Oil sardine and Indian mackerel: their fishery, problems and coastal oceanography

M. Madhupratap, S. R. Shetye, K. N. V. Nair and S. R. Sreekumaran Nair

The sardine and mackerel fishery is commercially exploited successfully along the west coast of India. The fish itself times its appearance to exploit the productive southwest monsoon period. The chain of events — physical, chemical and biological — leading to the productivity are examined to find their relationship to the fishery. However, this study attempts to point out the drawbacks in our understanding and proposes research problems that could be pursued.

INDIA with a coastline of over 7500 km and an exclusive economic zone of 2.02 million km^2 has large potential for capture fishery. At present she stands seventh among fishing countries and the annual catches are ca. 2.3 million tonnes per annum representing about 2.5% of the total world catch. Among a multi-species oriented fishery, the oil sardine [(*Sardinella longiceps*) (Valenciennes)] and the Indian mackerel [(*Rastrelliger kanagurta*) (Cuvier)] form the mainstay of Indian pelagic fisheries along its west coast (mentioned hereafter as sardine and mackerel). The former is distributed along the coastal waters of Arabian Sea ca. north of 8° N, and although recorded from the east coast of India, its appearances are rather sporadic (Figure 1). Its occurrence along the Philippine and Indonesian waters appears to be unconfirmed[1]. The mackerel appears to enjoy a much wider distribution, once again in the coastal waters, from almost 30° S to 30° N encompassing the Indian Ocean and western Pacific, but away from Indian and African coasts, it may be replaced by a closely related species *R. brachysoma* (Bleeker). Along peninsular India, 80 to 95% of the catch of sardine and mackerel is from the west coast (Figure 1). Over the period from 1960 to 1990, sardine and mackerel on the average formed 16.5% and 5.8% of the marine landings[2,3] of India (Figure 2). Commercial fishery is restricted to ca. 8–18° N. Both fisheries are shallow water-based, the usual depth of fishing confined to the foreshore area within 20 to 25 m depth.

The fishery of both species exhibits marked fluctua-

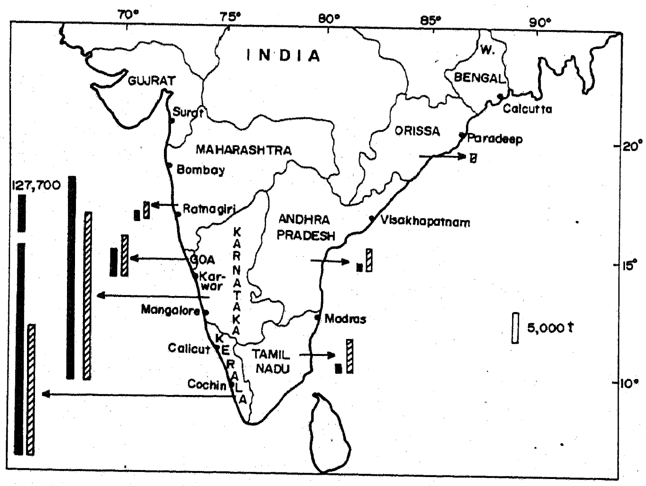

Figure 1. Average landings (blank bar indicates scale in tons) of oil sardine (solid bar) and mackerel (hatched bar) in the coastal states of India in the last decade (data from refs. 2, 3).

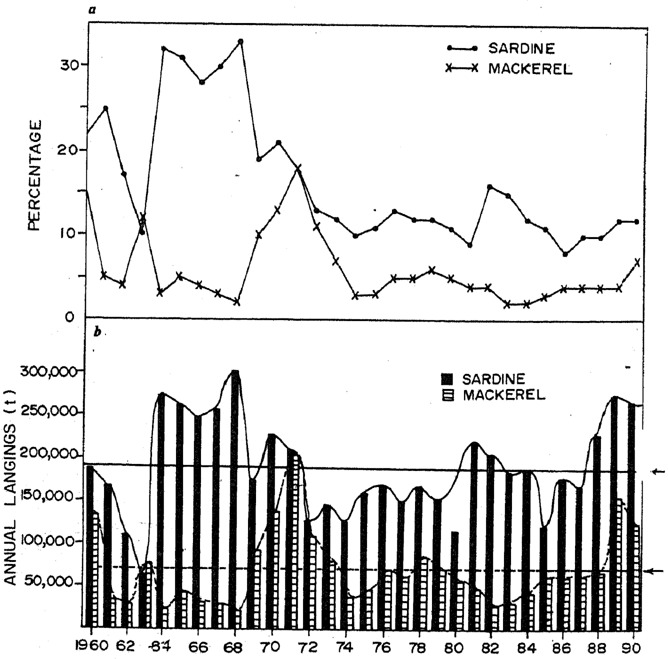

Figure 2. *a*, Percentage of sardine and mackerel landings calculated from all India marine landings (1960–90); *b*, Landings of sardine and mackerel, arrows indicate mean for 1960–90, sardine-continuous line; mackerel-broken line (data from refs. 2, 3).

