

Chapter 3

Tracking the survival of Indian oil sardine larvae using satellite-derived chlorophyll

3.1 Background

The interannual variability in the landings of Indian oil sardines, *Sardinella longiceps* Valenciennes, 1847 (hereafter called sardines) has been explained as an outcome of seasonal variability in the marine environment [Hornell, 1910a]. Based on the physical parameters and processes such as sea surface temperature, rainfall, sea level and upwelling, indices relating to total sardine catch with environmental factors are formulated [Longhurst and Wooster, 1990]. These indices formulated based on a correlation between sardine catch and rainfall, wind stress and sealevel failed with time as a result of large variability in landings and correlated factors [Madhupratap et al., 1994]. However, these indices should not be dismissed summarily on the assumption that data were faulty, the criteria for comparison were ill founded, or the relation was spurious; rather, the cause and effect should be explored in detail to explain the phenomena [Skud, 1983]. There are several interrelated factors that are responsible for the recruitment of fishes and their abundance and estimation of these environmental factors is a difficult task. Therefore, biomass based production models such as surplus production models, growth-recruitment models and time series models are used generally, but have have their own inherent limitations. Subsequently, models incorporating changes in physical factors affecting marine food-web gained significance. The concept of fish stock assessment rather concentrates now on predicting the expectant biomass based on ambient environment changes that have a trophic link [ICES, 2000]. Thus, the focus of this present study is to find out the influence of environmental parameters (for *e.g.* chlorophyll-a, as an indirect index of food availability) on the biology of Indian oil sardine [Grinson George et al., 2011].

3.1.1 Biology of sardine

Biological studies suggest an extended spawning period from May to September for sardines [Hornell, 1910a; Hornell and Nayadu, 1924a; Raja, 1969; Prabhu and Dhulked, 1970]. After occlusion from the egg, larval development is rapid in sardines with yolk sac absorption taking place in 3 days [Nair, 1960]. These larvae will undergo their critical first feeding period almost immediately after yolk absorption [Lasker, 1975; Hunter, 2010; Lasker, 1960]. The earliest spawned surviving individuals will be recruited to the fishery by the end of the spawning period, which in turn determines the yearly landings. Thus, larval ecology decides the later abundance of recruits to the fishery. Collating various information cited on young, juvenile and adult sardines and their feed during spawning period [Hornell, 1910a; Hornell and Nayadu, 1924a; John and Menon, 1942; Devanesan, 1943a; der Lingen, 2002], we can confirm that the larvae are predominantly surface and column feeders, with phytoplankton forming a major group, dominated by diatoms like *Fragillaria oceanica*, *Pleurosigma* sp. and *Coscinodiscus* sp. [Nair, 1959; Kuthalingam, 1960].

Sardines feature a fine-meshed filtering apparatus in their gillrakers with more than 130 gillrakers on the lower part of the gill arch [der Lingen, 2002]. They are able to filter smaller particles. Therefore, they thrive on very tiny particles that may predominate throughout their range of distribution in the coastal waters through which they continually migrate [Bakun and Broad, 2003]. Moreover, sardines are serial batch spawners (as are anchovies, sprats, tunas, *etc*). They spawn for several times during their protracted spawning season. The fact that sardines employ a combination of spawning, feeding and migratory habits, underlines the importance of studying sardines during the spawning season along with their feed availability in their course of migration.

The Hjort-Cushing hypothesis [Hjort, 1914; Cushing, 1974, 1990] refers to the critical first feeding period and the timing of the spring phytoplankton bloom. In the case of sardine larvae, upwelling-induced bloom decides its biology. Bloom initiation time and bloom intensity are the factors that could account for changes in the food supply of sardine larvae. These variations in food supply between different years will be reflected in the

larval development and further recruitment of sardines into the fishery. This aspect was not examined in the earlier studies on sardine landing variability.

3.1.2 Migratory pattern exhibited by Indian oil sardine

Sardines perform a normal migration from offshore to coastal waters and *vice-versa* coinciding with the customary wind conditions [Hornell, 1910b]. A gradual increase in temperature within the range of 26 to 28⁰C is favourable for the inshore migration of the juveniles, and during March to May they disappear to deeper waters due to increasing temperature (above 29⁰C) [Chidambaram, 1950]. The specific gravity of water (above 1.023) also promotes the disappearance of the shoals during the above period. The shoreward migration of spawners during SW monsoon season and their outward migration to deeper waters during postmonsoon months is for feeding [Nair, 1959] on phytoplankton that blooms up during the onset of monsoon and continues till post monsoon [Hornell and Nayadu, 1924b; Hornell, 1910b; Chidambaram, 1950; Nair, 1953]. The longitudinal migration either way is an excursion from offshore to inshore waters and *vice-versa* due to availability of food and favourable hydrographic conditions [Devanesan, 1943b]. The shoals start disappearing from the northern region first, and then from the southern Malabar area. From April to September, the shoals of spawners and juveniles migrate from offshore to inshore all along the west coast following the onset of bloom [Raja, 1943]. This observation suggests a northward migration of sardines steadily during SW monsoon season and retrogression from north to south in the NE monsoon season [Hornell, 1910a; Chidambaram, 1950; Panikkar, 1952] (Figure 3.1). Lack of continuous seasonal information to characterize synoptic scale variability in chlorophyll concentration of the region was an impediment to verifying the food availability between different years and to explain the interannual variability in sardine landings. Also, it was not feasible to study the spatial and temporal variations in chlorophyll concentration in these areas because of nonavailability of *in situ* data. With the advent of remote sensing, however, this was possible with ocean-colour data. Platt et al. [2003] applied remotely sensed ocean-colour data as direct evidence for a putative trophic link, and suggested it as an important link in future analysis of dwindling fish stocks. Time series of phytoplankton cycle derived

