</td>
<td>380.11</td>
<td>710.82</td>
<td>-111.21</td>
</tr>
<tr>
<td>Chl a (mg m⁻³)</td>
<td>2.25</td>
<td>8.49</td>
<td>3.47</td>
</tr>
<tr>
<td>Oilsardine (t)</td>
<td>49 364</td>
<td>67 412</td>
<td>85 602</td>
</tr>
<tr>
<td>Lesser sardine (t)</td>
<td>3 853</td>
<td>1 093</td>
<td>6 825</td>
</tr>
<tr>
<td>Indian mackerel (t)</td>
<td>8 967</td>
<td>20 753</td>
<td>17 753</td>
</tr>
</tbody>
</table>

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 concentration

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

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 2,504,699 t in 2007 (Fig. 4).
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

| CanCorr 1 | 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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Reference