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tions from year to year. References to their fisheries and fluctuations go back to the last century[4,5]. An important aspect from the point of view of economics and judicious exploitation is to address the reasons causing these fluctuations. Are they forced by the physical environment? Or are they mainly related to the dynamics of the ecosystem which supports the fisheries and is rooted in biological factors?

We do not seem to have proper answers to these questions. The purpose of this paper is threefold. First, we bring together briefly the available information on fisheries, biology and physical environment. Second, to try to understand how the fishery works and to point out the limitations in our understanding. Third, to suggest research directions which must be pursued to make progress towards understanding the biology and relationship to the environment.

Data set

In order to analyse the trends in the sardine and mackerel fishery we have chosen the landing data for the period 1960 to 1990 (source refs 2, 3). Although records of fish landings are available from 1920, we have deliberately chosen the last 31 years as the main data set because the data are more reliable and moreover marks a period when modern fishing techniques/facilities became available to the marine fishery sector. This data set is thus more representative of the available stock (the total fish landings from India were only ca. 0.6 million tonnes in the 1950s, Table 1). At the moment fishing is dependent on both artisanal modes and modern gear.

We assume that the landings are representative of the stock abundances and the catches of the two species are intercomparable. These assumptions are justified in that during the period of fishery, both species are coastal and are generally caught by the same fishing techniques/efforts which are carried out intensely throughout the season (mostly through gill net and boat seine and to some extent through purse and shore seines[6]). Further, general aspects of the known biology of both species do not differ much except in some details.

Fisheries and biology

The fishery of the sardine commences in June–July (taken as the biological year) with the entry of spawners which themselves were spawned in the previous year[1]. Spawning occurs usually from June to September with greater intensity during July–August (rarely extended to October). Fecundity is estimated as 37,000 to 38,000 ova per female, but it is not clear whether multiple spawning occurs. In general, fishery appears to start earlier in the southern regions than the northern areas while withdrawal of the season commences earlier in north. As the season progresses, by September–December, adults occur in reduced quantities while large shoals of juveniles spawned earlier in the same year occur. The numbers are reduced subsequently (by January–February especially in northern areas) and then they disappear for the next 2–3 months except in sporadic catches. In the next season the 0–1 year class virgin spawners which attain about 140–160 mm growth enter the fishery along with those which might have survived the previous season.

The mackerel fishery also starts along the southern regions with the onset of southwest monsoon and is mainly supported by sizes ranging from 160 to 229 mm believed to be one-year old and belonging to the maturing stage[7–10]. Spawning appears to be in batches, a female produces up to 94,000 ova. There is considerable controversy on the period over which mackerel spawns depending on the area of study. Apparently mackerel spawns from April to December along the west coast (some workers point out that mackerel has a further extended spawning period) with peak in July–August as in sardine and sometimes with a supplementary spawning in November–December. One major brood produced within a period of 2–3 months accounts for most of the recruitment[6]. Mackerel fishery also tends to start earlier and terminate later in the south compared to northern areas. The period of peak fishery coincides with that of sardine although in some years it extends up to March–April.

The coastal waters of Kerala and Karnataka account for the bulk of the catches of these two fishes. There are, however, some differences in the pattern of catches. Annual landings of sardine from the Kerala coast are about 4 to 7 times higher than that of Karnataka. Catches are fairly high throughout the year except in March–May while landings in Karnataka-Goa peak only in September–December. Annual catches of mackerel are more or less equal from the two states, but heavier catches occur once again in September–December along Karnataka–Goa coast.

Table 1. Decadal trends in the oil sardine, Indian mackerel and total marine landings (average values in tonnes, refs. 1, 2, 3)

	1930–39	1940–49	1950–59	1960–69	1970–79	1980–90
Oil sardine	14,787	3921	57,537	2,04,628	1,635,58	1,95,193
Indian mackerel	65,775	62,494	68,178	51,608	90,171	66,740
Total marine landing			634,259	805,405	1,294,830	1,734,607

Fishery trends

During 1960 to 1990, sardine landings were invariably larger than that of mackerel and were somewhat equal only in 1971 (Figure 2). However, from 1930s to 1957, mackerel catches were generally higher compared to sardine landings (Table 1, data prior to 1960 from ref. 1). This was probably the result of population crashes of sardine especially in the 1940s or it reflects the effects of changes in gear by 1960. Between 1960 and 1990 sardine landings averaged about 188,000 tonnes while it was 69,500 tonnes for mackerel. Within the period, the catches of both species fluctuated significantly ($p \leq 0.01$), but there were very few gross departures from the mean. This is also reflected in the cluster analysis (Figure 3, 4; clustering strategy from ref. 11) which showed high similarity (> 80) in landings between the years within each species.

