ROLE OF ENVIRONMENTAL VARIABLES ON SPAWNING AND RECRUITMENT OF SMALL PELAGICS IN AN UPWELLING SYSTEM : THE INDIAN OIL SARDINE - A CASE STUDY

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Introduction

The marine ecosystem is dynamic and the variations several abiotic and biotic factors directly and indirectly affect the fish stocks and their population structure. Spawning and recruitment success is to a large extent linked to these environmental variations. It is well known that resources occupy a particular habitat because of their preference to the environmental variables prevalent there and also due the availability of food. We have large shoal forming small pelagic fishes like the sardines and anchovies and the deep water large pelagic and demersals occupying the marine ecosystem from the upper pelagic zone to the benthic realms. Fishing is one of the major activities directly impacting the fish stocks and fishery records show several cases of overfishing leading to stock collapses. Definitely, fishery management tools have supported revival of several of these stocks but have failed to do so in few others. Almost equally important in inducing the biological changes that control maturation, spawning and recruitment are the some ocean atmospheric processes which change inter-annually in the tropics.

Globally, small pelagics serve as important forage species and support several higher tropic level fisheries. They also support coastal livelihoods and form an important source of low cost and high quality protein to several villagers. In addition to this, they serve as raw material to several post-harvest processing units which prepare canned, smoked and dried products regularly.

One common factor among most of these fishes is their ability to increase in biomass to very high levels and then suddenly decline and collapse. They revive slowly taking to 2 to more than 6 to 8 years depending upon the reason and the intensity of overfishing. All these changes in biomass, like the sudden increase and the low levels are mainly controlled by environmental factors. A recent study on the decline in sardine fishery along the Kerala coast revealed the role played by several abiotic and biotic ecological parameters which determine the recruitment success. The importance of environmental variables on recruitment success is detailed below through the recent investigations on sardine fishery.

Sardine Fishery of Kerala

The Indian oil sardine is a small shoal forming pelagic fish which is caught mainly by seines. Historic records describing the fish and fisheries of Kerala indicate that in the year 1320 Odoric has commented that there were plenty of fishes in coastal waters in Kerala, and this is presumed to be a one of the earliest reference to sardines. Apart from being used as food, sardines were used for oil extraction which was exported from Cochin port. Historic records show that sardine fishery has collapsed several till during the last two centuries and Day (1865) has observed the ill effects of unrestricted in diminished catches in later years. He also thought that oil sardine "*occasionally forsake their haunts for several consecutive seasons, returning again in enormous quantities*"

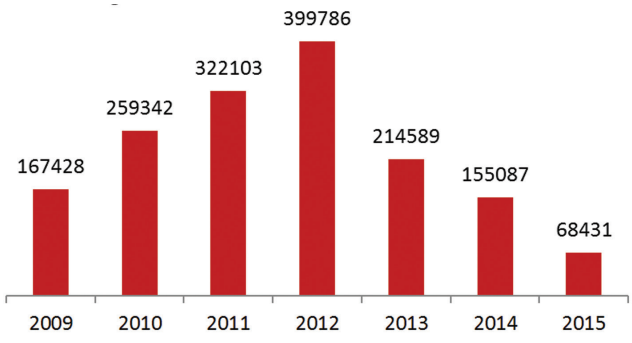


Fig. 1. Kerala Sardine Total Catch in tonnes

The sardine catch in 2012 was 3.9 lakh tonnes which was the highest during the last two centuries and then the decline started. The catch declined by 46 % in 2013 (catch 2.1 lakh tonnes), then by 61% in 2014 (catch-1.6 lakh tonnes) and by 82% in 2015 reaching 68431 tonnes (Fig. 1). Within a span of 5 years, the state witnessed the highest catch and lowest catch. During the period 1960 to 2015, the sardine stock has reached the collapsed status only once (1994.)

Most often, before a fishery collapse, over fishing of the stocks leading to imbalance in the population structure and biomass has been known to occur. As per an estimate of CMFRI based on 2005 to 2007 data the MSY of sardine along Kerala coast, is 2.3 lakhs tonnes. So during the period 2011 and 2012, the stock was fished above the MSY by harvesting nearly 2.5 lakh tonnes.