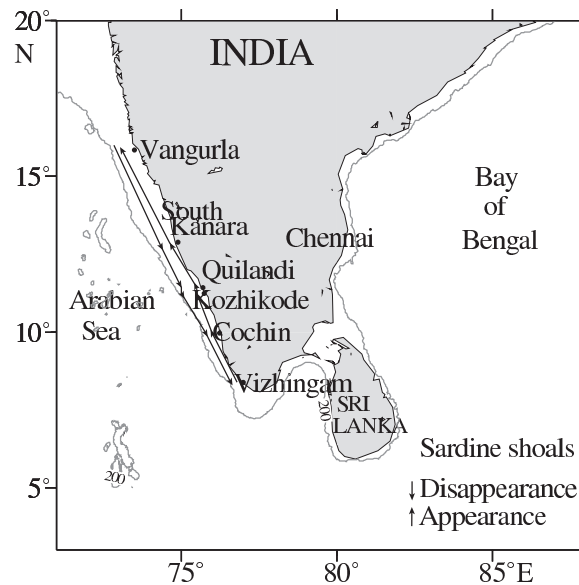


Figure 3.1: Schematic representation of progression of sardine shoals from Vizhingam to Vangurla [Hornell, 1910a; Chidambaram, 1950] and their departure in the reverse direction [Panikkar, 1952]

from satellite data can be used to construct a variety of ecological indicators of the pelagic system useful in ecosystem-based management [Platt et al., 2009].

3.1.3 Relevance of satellite data in explaining the biology and migration of Indian oil sardines

Remotely sensed sea surface temperature (SST) and ocean-colour images reveal eddies and fronts. These features frequently coincide with areas where fish species aggregate as a result of enhanced primary productivity and phytoplankton biomass, which in turn is linked with increased nutrient supply. Since, higher plant biomass is associated with zooplankton abundance, this could provide supplementary information on fish stock distribution from ocean-colour pigment fields. Ocean colour patterns were useful in differentiating the relevance of food over other environmental factors like temperature in fish aggregation, offering better information regarding the location of Albacore tuna [Laurs

et al., 1984]. It was originally assumed that tuna prefers to reside within certain limited temperature ranges, which explains their tendency to aggregate at temperature fronts. In instances where colour and SST fronts were spatially separated, they found that tuna actually tend to aggregate on the clear side of a colour front.

Ocean-colour pigments are relevant in detecting a bloom. Fragmented observations in the waters of the southwest coast of India hypothesized two seasonal blooms:

- (i) upwelling blooms in May-June coinciding with the arrival of pre-spawning adults and
- (ii) winter blooms in September-October coinciding with the main fishery for juveniles [Bensam, 1964].

For sardines, a planktivorous species, the amount of food ingested depends on chlorophyll concentration as well as copepods present in the ambient waters; better availability of food is expected in chlorophyll-rich waters. In the present study, variability in chlorophyll along the waters of the southwest coast of India had been quantified from satellite data and related to annual variability in the sardine landings. The synoptic scale spatial and temporal changes in chlorophyll-a are useful in explaining the appearance and disappearance of sardine shoals along the coastal waters.

3.2 Sardine variability and chlorophyll

The variability in sardine landings, chlorophyll and upwelling bloom initiation were examined for explaining the interannual sardine variability and sardine migration in the coastal waters.

3.2.1 Sardine landing variability

Sardine landing data reveal interannual variability with an increasing trend during the study period (1998-2006). Sardine landings showed a drastic decline in 1985 and 1994