In Figure 3 (sardine), cluster A represents average catches, cluster B denotes fairly high landings and the year 1963 stand separate with the lowest catch (63,647 tonnes) observed in the period. Subclusters AA, AB and AC represent medium, medium low and medium high landings whereas BA and BB represent years with highest and medium high catches respectively. In Figure 4 (mackerel), years grouped in cluster A had average catches, B had relatively high catches and C shows years of lesser abundances.

For sardines, the years 1964–1971, 1981–82 and 1988–90 were periods when their landings peaked. This modern period of fishery does not show strong decadal trends unlike earlier in the century[12] for the sardine fishery. Noble[13] commented that the mackerel fishery tends to reach a 'high' at the confluence of decades. Although this happened for a few years in the 60s, 70s and 90s the period from 1974 to 1988 had only poor to average catches and a definite trend could not be detected.

An inverse relationship between sardine and mackerel fishery has been postulated[5, 14]. Although this might appear to be true for some years (Figure 2), we did not find any correlation between the two fisheries (r = 0.17). This lack of correlation was observed also by Raja and by Longhurst and Wooster[12]. This is not surprising because the two species although seem to take advantage of the development of the same environmental conditions along the west coast (see below), are not competitors in the true sense. Although both species are omnivores, the adult sardine feeds mainly on diatoms while the mackerel is predominantly a zooplankton feeder[1, 8].

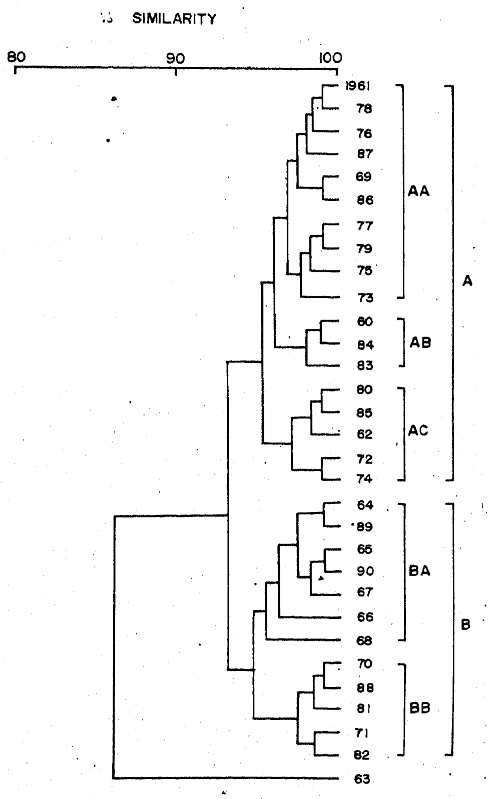

Figure 3. Dendrogram showing affinity between years (1960–90) for sardine based on landings (data set for clustering taken from refs. 2, 3).

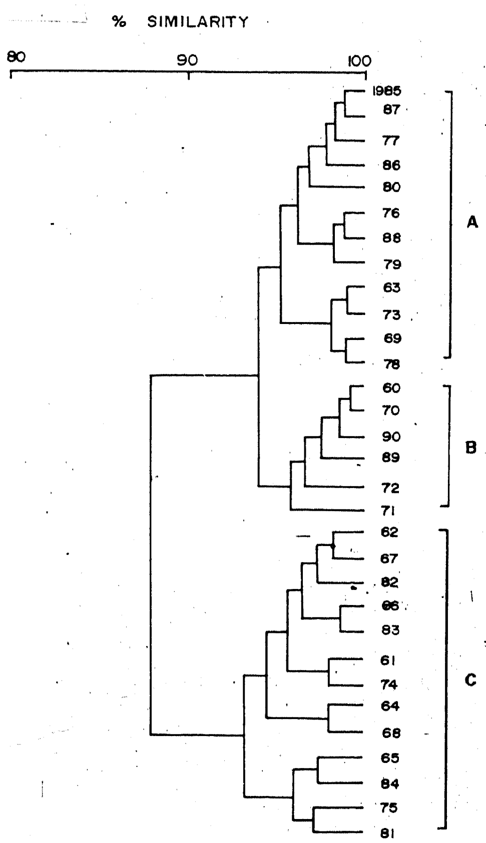

Figure 4. Dendrogram showing affinity between years (1960–90) for mackerel based on landings (data set for clustering taken from refs. 2, 3).

Coastal physical oceanographic conditions

Coastal biological productivity is closely linked to the availability of nutrients. It is thus more dependent on new production (nitrate-based) compared to open ocean waters where the production cycles may largely depend on availability of regenerated nutrients (based on ammonia, urea etc.) or the microbial loop. The availability of nutrients in coastal waters in turn is linked to the physical oceanography of the region. What then are the salient features along the west coast?

