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Inter-annual variations of selected oceanographic parameters and its relation to fishery of small pelagics off Kochi, southwest coast of India

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Original Article

Abstract

The availability as well as abundance of selected small pelagics along Kerala coast (south west coast of India) was highly variable during the past three decades. During the period 1980-2012 there have been several periods of abundance as well as population crashes in the oil sardine fishery. The present study revealed that the occurrence of low sea level during the month of May implies either early wind driven upwelling or early intensification of equator-ward coastal current and consequent upsloping of isopycnals. The occurrence of low sea level (6857) as early as in May and upwelled water in August with low dissolved oxygen (0.68 ml l^{-1}) with low sea water temperature (24˚C) at the bottom at 10 m depth, off Kochi was found to affect the sardine fishery in the year 1994, when the landing at Kochi was only 15 t. Mean sea level was found to be a sign of upwelling and the real time observations of dissolved oxygen indicated wide variations during the upwelling period.

Key words*: Upwelling, hypoxia, fishery, small pelagic, sardine, mackerel*

Introduction

The total marine fish landings along the Kerala coast during the year 2012 was 8,39,185 tones against 7,43,123 t during 2011, an increase of 12.9% compared to previous year (CMFRI, 2013). The overall increase recorded was due to the increased landings of pelagic resources. The major pelagic groups which contributed to the fishery were oil sardine (47.6%), Indian mackerel (4.8%) and *Stolephorus* spp. (9.6%).

There have been several attempts to correlate oceanographic conditions along Kerala coast (south west coast of India) with availability as well as abundance of major pelagics. Hornel (1910), Bristow (1938), Devanesan (1943), Nair and Chidambaram (1951), Banse (1959), Nair (1959), Ramamritham and Jayaraman (1960), Murthy (1965, 1974, 1985), Murthy and Edelman (1966, 1971),Murthy and Vishnudatha (1976), Darbyshire (1967), Raja (1969), Shah (1973), Rao *et al.* (1973), Pillai (1983, 1991, 1993), Johannessen *et al.* (1987), Mathew (1982), Premchand *et al.* (1988), Longhurst and Wooster (1990), Madhupratap *et al.* (1994), Srinath (1998), Harikrishnan and Kurup (2002), Jayaprakash (2002), Pillai *et al.* (2003), Yohannan and Sivadas (2003), Vivekanandan *et al.* (2005), Krishnakumar *et al.* (2008), Nandakumar (2008),

Vivekanandan *et al.* (2009), Xu and Boyce (2009), Manjusha *et al.* (2013) are worth mentioning in this context.

The upwelling zone along the Kerala coast is one of the important upwelling systems of the world and contributes to more than 20% of the total marine fish landings of the country. The striking feature is the predominance of pelagic resources such as oil sardine (*Sardinella longiceps*), Indian mackerel (*Rastrelliger kanagurta*) and white bait which support the Western-Indian Ocean's largest coastal pelagic fishery (Vivekanandan *et al.*, 2005). Historically the fishery for these small pelagics has shown wide fluctuations. During the past 100 years, there have been several periods of relatively high abundance and several population crashes for oil sardine (Krishnakumar *et al.*, 2008).

In the past, many researchers have tried to predict the availability of small pelagics in general, and oil sardine in particular from the relationship between catches/landings and major climatic as well as oceanographic features such as sea water temperature, salinity, rain fall, upwelling and chlorophyll concentration along the sea coast of India. (Banse, 1959; Pillai *et al.*, 1980; Yohannan and Abdurahman, 1998; Longhurst and Wooster, 1990; Madhupratap *et al.*, 1994; Jayaprakash, 2002; Xu and Boyce, 2009). These studies were mostly based on 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 along with related oceanographic parameters provide better projection of their relationship.

Recent investigations on the impact of sea water warming on *S. longiceps* have shown an extension of northern and eastern boundaries of distribution of the fish along Indian coast in the last 2 decades. It was also shown that the catches of oil sardine along Kerala coast have increased indicating that the changing climatic and oceanographic parameters are advantageous for the distribution and abundance of oil sardine (Vivekananandan *et al.*, 2009). In order to elucidate the mechanism that helped to increase the abundance reflected in the landings, we examined the relationship between early remotely forced upwelling intensities off Kochi (representative for the area) and landings of small pelagics, *viz.*, oil sardine, mackerel and whitebait which together contributed to nearly 50% of the total landings along the Kerala coast.

