CMFRI

Winter School on

Towards Ecosystem Based Management of Marine Fisheries – Building Mass Balance Trophic and Simulation Models

INFORMATION ONLY

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Technical Notes

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MARINE FISHERIES IN INDIA

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1. Introduction

Endowed with a long coastline of 8129 km, 2.02 million sq.km.of EEZ, and 0.5 million sq.km. of continental shelf and with an annual marine fishery potential of 3.93 million t, India occupies a unique position among the countries bordering the Indian Ocean. India is one of the leading nations in the world in marine fishery exports. From the traditional subsistence level, the Indian marine fisheries grew to an industrial status over a period of half a century since independence. The subsistence fisheries during the early 50's produced about 0.5 million tonnes annually. Currently, the total annual production is of the order of about 2.6 million tonnes. This increase is the result of improvements in the harvesting methods, increase in the fishing effort and extension of fishing into relatively deeper regions. Fleet size and operations underwent quantitative and qualitative change. Traditional boats are being increasingly motorized and the mechanized sector operating trawlers and gill-netters are resorting to multi-day fishing equipped with the state of the art technologies for communication and fish finding, contributing to increase in fishing pressure. The increased effort over time and space is the consequence of ever-increasing demand for marine food both from external and internal markets. This growth, no doubt resulted in increased yields, employment and exports but, has also led to increased and excessive fishing effort, overexploitation of certain resources from the inshore grounds and increased conflicts among different stakeholders. In spite of the phenomenal growth, the marine fisheries sector has been largely depending upon inshore fisheries and did not make any headway in harvesting the resources available beyond the shelf. Over the years this situation has led to concentration of fishing in the inshore waters, poaching in the EEZ mainly for the oceanic resources and the attempts made by the government for introducing the so called deep-sea fishing have not been fully successful owing to several reasons including the conflicts in different sectors of the industry.

2. Marine fish production

2.1 Resources

Characteristic of the tropical seas, the Indian marine fisheries are multispecies comprising over 200 commercially important species of finfishes and shellfishes and multigear with fishing practices varying between different regions depending on the nature of the fishing grounds and the distribution of the fisheries resources. Pelagic fish (mackerel, sardines, whitebaits, ribbonfish, carangids, seerfishes, tunas), demersal fish (croakers, threadfin breams, silverbellies, catfish, lizard fish, flatfish, snappers, breams, groupers, bull’s eye, goatfish), crustaceans (prawns, crabs, lobsters and stomatopods) and molluscs (gastropods, bivalves and cephalopods) are the major resources exploited. The abundance of these stocks is different between regions, with the large pelagics like tunas being more abundant around the islands and small pelagics like sardines and mackerel supporting a fishery of considerable magnitude along the southwest and southeast coasts. The Bombay-duck (*Harpodon nehereus*) and non-penaeid prawns form a good fishery along the northwest coast (Devaraj *et al*., 1998). Croakers are important all along the coast (Rao *et al*., 1994), threadfin breams are predominant along west coast (Murty *et al*., 1994a), pomfrets along northwest coast and perches (pigface breams, groupers and snappers) are dominant in the southwest and east coasts, especially in the Gulf of Mannar, Palk Bay and Wadge Bank areas (James *et al*., 1994). Silverbellies form a major fishery along the southeast coast (Murty *et al*., 1994b).

Currently 2251 traditional landing centres, 33 minor and six major fishing harbours serve as bases for about 208000 traditional nonmotorised crafts, 55,000 small scale beach landing, motorised crafts, 51,500 mechanised crafts (mainly bottom trawlers, drift gill netters and purse-seiners) and 180 “deep-sea” fishing vessels of 25m OAL (Anon., 2001).

2.2 **Production trends**

It was estimated that the total marine fish production in the country during 1947-48 was only 3.73 lakh tonnes. The estimated total marine fish production in India had risen to about 2.6 million tonnes in the year 2003. The growth rate since 1981 had been on the decline and during 1991-2000 it was only 1.9%. The trend in the production since 1961, over different phases of development of marine fisheries is depicted in the Figure 1. Phase –I corresponds to the predevelopment stage where the fishing was predominantly by the indigenous craft and gear and the process of mechanization was in the initial stage. Phase – II is characterized by the substantial increase in the use of synthetic gear materials, export trade expansion, increased use of mechanised craft, establishment of fishing harbors, introduction of purse-seining and initiation of motorization of country craft. Phase –III witnessed substantial growth in motorization of artisanal fleet, increased use of ring-seines, extension of fishing grounds and increase in fishing hours by resorting to voyage fishing and introduction of seasonal closure of the fishery.

2.3 Sectoral trends

Among the different gears, drift and set gillnets and bag nets of varied mesh sizes are widely used along both the coasts while ring-seines, purse-seines and mechanized gillnets are confined to the southwest coast. Trawlers upto 11 m OAL are operated along the entire coast, while the second-generation large trawlers (13-17m) are operated from selected harbours along both the east and west coasts. The share of mechanized sector to the total landings increased from 20% in 1969 to 65% during the year 2003. The total landings increased from about 1.8 lakh tonnes in 1969 to 16.9 lakh tonnes in the year 2003. The motorized fishing craft accounted for 25% of the total landings in India. The landings by this sector have increased from about 1.8 lakh tonnes in 1986 to 7.1 lakh tonnes in the year 2003. The unit-operations by the mechanized craft during the last 15 years has been fluctuating around 3.05 million operations annually. However, the unit-operations by the motorized sector have significantly increased from about 0.94 million unit-operations in 1986 to about 5.91 million in the year 2003. The constancy in the unit operations by the mechanized sector does not however imply that the fishing activity has remained constant over the years. The amount of time expended for actual fishing by this sector has almost doubled during the last 15 years rising from about 17.4 million hours during 1986 to 46.8 million hours during the year 2003. This was mainly due to introduction and increase in voyage fishing activity by this sector in all the maritime states of India. In the motorized sector not only has there been increase in the unit operations but also in the fishing hours from about 3.3 million hours in 1986 to about 27 million hours during the year 2003. Consequent on the growth in these sectors, the purely artisanal sector has gradually been marginalized over the years. The average annual growth of the different sectors during the five-year periods from 1986 is summarized below (see also Fig. 2).

Average annual landings (lakh tonnes) and growth rate(%)during the five year periods

YEAR	Mechanised	Motorised	Artisanal	TOTAL
1986-90	12.84	2.76	3.34	18.93
1991-95 Growth	16.05 6.2	3.70 8.6	2.84 -3.7	22.59 4.8
1996-00 Growth	18.04 3.1	5.30 10.8	2.20 -5.6	25.54 3.3

Average annual unit operations(millions) and growth rate(%)during the five year periods

YEAR	Mechanised	Motorised	Artisanal	TOTAL
1986-90	3.018	1.785	8.764	13.567
1991-95 Growth	2.926 -0.8	2.601 11.4	6.451 -6.6	11.978 -2.9
1996-00 Growth	3.201 2.3	4.622 19.4	4.367 -8.1	12.190 0.4

Average annual fishing hours (millions) and growth rate (%)during the five-year periods

YEAR	Mechanised	Motorised	Artisanal	TOTAL
1986-90	20.803	6.639	31.204	58.646
1991-95 Growth	27.373 7.9	12.330 21.4	23.595 -6.1	63.298 2.0
1996-00 Growth	35.039 7.0	18.774 13.1	14.731 -9.4	68.544 2.1

2.4 Resource trends

The production from the pelagic fish resources in the country had a three-fold increase since 1961, reaching 1.39 million tonnes in 2003 with a peak of 1.41 million tonnes in 2002 (Fig. 3). However, its relative contribution to the total landings declined from about 71% in 1965 to 50% in 2000 There was a quantum leap to 1.34 million tonnes in 1989 from 0.92 million tonnes in 1988. From 1989 to 2003 the landings fluctuated around 1.3 million tonnes annually. The major constituents of the pelagic resources such as the oil sardine, mackerel, Bombayduck and lesser sardines fluctuated with high inter-annual variations. Other pelagic groups such as the carangids, seerfish and tunnies, showed a general increasing trend.

The landings of the demersal resources including the demersal finfish, crustaceans and molluscs (only cephalopods) have enhanced from 0.23 million tonnes (34% of the total) in 1961 to 1.19 million tonnes (50% of the total) in 2003 (Fig. 3). A steep increase in the demersal landings occurred in 1973, especially along the southwest coast. On an all India basis, except the landings of the resources such as catfish, elasmobranchs, whitefish, silverbellies and pomfrets the landings of all other major resources namely, the perches, croakers and the soles including the penaeid and non-penaeid prawns and cephalopods (squids and cuttlefish) had shown increasing trend. However, the trend in the aggregated landings of the demersal fish resources leveled off since 1994.

The overall trends may mask the regional differences in the development of fisheries and variations in resources availability and abundance. Hence the resource trends in each of the four regions namely the northeast (West Bengal and Orissa), southeast (Andhra Pradesh, Tamil Nadu and Pondicherry), the southwest (Kerala, Karnataka and Goa) and the northwest (Maharashtra and Gujarat) are discussed separately (The island territories of Lakshadweep and Andaman & Nicobar are not taken into account).

2.5 Northeast

The landings in this region increased from 9.2 thousand tonnes during 1961 to about 262 thousand tonnes during the year 2003 (Fig. 4) forming 1.3 and 5.9% of the total all India landings. Up till the year 1991, the state of Orissa used to be the major contributor to the regional landings. Since 1992, the state of West Bengal emerged as the dominant contributor. The annual rate of growth for each decadal period from 1961 was gradually declining (27% during 1961-'70; 16.9% during 1971-'80; 11.7% during 1981-'90 and 404% in 1991-2000). Thus, the declining trend in the rate of growth clearly suggests that the production from this region would soon reach an asymptotic level.

Although the states of West Bengal and Orissa are grouped in a single region, there are differences in the development and type of fisheries between there to states. In West Bengal the contribution of the pelagic and demersal resources were more or less the same from 1976 to 1988. However since 1989, there was quantum leap in the production of pelagic groups, especially the *Hilsa shad* and since then the landings of the pelagic groups was about double that of the demersal resources. Contrastingly, in Orissa the landings of the demersal resources were generally higher than the pelagic resource landings. In Orissa, the landings of the latter fluctuated around 16 thousand tonnes. However, the landings of the demersals showed a declining trend from about 40 thousand tonnes in 1993 to 19 thousand tonnes in 1998.

Major constituents of the pelagic landings in West Bengal are the *Hilsa shad*, Bombayduck, carangids and seerfish. The landings of carangids had exhibited general increasing trend. The Bombayduck production which was very low up to the year 1988, suddenly began to increase, reaching a peak of about 20 thousand tonnes in 1993 and since then it fluctuated about 10 thousand tonnes annually.

Elasmobranchs (sharks, skates and rays), catfish, croakers, pomfrets, penaeid prawns and non-penaeid prawns are the major contributors to the demersal resources landings. The production of the catfish and pomfrets leveled off after the year 1991 to around 4,500 and 2,500 tonnes annually. There was a general increasing trend in the landings of the penaeid and non-penaeid prawns, with some inter annual variations.

2.6 Southeast

Although the total landings in the region increased by 3.5 times from the year 1961 to 5.62 lakh tonnes during the year 2003 (Fig. 4) its share in the all India total landings fluctuated, with little variation, between 26% in 1961 to 21% in the year 2003. The increase in the landings was mainly due to spurt in the landings of the small pelagics especially the oil sardine, mackerel and carangids. In each of the three decadal periods since 1961 the rate of growth was gradually declining with 3.8, 3.8, 2.8 and 2.3% respectively. The declining rate of growth during these periods amply suggests that the landings will soon level off.

The main feature of the fisheries of this region is the increased landings of the pelagic resources. Up till the year 1985, both the pelagic and demersal resources were increasing with more or less same rate of growth, however from 1986, there was a sudden jump in the rate of pelagic fish landings. A significant development in this region was the emergence of oil sardine as an important source of production. Its landings increased from about 19 thousand tonnes in 1989 to 110 thousand tonnes in 1997. During the year 1997 and 1998, it had been the single largest contributor to the total landings in the states of Andhra Pradesh and Tamil Nadu. The combined landings from these two states was higher than the traditionally high yielding states of Kerala and Karnataka. Similarly, the landings of mackerel, carangids had increased considerably.

The demersal fish landings had much less rate of growth than the pelagics. In Andhra Pradesh, the demersal fish landings were more or less about 20 thousand annually during the period 1961 to 1971. It rose to about 60 thousand tonnes in the year 1975 and from 1976 to 2000, the annual landings were more or less invariant around 40 thousand annually. The major demersal fish resources are the elasmobranchs, catfish, perches, croakers and silverbellies. Penaeid prawns, crabs and non-penaeid prawns form the bulk of the crustacean landings. Cephalopods form an economically important component of the trawl fishery.

2.7 Southwest

The region comprising the states of Kerala, Karnataka and Goa had been the most productive region and was the largest contributor to the country's total marine fish landings till 1994. Since then, it had been relegated to the second position by the northwest region. The relative contribution of the southwest region to the country's total production had dwindled from about 51% in the year 1965 to 31% in the year 2000 (Fig. 4). The marine fish landings of the region are characterized sudden jumps in production after periods of stabilized production. However, after registering peak landings of about 1.02 million tonnes in the year 1989, there had been gradual decline. The growth rates during the different decadal periods since 1961 were 9.4, - 3.2, 10.7 and 0.7%. The growth during the latest phase is the indicative of the present status of the fishery. This clearly indicates that from the presently exploited grounds off this region with existing technology, there would not be any augmentation in the total landings.