The currents along the west coast of India have a distinct annual cycle. Ship-drift data show that the coastal current along the west coast of India turns equatorward in February. The current gets stronger with time and by June is well developed along the south-west coast of India. It is most energetic during July–August, the peak southwest monsoon season. It then decreases in strength, vanishes and reverses direction by October–November. The northeast monsoon coastal current flows away from the equator during November–January.

During 1987–88 extensive hydrographic data were collected in the coastal region off the coast of India to elucidate the conditions during the southwest and northeast monsoon seasons. The southwest monsoon data showed that upwelling occurred in the southernmost part of the west coast of India by June (ca. 8–10° N), the near shore surface temperature being lower (maximum of 2.5° C off southern most tip) than farther offshore. There was a shallow (approximately 75 to 100 m deep) equatorward surface current, below which there were signatures of downwelling indicative of a poleward under-current hugging the continental slope. T–S characteristics showed that the under-current carried low salinity waters found in the southwestern Bay of Bengal. Similar conditions existed up to around 15° N but the intensity of upwelling and the signatures of the surface current and the under-current grew weaker progressively from south to north, and ceased to be noticeable at about 20° N. The width of the surface current was about 150 km, whereas the undercurrent was about 50 km wide. The transport of the equatorward surface current increased from less than 0.5×10^6 m^3/s to about 4×10^6 m^3/s from the northern to the southern end of the west coast. The winds during this period varied between west-northwesterly near the southern end of the coast to west-southwesterly near the northern end. The longshore component of the wind stress was generally equatorward. Its magnitude was maximal (0.5 dyn/cm^2) near the southern end. On the basis of these observations, Shetye *et al.* [15] argued that the coastal circulation off the west coast of India during the southwest monsoon is dynamically similar to the wind-driven eastern boundary currents found elsewhere in the oceans.

Though this is true during the southwest monsoon, it is not clear that it is the case during February–May when the monthly mean longshore component of wind, though upwelling favourable, is only about 0.2 dyn/cm^2 or less[16]. McCreary *et al.*[17], based on numerical experiments, suggest that an early remote-forced upwelling in this area may result from Kelvin waves originating in the Bay of Bengal.

Observations during northeast monsoon showed the presence of a poleward surface coastal current along the west coast of India that flows against weak winds. Near the southern end of the coast, at about 10° N, the current was approximately 400 km wide, 200 m deep and carried the low salinity equatorial surface water. The isopycnals tilted down on approaching the coast. Near the northern end of the coast, at about 22° N, the flow was restricted mainly to the vicinity of the continental slope; the current was a narrow (100 km), 400 m deep jet with a transport of about 7×10^6 m^3 s^{-1}. Along most of the coastline, a southward moving undercurrent was inferred from the distribution of salinity, temperature and dynamic topography. Shetye *et al.*[18] proposed that the surface current is driven by a longshore pressure gradient which develops along this coast during the northeast monsoon and overwhelms the influence of winds during this season. The study of McCreary *et al.*[17] suggests that part of the driving for this current could also come from Kelvin waves triggered by the collapse of winds along the east coast of India as the southwest monsoon dies and the northeast monsoon sets in.

The most notable points in view of biological productivity of the region are: (i) though upwelling seems to set in along the west coast of India around April, the most active period is June–September (ii) the region where upwelling is most active is the south and central west coast of India (iii) during its most active phase, upwelling is predominantly driven by the longshore components of the winds.

Biology of the ecosystem

The distribution of nitrate (15° N, Figure 5) clearly shows the relationship between the intensity of southwest monsoon and availability of nutrients in surface waters. The low surface nitrate in June at this latitude is probably because of a time lag in the progression of upwelling from south to north[19]. Nutrient enrichment in coastal waters also occurs through river runoff during this period. A dense network of small rivers, originating from the western ghats, feeds the coastal waters of west coast. River runoff enhances production also through entrainment and stratification[20]. A third input from the introduction of freshwater is the increase of secondary production through the microbial loop (see below). However, even during the upwelling phase, nitrate is usually

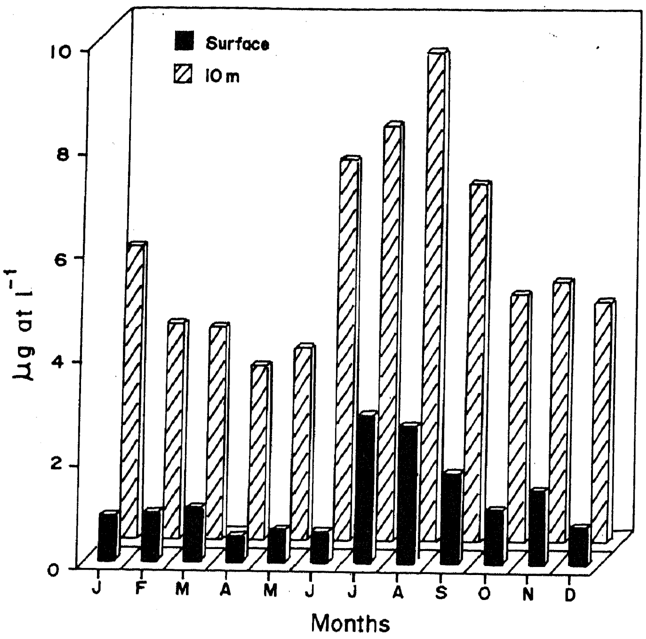

Figure 5. Distribution of nitrate off Goa in the year 1991 (data courtesy. M. D. Rajagopal).