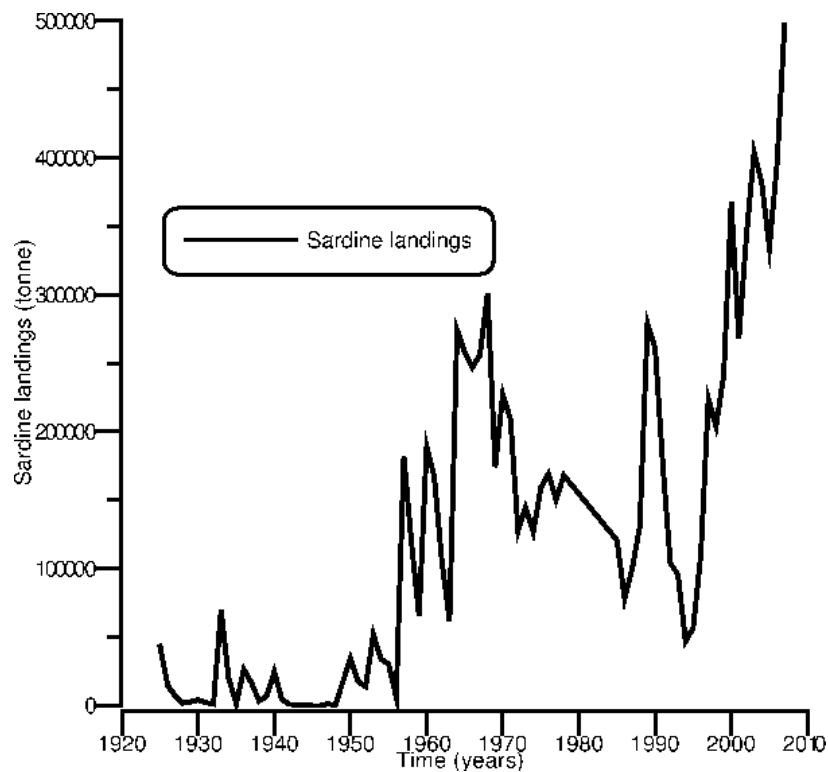


Figure 3.2: Inter annual variability in sardine landing (1925-2006)

(Figure 3.2). Marine fisheries of the southwest coastal waters of India are characterized by predominance of pelagic fish resources (sardines and Indian mackerel *Rastrelliger kanagurta*), which support the largest coastal pelagic fishery along the west coast of India. Alternating patterns of abundance between sardines and mackerel could have been the reason for two major falls in sardine annual landing in 1985 and 1994. The landing pattern of these two species (Figure 3.3) could be compared with the alternating patterns of abundance between sardines and anchovies observed in other upwelling areas of the world. The period 1998-2006 was a sardine dominant period (period of high sardine and low mackerel). Figure 3.3 shows a sardine revival phase, and the period reflects an ideal phase for the study of sardines without interference from the mackerel fishery.

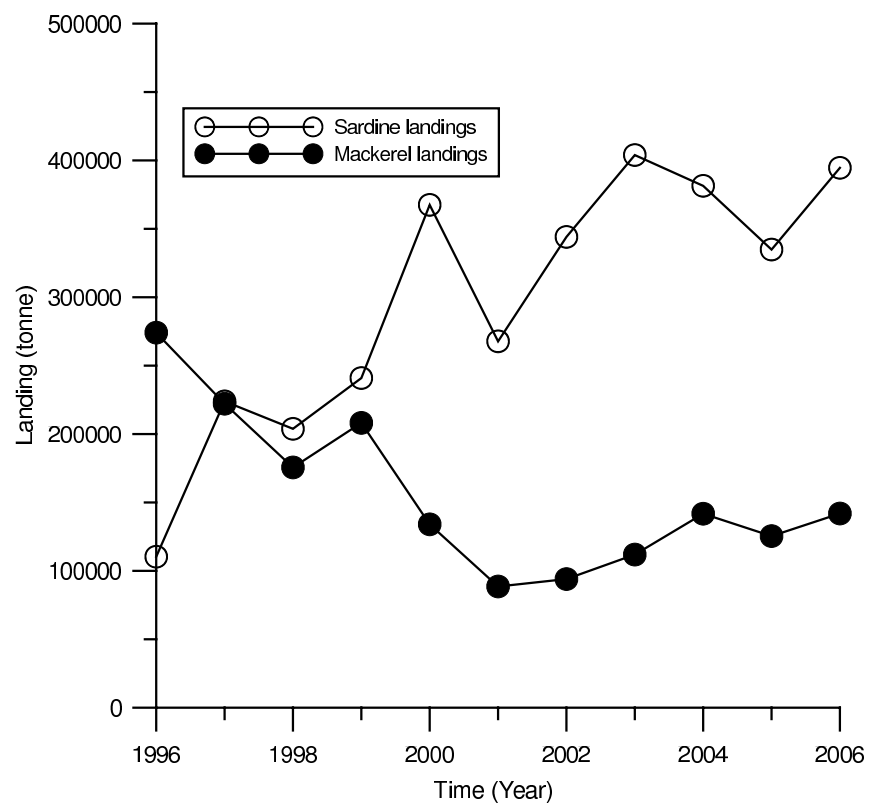


Figure 3.3: Comparison between sardine and mackerel landings (1985-2006)

3.2.2 Chlorophyll variability in the study area

Observed chlorophyll in the study area (Figure 1.1) during 1984-2006 ranged from 0 to 6.25 mg.m^{-3} with a mean value of 0.32 mg.m^{-3} and a standard deviation of 0.59 mg.m^{-3} , indicating that chlorophyll available in the coastal waters is highly variable. *SeaWiFS* chlorophyll values remain within the maximum-minimum limits of *in situ* chlorophyll (Figure 3.4) except for the month of August 2002 (6.557 mg.m^{-3}), which may be due to an unusually high upwelling bloom.