The feature of the marine fisheries of the region is the predominance of the pelagic resources. However, their contribution to the total marine fish production had fallen from about 80% during 60's and 70's to just above 50% in the late nineties, this was compensated by increased representation from the demersal resources. The total landings of pelagic groups remained more or less around 3.3 lakh tonnes annually during the period 1964-'88. There was a quantum jump to 7.2 lakh tonnes in the year 1988, owing mainly to bumper landings of oil sardine and mackerel. A significant event had been the set back to the oil sardine fishery during the year 1994, yielding a meager 3 thousand tonnes. However, the landings tended to increase and registered a peak landing of 3.1 lakh tonnes in the year 2003. The other pelagic resources such as the mackerel, carangids, tunas and seerfish, though generally exhibited increasing trend up to 1990 and of late, their production seemed to level off.

Unlike the pelagic fish production which had shown high inter annual variations, the demersal fish landings increased steadily from about 35 thousand tonnes in 1961 , attaining a peak of 1.8 lakh tonnes in 1993. Except the landings of the elasmobranchs (mainly sharks) catfish and silverbellies other demersal fish resources exhibited general increasing trend in the landings. Among the resources which recorded decreased landings over the years, Catfish resource was the most prominent. From a historical peak of about 38 thousand tonnes in the year 1975, the landings dwindled to 250 tonnes in 2000.

The landings of the crustacean resources (mainly the penaeid prawns, non-penaeid prawns, crabs, lobsters and stomatopods) attained an all time peak of about 1.6 lakh tonnes in the year 1994 and suddenly slumped to about 90 thousand tonnes in 1995. Since then there was an improvement in the landings.

2.8 Northwest

There was a spectacular growth of marine fish production of this region from about 0.2 million tonnes in the year 1961 to 1.1 million tonnes in 2000 (Fig. 4) owing primarily to the rapid development of fisheries in the state of Gujarat. Since the year 1994, this region had emerged as the single largest contributor to the total marine fish landings in India. The annual growth rate during each of the decadal periods since 1961 were 3.9, 5.1,3.8 and 3.9%. For the last phase the growth rates in Gujarat and Maharashtra were 6.2 and –0.46% respectively, indicating differential growth pattern among the constituent states of the region.

The pelagic finfish production in this region increased from about 1.2 lakh tonnes in 1961 to 3.9 lakh tonnes in 1998, the relative contribution however declined from about 57% in 1961 to about 35% in 1998. Bombay duck, ribbonfish, carangids, mackerel, seerfish and tunas are the major components of the pelagic finfish production. In Maharashtra, the landings of Bombay duck have been declining from about 82 thousand tonnes in 1980 to about 10 thousand tonnes in 1996, whereas in Gujarat the production is fluctuating between 60–80 thousand tonnes during 1991-2000. In both the states the ribbonfish landings had registered high growth rate reaching the peak production in the year 1997.

Unlike the pelagic landings, the development of demersal fisheries was spectacular which registered an eight-fold increase in the landings from about 0.85 lakh tonnes in 1961 to 7.1 lakh tonnes in 1998. This phenomenal growth was mainly due to increased production from Gujarat. In Maharashtra the demersal fish production leveled off around 80 thousand tonnes since 1985, whereas the production of the crustaceans and cephalopods (molluscs) showed a general increasing trend in both the states.

3. Status of exploitation, resources and the fisheries potential

Until the 1970s, the emphasis of marine fisheries management in India was to increase production through improved fishing technology, infrastructure (harbours, roads, processing and market facilities) development and incentives and subsidies to the fishermen. This has led to increasing the marine fish production from 0.5 in 1950 to 2.6 million tonnes in 2003 (Fig. 1). However, during the 1980s, concerns were expressed on the unrestricted growth of the fishing fleet and its possible adverse impact. The researches carried out on different species stocks also voice these concerns (See Murty and Rao 1996). As already indicated the mode and method of exploitation over the years has under gone tremendous changes, resulting in increased fishing pressure. The coastal fisheries exploit a large number of species using different craft and gear combinations mostly in the depth range of 0 to 50 m though in recent years, this has been extended to about 120 m in some regions.

From the analysis of the resource trends it is evident that in most of the regions the production from the exploited resources appears to have been fast reaching the asymptotic level and in some cases the production seems to have reached the limiting value. Some of the resource-region combinations have exhibited even declining trend. The stock assessment studies carried out by the CMFRI for more than 50 resources (or species) have also indicated in most of the regions the stocks are either fully exploited or over exploited. The exploitable potential fishery resources have been revalidated at 3.93 million tonnes. This revalidation was done in the year 2000 by the Ministry of Agriculture, Govt of India. The working group on revalidation observed that the fishing effort expended in the shelf waters was optimal and recognized that chances of any significant improvement in the total landings would be remote. For exploiting the potential yield there was urgent need to diversify the fishing activities in the EEZ through directing the fishing towards deep-sea resources such as sharks, tunas, squids etc. Oceanic resources consist of tunas (*Thunnus albacares, T.obesus, Katsuwonus pelamis*), billfishes, myctophids (*Benthosema* spp., *Myctophum* spp. and *Diaphus* spp.) and oceanic squids (*Symplectoteuthis oualaniensis, Onychoteuthis banskii*, *Thysanoteuthis rhombus*). But there was no directed fishery for these species, except some exploitation by chartered vessels which operated under the deep-sea fishing schemes in the nineties. Logline surveys conducted by Fishery Survey of India (FSI) have also revealed the abundance of yellowfin tuna and pelagic sharks (Somavanshi, 2001).

For conservation and for obtaining sustainable yields many of the maritime states have enacted marine fishery regulation acts banning fishing activities by certain section of the fishery sectors during certain period of the year. In the west coast, there is ban on fishing by the trawlers during the monsoon season for a period ranging from 45 to 60 days. In the east coast the ban on fishing was implemented from 15 April to 31 May. Whether such a regulation yielded the desired results is still a debatable issue. However, it was felt such a regulation would give respite not only to the resources, which are under heavy exploitation but also to the ecosystem to regain its productivity.

4. Issues

4.1 Declining catch rates and excess fleets

The annual growth rate of marine fisheries sector increased from 4.3% during the seventies to 4.8% during the eighties and declined to 4.0% during the nineties (Anon, 1997) and the fall in the growth rate is reflected in the annual catch attaining the optimum levels in the inshore fishing grounds (upto a depth of 50 m) of about 0.18×10^6 sq km area. The substantial increase in fishing effort since the 1970s has resulted in the decrease in per capita area per active fishermen and per boat in the inshore fishing grounds and also in the catch rates, which in turn have given rise to conflicts among different categories of fishermen, especially artisanal and mechanised sectors (Sathiadhas, 1996). Technological improvements in capital-intensive fishing implements have also rendered existing older units less economical or non-operational, leading to substantial idling of fleets and underemployment (Sathiadhas *et al*., 1999).

4.2 Impact of bottom trawling on sea bottom and benthic biota

At present about 45,000 bottom trawlers operate (mainly targeting shrimps) in the entire inshore region. This kind of excessive bottom trawling is feared to have far reaching consequences such as degradation of the sea bed ecosystem and its biodiversity as a large number of non-target groups comprising of juveniles and sub-adults of economically important finfishes and shellfishes and also benthic organisms, most of them with little edible value but occupying key positions in the marine food web are also destroyed (Anon, 2000a).

4.3 Discards/exploitation of juveniles and sub adults

The discards in the Indian Ocean region account for 2.27 million t forming nearly 8.4% of the total global discards (Alverson *et al*., 1994). Though there are no precise estimates of discards in the Indian seas, certain studies suggest that about 0.3 million tonnes is discarded by shrimp trawlers annually. The trawl by-catch includes on an average of 10% juveniles/sub adults of several coastal species. Large-scale removal of young fishes by gears like ring-seine has been a cause for major concern in respect of certain pelagics. Large-scale removal of juveniles of fishes and prawns along southwest and southeast coasts respectively has been going on by ‘mini trawls’ and certain artisanal gears in shallower regions less than 5m. The quantity of discards from trawlers may further increase in view of the rapid expansion of the multiday fishing. Therefore there is an urgent need to devise suitable measures for reduction/prevention of juvenile exploitation along with measures for onboard collection/preservation of ‘discards’ and their value addition to prevent economic waste.

5. Initiatives for Fishery Resources Conservation and Management

5.1 Policy support: In 1979 the Ministry of Agriculture (GOI) prepared a Model Bill to regulate coastal fishing and circulated it to all coastal states of India. It suggested demarcating an area upto 10 km from the coast exclusively for traditional craft and beyond the 20 km limit for deep-sea vessels. Subsequently, from 1980 onwards, the Marine Fishing Regulation Acts (MFRA) aiming at sustainable fishing were passed by various maritime states with measures like:

- Imposing closed season during monsoon
- Restricting fishing effort
- Banning destructive gears/ fishing methods

Recently, based on discussions the Ministry of Agriculture (GOI) had with coastal states/UT and CMFRI and FSI, the GOI has initiated a move to impose a uniform ban on trawl fishing during the monsoon months along the entire Indian coast.

Potential yield of Fishery Resources in the Indian EEZ was estimated in 1991. Revalidation of this estimate has been done in 2000 (Anon. 2000b) taking into account the additional information on commercial catches, exploratory surveys and fishing results from chartered/ joint ventures that have accrued since the estimate of 1991. This will help in proper management of the fisheries by suitably redeploying the effort.

The Government of India have appointed an Expert Group to formulate the National Marine Fisheries Policy. The expert group has since submitted the report with several important recommendations (Anon, 2001).

5.2 Research Support

Collection and analyses data on landings to understand interannual and seasonal variability, species composition and length composition of catches and research on biology and population dynamics are carried out by the Central Marine Fisheries Research Institute. Holistic models such as the ecopath model are being applied in recent years. Studies are also being carried out on the effect of technological advancements on the socioeconomic conditions of the fishermen community. Training for empowerment of the fishermen community is also undertaken. Installation of Artificial Reefs to enhance productivity of coastal waters to benefit the traditional fishermen and sea ranching (Pearl oysters in traditional Pearl Oyster Banks in Gulf of Mannar, Clams in Cochin and Quilon backwaters, *P. semisulcatus* in sea grass beds off Mandapam) have also been done by the Institute.

6. Projection

The relative annual rates of growth in total landings for three decadal periods from 1961 and during 1991- 2000, by all India bases, by region and by the individual maritime state were considered for making projections. It is observed that in some of the regions and states the rates of growth are approaching or crossed zero growth. In some states there was still a positive growth indicating possibilities of enhanced landings. However, the declining rate of growth over the years indicates that the production would soon level off.

Based on the rates of growth, the projections for the year 2005 were made by taking the year 2000 as the base. The optimistic projections suggest that the total production in the year 2005 will be to the tune of 2.9 million tonnes. The pessimistic projections were made assuming that the growth rate would halve from 2000. These projections indicated that the total production would be around 2.8 million tonnes.

It was mentioned earlier that the pelagic resources dominated the marine fish production in India. Most of these stocks are annual crops, meaning that they are predominantly O year class, whose abundance depends on the variations in the recruitment. It is well known that the abundance of the pelagic stocks depends more on the fishery independent factors, such as the water chemistry, oceanographic parameters, meteorological variable and food availability. Any future projections thus should take into consideration these variables. Among the pelagic resources, oil sardine, mackerel, ribbonfishes, Bombayduck and carangids are the major contributors. The variations in the abundance of any one or all of them would affect the total production. Assuming, for pessimistic projections there is a reduction of 10-30% in resource availability and assuming the resource availability is directly proportion to the landings, the total landings including all resources is likely to reduce and will be in the range of 24.5 to 26 lakh tonnes. Thus, upto the year 2005, the total production may fluctuate between 2.4 to 2.9 million tonnes.

7. Conclusion

The production trends indicated regional and intra regional variations in the major exploited resources. Trends in the landings of the different resource assemblages such as the pelagic and demersal resources together with the trends in the effort expended by different sectors namely the mechanized and motorized brought out the differential fishery developments between the regions.

Another significant observation was that the landings of the aggregated demersal fish resources in most of the regions had either leveled off without any signs for further enhancement. Thus only expected gains could be from the pelagic resources and other crustacean and cephalopod resources. Stock assessment studies by the CMFRI also indicated in most of the regions, the species of the resources indicated above are either fully exploited or over exploited. The estimates of the potential yields obtained from the currently exploited areas into the existing harvesting practices, indicate a possibility of additional yield of about 4 to 5 lakh tonnes. This is expected to be achieved if the resource groups could be restored to their historical maximum values, through proper fishery management strategy.