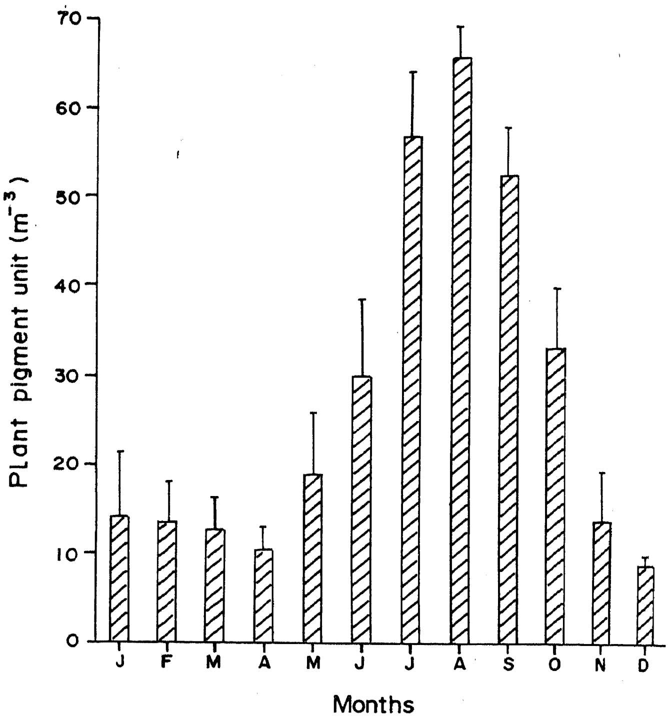

Figure 6. Distribution of phytoplankton pigments (units in thousands) off Calicut plus SD during 1955–62 (adapted from ref. 22).

at undetectable levels in distant neritic and oceanic surface waters probably because of lesser input and active uptake by phytoplankton. Though northeast monsoon current is important from the point of view of advective field in the region, it causes strong stratification and decreased vertical mixing resulting in very low nutrient concentrations in surface waters[21].

In response to the availability of nutrients in the euphotic waters, primary production shoots up in coastal waters during southwest monsoon as evident from pigment concentrations[22] (Figure 6). More recent estimates of standing crop (chlorophyll *a*) and productivity (using ^{14}C) also show these changes (not presented because of lack of time series data). Chlorophyll *a* and productivity values go up from an average < 0.5 mg m^{-3} and ca. 50 mg C m^{-3} day^{-1} respectively in January–April to 2.5 to > 7 mg m^{-3} and > 200 mg C m^{-3} day^{-1} during southwest monsoon period (productivity values even reach > 1 g C m^{-3} day^{-1} during bloom situations, V. P. Devassy pers. comm.). Diatoms form the bulk (> 90%) of the phytoplankton[23,24] and consist of many species which commonly form blooms during the southwest monsoon period[25,26]. They vary in sizes, but generally consist of medium to larger forms (mostly 10–100 μm, a few 100–500 μm).

Concomitant changes are discernible in zooplankton population[27] (Figure 7). High density of population is sustained even after the southwest monsoon period up to December[28]. During upwelling period, biomass values

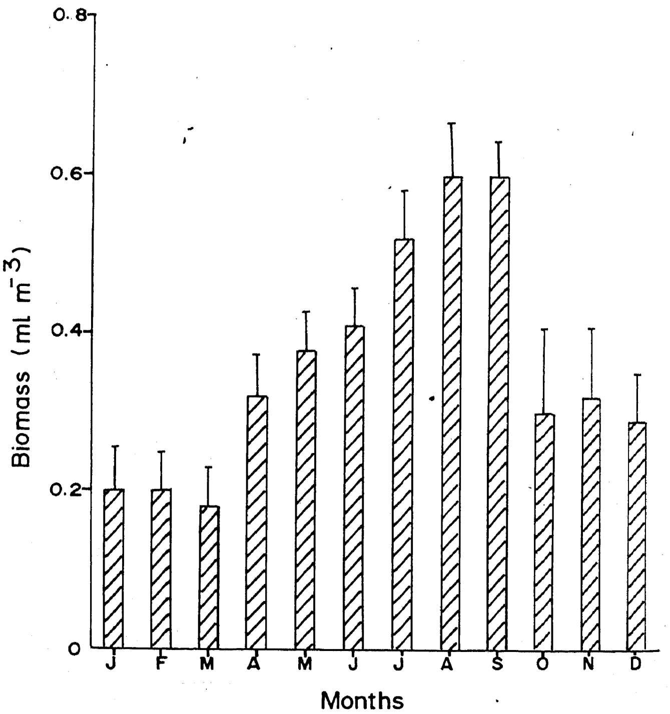

Figure 7. Distribution of zooplankton standing stock off Cochin plus SD during 1972–75 (adapted from ref. 27).