Excessive harvest of juveniles: About 16,040 tonnes of juveniles (less than 10cm) forming 4% of the total catch were harvested in 2012 and about 4802 tonnes in 2013. This would have affected the spawning biomass of 2013, 2014 and 2015. (16,040 tonnes of less than 10cm sardine would have contributed to a biomass of 5,61,400 tonnes at 30% mortality in the subsequent years . Similarly if the 4802 tonnes of juveniles were allowed to grow, it would have supported a spawning population of 1,68,070 tonnes of sardine)

The Indian oil sardine is known to move to inshore waters for spawning in large shoals. This is the time when the sardines have been fished in large quantities. After spawning, the young ones grow rapidly in the near-shore area (Fig 2). The environmental variations affect all the biological processes.

Role of Fishery dependent factors in reducing fish stocks

Usually age structure in a fish population is balanced. However, due to intense fishing pressure, either due to growth overfishing or due to recruitment overfishing, the fish stocks can be affected and in such instances they become vulnerable to adverse environmental conditions. Less than one year old sardines have always formed a major component of sardine population. However, during the period Oct 2012 to Feb 2013 about 1,17,823 tonnes of 10 to 14 cm size sardines were harvested. The large scale removal of this group also would have affected the potential spawning population of 2013 and 2014. Thus the population of sardine was affected. So by the beginning of 2013, the sardine stock off Kerala was severely affected-low biomass and less number of potential spawners. What followed after that was adverse environmental conditions, though not continuous, affected spawning and recruitment.

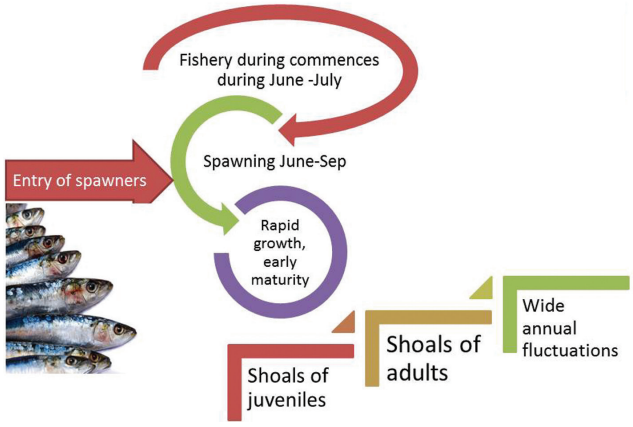
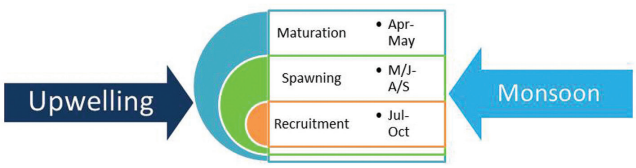


Fig. 3. Time line of reproductive phases and key environmental process

Environmental factors controlling sardine maturation and spawning

Upwelling and monsoon are two major ocean –atmospheric processes which are known to influence sardine maturation and spawning (Fig 3). They are known to mature by April –May and spawn from end of May to August/September. Recruitment is usually from July/ August onwards.



Upwelling and Recruitment

Upwelling is a process in which deep, cold water rises toward the surface. *Upwelling* occurs when winds push surface water away from the shore and are replaced by cold, nutrient-rich water that wells up from below (Fig 4). Deep ocean water is more nutrient-rich than surface water as nutrients, dead and decaying plankton and other fish carcasses sink to the bottom. During upwelling these are brought back to the surface and these fertile systems support blooming of diatoms and zooplankton. This rich food supports growth and maturation of several fishes.

Upwelling is most common along the west coast of continents (eastern sides of ocean basins). In the Northern Hemisphere, upwelling occurs along west coasts (e.g., coasts of California, Northwest Africa, India) when winds blow from the north (causing Ekman transport of surface water away from the shore). Along the Indian west coast, upwelling is strong along Kerala coast and is known to occur in varying intensities.