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Fig. 1 Estimated total marine fish landings in India over different growth phases

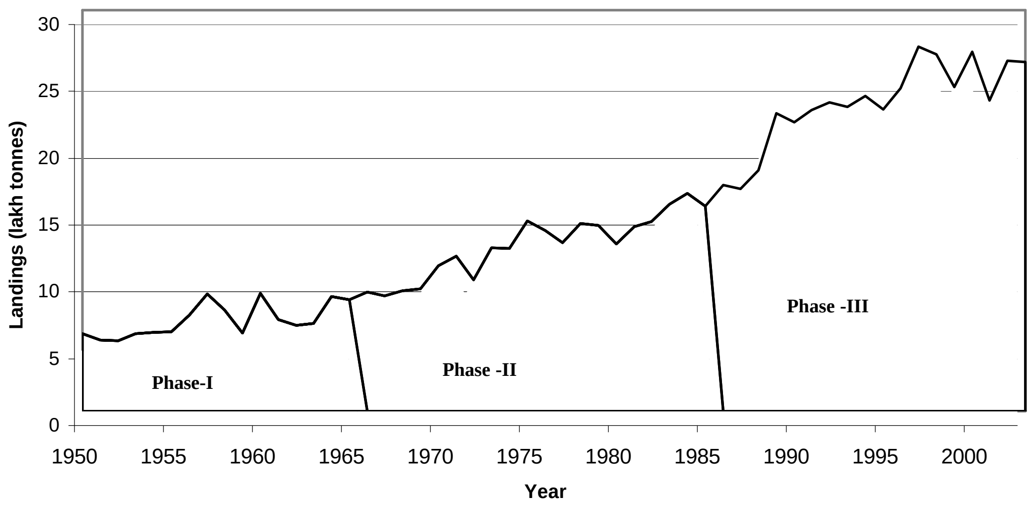
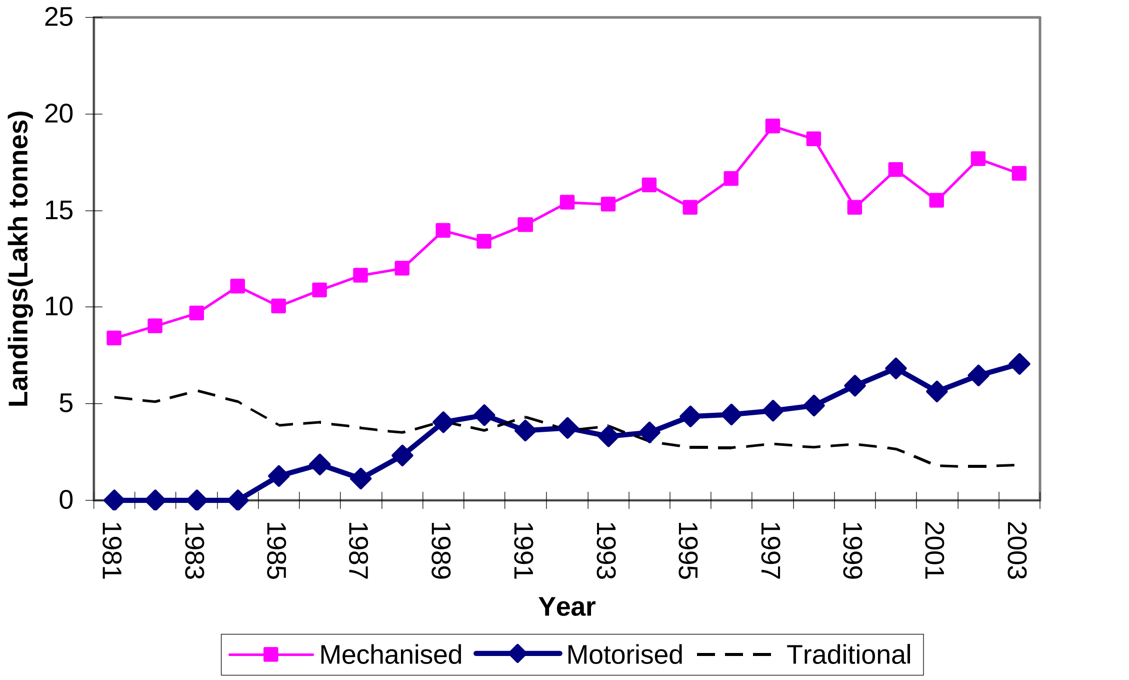


Fig.2 Trend in total landings by different sectors in India during 1981-2003



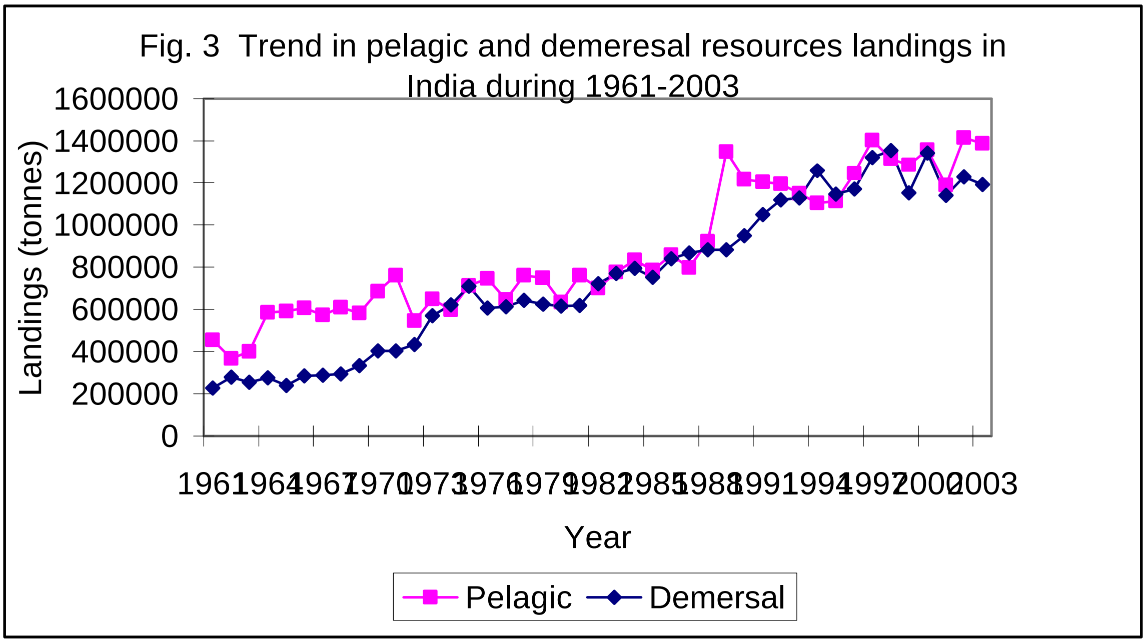


Fig. 3 Trend in pelagic and demeresal resources landings in India during 1961-2003

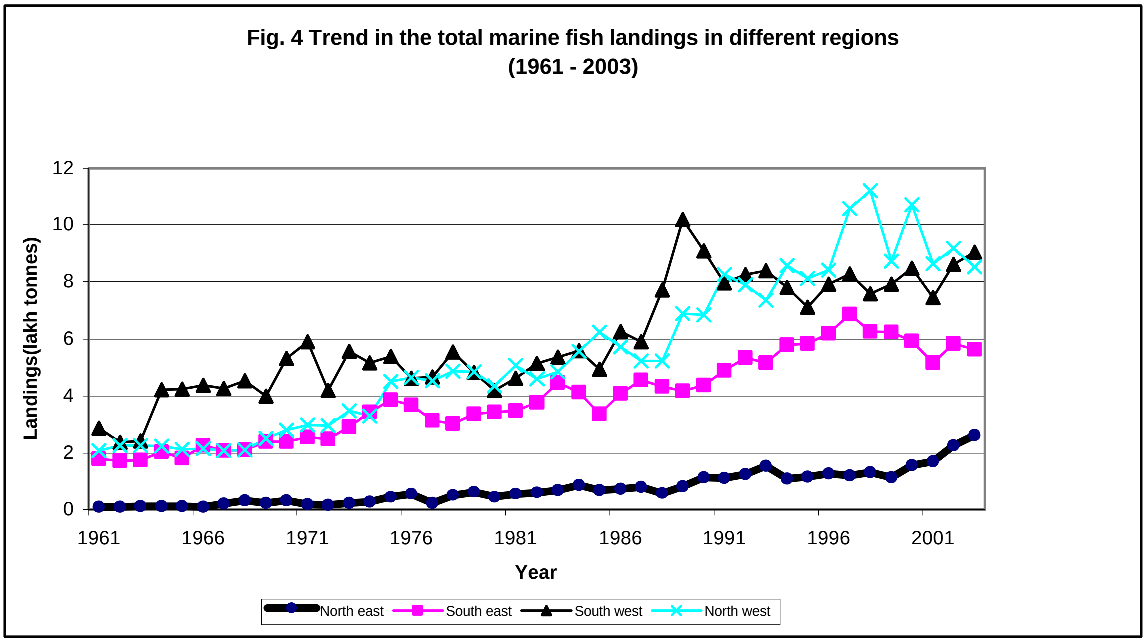


Fig. 4 Trend in the total marine fish landings in different regions (1961 - 2003)

2

PELAGIC FISHERIES RESOURCES OF INDIA

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Introduction

The marine fish production in India has progressively risen to the tune of 2.7 million t in 2000 due to the introduction of larger mechanized boats, motorisation of the country crafts, modernization in harvesting sector coupled with extension of fishing to deeper grounds since the late 1950s. The average annual marine fish production of India for the period 1985 to 2003 was 2.5 million t of which the pelagics contributed 1.4 million t accounting for 51% against a potential yield of 1.92 million t of this group from the Indian EEZ During the last decade pelagic resources contributed 46-56% (avg. 51%) of the total marine fish production. Almost 70% of the production was obtained from within the 50 m depth zone. As per the revalidation, annual potential yield from the EEZ of India is 3.9 million t, out of which 2.21 million t are from within the 50 m depth zone and 1.69 million t from beyond it (Anon, 1991). The current yield from 0-50m depth zone is at the optimum level, and hence does not offer any scope for increasing the yield and in fact this zone requires regulatory management for sustaining the yield. Therefore, the region beyond 50 m depth has to be the focus of expansion.

Exploitation of pelagic resources

The pelagics have been exploited by the conventional crafts and gears and as a consequence of modernization in the harvesting sector, new inboard/outboard engine fitted crafts and innovative gears such as ring seine, *matta vala* (disco net) etc. gradually replaced many of the traditional fishing gears. Mechanized fishing by trawls, purse seine, gillnets etc. also supported the growth of the pelagic fisheries.

Trend in production: The pelagic fisheries resources of India are largely of multispecies multisector fisheries. There are about 240 species contributing to the fishery(Table 1). A few species enjoy wide geographical distribution, while the others, such as the shads and the Bombayduck have rather restricted distribution.

Table 1. Major taxonomic categories of small pelagics and their species diversity

Family	Group/species	Number of species
I Clupeidae	1. Oil sardine*	1
	2. Lesser sardines* (including rainbow sardines)	14
	3. *Hilsa* spp. & other shad	15
	4. Whitebaits*	24
	5. *Thryssa* and *Thrissocles* spp.	10
	6. Wolf herrings	2

	7. Other clupeids	40
II Scombridae	1. Coastal tunas 2. Oceanic tunas 3. Seerfishes & wahoo 4. Mackerels*	5 2 5 3
III Trichiuridae	1. Ribbonfishes*	8
IV Carangidae*	1. Round scads 2. Golden scads 3. Hardtail scad (or horse mackerel) 4. Jacks 5. Black pomfret 6. Others	2 6 1 17 1 19
V Harpodontidae	1. Bombayduck	1
VI Stromateidae	1. Pomfrets	2
VII Coryphaenidae	1. Dolphinfishes	2
VIII Rachycentridae	1. Cobia	1
IX Mugildae	1. Mullets	22
X Sphyraenidae	1. Barracudas	7
XI Exocoetidae	1. Flyingfishes	10
XII Bregmacerotidae	1. Unicorn cod	1
XIII	Others	19
Total small pelagics		**240**

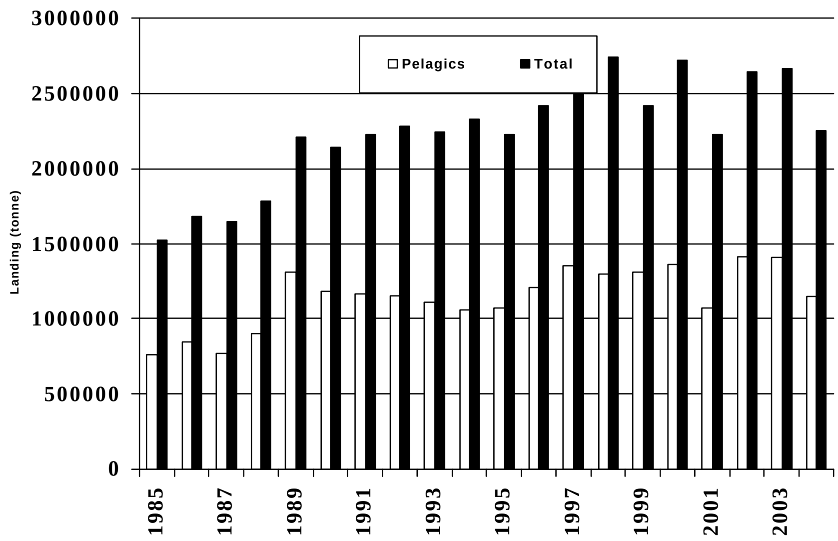
Srinath (1989), James and Alagarswami (1991) analysed the pattern of development of the pelagic fishery based on historical data relating to 1961-85 and 1979-85 respectively. Pillai (1992) has given a comprehensive account on the results of the stock assessment of the major pelagics. Devaraj et al (1997) has given an exhaustive account on status, prospects and management of the small pelagic fishes of India. Until the mid-seventies, the share of the pelagic stocks in the overall production remained very high with a consistently increasing trend from 54% in 1950 to 71% in 1960, and thereafter, at around 65% till the early seventies. The pelagic catches increased from 309,000 t in 1950 to the current 14,14,064 t (2002) registering over a fourfold increase. The growth in the production of the pelagics vis-à-vis the overall production could be gauged from Table 2 and Fig. 1.