of > 1 ml m^{-3} are common and up to 12 ml m^{-3} have been recorded[19]. Zooplankton concentrate in the upper shallow mixed layer avoiding the low oxygen waters and smaller forms contribute to the bulk of the standing crop.

The increase of zooplankton need not necessarily depend on phytoplankton abundance alone but can happen through the microbial loop (bacteria-heterotrophic flagellates-microzooplankton-mesozooplankton[29]) or a short-circuit of the loop (bacteria-ciliates-mesozooplankton). A simulation model by Parsons and Kessler[30] shows that the presence of microzooplankton during introduction of freshwater plumes can enhance zooplankton production by several hundred percent. This input of microzooplankton during rainy season happens along the coastal waters of the west coast. High zooplankton densities were recorded in the presence of ciliates in 1987 (ref. 28). This was an year when upwelling was weak, rains were episodic and phytoplankton standing stock was very low. The dynamics of the Arabian Sea food chain are surprisingly different from other oceans in that the available estimates of primary production seem to be theoretically unable to support the secondary production[31,32]. Incidentally, the production in the Arabian Sea also supports an amazingly large biomass (ca. 100 million tons per year) of mesopelagic myctophid fish population which are mainly zooplankton feeders[33]. Zooplankton also contributes to regenerated primary production and this happens even in upwelling areas[34].

Overview

The scene of high productivity depicted during the southwest monsoon is essentially confined to a narrow strip hugging the coast (ca. 70 km). Ekman transport may carry some of these elements further offshore, but this effect is not as pronounced as in the western Arabian sea where more extensive upwelling takes place. This confinement to coastal areas appears especially true for primary production. Zooplankton biomass is highest in nearshore waters, but fairly dense populations occur up to a few hundred kilometers offshore.

Sardine and mackerel obviously take advantage of the situation and time their appearances and spawning to coincide with the productive conditions during the southwest monsoon period. Interannual variability in the above scenario due to weak monsoon and a reduction of coastal upwelling will ultimately affect fisheries/recruitment. But as mentioned earlier it need not necessarily affect zooplankton standing crop unless total drought conditions occur. Larvae of both sardine and mackerel predominantly feed on small zooplankton[1].

Longhurst and Wooster[12] found sardine landings and the premonsoon (February–May) Cochin sea level correlated and hypothesized that an early upwelling (indicated by low sea level in April) would lead to inhibition of recruitment through exclusion of spawning fish in neritic zone by oxygen-deficient upwelled water. An analysis of the sea level anomaly (Figure 8) shows that the level was low from 1940 to 1947, started increasing from 1948 to 1957 and rose further during the period 1958–64 and remained fluctuating thereafter. By comparison, sardine catches were poor in the years 1941–49 (< 5000 tonnes), moderate during 1950–56 and increased from 1957. Between 1900 and 1940 also sardine catches were generally low (catches exceeded 10,000 tons only during 9–10 seasons) whereas mackerel fishery had very few poor seasons[1,12]. We did not get a correlation between sea level and sardine or mackerel landings for the period 1960–90. Nor was an April sea level low observed in 1962–63, a time (1963) when the sardine catches fell below 100,000 tonnes (Figure 2).

One point to be noted is that sea level was low more or less *throughout* the year (data not presented) during ca. 1940–57. Hence it is doubtful if the April sea level can be taken as an indication of early remote forcing for those years. Further, a consistent low sea level during monsoon months, which would show favorable upwelling, was not discernible during periods of peak sardine fishery. We do not seem to have a reliable time series index (such as an oxygen isotopic record of corals) as a proxy for past upwelling. In fact, some upwelling as early as April–May, appears to be a frequent feature along the southernmost areas[35,36]. Zooplankton biomass also shows an increase in the south by this time (Figure 7; ref. 37) perhaps attracting early shoals. The upper layer (10 m) is well oxygenated (2 to 4 ml l^{-1}), compared to slightly deeper waters (15 m – oxygen level < 1 ml l^{-1}) during upwelling period[19] probably limiting the shoals to surface.