Material and methods

Monthly hydrographic data collected off Kochi at fixed locations *viz.* 5 m, 10m, 20 m and 30m depth stations (Fig.1) at surface and sub-surface levels during the period 1992-2012 were utilized for the study. "Cadalmin" series of coastal

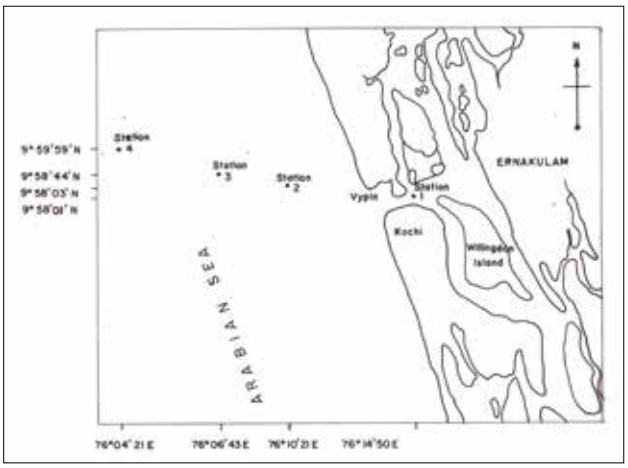

Fig.1. Map showing sampling stations off Kochi

oceanographic research vessels of Central Marine Fisheries Research Institute (CMFRI) with more or less same. Overall Length and Horse Power were engaged for the purpose. Nansen reversing water sampler (Hydrobios) was used for water sample collection. Sea water temperature and dissolved oxygen levels were estimated using standard procedures (Strickland and Parsons, 1968). The methodology adopted for analysis of water samples was uniform, during these two decadal periods thereby making the data highly comparable.

PSMSL is the acronym for Permanent Service for Mean Sea Level located at Bedson observatory, UK responsible for the collection and distribution of sea level data from the global net work of tide gauges. Monthly mean sea level values for Kochi were obtained from this data registry for the period of 1992 - 2008. Since these values were available only upto 2008, analysis were carried out for the period 1992-2008.

Kochi section, is representative of the region where most of the small pelagics, especially oil sardine spawns and recruitment to the fishery takes place, which is directly influenced by the changes in the environmental conditions leading to the phenomenon of upwelling. The catch data of sardine and mackerel in the Cochin Fisheries Harbour and other minor landing centres collected through trained field staff of CMFRI were used in the study.

Results and discussion

Off Kochi, sea level was the highest (indicating least upwelling) during December to March (Table 1). Low sea level (indicating strong upwelling) was observed from July to September except during the year 1994 and 2003, when low sea level was observed as early as May. Comparatively low sea water temperature was observed at 10 m depth off Kochi (22.4°C to 26.5°C with an average of 23.8°C) between

Table 1. Dissolved oxygen concentration and water temperature (lowest values) at 10 m depth, off Kochi during 1992-2012 along with PSML values at Kochi

	Dissolved Oxygen (mll^{-1})		Temperature (o C)		High PSML		Low PSML	
Year	Lowest value	Month	Lowest value	Month	PSML Value	Month	PSML Value	Month
1992	0.07	Jun	23.8	Jun	7085	Dec	6834	Aug
1993	0.95	Aug	22.8	Aug	7053	Dec	6811	Aug
1994	0.68	Aug	24	Aug	7112	Feb	6857	May
1995	0.99	Aug	22.97	Aug	7042	Mar	6874	Aug
1996	0.48	Aug	23.1	Aug	7086	Dec	6864	Jul
1997	2.72	Aug	24.3	Aug	7054	Jan	6854	Aug
1998	3.03	Sep	26.3	Sep	7002	Feb	6952	Aug
1999	1.41	Sep	24	Jun	7143	Feb	6833	Sept
2000	0.68	Jul	22.4	Jul	7154	Jan	6831	Jul
2001	0.73	Aug	22.4	Aug	7077	Dec	6850	Aug
2002	0.94	Jul	24.3	Jul	7077	Mar	6847	Jul
2003	0.79	Aug	23.2	Aug	7096	Nov	6842	May
2004	0.57	Jun	22.7	Jun	7132	Jan	6849	Sept
2005	0.73	Aug	23.8	Sep	7124	Dec	6916	Aug
2006	Not sampled	Mar	Not sampled	Sep	7168	Jan	6899	Jul
2007	1.06	Aug	26.5	Aug	7143	Dec	6959	Jul
2008	0.53	Sep	24.9	Sep	NA			

July and September and corresponding low dissolved oxygen values at the same depth (0.07 to 2.72 ml l^{-1}) except in 1998 clearly revealed the presence of upwelled water, off Kochi in the shallower regions of the continental shelf.

According to Longhurst and Wooster (1990), events during the early part of the year especially March-April have the greatest influence on the size of the sardine stock in the subsequent fishing season. Dineshkumar (2001) after examining the monthly mean values of sea level at Kochi for the period 1949-1998 opined that PSMSL was lowest during SW monsoon season.