The chlorophyll-a concentration remained high from May to September, but the peaks varied from year to year. Periods of higher chlorophyll-a concentration match with the active breeding period of sardines (Figure 3.5). The biological calendar of sardines (Figure 3.5) commences with the entry of spawners in May, followed by fresh juveniles during July to August. During September to December, the adults occur in reduced numbers, and the adult population is replaced by large shoals of juveniles. They, however, get numerically reduced in January and February, and subsequently disappear and reappear during May to July. With the onset of pre monsoon showers or SW monsoon rains, they move toward the inshore waters with the gonads in various stages of ripening. The spent and resting adults, on the other hand, appear in small quantities along with their juveniles during January and February, and disappear in the following months along with the juveniles and re-enter for their second spawning along with the virgin spawners. For numerically representing the average chlorophyll, which determines the active breeding phase, chlorophyll concentrations $\geq 1 \text{ mg.m}^{-3}$ can be a threshold mark as calculated for the entire study period (Table 3.1). The average monthly chlorophyll-a values in May reached a threshold level of $\geq 1 \text{ mg.m}^{-3}$ (Table 3.1). We have examined the suggestion by Madhupratap et al. [1994] that a mismatch *viz.* an early spawning and a time lag in development of food (through a break in monsoon or upwelling) would be detrimental to recruitment.

3.2.3 Sardine landings *vis-a-vis* chlorophyll during bloom initiation

We tested the null hypothesis that the variability in sardine landings was independent of fluctuations in average chlorophyll during bloom initiation month. We could confirm that

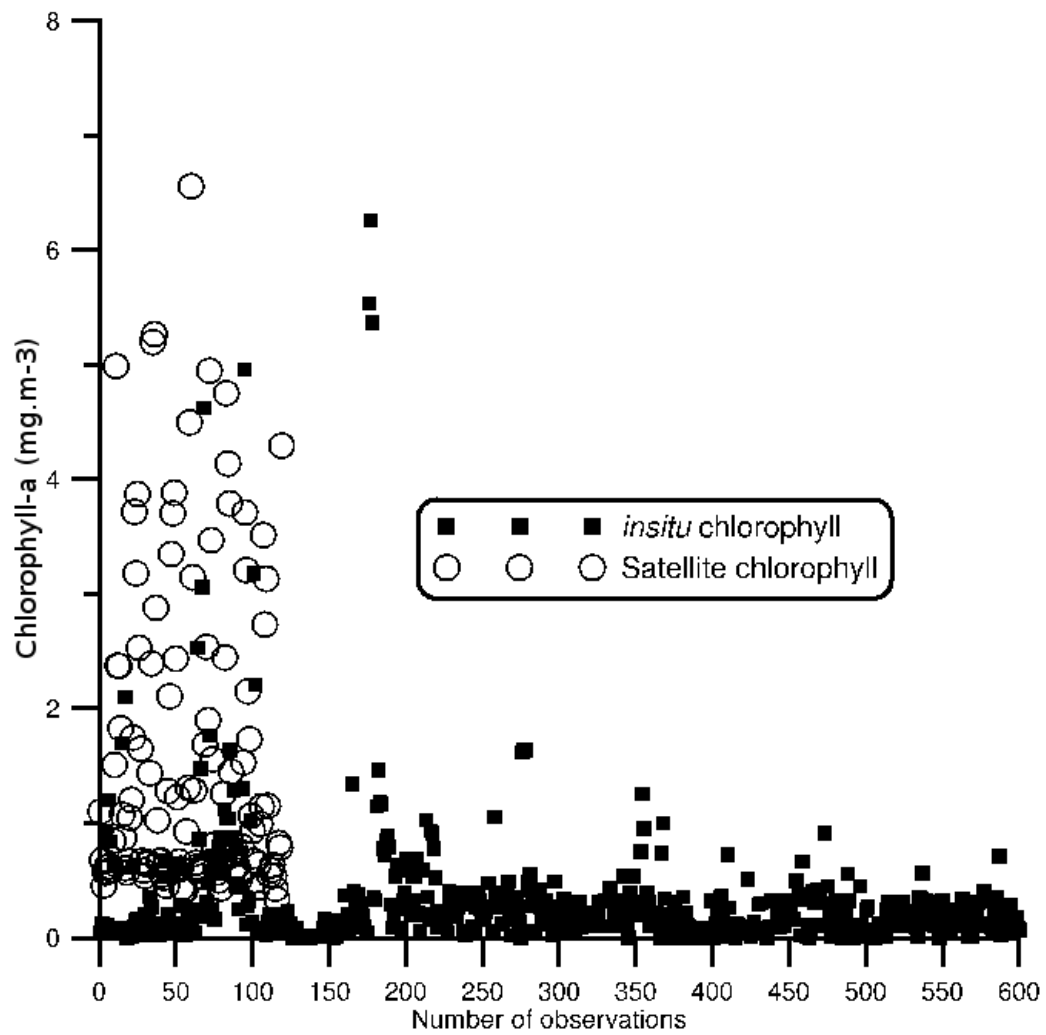


Figure 3.4: Comparison between observed and satellite derived chlorophyll-a during 1984-2006 (data source: NIO Data Centre)