The reasons for very low sardine landings in 1940s and earlier have to be looked elsewhere but is difficult to postulate *a priori*. It might have happened through a combination of factors (see below). Further, it may

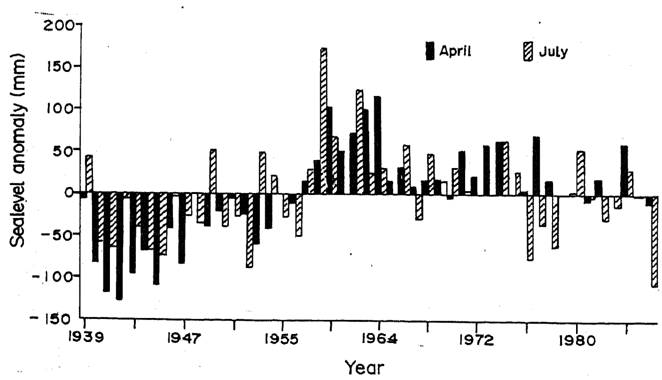

Figure 8. Sea level anomaly at Cochin during 1939–86 (data set from Permanant Service for Mean Sea Level, Proudman Oceanographic Laboratory, Bidston, UK).

be futile to look for strong decadal or secular trends in a fishery which is dependent on 0–1 year class. We feel that the increase in sardine catches in recent years is due to mechanisation and introduction of synthetic material in the traditional sector. The fact that mackerel catches have remained fairly stable over the years (Table 1) shows that traditional gears were equally capable of capturing them although we note that in recent times purse seining is very common in mackerel fishery. The stability of catches in modern times indicates that they are being fished at an optimum and is sustainable at the present level. The legislation limiting mechanised fishing to outside 3–5 miles imposed by maritime states is however important in not only protecting the interests of fishermen using traditional gear but also in avoiding indiscriminate capture of spawners.

The argument that a late arrival of southwest monsoon coincides with low sardine catches[12] does not appear tenable. The 1920s, 1930s and 1940s had more or less equal late arrivals (6, 7 and 6 respectively)[38]. The annual rainfall has fluctuated considerably in this century[38] and did not correlate with sardine/mackerel catches for the period 1960–90 ($r = 0.10$ and 0.09 respectively). In fact, the period 1930–60 had better rainfall with less inter-annual variability compared to subsequent years[39]. Years with very less rainfall in the recent past (1965, 1966, 1972, 1979, 1982, 1985, 1987) also did not particularly affect the fisheries. Apparently, a casual relationship with any of the above mentioned factors is difficult to be established. These lack of correlations are not really surprising considering the complexity of the physical and biological processes. We are beginning to understand these processes, but they are not yet fully mapped to withstand testable hypotheses. As pointed out by Mann[20], the presence of a correlation does not imply cause-and-effect and correlations hold good for a few years, then break down.

Nonetheless, three factors seem to dominate the processes controlling the fishery: (i) Wind-driven upwelling which is an annual feature brings up nutrients to the euphotic zone and triggers production of phytoplankton and subsequently zooplankton. In order to exploit this situation, surface cooling (which could be remote-sensed for fisheries prediction) and probably leaving the poorly oxygenated subsurface waters, sardine and mackerel shoals appear first along the southern region. (ii) An early remote forced upwelling may cause their earlier appearance and the interannual variability observed by many workers. (iii) River runoff contributes through enrichment of coastal waters or the development of high zooplankton population through the microbial loop.

Once the monsoon and upwelling progress northward, the shoals also follow the trend and spawn intensely during a period (typically June–September) when larval food is maximum. A mismatch[40] i.e. an early spawning and a time lag in development of food (through a break in monsoon/upwelling) would be detrimental to the recruitment.

Other research problems

One question that may be posed is why sardine and mackerel are not distributed north of ca. 18° N except occasionally. An obvious explanation is that upwelling is restricted to about this latitude. However, despite lack of upwelling, the northern region is quite productive during the southwest monsoon season probably due to river runoff[28,41]. In fact, high productivity in this area continues during early part of the northeast monsoon season through nutrient supply to the mixed layer from convective overturning of surface waters[42]. Surface waters are cool during this period, and one would naturally expect a progression of the fisheries to north during both seasons. We feel that the answer may be found in the pattern of surface currents. It is known[43] that most fishes head into a strong current (3 to 9 cm/s). The shoals which appear in the south swim against the equatorward surface current during the southwest monsoon up to a point where the currents become weak. A development of a stronger current in some years in the northern region will account for the interannual variability of catches in the north. Once the northeast monsoon sets in and the current reverses, the shoals would head south leading to earlier termination of fishery in the north.