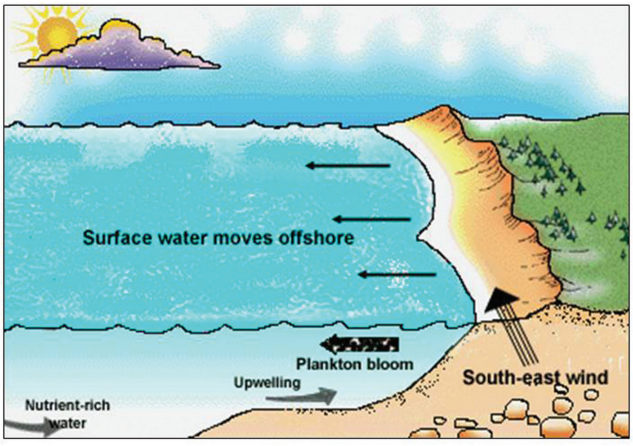


Fig. 4. Schematic diagram of Upwelling

Upwelling and Fish Maturation

As mentioned earlier, upwelling triggers blooming of diatoms and these provide food for the maturing fishes like sardine. Along Kerala coast upwelling sets in by May -June and this suddenly increases the Gonado-Somatic Index of sardine making them ready for spawning. When there is poor upwelling, the major factors supporting gonad development like blooming of diatoms and lowering of ambient temperature does not happen and this can lead to poor maturation or delayed maturation. In 2015, upwelling was poor and maturation was affected.

Upwelling and Dissolved Oxygen

Upwelling can also bring in low oxygen water which can lead to hypoxic conditions. Sometimes along Kerala coast, low oxygen in upwelled waters can be seen in the sardine habitat during August –September. If the dissolved oxygen levels are below one ml /l then this has been found to affect recruitment and the fishery. In the sardine habitat along Kerala coast, the influx of upwelled waters with low oxygen (0.7 to 0.8 mg per litre) was found in the main sardine habitat during August 2013 .Low mixing of waters can cause stratification and along with hypoxic conditions cause stress to the early life stages.

Upwelling and Jellyfishes

Jellyfishes are known to bloom and survive in adverse conditions. When upwelling creates low very oxygen conditions jellyfishes are not affected. Hence they also proliferate in the coastal waters. These can increase the biotic pressures on the larval and juvenile stages through predation.

Timing of Upwelling

If upwelling occurs very early and if the intensity is high with low oxygen waters in the habitat, this can prevent the spawners from entering the coastal waters for spawning. In such cases, spawning may be delayed.

Monsoon-Rainfall and Recruitment

When maturation is largely influenced by upwelling, the onset and intensity of southwest monsoon has a good influence on sardine spawning and recruitment. Though there is no direct affect, the changes triggered by monsoon especially the blooming of plankton in near-shore waters supports early larval development. The high levels of phosphate, nitrate and silicate in the river runoff triggers and supports blooming of diatoms. These support the large shoals of early life stages of sardine. Similarly, there will be negative impacts when the riven runoff is high and there is no proper mixing. This can lead to stratification and adversely affect recruitment.

In 2013 there was good maturation in sardines during pre-monsoon period, but the spawning and recruitment processes were affected by the above normal rainfall during June and July. The rainfall during June and July of 2013 was 60 and 14% more than the normal.

The sardines were exposed to "stress" due to salinity stratification i.e extremely low salinity due to excessive river runoff in the surface waters and higher saline waters in the bottom.

Deficit Monsoon

In 2014 there was good maturation in sardines during pre-monsoon. However, since the monsoon was deficient during June/July it delayed the spawning period. A successful spawning as in normal years was not observed in spite of good maturation. Sporadic spawning was observed from April to Sep/Oct (7 months). Though spawning was observed during third week of June it was not complete.

Excess Rainfall During Late Monsoon

In 2014, monsoon was excess by 74% and 22% during August and September than the normal. This resulted in low saline waters and salinity stratification which affected recruitment.

Ocean Atmospheric Processes

El Niño

El Niño is the warm phase of the El Niño Southern Oscillation (commonly called ENSO) and is associated with a band of warm ocean water that develops in the central and east-central equatorial Pacific . ENSO refers to the cycle of warm and cold temperatures, as measured by sea surface temperature, SST, of the tropical central and eastern Pacific Ocean. El Niño is accompanied by high air pressure in the western Pacific and low air pressure in the eastern Pacific. The cool phase of ENSO is called "La Niña" with SST in the eastern Pacific below average and air pressures high in the El Nino affects the global climate and disrupts normal weather patterns, which as a result can lead to intense storms in some places and droughts in others. At least 26 El Niño events since 1900 have been identified, with the 1982-83, 1997–98 and 2014–16 events among the strongest on records. ENSO is the most important coupled ocean-atmosphere phenomenon to cause global climate variability on inter-annual time scales.