Table 2: Growth in the average annual overall and pelagic fish production through the five decades from 1950 to 2003

Period	**Production (t)**		**Relative growth (%)**	
	Pelagics	**Overall**	**Pelagics**	**Overall**
1950-59	362,548	618,501	-	-
1960-69	527,211	814,721	+ 45	+ 31
1970-79	643,142	1,243,707	+ 22	+ 27
1980-89	819,093	1,579,836	+ 27	+ 27
1990-99	1,116,792	2,258,874	+ 36	+ 43
1996	1,243,424	2,422,043	+11	+7

The average annual landings of the major pelagics in the initial stages of mechanization (1961-65) to 1995-96 is given in Fig. 2. In the early years (in the development of marine fisheries) the growth rate in the production of pelagic fishes had been conspicuously higher than that of the overall production. This trend got reversed during 1970-79 because of the rapid expansion of commercial trawling for shrimps for exports by the industrial sector. Commercial trawling resulted in significantly high production of demersal finfishes also, besides shrimps, crabs, lobsters and cephalopods. Although the pelagic fish catches increased by 22%, the trend in the overall production was set by the demersal finfish and crustacean catches. The next decade (1980-89) witnessed a growth of 27% in the pelagic catches as well as in the overall production. During this decade there was rapid motorization of traditional fishing craft, particularly in the latter half of the eighties. As a result, the stagnation in marine fish production witnessed in the first half of the eighties gave way for accelerated production in the latter half. Intensive motorization of the traditional fishing crafts resulted in a remarkable increase in the annual production, especially of the total pelagics, which increased from 769,000 t in 1985, 1,313,000 t in 1989, registering a 71%increase (Fig. 1).

Fig.1 All India landing of total marine and pelagics during 1985-2003



Statewise contribution: The state-wise average contributions to the pelagic fish production showed that Kerala ranked first among the maritime States of India contributing about 31% of the total pelagic fish catch, followed by Gujarat and Tamil Nadu contributing 13.7% and 13.0% respectively. The contributions by other States were: Maharashtra 10.8%, Karnataka 10%, Goa 7.1%, Andhra Pradesh 6.9%, West Bengal 3.8%, Orissa 1.4%, Andaman and Nicobar Islands 1%, Pondicherry 0.8% and Lakshadweep 0.5%. Fig3. This shows that the southwest region comprising Goa, Karnataka and Kerala continued to be the highly productive area (36%) followed by northwest, southeast and northeast regions and the Island territories (Fig.4).

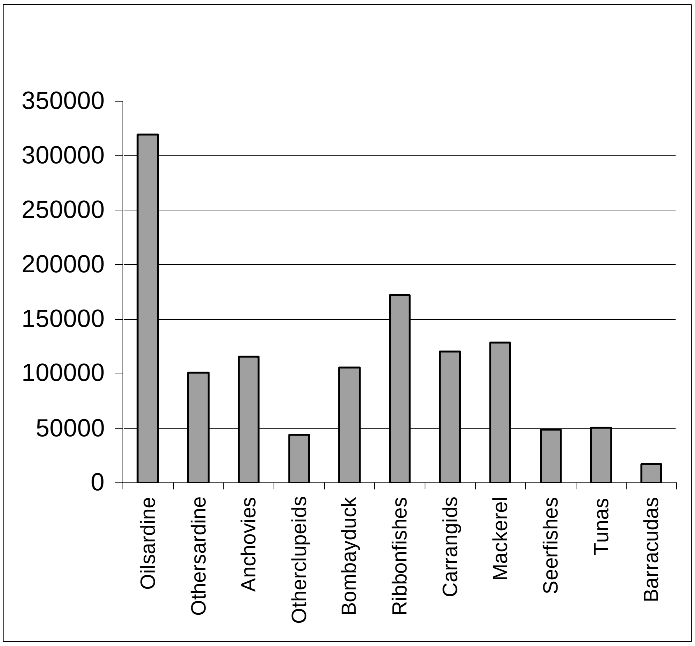


Fig.2 Landings of major groups of pelagic finfish (avg.) during 1999-2003

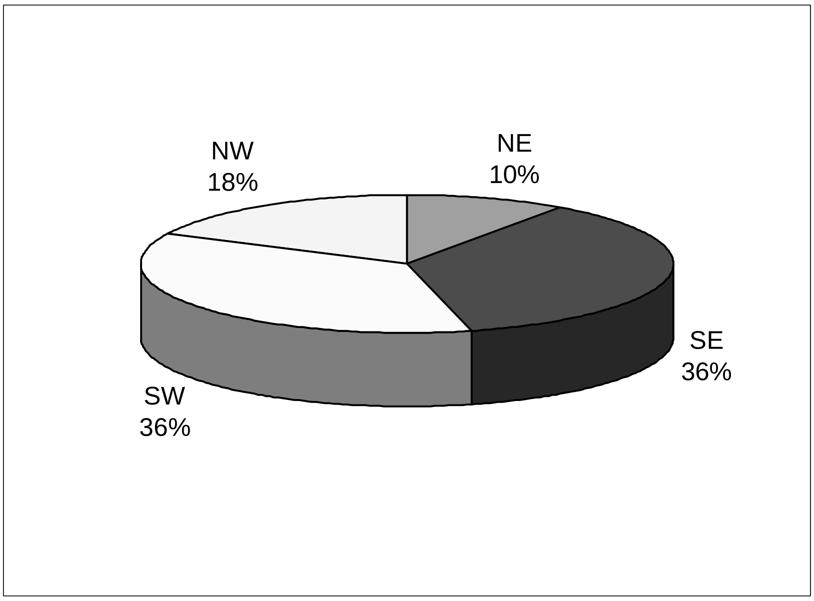


Fig. 4 Region-wise pelagic finfish landings during 2003

Major pelagic stocks: Out of the 240 species that contribute to the pelagic fisheries along the Indian coast, only about 60 species belonging to 7 groups viz., the oil sardine, lesser sardines, anchovies, Bombayduck, ribbonfishes, carangids and Indian mackerel form the major fisheries. The annual production of these groups during 2003 is 1.17 million t forming 85.4% of the pelagics and 43.98% of the total marine fish landings. The other pelagic groups which include the wolfherrings , shads, barracudas, unicorn cod, mullets, seerfishes and coastal tunas formed only 14.6% of the pelagic fish landings. The percentage contribution by the pelagic groups ranged from 1.0% in the case of barracudas to 14.0% by oilsardine. The groups, which exceeded one lakh t in production per year were mackerel, oil sardine, anchovies, carangids, ribbonfishes and Bombayduck. The oil sardine and ribbonfishes were the most predominant, contributing 14% and 6.8% respectively to the overall marine fish landings during 2003. Anchovies formed 4.8%, followed by the Bombayduck (4.9%), ribbonfishes (6.8%), lesser sardines (4.25%), wolfherring(0.57%), Hilsa shad (1.68%) and barracudas (0.62%) in the overall marine fish landings during this period. (Fig.5)

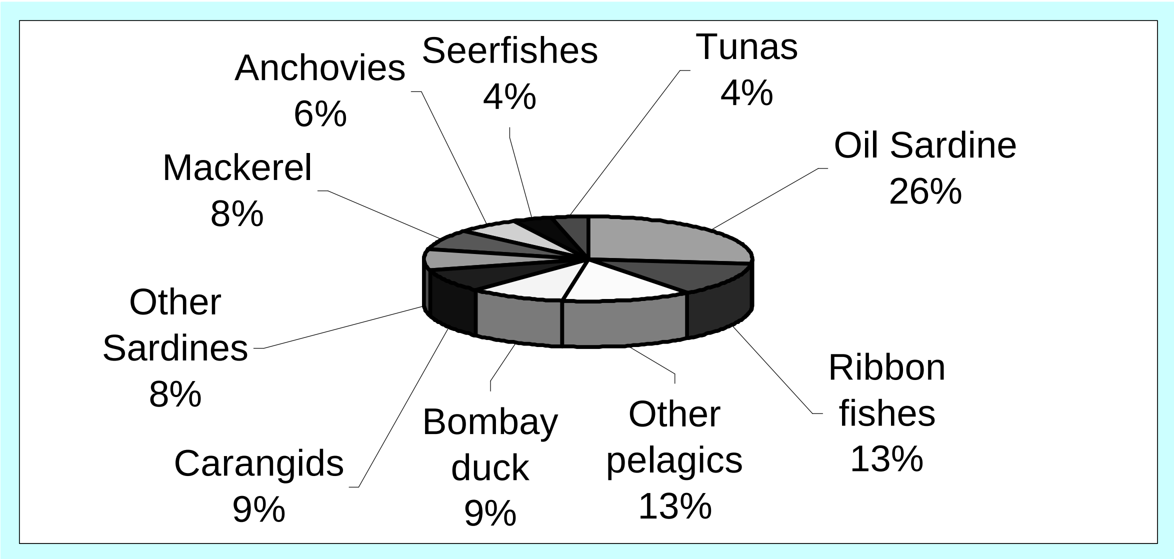


Fig. 5 Components of pelagic finfish landings in the total pelagics (2003)

The major single-species fisheries of the pelagic resources, the oil sardine (*Sardinella longiceps*), (Fig. 6.) the Indian mackerel (*Rastrelliger kanagurta)* and the Bombayduck (*Harpodon nehereus*) showed wide fluctuations in their availability for exploitation.

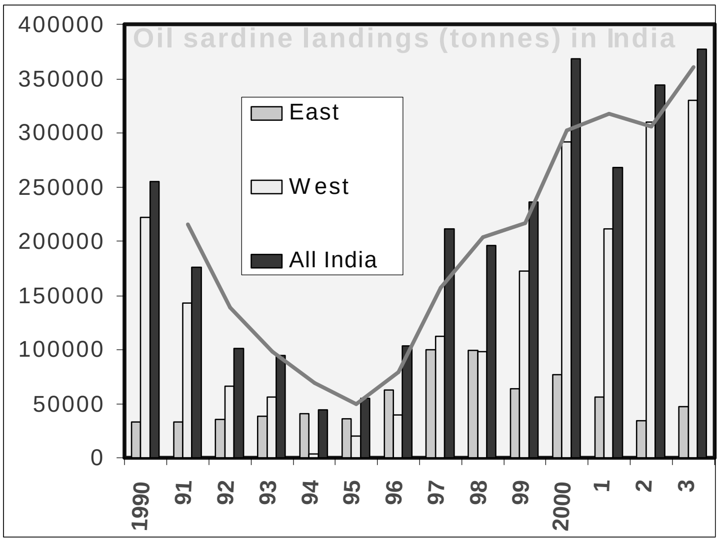


Fig. 6 Oil sardine landings in India

The Indian oil sardine is a very important pelagic fish species which contribute to about 15% of the total marine fish production in the country. The oil sardine fishery has been most strikingly characterized by wide fluctuations in the annual landings from the very early years of exploitation. There have been several periods of high abundance as well as major population crashes during this century. The variability in abundance of the oil sardine is cyclic.

During the last fifty years, the all –India production of the oil sardine ranged from 14,000 t in 1952 to all-time high of 3 lakh t in 1968 contributing 0.1% to 31.9% to the total marine fish landings in India. The oil sardine catch increased from 78,000 t in 1986 to 2,79,000 t in 1989, to decline again to 47,000 t in 1994. The resuscitation of the oil sardine stock after an ever-lowest landing of 47,000t in 1994 was manifest from the heavy recruitment that followed, which culminated to a highest production of 3.72 lakh tonnes in 2003(Fig.6). The average (1985 to 1996) annual landings of the oil sardine on the west coast were 128,282 t (86%) and the east coast 21,262 t (14%). Of late it has become an established fishery on the east coast (Luther,1988). Till the close of 1970s, artisanal fishing gears mainly boat and beach seines, cast nets and small meshed gill nets were the major gears operated along the southwest coast. With the introduction of mass harvesting gears like purse seines in the late 70s and ring seines in the late 80s along with a steady rise in the motorization of the traditional fishing crafts, many of these traditional fishing methods have become redundant. Along the east coast mainly boat seines, gillnets and bag nets dominate. In Tamil Nadu coast, pair trawlers are also operated while ring seines have been recently introduced in the Palk Bay.

The lesser sardines comprise several species of *Sardinella* other than *S.longiceps* show wide distribution in the tropics and are one of the major pelagic fishery resources of our country. Though occurring in the landings of all the maritime states, they particularly contribute to a lucrative fishery along the southeast and southwest coasts. Of the 15 species of lesser sardines in the Indo-Pacific region, 12 occur in the Indian waters. The resource comprised 3-7% of the total annual marine fish production of the country during 1986-2000. During this fifteen year period the lesser sardine landings ranged from a low of 68,267 t in 1986 to a high of 1,28,021 t in 1995 (Fig.7).The east coast contributed 65% wuith an average annual production of 67,172 t during 1986-2000.The annual production along the west coast during this period was 35,449t.The dominant species contributing the fishery are *Sardinella albella, S. gibbosa S. fimbriata, S .sirm and S. dayi.* The traditional, motorized and mechanized crafts employ a variety of seines, gill nets and trawls to exploit the lesser sardines.