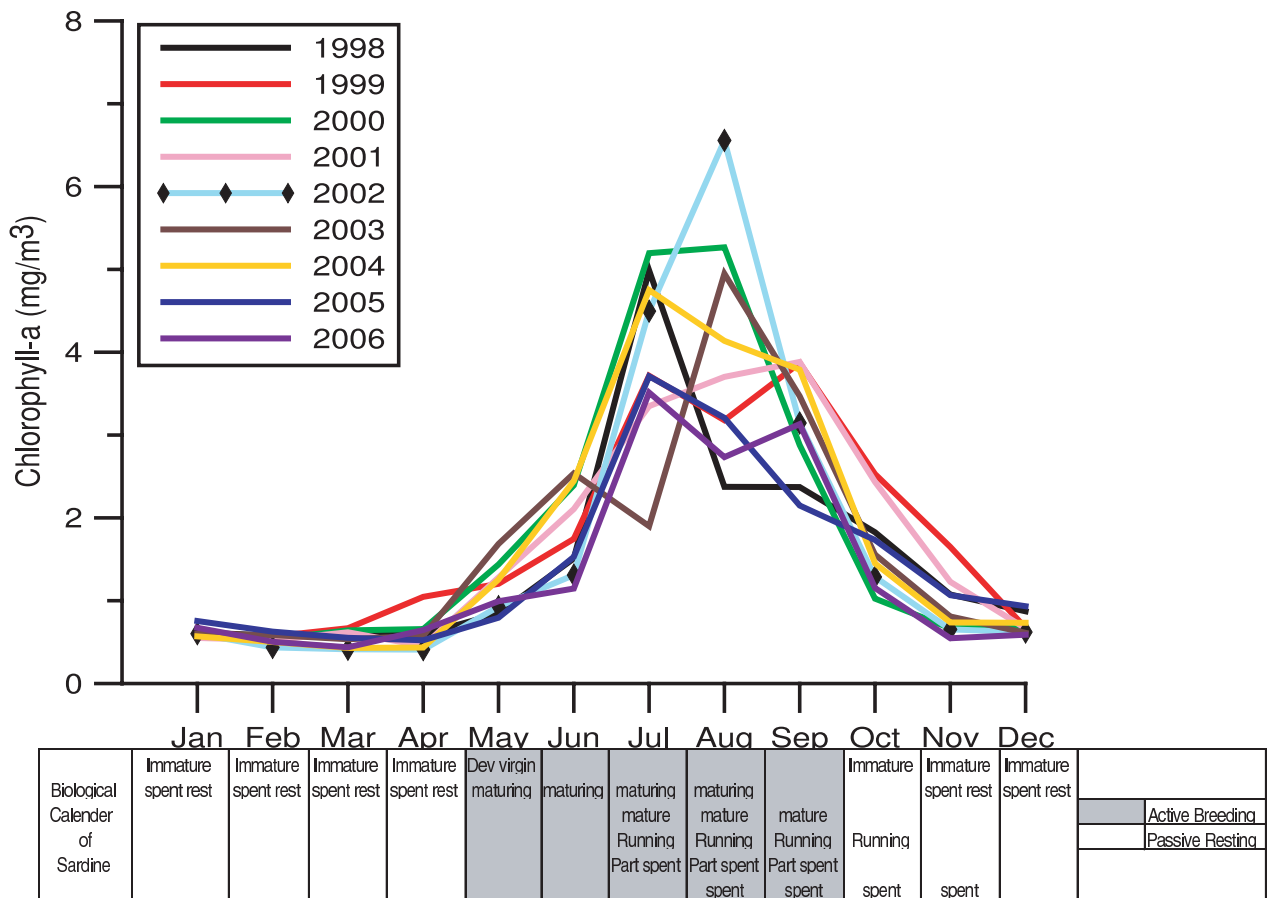


Figure 3.5: Monthly satellite chlorophyll concentration for the period 1998-2006 in relation to biological calendar of sardine. Grey coloured columns in the table show the active breeding phase and remaining columns show the passive resting phase in sardine.

Table 3.1 Monthly averaged chlorophyll during 1998-2006 and corresponding life stage of sardine

Month	Average chlorophyll ($mg.m^{-3}$) during 1998-2006	Life stage of sardine
January	0.618333	immature, spent resting
February	0.540444	immature, spent resting
March	0.546444	immature, spent resting
April	0.593778	immature, spent resting
May	1.158222	maturing, developing virgins
June	1.858333	maturing
July	3.957667	maturing, mature, running, partially spent
August	4.011889	maturing, mature, running, partially spent
September	3.187778	mature, running, partially spent, spent
October	1.666556	Immature, running, spent
November	0.937333	immature, spent resting, spent
December	0.708000	immature, spent resting

39% variability in sardine landings was related to average chlorophyll-a concentration during the bloom initiation month. Figure 3.6 clearly depicts an increase in chlorophyll-a, which is associated with high landings (match), and a decrease in chlorophyll-a, associated with reduced landings (mismatch), except for the year 2002. Apart from chlorophyll, there could be other factors affecting the sardine biomass. But, availability of chlorophyll-rich water in the bloom initiation month will help in better survival of sardine larvae. Early food availability by an upwelling bloom indicated as higher chlorophyll-a in Figure 3.6 is reflected in increased sardine landings, since many of the total larvae recruited were able to survive because of surplus food. Even though *SeaWiFS* data are short, the data do indicate a definite link between chlorophyll-a and sardine landings. Early initiation of phytoplankton bloom may not be sufficient to ensure a higher survival of sardine larvae in the same year, but it is definitely a necessary condition as envisaged in this study. This is well reflected in the sardine landings, since the fishery was dominated by 0-year class fishes (Table 2.1). An unprecedented blooming was observed in 2002 when chlorophyll-a values were the highest during the study period. Thus, the year 2002 was exceptional to have a low chlorophyll in May followed by an unanticipated high chlorophyll period