Sea level in April signals the setting up of oceanographic conditions which manifest several months later as a coastal regime inimical either to the entry of spawning shoals into the coastal waters or to the survival of larvae at the time of their critical first feeding or alternatively early remotely forced equator-ward flow with upsloping of isopleths towards the coast depress the pre spawning maturation process so that subsequent spawning is relatively poor. The lowest landings of oil sardine at Kochi during the fishing season of 1994 corresponds to low sea level (PSMSL) observed off Kochi as early as May (6857) indicating early remotely forced equator ward flow with upsloping of isopleths towards the coast which in turn would have possibly depressed the pre spawning maturation process of oil sardine thereby making subsequent spawning relatively poor. One of the lowest sea levels (PSMSL) recorded at Kochi (6811) was in the year 1993 during the month of August. The sea water temperature recorded at a depth of 10 m in 1993 was the lowest (22.8°C) along with very low dissolved oxygen values (0.95ml l^{-1}) in the same month (Table 1). All these features support a very strong upwelling during August 1993 off Kochi which possibly would have resulted in a comparatively higher primary productivity and subsequently a high secondary production providing a conducive environment for the survival of oil sardine larvae at the time of their critical first feeding resulting in a landing of more than 2852 t at Kochi during the year 1993 (Fig. 2).

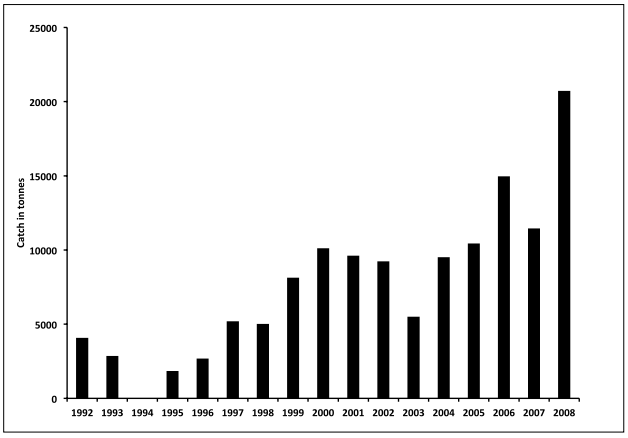

Fig.2. Landing of oil sardine at Kochi during 1992 - 2008

It is already established that stock abundance is not necessarily related directly to landings but we assume this to be so for oil sardine because:

- Reproduction occurs near the coast so that the whole reproducing population is available for the fishery.
- Fishing effort for most of the period is artisanal.
- Total catch of the fishery is unregulated except for a brief period of closure (that too not for Kerala coast)
- Oil sardine shoals do not perform long distance migrations like anchovies which concentrate south of Cape Comorin during the summer monsoon period and then spread northwards along the Malabar coast during the dry season (November onwards).

One explanation might be supported by the invasion of the shelf with water of extremely low dissolved oxygen content which might prevent oil sardine from approaching the coast to spawn. Oxygen deficient water is not solely a near- bottom feature, and sometimes such hypoxic waters rises to within 10 m off Kochi towards the end of the monsoon period (Banse, 1968; Shah, 1973; Johanssen *et al.*, 1987). Perhaps oil sardine appear at the surface near the coast during the upwelling season simply to avoid oxygen deficient water. By doing this, oil sardine may be able to tolerate the arrival of upwelled water in most years.

If one examines the 1977 upwelling phenomenon off Kochi, based on the results of survey conducted by the erstwhile FAO/UNDP Pelagic Fishery Project (1971-78) subsurface waters from a depth of 110 m were inducted upwards upto a depth of 7 m (FAO, 1973, 1976). The speed was calculated to be 73.6 cm day-1, perhaps the strongest upwelling recorded during 1973-78 period (Table 2). It is likely that in years of very strong upwelling oxygen deficient water may even break the surface. In such a case, oil sardine might be held offshore and excluded from spawning and juvenile nursery grounds as it might have happened during the year 1994. During May 1994, the PSMSL at Kochi was very low (6857) indicating the possibility of intensive upwelling during the latter half. The sea water temperature at 10 m off Kochi during August 1994 was only 24°C with low dissolved oxygen value of 0.68 ml l^{-1}. The lowest landing of oil sardine ever recorded (15 t) at Kochi was observed during 1994.

During the year 2003 low PSMSL (6842) was recorded during the month of May (Table 1). But oil sardine landings at Kochi did not indicate any fall during 2003. Possibly major part of the stock would have remained near the surface in coastal waters and avoided the oxygen deficient water resulting from strong upwelling.

Correlation between landings of both mackerel and anchovy and monthly sea level was much weaker than that for oil sardine and showed no seasonal pattern although these are also shoaling species taken in the same fishery approximately during the same season as oil sardine.