The whitebaits that comprise a group of small pelagic fishes belonging to the genus *Stolephorus* and *Encrasicholina* are widely distributed in our waters. This resource contributes on an average to 64,000 t(1991- 2003) forming 1.7-5.8% of the total marine fish landings in the country (Fig.8).Ten species of whitebaits have been found to occur in our seas. Among these species, *E.devisi, E.punctifer, S.waitei, S. commersonii* and *S.indicus* supported the fishery.Boat seine, shore seine, gill nets, ring seine and trawls are employed to exploit the resource in Andhra Pradesh, Tamil Nadu and Kerala coasts.

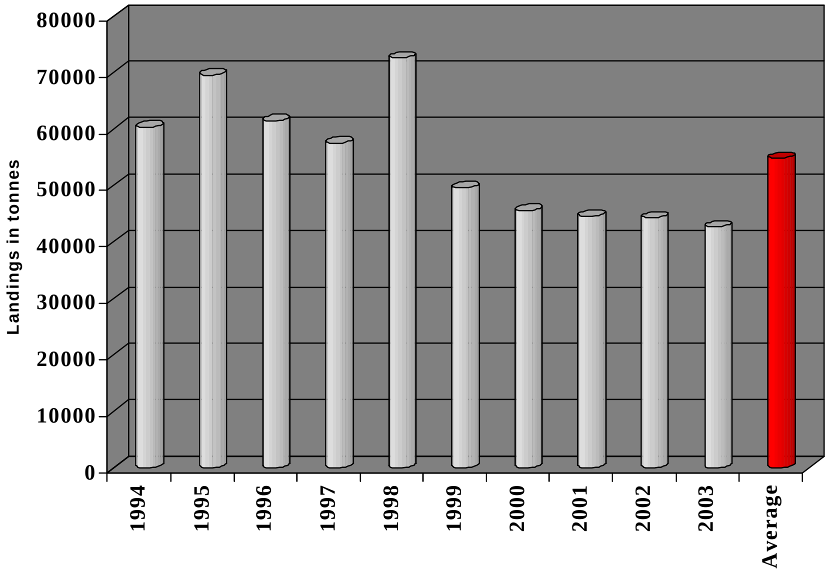


Fig. 8 Landings of Whitebaits during 1994-2003

The annual production of the Indian mackerel is also characterized by wide fluctuations as evident from the catch records of the past fifty years. During the last 20 years, the production ranged from 113,000 t in 1991 to 290,000 t in 1989.The mackerel fishery showed a declining trend from 1999(2.1 lak t in 1999 to 0.9 lakh t in 2001) and showed marginal improvements during 2002 and 2003 when the catch increased to 0.96 lakh t and 1.12 lakh t respectively (Fig.9).The large scale exploitation of the juveniles along the southwest coast is the key factor which limits the yield from the mackerel stock.Fishes below the size of 15 cm form about 42% of the catch from west coast. Increasing the size at first capture from 140 mm to 160mm by controlling exploitation during the major recruitment period (July-September) or increasing the mesh size of the larger seines to minimum of 35mm can be employed to control the growth overfishing.

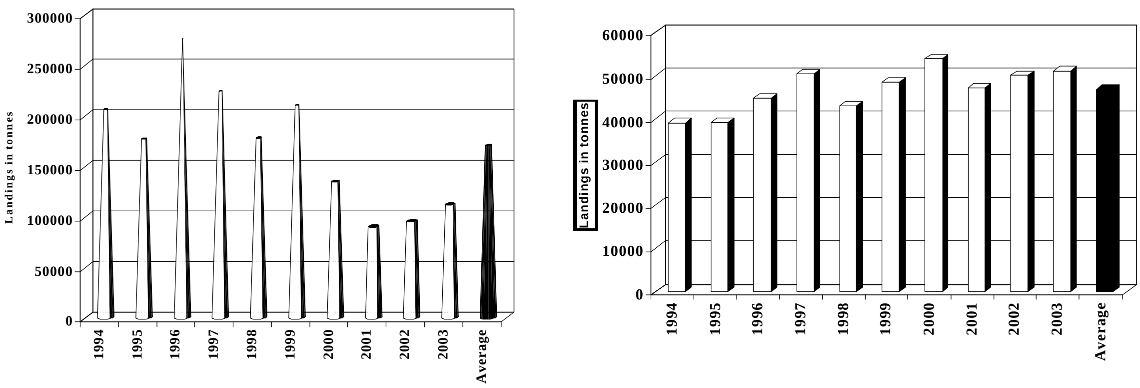


Fig. 9 Landings of Mackerel and tunas during 1994-2003

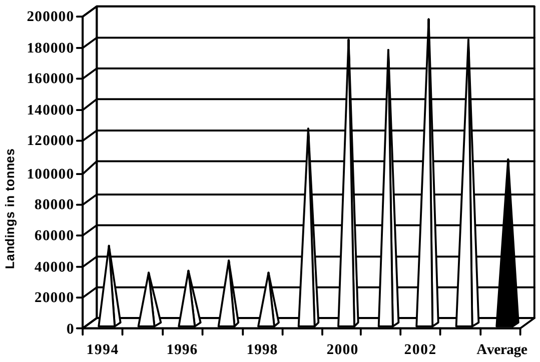
Tunas constitute one of the economically important marine fisheries resources and during, their production from Indian seas fluctuated between with an annual average production of forming 3.6% of the total pelagic fish production (Fig. 9). The tuna fishery in India is limited to the small-scale sector with negligible inputs from the industrial sector. The commonly occurring coastal tuna species in the small scale fisheries are *Euthynnus* *affinis* (little tuna), *Auxis thazard (*frigate tuna), *A.rochei* (bullet tuna), *Sarda orientalis* (striped bonito), *Thunnus tonggol* (long tail tuna) and oceanic species *Katsuwonus pelamis (*skipjack tuna),*T.albacares*(yellowfin tuna). *E. affinis* and *A. thazard* constituted the major species along both the coasts whereas *T.tonggol* and *T. albacares* along the northwest coast. . The drift gill net is operated all along the Indian coast, the purseseine southwest and the hooks and line off Vizhinjam. The pole and line and troll line are operated in Lakshadweep Island.

Tunas of the oceanic region largely remain under-exploited in the Indian EEZ.The Fishery Survey of India has been undertaking survey programmes to study spatial distgribution and abundance of these highly migratory species in the Indian EEZ by long line since 1983. Among the resources identified, the yellowfin tuna constituted the major species in all the regions.Big eye tuna was dominant in the equatorial region, while skipjack tuna was abundant in the northwestern region.

Seerfishes are one of the commercially important pelagic finfish resources of India of high commercial value.The seerfish catch of 50,376 t in 2000 which was just 1.85% of the marine fish production was valued at 4.03 billion rupees. Owing to their high unit value and economic returns, they support artisanal fisheries and is a major source of income for gill net and hooks and line fishermen of the country. Out of the four species viz., the king seer (*Scomberomorus commerson*), the spotted seer (*S.guttatus)*, streaked seer (*S.lineatus)* and the Wahoo *(Acanthocybium solandri*), the fishery is sustained by the first two species. The king seer was dominant along the coasts of Orissa, Andhra Pradesh, Tamil Nadu, Kerala and Karnataka. The spotted seer is more abundant than the king seer along the coast of West Bengal, Maharashtra and Gujarat coasts.

Carangids occupy 9^{th} position with a production of 1.11 lakh t, constituting 4.1% of the total marine fish production. The resources is comprised mainly of horse mackerel, round scads, queenfishes, trevallies, leatherjackets and pompanos and has emerged as one of the important pelagic fish resources especially in the mechanized sector. Carangids are extensively exploited by a multitude of gears like trawls, drift gill nets, bottom set gill nets, hooks and line, shore seine, ring seine purse seine etc.Many species support the the carangid fishery and the species composition in the catch depends on the selective properties of the gears employed. The non-selective trawls mostly exploited scads such as *Decapterus dayi, D.macrosoma, Selar crumenophthalmus,* horsemackerel *Megalaspis cordyla,* and trevally *Caranx para, C.carangus, Selaroides leptolepis.*

The ribbonfishes, also known as hair-tail or cutlass, form a major pelagic fishery resources of the Indian seas.The ribbonfishes landings has shown an increasing tren with considerable annual fluctuations.During the years from from 1956 to 2000, the landings fluctuated between 16,452 in 1963 to 1,82383 t in 2000 with an average landings of 63669t (Fig. 10).*Trichiurus lepturus* is the dominant species among ribbonfishes and supports a fishery all along the Indian coast. It forms more than 95% of the total ribbon fish landings. Other species noticed in the catches are *T.ruselli*, *Lepturocanthus saval, L.gangeticus, Euplurogrammus muticus and E.glassadon.* Ribbonfishes are exploited all along the coast and the bulk of the landings came from Gujarat and Maharashtra followed by Kerala, Tamil Nadu and Andhra Pradesh.



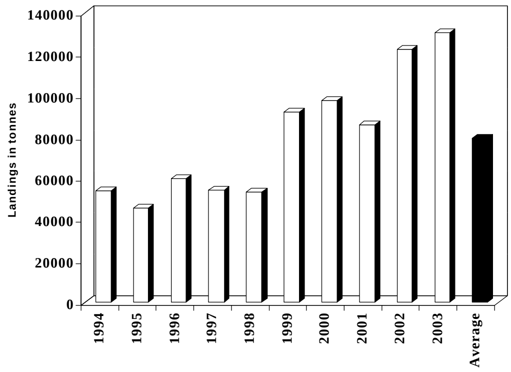


Fig.10 Landings of Ribbon fishes and Bombay duck during 1994-2003

As in the case of the oil sardine and the Indian mackerel, the Bombayduck along the northwest coast also exhibited wide annual fluctuations in production. The fishery is mostly supported by a single species, *Harpadon nehereus*, popularly known as Bombayduck . The landings of this species contribute about 5% of all India marine fish landings.The average annual catch of Bombayduck has been estimated at 1.1 lakh t by traditional and industrial sector (trawlers) along the northwest (88%) and northeast (12%) coasts of India. (Fig.10). The annual catchable potential yield is estimated as 1.16 lakh t (Anon.2000) .Fishing for Bombyduck is traditionally carried out by a stationary bag net called *dol* net worked entirely by the forces of tide along Maharashtra and Gujarat coasts.Though *Harpadon nehereus* was the sole contributor along the northwest coat, at Kakinada *H.squamosus* (195-214mm) accounted for 56% of the Bombayduck landings.

Impact of environment on pelagic fisheries:

Year after year, the success of pelagic fisheries is a delicate balance between physical oceanographic factors and effects of fishing on the stock. Numerous studies conducted confirm that seawater temperature, dissolved oxygen levels, salinity, phytoplankton and zooplankton concentrations play a vital role in controlling the distribution and abundance of pelagic fishery resources. Thus fishery environment data has become crucial to addressing productivity of fishing grounds, annual/ long term fluctuations in fish catches and making fishery forecasts. Today, parameters like Sea Surface Temperature (SST) and phytoplankton pigments (Chlorophyll *a*) using satellites are available from agencies like the Indian National Centre for Ocean Information Services (INCOIS) and are used in prediction of Potential Fishing Zones (PFZ). Dissemination of information of PFZ's among the fishermen in Kerala and Lakshadweep had been facilitated by CMFRI and feedback received indicated that considerable reduction in cost of fishing by saving time and fuel for locating fish shoals could be achieved. This technology requires further strengthening and validation. Creation of maps indicating the spatial and temporal distribution patterns of pelagic fishes and their prediction on a Geographical Information System (GIS) platform is another potentially powerful technology that could be developed.

Fish migration behaviour

Almost all marine fishes undertake some form of migration and pelagics are no exception. While the small pelagics like sardines and anchovies perform migrations along the coast, mackerels, scads and coastal tunas migrate fairly long distances between inshore and offshore waters. Oceanic tunas undertake even longer migrations and stocks are frequently shared by many countries. Therefore understanding the migratory patterns of pelagics, especially highly valued large pelagics like tunas is crucial for planning a successful fishery and its management. Tagging is the best way to study migration and sophisticated acoustic and telemetric have been developed to allow continuous observations of the movements of a single fish. Tagging studies for small pelagics like oil sardine and mackerel has already been conducted in Indian waters. A collaborative mega project with external funding support is envisaged to undertake a tagging programme for the highly migratory and straddling stocks of oceanic tunas also.

Enhancement of fish production

Fish aggregating devices (FADs) are used to artificially create special conditions where plenty of hiding sites and abundant forage are available for fishes and thereby attract them for feeding and even spawning. These have been found useful for aggregating oceanic tunas and a project for evaluating an FAD associated tuna fishery in Lakshadweep waters is being implemented. The project is expected to understand the aggregation dynamics of tunas and their feeding behaviour so that appropriate management measures can be formulated for the tuna fishery of the Lakshadweep islands.