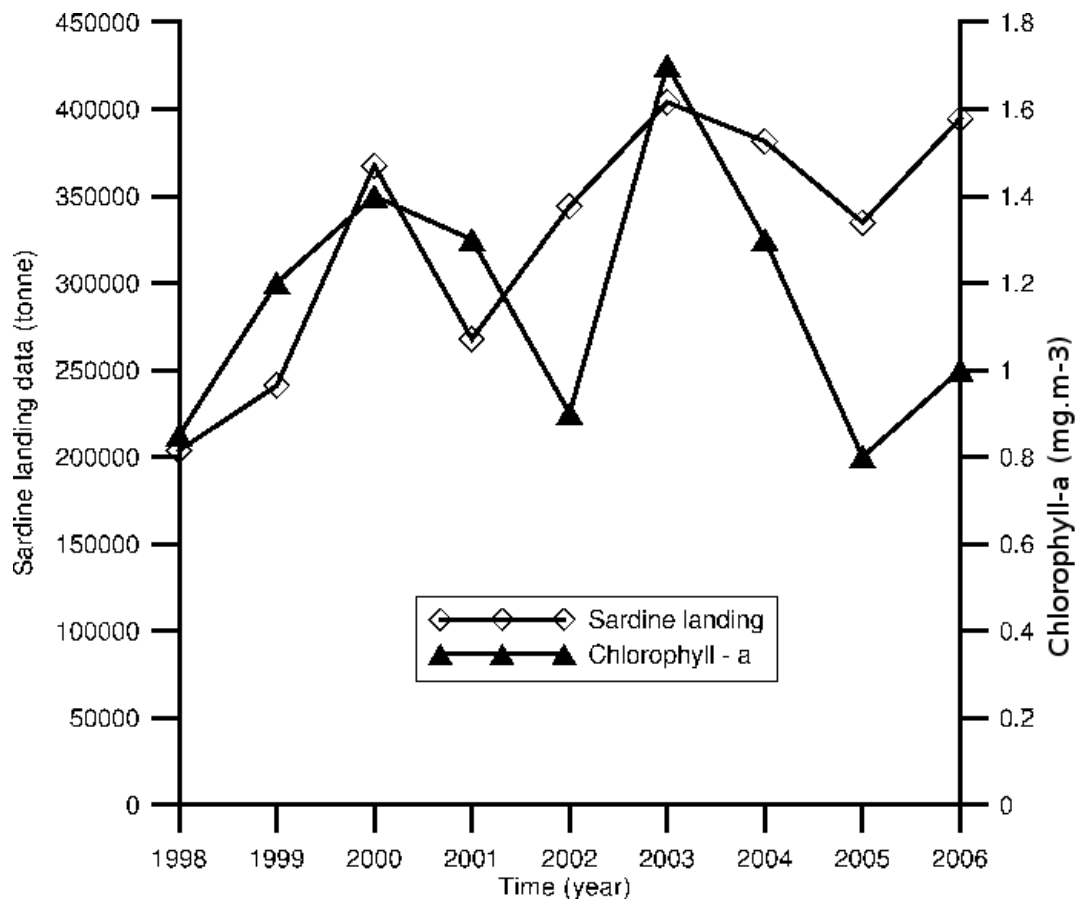


Figure 3.6: Comparison between chlorophyll-a concentration during bloom initiation month and sardine landing

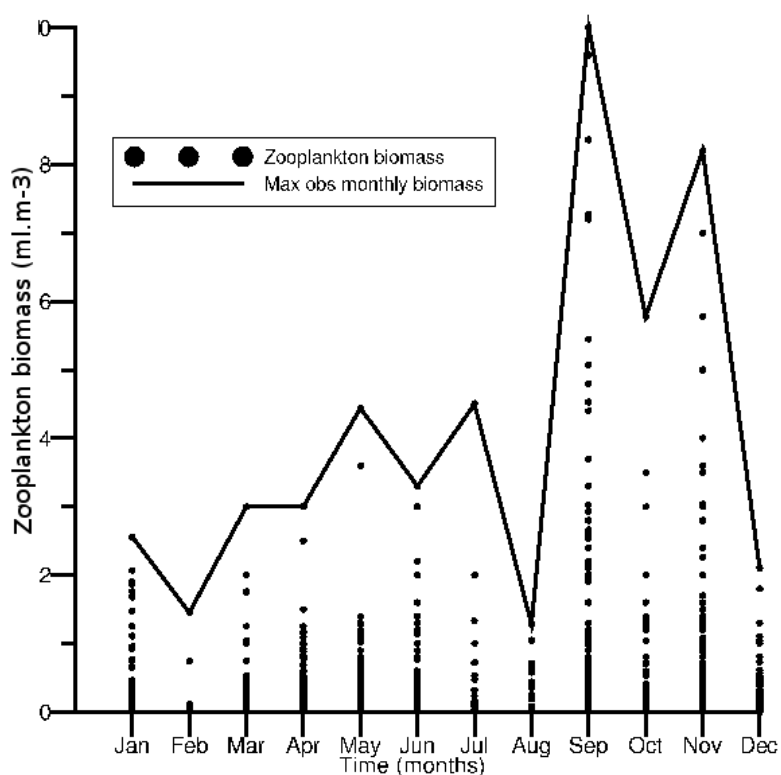


Figure 3.7: Monthly observed zooplankton biomass during 1984-1996 (data source: NIO Data Centre).