Yet another problem is as to where the stocks disappear during March–May. There have been speculations that they might migrate offshore or become demersal. There is no data to corroborate that stocks might move offshore and remain pelagic. On the other hand there is increasing evidence that at least mackerel might move away from inshore waters and become demersal during this period. Recent demersal trawl survey results indicate presence of mackerel in significant quantities beyond conventional zone even up to 100 m depth all along west coast up to 18° N. Appreciable catch rates of 4 to 16 kg per hour were recorded from depths 50–100 m during April–May[44, 45]. Sudarsan *et al.*[46] observed that mackerel form 1 to 10% of demersal catches along west coast especially between 8° and 18° N. We examined the gut content of mackerel from near bottom (depth 50 m) off Malwan (near Ratnagiri) caught during March. It exclusively consisted of poecilostomatoid copepods and ostracods suggesting that their mode of feeding is pelagic and not benthic although the mackerel itself becomes demersal. Specimens consisted of both sexes with a size range of 105–235 mm (> 80% above 200 mm). The ova diameter of females ranged from 0.37 to 0.5 mm belonging to maturity stages III and IV (ref. 8; a few were 0.28 mm—maturity stage II). In all probability, in association with increase of sea surface temperature and a paucity of food in upper mixed layers, it migrates to deeper waters. It is known that in association with deepening of mixed layer (as it happens during northeast monsoon), fish goes close to the bottom[43]. We cannot say that sardine also becomes demersal with the same confidence since the demersal catches did not contain them. However, Dulkhed[47] postulated that sardine might become demersal during March–April as evidenced from the gut content of specimens taken from bottom nets.

Location of spawning areas of sardine and mackerel has remained an enigma despite intense efforts during 1971–75 (ref. 27, 48) and various other oceanographic surveys. This is an important aspect in understanding the biology, recruitment and assessment of stocks. The survey (1971–75) could locate only a few larvae (expressed as numbers m^{-2}, ref. 27) and concluded that sardine spawns close to shore while mackerel may do so further away from the coast. We feel that both species spawn inshore, close to the coast especially in bays. The only zooplankton samples we have observed to contain thousands of fish eggs and larvae (unidentified) per cubic meter (2000–7000 m^3, as should be expected when such huge stocks spawn) were collected from inshore waters and embayments (5–20 m depth) during southwest monsoon along the west coast (during 1990–91 from Ratnagiri and Karwar).

There is evidence that the Atlantic mackerel *Scomber scombrus* spawns in inshore and inner continental waters and the larvae are restricted to certain areas[49]. Oil sardine eggs and larvae along with spawners have been observed close to coast (2 fathoms) off Vizhinjam, Kerala[50]. There are numerous examples from other upwelling areas (Peru, eastern Atlantic) where the fish spawns close to the coast. In higher latitudes, shoaling and spawning of many species of fish coincide with spring–summer blooms. The point is that in all surveys so far, the transects have been chosen perpendicular to the coast thereby having very few coastal collections and practically without sampling inshore waters. We recommend that future attempts should be directed to sample waters close to the coast in parallel tracks in oblique tows and/or stratified hauls (fish eggs and larvae may undergo ontogenetic vertical migrations[51]). It is logical that the fish would spawn in inshore areas where maximum food is available. Dispersal of eggs and larvae through currents and effects from predation are other aspects requiring attention. It will be interesting to find if larvae and juveniles take advantage of the gyre circulation pattern to return to the feeding and spawning grounds.

Finally, how does the food chain work with regard to these fisheries? The simple relationship diatoms-herbivores-carnivores proposed by Cushing[52] as the traditional food chain for the great fisheries in weakly stratified waters (model 1, Figure 9) may be partly

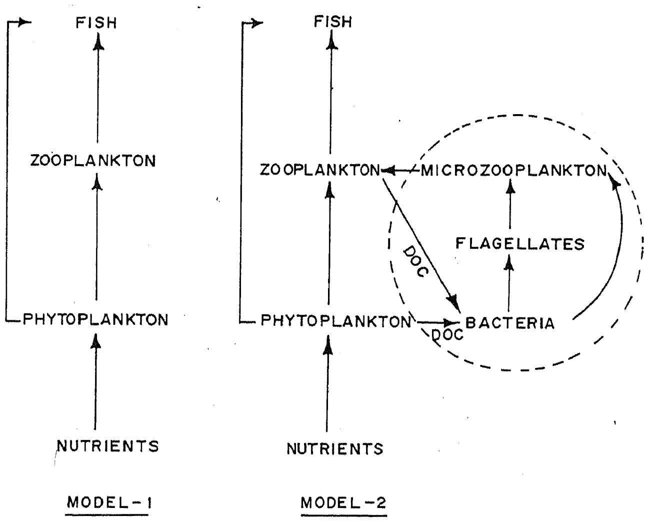

Figure 9. Models depicting two possible food chains with regard to sardine and mackerel (DOC-dissolved organic carbon).

applicable here. However, the pathway through the microbial loop (model 2) will assume importance especially in those years when the upwelling/monsoon is weak or episodic. This will also act as a safety valve with regard to recruitment of both sardine and mackerel. Estimates of new and regenerated production and quantification of microbial loop from coastal waters are other aspects requiring attention. The research problems outlined above appear to be capable of being tackled with the infrastructure available in the country.

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