Development of predictive models

Reliable estimation of stock size is required to formulate any fisheries management policies but pelagic fish stocks are notorious for their unpredictable catch fluctuations. Stock estimation using classical models have many limitations is being applied to pelagic fisheries as these fishes have highly variable recruitment pattern and environmental – biological interactions in these fisheries is extremely complex. Therefore appropriate new stock assessment models using time series data on phytoplankton, zooplankton, fish catches, hydrography and climate data that will bridge the interface between physics and biology will have to be developed. Already some attempts have been made to understand the dynamics of these fisheries through mathematical modelling of fishery dependant and independant factors. Predictions for oil sardine fishery along the Indian coast based on sunspot activity, rainfall intensity, sea level change and duration and upwelling indices have proved successful and could be attempted in other pelagic species also.

Resource conservation

Many of the world's greatest fisheries particularly for pelagics like sardines have collapsed owing to recruitment failure caused by high fishing pressure on the spawning stock emphasizing the need to study stock – recruitment relations. However, such studies are complicated due to the fact that there is significant influence of environment in determining recruitment success of pelagic species every year. Hence it is imperative that a precautionary approach whereby spawners are protected and allowed to replenish the population is in place. Vessel based stripping of ripe spawners of mackerel captured in the nets and releasing the eggs in the fishing grounds itself has been tried on an experimental scale. Such programmes in addition to existing restrictions on fishing for spawners and in spawning grounds will have to be strengthened. Increased capture of juveniles in ring seines has also to be avoided to prevent growth overfishing which causes huge economic loss. It is therefore vital to make periodic assessments of the pelagic stocks, the fishing practices adopted and the juvenile and spawner components of the catches. Based on this need based management measures can be formulated either as input controls (restriction of fleet size, mesh size, closed season) or output control (restriction on fishery for certain species, size of fish caught etc.) Awareness creation among all stakeholders against non-sustainable fishing practices with a participatory management approach has become inevitable in fisheries management.

Future prospects

Though a progressive trend is noticeable in production of most of the pelagics, many of them, especially the oil sardine, mackerel, Bombayduck,seerfishes, ribbonfishes and tunas have reached the optimum level of exploitation in the conventional fishing ground(Fig.15). The stock assessment studies conducted for 19 species of exploited pelagic finfishes have shown that the present effort expended is close to or in some cases even crossed the level of MSY and further increase in effort in the coastal sector would be detrimental to sustainable yield (James, 1992). The groups, which are expected to contribute significantly to the additional yield from beyond the conventional belt, where the rate of exploitation is limited at present, are whitebaits, carangids, ribbonfishes, oceanic tunas and pelagic sharks. The options available for the exploitation of their potential resources from the 50-200 m depth area are extension of the operational range of crafts, introduction of combination vessels (drift gillnetting and longlining) for multiday fishing, widespread employment of 'light luring purseseiners', conversion of trawlers for offshore drift gillnet and tuna longline fishery, providing chilling and cold storage facility on board the vessel and implementation of suitable post-harvest technology for utilizing the products for internal as well as export market Besides the above groups, the deeper areas of the oceans contain huge mesopelagic resources, such as file fishes, lantern fishes etc. which can be converted into fish meal. According to a recent observation the mesopelagic fish fauna in the Arabian Sea is dominated by myctophid fishes. Among them, one species *Benthosema pterotum* is arguably the largest single species population of fish in the world, with stock estimates ranging upto 100 million t per year. Similar populations, but of lesser magnitude, may be available in the Bay of Bengal also. Effective methods of their exploitation, handling, processing and utilization will have to be evolved. However, the fishing activities in the offshore and the high sea areas are at present restricted since such activities are capital-intensive and require offshore fishing vessels (longliners, purseseiners, midwater trawlers), infrastructures, shore facilities, expertise and skilled manpower. Development of the above for offshore fishing operations, coupled with value added product development, marketing and export would provide the necessary impetus for further development of pelagic fisheries in the country.

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3

DEMERSAL FISHERY RESOURCES OF INDIA – AN UPDATE

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Introduction

The continental shelf of Indian EEZ extending upto 200 m depth is a rich abode of a variety of demersal finfish resources contributing substantially to the total marine fish production in the country. The major demersal fin fish resources are the elasmobranchs, major perches, catfishes, threadfin breams, silverbellies, sciaenids, lizardfishes, pomfrets ,bulls eye, flatfishes, goatfish and white fish. A review of the literature shows that the demersal fisheries in India had been growing in a phased manner during the past 5 decades thanks to the development envisaged through different 5 year plans since the country`s attaining independence. On the flip side we have several issues adversely affecting the increase in production of the resources such as growth overfishing, recruitment overfishing,increased operation of units through multiday fishing, scraping the benthic biota etc.In this chapter, an attempt is made to examine the present status and future needs of the demersal fisheries sector of India.

Demersal fish production

Past and the present (Fig.1)

It may be seen that the demersal fish landings has increased from 164016t in 1961 to 174803t during 1964 but declining to 159912t during 1965 .The catch however, indicated an increasing trend thereafter reaching a peak of 879786t in 1998 but declining to 788472t in 2000. The contribution of demersal finfish resources in total marine landings was 27. 45% (Table 1).

Coastwise landings (Fig.2)

Of the Indian coastline of 8129 km length, west coast forms 41% with the east coast contributing to 32.85% and the rest by Andaman- Nicobar and Lakshadeep islands.The demersal fish production along the west coast during 1981-2000 indicated an increase from 291078t in 1981 to 644117t in 1998 but declining thereafter to 434890t during 1999 and 548884t during 2000 with an average of 429370t .Along the east coast, the demersal fish catch increased from 188735t in 1981 to 235669t in 1998 but declined to 239588t in 2000, the average being 227881t. The contribution by west coast and east coast was 65.33% and 34.67% respectively.

Statewise landings: State wise contribution of total demersal fish landings during 1981-2000(average) is presented in **Fig.3.**

Gujarat contributed to the maximum of 29.47% followed by Tamil Nadu (20.4%),Kerala(15.55%), Maharashtra(12.66%), Andhra Pradesh((6.6%) and Orissa(5.04%) of the average annual demersal fish landings of 657251t during 1981-2000.

Depth-wise landings

All the commercial boats operate within the depth range of 70-80 m and detailed depthwise catch data is not available from commercial landings. However, exploratory surveys cunducted along the Indian EEZ had generated information on the bathymetric distribution of major resources. Accordingly, threadfin breams are distributed in 100-200m depth while catfish are distributed in 50-100m depth. Major perches were found more abundant below 50m depth off Wadge Bank while at Gulf of Mannar, their depth of occurrence was 50-100m. Lizard fishes were distributed more in 100-200 m depth along the shelf waters of west coast. Black pomfrets were found more in 55-125m depth while silver pomfrets were abundant in 90-125m depth range. Sciaenids were found more in 50-100m depth along upper east coast and at 50-200m depth along lower east coast. The depth of occurrence of elasmobranchs was 100-200m off Gulf of Mannar while along north west coast, their distribution was more in shallow waters upto 100m depth.

Fishery of major demersal fishes

Elasmobranchs

In India the average landings of elasmobranchs during 1990-2003 amounted to 63010t contributed by sharks (39437t, 62.6%), skates (2323t, 3.68%) and rays (21250t, 33.73%). The annual landings increased from 50690t in 1990 to a peak of 75304t in 1994 but declining thereafter. Statewise, Tamil Nadu (27.5%) contributed to the maximum followed by Gujarat (19.5%) , Maharashtra(16.7%) and Andhra Pradesh(15%) (Fig.4A). Group wise, sharks were more abundant off Gujarat and Maharashtra while rays were more distributed off Tamil Nadu and Andhra Pradesh. Major species landed are *Scoliodon laticaudus*, *Carcharhinus sorrah*, *C.limbatus* and *Sphyrna zygaena* among sharks, *Aetobatus narinari, Himantura uarnak, H.bleekeri & Taeniura melanospilos* among *rays* and *Rhinobatus typus & Rhynchobatus djiddensis* among skates.

Management: Information on the species diversity and biology of elasmobranchs is scanty.Elasmobranchs are slow growing, viviparous, low fecund fishes with longer gestation period. To maintain regular fishery, management measures such as protection of females, observing their nursery ground as closed areas and protecting vulnerable species are required. Above all, a good data base on the specieswise landings and trade are to be generated.

Catfishes

With an average annual landing of 46012 t during 1990 – 2003, the catfish resources contributed to 6.87% of the demersal fish landings. West coast especially Gujarat & Maharashtra contributed to 70 % followed by east coast (Tamil Nadu & Andhra Pradesh) (30%). The resource was mainly exploited by gill net, hooks&line, purse seine, boat seine and other artisanal gears. The production indicated an increasing trend from 38230 t during 1990 to 58352t during 2000. Until 1980, south west coast was the dominant catfish producing region along the west coast but from 1981-85 onwards, northwest coast produced 72.5% (Fig.4B) of the catfish production from the west coast. This may be due to the purse seine operation along the Karnataka/Kerala region capturing mouth breeding male catfishes especially of the species such as *Tachysurus thalassinus, T.tenuispinis, T.dussumieri* and *T.serratus*.

Management: Stock assessment studies recommend strengthening of hooks&line and gill net fishing, willful avoidance of shoals and trawling in the grounds beyond 50m. depth.

Major perches

The average annual production during 1990-2003 by major perches amounted to28776.8t contributed by rock cods (14827t; 51.52 %), snappers (4284t; 14.88 %) and pig face breams (9665t; 33.59%). The contribution of the group to total marine landings was 4.28%. These fishes inhabit the rocky grounds of Tamil Nadu, Gulf of Kutch, Gulf of Mannar, off Paradeep and Andaman seas. The potential yield of the group is estimated as 1,14,000t within 50m depth and 1,25,000t beyond 50m depth. They are caught in traps , hooks & line and dol net. The major species of groupers caught are *Epinephelus chlorostigma, E.diacanthus,E. areolatus, E. tauvina, E.morrhua* & *Pristipomoides typus*.Among snappers ,*Lutjanus gibbosus, L.rivulatus & L.lutjanus* are the major species landed. *Lethrinus nebulosus* , *L.ramak* and *L.elongatus* are the major species landed among pig face breams. Studies on the size frequency distribution indicates that the mean size of *E.malabaricus* along south west coast is reduced over the years indicating fishing pressure on the species. Information on the biology of the species is scanty. However, it has been reported that the spawning season of *P.typus* off Kerala is February –June while in *E.areolatus* and *E.chlorostigma*, it is during June-July months.

Management: There is considerable scope for increase in production of major perches. Efforts have to be made to effectively exploit the stock by developing suitable fishing gears.

Threadfin breams

Popularly known as “Pink perch”, the nemipterids contributed to 12.97% (86940t) of demersal fish landings in the country during 1990-2003. Statewise, the major contributors are Maharashtra (25.72%), Kerala (21.78%), Karnataka (21%) and Gujarat (21%) (Fig.4C).Fishery of threadfin breams are known to be influenced by upwelling and are known to move to inshore waters during monsoon along the west coast of India. Major species are *Nemipterus japonicus, N.mesoprion N.delagoae* and *N.luteus*. They are fractional spawners with protracted spawning season.

Management: Since threadfin breams inhabit deeper waters of 100- 200m depth, trawling in this depth has to be increased. The potential yield is 1,28,000t while the present yield is 1,16,680t (as on 2000) which is within the permissible level.

Silverbellies

The silverbellies (Family: Leiognathidae) with an average landings of 57823 t contributed to 8.6% of the total demersal fish landings in India.Statewise, Tamil Nadu contributed to maximum of 57.31% (Fig.4D). of the landings. They are principally shallow water fishes distributed in the 0-40m depth range. The silverbellies are exploited mainly by trawl and a variety of artisanal gears like shore seine, boat seine, gill net etc. Of the 21 species of silverbellies distributed along the Indian coast, *Leiognathus dussumieri, L.jonesi, L.splendens L.brevirostris* and *L.equulus, Secutor insidiator and Gazza minuta* are mainly represented in the landings.

Biology of *L. bindus* showed that they spawn almost throughout the year with peak during December-January months. Along Andhra Pradesh, *L.dussumieri* is reported to spawn during April-May while along the Gulf of Mannar, *L.brevirostris* is found to be a continuous spawner and along the Palk Bay and Gulf of Mannar, silverbellies are fractional spawners spawning throughout the year with one or two peaks of longer duration each year. The length at maturity ranges from 62 to 100mm with values of majority of species falling in the range of 80-95mm. They prefer zooplankton as food.

Management: Stock Assessment studies indicate that the management measures should be of a continuous nature taking into account changes in species composition, changes in the average length, life span, length at maturity and growth. Similarly, small scale industries such as making palmyra basket etc have to be developed for meeting the requirements of sun drying and salt cured silverbellies and transporting them to interior markets. Further, studies are also to be continued on the species diversity, revision of the potential yield etc which at present is lower (39,000t) than the landings (57,823t) (Table-2).

Pomfrets

Pomfrets are export quality food fishes distributed along the Indian coast. This resource represented by 3 species namely *Pampus argenteus* (Silver pomfret), *P.chinensis*(Chinese pomfrets) and *Formio niger*(Black pomfrets) are caught mainly in trawl, gill net and dol net. Pomfret fishery in India brought an average landings of 40312t (6% in demersal landings) contributed by *P.argenteus*(63.86%),*F.niger* (34%) and *P.chinensis*(2.16%). Satewise, Gujarat contributed to the maximum(20.5%) followed by Maharashtra(18.4%) and west Bengal(17.23%)(Fig .4E). *P. argenteus* feeds on zooplankton such as copepods, jellyfishes and decapods. Stock assessment studies indicated that *P.argenteus* is subject to growth overfishing while in *F.niger*, there is need to reduce the fishing effort.