(Figure 3.6). Since the spawning period of sardines is protracted, higher survival of the later spawned larvae also could make up for poor survival of early spawned larvae. Gut analysis of sardines shows that, being filter feeders sardines ingest the particulate phytoplankton and zooplankton available in the ambient waters. The phytoplankton bloom (mostly diatoms and dinoflagellites) results in better productivity enhancing the microzooplankton and zooplankton in the Arabian Sea [Madhupratap et al., 2001]. This is true because zooplankton biomass observations in the study area also show several peak values during the months from September to December (Figure 3.7), following the increase in chlorophyll-a.

3.2.4 Seasonal appearance of sardines and chlorophyll

The present study clearly reveals the synoptic scale temporal changes (1998-2006) with respect to chlorophyll availability in the three prominent sardine landing maritime states (Figure 3.8) of India- Kerala, Karnataka and Goa. Figure 3.8 illustrates how chlorophyll-rich waters appear earlier in the south (off Kerala) and move gradually northward, and the pattern reverses during the retrieval of monsoon. The changing intensities of chlorophyll in the coastal waters (area under the graph for each year (Figure 3.8)) of the states describe the possible appearance and disappearance of sardine shoals during the active breeding phase. The quarterly sardine landing in each maritime state (Figure 3.9) follows a proportional change in the chlorophyll concentration. This shows an aggregation response of larval sardines to chlorophyll concentrations.

3.3 Discussion

There was very little change in the fishing effort during 1998-2006, with 238,772 fishing crafts in 2005 [CMFRI, 2005] in comparison to 239,000 crafts in 1997 [Sathiadhas, 2006]. Thus, the increase in sardine landings during the study period, despite steady fishing effort, indicates a link between the food available for sardine in the study area and its intensity, as a reason for the revival of the fishery. Sardines feed predominantly using the fine branchial apparatus on phytoplankton and zooplankton in ambient waters. Chlorophyll-a in a given area, as an index of phytoplankton biomass, is capable of assessing the food availability for sardines.

Summer surface chlorophyll-a concentration estimates from the study area are reported to be 0.1 to 5 $mg.m^{-3}$ for a normal distribution and can be very high, from 5 to 10 $mg.m^{-3}$, during bloom period [Raghavan et al., 2006]. Heavy blooms of *Fragillaria oceanica* were observed in 1949 and 1953 when sardine stock was rebuilt after the population crash of 1940s [Nair, 1953]. This strengthens the view that an early bloom is advantageous for increased larval survival which, otherwise could have perished due to lack of food.

The life cycle of sardines depicts a clear picture of an active breeding season from May