The reproductive ecology of the three species is quite different:

- Mackerel reproduces intermittently throughout the year and the erstwhile FAO/UNDP Pelagic Fishery Project records clearly indicate that mackerel larvas occur in all the months (Blindheim and Monstad, 1976).
- Anchovy tends to congregate south of the region of the oil sardine fishery around Cape Comorin during the south west monsoon and migrate northward along the Malabar Coast during the dry season.

Hence, anchovy and mackerel spawning is not influenced

Table 2. Upwelling intensity off Kochi based on the vertical movement of 23°C Isotherm. (source; Pillai *et al.,* 1980)

Year	Duration (days)	Upward movement (m)	Speed (cm/day)	Least depth of occurrence of 23°C isotherm (m)
1973	211	93	55.9	20
1974	212	114	53.8	16
1975	195	96	49.2	17
1976	167	106	64.7	16
1977	140	103	73.6	7
1978	201	88	43.8	24
Year		Period/Upward movement (m)		
1973	January-August	93 m	(110 m to 20 m depth)	
1974	January-August	114 m	(130 m to 16 m depth)	
1975	February-September	96 m	(115 m to 17 m depth)	
1976	February-September	106 m	(120 m to 16 m depth)	
1977	March-July	103 m	(110 m to 7 m depth)	
1978	March-July	88 m	(112 m to 24 m depth)	

Note: Upwelling was strongest during 1977.

by monsoon conditions and upwelling in the same manner as for oil sardine. Each of these three species may respond differently to low sea level (indicating upwelling) during March and April. However, for oil sardine this would interfere with successful spawning. An inverse relationship between oil sardine and mackerel abundance was not observed in the landings during 1973-77.

It is quite possible that during years when phytoplankton population is comparatively high, large stocks of oil sardine a herbivore, consume most of the available phytoplankton thereby reducing the possibility of an increase in zooplankton population and bringing down the stock of mackerel, which is primarily a zooplankton feeder. This could be a possible reason for the inverse relationship between oil sardine and mackerel population during different years as reported by earlier workers.

During the year 1978, landings of both oil sardine and mackerel were very high, possibly due to the very high intensity of upwelling during 1977. Contrary to the above, PSMSL was lowest during July 1986 (6770) and the landings of both oil sardine as well as mackerel were very poor during the year 1987.

The present study revealed that the occurrence of low sea level during the month of May implies either early wind driven upwelling or early intensification of equator-ward coastal current and consequent upsloping of isopycnals. The authors are of the view that the PSMSL during the month of May can be an indicator for oil sardine abundance or absence in that area for the particular year. Low PSMSL during the month of May can depress the pre-spawning maturation process of oil sardine thereby making subsequent spawning relatively poor as observed during 1994. On the contrary, it can also lead to strong upwelling, resulting in comparatively high primary production and in turn good landings of oil sardine in the area as observed in 2003. Possibly, major part of the stock would have remained near the surface in coastal waters and avoided the oxygen deficient upwelled water. A regular monitoring of the coastal waters assumes great significance in this regard.

The authors are of the opinion that correlation between landings of both mackerel and white bait and monthly sea level is much weaker than that for oil sardine as opined by Longhurst and Wooster (1990).

The oil sardine fishery along Kerala coast has shown a phenomenal increase in landings after the year 2000 and has reached a record high during 2012 (Fig. 3), possibly due to major changes observed in different oceanographic parameters caused by the global warming process resulting in comparatively higher sea water temperature and subsequent increase in primary productivity leading to the availability of preferred food for oil sardine. Increase in fishing effort and extension of fishing area also would have supported increase in sardine landing.

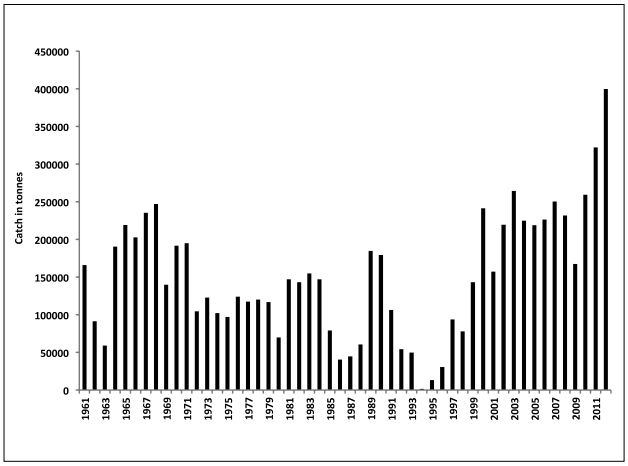

Fig.3. Oil Sardine landings of Kerala during 1961-2012

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