Croakers

Sciaenids , popularly known as Jew fishes are one of the major demersal fishery resources of India. The annual average landing during 1990-2003 was 156280 t contributing to 23.33% of demersal fish landings of the country. North west coast represented by Gujarat and Maharastra brought the major share of more than 50% of the total catch of this resource. Gujarat (30%) and Maharashtra (23.8%) contributed to the bulk of the landings (Fig.4F). Sciaenids are caught in trawl, dol net, gill net, shore seine and hooks & line. About 20 species represented by *Otolithus cuvieri, O.ruber, Johnius Spp., Johneiops Spp, Atrobucca nibe , Protonibea diacanthus , Otolithoides biauritus* , & *Kathala axillaris* are the major species contributing to the fishery.

Capture of juveniles. The capture of juveniles of sciaenids was more during monsoon and post monsoon months off Veraval, Mumbai and Kakinada. The air bladder of larger species such as *P.diacanthus and O.biauritus* are dried and are exported to far eastern countries for being used in the manufacture of isinglass, while smaller species are sold in fresh condition or are iced and transported to distant places. The sciaenids caught during multiday fishing are also salted and sundried. The juveniles caught are sundried for preparation of fishmeal.

Management: With a view to check capture of juveniles, it is necessary to check capture of immature fish by regulating the size of cod end mesh to 25-30mm. And also the shallow protected coastal areas have to be declared as closed areas .

Lizardfishes

Lizardfishes belonging the family Synodontidae forms an important bycatch in shrimp trawlers in tropical and sub tropical seas. The all India lizardfish landings during 1990-2003 amounted to 26593t contributing to 3.97% of the demersal fish landings . Statewise, Kerala contributed to the maximum (37%) followed by Gujarat(21%) and Tamil Nadu(13%)(Fig.4g). *Saurida tumbil,* S. *undosquamis, S.micropectoralis* and *Trachinocephalus myops* are the major species represented in the landings. Lizardfishes are carnivores, feeding on fishes and crustaceans and are also cannibalistic

Juvenile capture using small meshed cod end of trawlers is a major threat to the sustenance of lizardfish fishery. Off Chennai, the juveniles caught ranged between 32% and 55% of the exploited population of the resource. As in other groups, implementation of regulatory measures such as closed season and mesh size regulation are the immediate management measures to be initiated to maintain the MSY.

Flat fishes

Fishes belonging to the families Cynoglossidae (Tongue soles), Psettodidae (Indian Halibut) Bothidae (flounders) and Soleidae (Soles) are popularly known as flat fishes. They are bottom dwelling fishes occupying muddy or sandy bottom of shelf areas. The average annual landings of flat fishes amount to 44764 t (6.68%). They are contributed the maximum from south west coast particularly Kerala (46.33%)(Fig.4H). Among all the species of flat fishes, *Cynoglossus macrostomus* is the most dominant species along the south west coast. Other major species are *C.bileneatus, C.macrolepidotus, Psettodus erumei* and *Zebrias quagga*.Juveniles form sizeable quantities of the landings of *C.macrostomus* contributing to 33 to 49% of the landings during 1997-2001. Stock assessment studies indicate that there is no evidence of overexploitation of flat fishes along the Indian coast. However, it is essential to adopt regulatory measures for sustaining the stock.

Goat fishes

The goat fishes (Family: Mullidae) are small sized fishes distinguishable by their bright colouration and a pair of barbels on the chin. With an average annual landings of 15432t- during 1990-2003, they contributed to 2.3 % of demersal fish landings of the country. Regionally, goat fishes are landed the maximum from Andhra Pradesh(40%) followed by Tamil Nadu(37.21%)(Fig.4I). A total of 16 species are reported to occur along the Indian coast of which the major species contributing to the fishery *are Upeneus vittatus, U.bensasi,U.sulphureus, U.tragula, U.taeniopterus & Parupeneus indicus.* Juveniles contributed to sizeable quantities of the landings of goat fishes. However, since there is no targeted fishery, it may not be possible to implement management measures .

White fishes

The white fish (Family: Lactaridae) represented by a single species *Lactarius lactarius* is a good quality fish of consumer preference. The annual average landings amounted to 6346t (0.94%) during 1990-2003 with major contribution from northwest coast (43%) followed by south west coast (32%) and South east coast (24%). Stock assessment studies indicated that the current exploitation rate (0.68) is above the optimum level (0.50). Irrational bottom trawling is known to affect the benthic stock and subsequently the white fish stock particularly along the south east coast. Since there is no targeted fishery for white fish, separate management measures are not possible.

Non conventional fishery resources

Exploratory surveys conducted along the Indian EEZ had shown that there is rich abundance of non conventional fishery resources such as Bulls eye (*Priacanthus Spp*), Indian drift fish (*Ariomma indica*), and Black ruff (*Centrolophus niger*) in waters of 50-300/500m depth especially off south west coast of India where an estimated potential of 2,75,00t of these fishes is reported (Sudarsan, 1993).

Harvestable Potential: (Table 1)

The estimated potential yield and current yield of major demersal fishes along the Indian EEZ are presented in Table-1. It may be seen that most of the resources except the perches have been exploited to the optimum level from waters upto 50 m depth. Beyond 50 m depth, the major potential groups are elasmobranchs(1.03 lakh t) catfishes(0.63 lakh t), sciaenids(22000t) and pomfrets(12,000t).

The future

It may be seen from the foregoing account that most of the resources are almost fully exploited or have exceeded the potential level. This situation is created because of the continuous scraping of the bottom destroying the ground fishes, their favourite benthic food items and the exploitation of juveniles resulting in growth overfishing and capture of brooders leading to recruitment overfishing. Therefore, it is hightime that management measures such as enforcing mesh size regulation and gear regulation, observing closed season, identifying and declaring closed areas, and minimizing bycatch/discards from the inshore waters are implemented. Besides, steps are also to be taken for diversification of fishing effort to exploit ground fish inhabiting the rocky areas along the continental shelf edge and to extend fishing to deeper waters to tap the nonconventional fishery resources. It is also necessary to check fishing pressure by undertaking voyage fishing and the use electronic devices for fish finding and fishing. And there is need for policy intervention between state governments and at national level to enforce the regulations to uplift the socio-economic condition of fishermen simultaneous with attempt to develop alternate means of enhancing fish production through mariculture.

Suggested Readings:

Mohan Joseph Modayil & A.A. Jayaprakash (Eds)2003. Status of Exploited Marine fishery Resources of India. Central Marine Fisheries research Institute, Kochi-682014, India: P.308.

Sudarsan, D.1993. Marine fishery resources in the Exclusive Economic Zone of India In: *Proc. Low Energy Fishing*. P.4-11.

Fig.1. Demersal fish landings in India during 1961 - 2000.

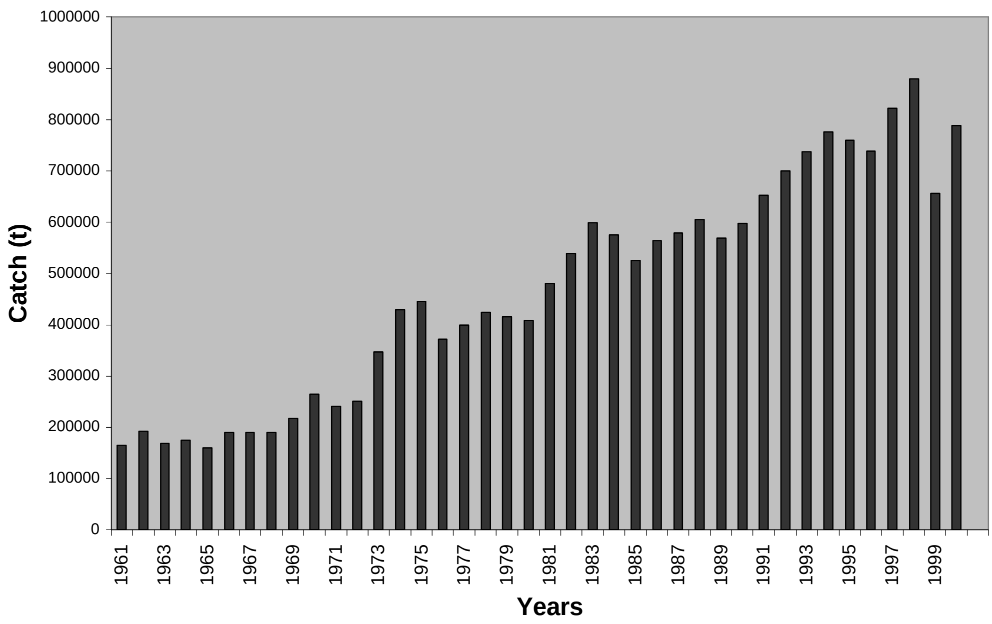


Fig. 2 All India Demersal fish landings West coast and East coast during 1981 - 2000.

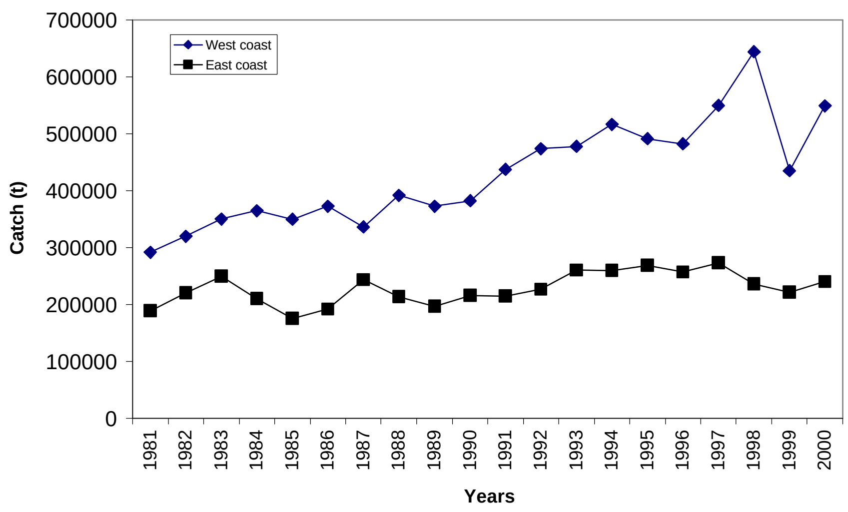
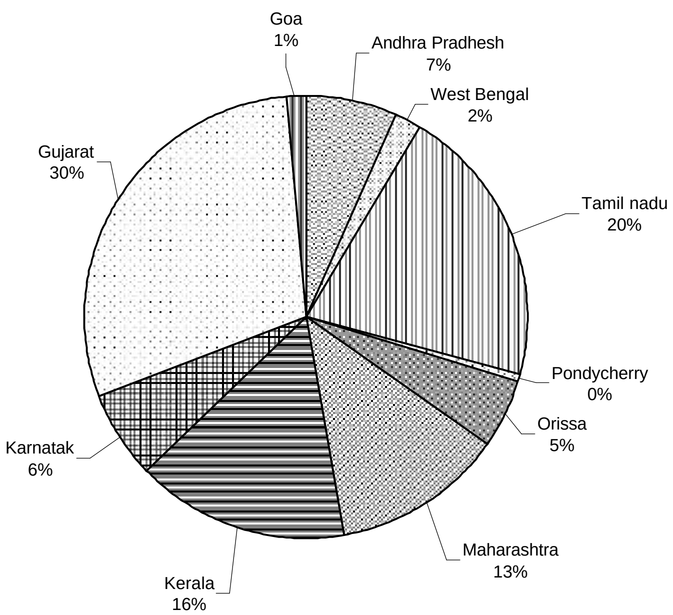


Table-2. Current yield and potential yield of major demersal finfishes of India

Groups/Year	Current Yield(1000t)		Pot. Yield	(1000t)	Total P.Y.
	2002	2003	Upto 50m	Above 50m	(1000t)
Elasmobranchs	59.8	58.3	65	103	168
Catfishes	58	56	60	63	123
Lizardfishes	27	29	27	21	48
Perches	153	137	114	125	239
Goatfishes	12	12	20	0	20
Croakers	125	125	120	22	142
Silverbellies	62	52	82	4	86*
Pomfrets	41	40	42	12	54
Soles	40	46	38	0	38

* Including Andaman & Nicobar Islands.

Fig. 3. Statewise Demersal Fish Landings during 1981 - 2000 (average %)



4

CRUSTACEAN FISHERY RESOURCES OF INDIA

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Introduction

Crustaceans comprising numerous edible species of prawns, lobsters and crabs inhabiting different ecosystems form significant portion of the aquatic food resources of the world. The average annual production of edible marine crustaceans of India during 1995-2001 was 0.36 million tonnes. Due to ever increasing demand for edible marine crustaceans from foreign markets, there has been heavy exploitation of these resources in an unprecedented scale from the Indian seas. Enhancement of fishing effort in deeper grounds, modernization of craft and gears and intensive fishing has resulted in enormous fishing pressure on these resources.