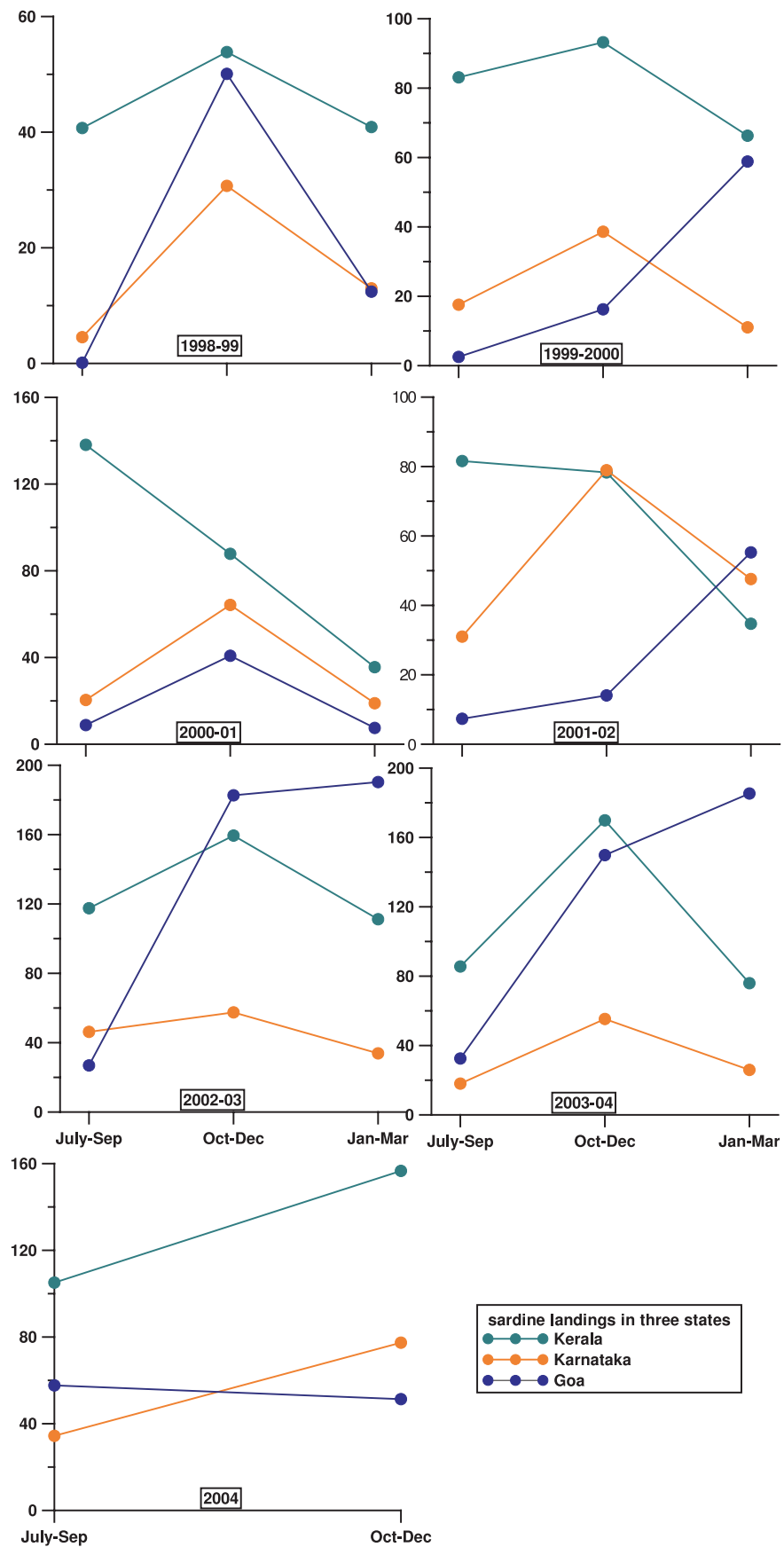


Figure 3.9: Quarterly sardine landing per kilometre of coastline in the three maritime states.

to September. This coincides with the high chlorophyll concentration seen during May to September every year. Thus, we find a probable connection between the life history and biology of sardines to phytoplankton bloom dynamics. This supports the finding that the fish itself times its appearance to exploit the productive southwest monsoon period [Madhupratap et al., 1994]. The upwelling bloom can be characterized with respect to its peak amplitude *viz.*, timing of peak, timing of initiation and duration. In this study, magnitude of the bloom during initiation month is considered for characterization of bloom, which naturally falls in the month of May every year. May is the most critical month for sardines because both bloom initiation and the beginning of sardines' active breeding phase occur during this month.

A delay in the initiation of bloom in the area results in hampering the congenial conditions for survival of sardine larvae. In the prevailing rough conditions when fishing activity is slackened, there may be an apparent paucity of sardine. But, as we find in the published reports [Raja, 1969; Longhurst and Wooster, 1990] when there was fishing during July and August, it was noticed that the spawners enter the coastal waters due to increase in food production, and migrated beyond the usual fishing belt (30 m depth) for spawning. The spawners again made a re-entry to compete with the juveniles for feeding. The juveniles enter the coastal waters gradually for feeding during January to March and steadily migrate to deeper waters with reduced food. The disappearance initiates from the north sardine fishing ground and ends up in the southern areas later.

Recent works on the survival and early life history of fishes elucidates various factors including predation, drift pathways and changing environmental conditions in addition to variation in food [Houde, 1987; Miller et al., 1988; Leggett and Deblois, 1994; Cury et al., 2000; Bakun and Broad, 2003]. Upwelling in the waters of the southwest coast of India is restricted to 5 to 15°N, and the variability in physical parameters is manifested in the chlorophyll intensity [Smitha et al., 2008]. A correlation between available environmental datasets (SST, sea bottom temperature, surface salinity, surface dissolved oxygen, bottom dissolved oxygen, pH, nutrients, chlorophyll, zooplankton, rainfall, multivariate *El Nino* Southern Oscillation index, coastal upwelling index, and derived SST) and sardine catch from the study area vividly segregate the significance of chlorophyll

from other environmental factors in explaining the sardine catch from the Malabar upwelling area [Krishnakumar and Bhat, 2008]. A similar analysis of data sets is redundant in the context of this investigation. Hence, this investigation focused on food alone, the lone implicated factor chlorophyll-a (as an index of phytoplankton biomass), and explored various avenues of this factor in explaining sardine variability.

A fine scale spatial and temporal pattern of egg and larval stages of sardines in relation to chlorophyll concentration could have yielded a proper model for describing the presence or absence of sardines in coastal waters within a definite chlorophyll range. There are sparse reports of sardine eggs from Quilandy [Devanesan, 1943b] and Kozhikode [Nair, 1953] and also descriptions of the larval and postlarval stages of sardines in these regions [Nair, 1959]. But the lack of information on the distribution of eggs and larvae emphasizes the need for sampling of early life history stages of sardines over many years for determining the annual condition of larval and juvenile sardines in relation to chlorophyll concentrations.