Multivariate ENSO Index

The multivariate ENSO index, abbreviated as MEI, is a method used to characterize the intensity of an El Niño Southern Oscillation (ENSO) event. Given that ENSO arises from a complex interaction of a variety of climate systems, MEI is regarded as the most comprehensive index for monitoring ENSO since it combines analysis of multiple meteorological and oceanographic components such as sea-level pressure (P), zonal (U) and meridional (V) components of the surface wind, sea surface temperature (S), surface air temperature (A), and total cloudiness fraction of the sky (C).

Impacts on Ecosystems and Fisheries

In Peru, the warm water and low food availability that accompany El Nino have led to decline in anchovies that make up the largest fishery on Earth. Global total capture fishery production in 2014 was 93.4 million tonnes, of which 81.5 million tonnes from marine waters and 11.9 million tonnes from inland waters. (FAO, 2016). For the first time since 1998, anchoveta was not the top-ranked species in terms of catch as it fell below Alaska Pollock.

In 2015, it was observed that upwelling was low and the sardine habitat changed considerably. There was no good maturation and spawning during 2015, consequently poor recruitment. Though maturation was observed during May/June, it was not as healthy as in previous years. Globally, 2015 has been considered as a warm year with high temperature and low food. The average seawater temperature in sardine habitat was 29.8° C during 2015, which is nearly 1.1 deg C higher than the average observed (28.6 ° C) for the last 5 years. Positive SSTA exceeding 0.6°C dominated in the tropical Indian Ocean. There was a substantial warming in the tropical Indian Ocean, partially due to influences of the 2015 El Nino. The mean SST in the tropical Indian Ocean was reported to increase by 0.13-0.2°C in 2015. Phytoplankton density was also low during April/May 2015 compared to the high during 2012. This low food availability in the habitat was found to affect maturation which resulted in poor recruitment.

Combined Effects of Overfishing and Environmental Stress

Thus the cumulative effect of overfishing above MSY in 2011 and 2012 including the exploitation of nearly 16,040 tonnes of juveniles in 2012 affected the sardine population/ biomass. This was followed by poor recruitment in 2013 and 2014 due to environmental stress due to salinity stratification (due to excessive rains in late monsoon) and hypoxic condition (due to upwelling) in inshore sardine habitats.

Low food availability and comparatively higher temperature due to poor upwelling led to poor maturation and subsequent recruitment success. In 2015, these changes were compounded mainly by global ocean –atmospheric process like *El nino*. The various factors affecting maturation, spawning and recruitment of oil sardine is given in Table 1.

Table. 1 Factors affecting maturation, spawning and recruitment in oil sardine

Parameter	Maturation	Spawning	Recruitment	Level of impact
Upwelling in April/May	**Favourable**			Very strong
Good diatom bloom				Very strong
Monsoon on-start -May				Mildly strong
Monsoon normal				Very strong
Delayed monsoon		**Unfavourable**		Mildly strong
Excess rainfall (floods)				Mildly strong
Low oxygen in inshore waters	**Unfavourable**		**Unfavourable**	Very strong
Noctiluca /Jellyfish bloom				Mildly strong

Policy Support for Protecting Sardine Stock for Revival

Sardine fishery has collapsed during last century also. To revive the stocks, Government of Madras introduced restricted legislation in Malabar and South Kananra Districts in 1943; then extended to another two years from 1945 to prohibit use of the following nets for immature sardine all throughout the year. Landing of immature oil sardine below 15 cm not exceeding a total weight of one Maund (28 maund =1 ton) was also prohibited. The legislation lapsed in 1947 due practical difficulties encountered in enforcement such as (1) lack of preventive staff all over the coast (2) lack of legislation in adjacent states

The drastic decline after 2012 affected the fishing industry very badly, especially the traditional fishermen and those fishers who had invested heavily on fishing. In a move to protect the resource, the Department restricted fishing of juveniles of fishes based on scientific advisory by CMFRI and the Minimum Legal Size (MLS) was introduced for 14 species. For sardine the MLS was 10 cm.

In almost all major sardine and anchovy fisheries, when the fishery is showing a downward trend, the scientists and administrators join together and introduce Total Allowable Catch or close the fishery for a specific period. The stocks are influenced both by overfishing and by extreme events.