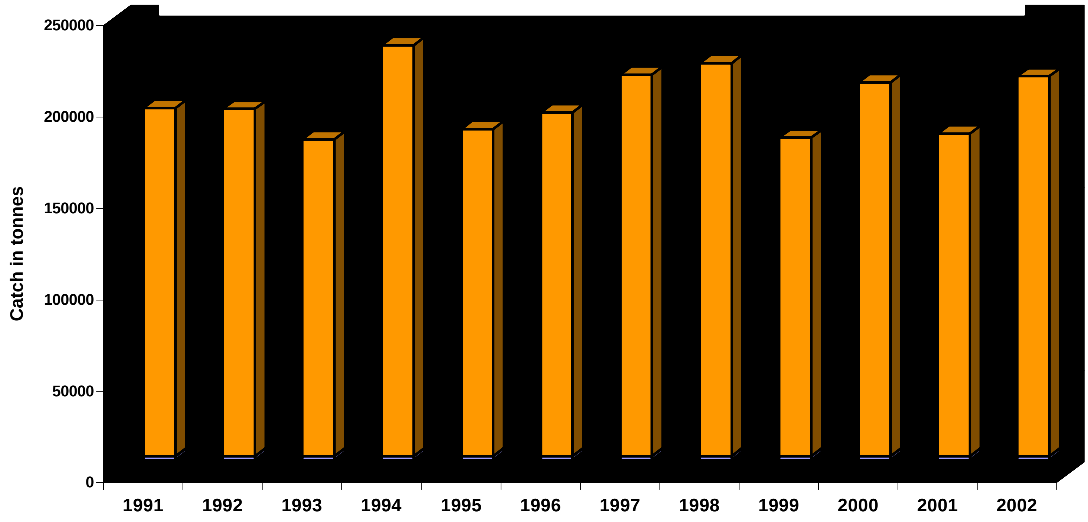
Craft and gear

Mostly medium sized mechanized vessels (38-48') operate trawl net to exploit the marine crustaceans from inshore to deep sea grounds. During this decade trawlers contributed to about 80% of penaeid shrimp landing in the country. Mesh size of cod end of the trawl net measured between 18 and 20 mm in most of maritime states. In Gujarat the mesh size of cod end of trawl net was reduced to 12-15 mm in order to catch non-penaeids. From mid eighties most of the units operating along Indian coast switched over to multiday fishing operation in order to exploit midshelf grounds combining both day and night fishing which also saves the fuel cost. At present, the fishery operation by most of the units usually is carried out within 100 m. However, from late nineties some of the commercial boats having higher engine power with modification of winches and addition of wire ropes (upto 1800 m) started operating in deep sea grounds in the depth range of 175-400 m along the Kerala and South Kanara coast, to fish deep sea shrimps and lobsters. The traditional 'Dol nets' are operated along the northwest coast to fish non-penaeid shrimps and smaller varieties of penaeid shrimps. Mini-trawls and 'thalluvalai" (the smaller versions of shrimp trawl) are regularly operated by indigenous wooden crafts in the nearshore waters to catch juveniles of shrimps along the Kerala and Tamilnadu of coast, respectively. Trammel net along the Vizhinjam-Manakudy coast, bottom-set gill net and disco net along the southeast coast exploit shrimps, lobsters and crabs regularly. Stake nets are operated in the backwaters of both the coasts to fish juvenile shrimps. In addition to these gears, postlarvae and juveniles of shrimps are handpicked or collected by using mosquito nets from creeks in order to supply to the shrimp farms.

Penaeid shrimps

Commercially important shrimps from inshore grounds are largely constituted by two groups namely penaeids mainly belonging to the family Penaeidae and non-penaeid shrimps belonging to Palaemonidae, Hippolytidae and Sergestidae. During 1991-2002 penaeid shrimps contributed to 56% of total edible crustacean landings along both the coasts. The all-India annual penaeid shrimp production during the above period ranged from 1,73,204 tonnes (1993) to 2,24,621 tonnes (1994) with an average annual yield of 1,94,177 tonnes. Nearly 75% of the penaeid catch was harvested along the west coast. Kerala and Maharashtra were the major contributors to the penaeid shrimp fishery with an average annual landings of 51832 tonnes (27%) and 50975 tonnes (26%), respectively. Gujarat, Tamilnadu and Andhrapradesh are the other important maritime states contributing to the penaeid shrimp landings.

Annual penaeid shrimp landing (1991-2002)



Species composition

The major constituents of the shrimp fishery along the west coast during 1991-2002 were *Parapenaeopsis stylifera* (Kiddi prawn), *Metapenaeus dobsoni* (Flower tail prawn), *M. monoceros* (Speckled prawn), *Solenocera crassicornis* (Coastal mud prawn) and *Penaeus indicus* (Indian white prawn) However, with the extension of trawling operations in the midshelf waters and night fishing, species such as *Trachypenaeus curvirostris, S. choprai*, *P. canaliculatus* and *P. japonicus* were added to the shrimp resources. *S. crassicornis* emerged as the prime contributor to the fishery along the northwest coast and *S. choprai* as one of the main constituents in the shrimp fishery along the south Karnataka coast during 1999-2001. However, along the Kerala coast, *P. stylifera* and *M. dobsoni* remained the major contributors to the shrimp fishery. *P. semisulcatus, Metapenaeopsis stridulans* and *T. granulosus* were the major species along the southeast coast. *M. dobsoni* and *P. indicus* formed a good fishery along the Chennai coast. Along the Andhra coast, *M. monoceros, M. dobsoni, M. brevicornis* and *Solenocera* spp. were the main contributors. The shrimp catch of the commercial trawlers from the deep sea grounds of the southwest coast consisted of penaeid species namely, *Metapenaeopsis andamanensis, Aristeus alcocki, Penaeopsis jerryi* and *Solenocera hextii* and the pandalid shrimps such as *Heterocarpus woodmasoni, H. gibbosus* and *Plesionika spinipes*.

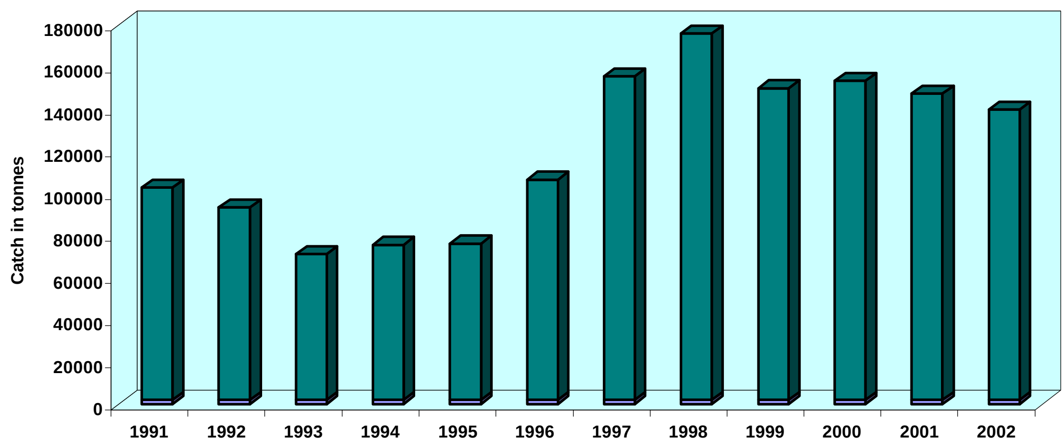
Biological characteristics

Among the marine penaeid shrimps, *Penaeus* species are larger in size. Penaeids are heterosexual and females are generally larger than males. Growth rate varies in different species and at different phases of life depending on the environmental conditions. Penaeids feed mainly on animal food items and decomposing organic matter. They have high fecundity and the number of eggs vary between species mainly in proportion to size of the females and the ovary weight. Eventhough the spawners are available throughout the year, there are certain peak spawning periods which vary sometimes between years. Life span of penaeid shrimp is around two years and 0-year group contributes mainly to the fishery.

Non-penaeid shrimps

Non-penaeid prawns constitute one of the important fishery resources contributing to 5.8% of total marine fish production. This resource is characteristic of the northwest coast, which accounts for almost 90% of the total non-penaeid prawn production in the country. The annual average landing of non-penaeid prawns was 1.14 lakh tonnes during 1991-2000. Among the maritime states, Gujarat contributed maximum (57.5%) followed by Maharashtra (33.1%). The catches in the other states were sporadic and in negligible quantities. However, with the advent of trawlers in fishing non-penaeid prawns, the annual average catch in Gujarat increased from an average of 6,537 t during 1979-88 to 84,156 t in 1996-2000. Reduction of the cod-end mesh size of trawl nets and fishing operations in the coastal sea coupled with the development of fish meal industry at Veraval were responsible for the enormous landings of this resource in Gujarat.

Annual non-penaeid shrimp landings during 1991-2002



Species composition

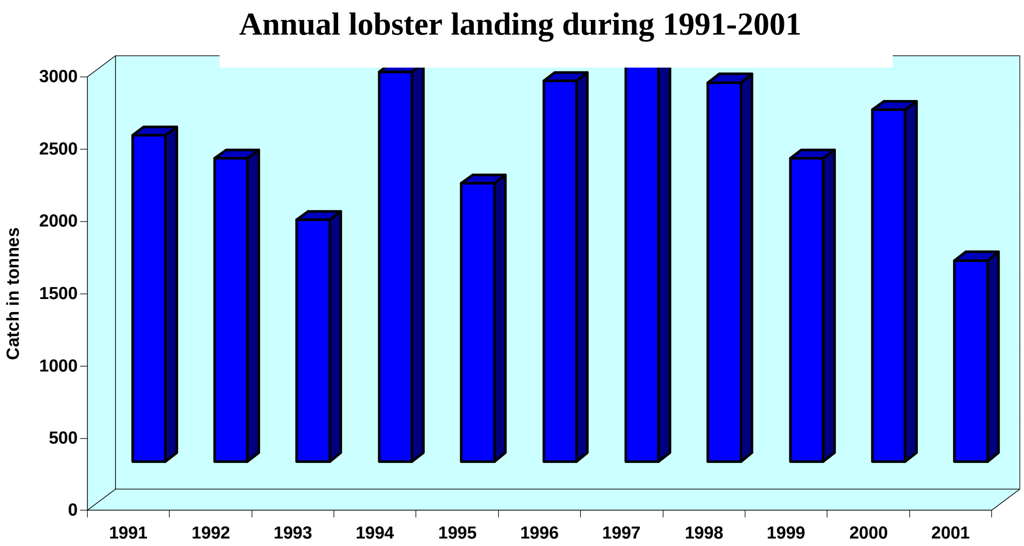
The non-penaeid prawn resource is multi-species, mainly supported by tiny species of the genus *Acetes*, in addition to *Nematopalaemon tenuipes* and *Exhippolysmata ensirostris*. There are five species of *Acetes* namely *Acetes indicus, A. johni, A. sibogae, A. erythraeus* and *A. japonicus*. Among these the first two support the commercially important fisheries from marine waters. During 1991-2000, the percentage contribution of *Acetes* spp. *N.tenuipes and E. ensirostris* were 81.2%, 18.2% and 0.6% in *dol* nets and 0.3%, 97.3% and 2.4%, respectively in trawlers in Maharashtra. In Gujarat, these species formed 68.9%, 21.9% and 9.2% in *dol* nets and 98.9% , 0.8% and 0.2% in trawlers, respectively.

Biological characteristics

Acetes indicus is an epipelagic planktonic prawn, which forms large shoals in coastal waters. Generally, the size ranges from 8-38 mm. Their fishable life span is about 3-6 months. The species mainly feeds on detritus consisting of fibrous and granular material of phyto and zooplankton origin. *Nematopalaemon tenuipes* exhibits differential growth rates with males and females reaching 57 mm and 64 mm in total length, respectively at the completion of one year. The life span of the species is a little more than a year. Being a caridean prawn, they carry yolky eggs attached to their pleopods for incubation. *E. ensirostris*, the largest among the coastal non-penaeids, is a hermaphrodite. It is highly predaceous and feeds on *Acetes*, polychaetes and young ones of fish and shrimps. It attains 92.8 mm at the end of one year and the fishable life span is about one year. *E. ensirostris* breeds throughout the year with peaks during May-September and December-January.

Lobsters

The annual catch of lobsters fluctuated from 1389t to 2787t during 1991-2001 Though lobsters are widely distributed in the coastal waters of India, major landings are reported from the northwest coast. The average annual landing during 1991-2001 were 1556 tonnes, 402 tonnes and 264 tonnes from the northwest, southeast and southwest coasts, respectively. Statewise, Gujarat contributed maximum (1018 tonnes) followed by Maharashtra (538 tonnes), Tamil Nadu (389 tonnes) and Kerala (249 tonnes). In Gujarat the catch declined from a maximum of 1305 tonnes during 1997 to 241 tonnes during 2002, in Maharashtra from 1132 tonnes during 1996 to 402 tonnes during 2002 and in Tamil Nadu from 998 tonnes during 1998 to 195 tonnes during 2002. However, Kerala showed an improvement in recent years due to landing of deep sea lobster *Puerulus sewelli*. The annual landings of *P. sewelli* in the state were 513 tonnes and 535 tonnes during 1999 and 2000, respectively. However, the catch decreased to 264 tonnes and 395 tonnes during 2001 and 2002, respectively. About 95% of the lobster landing along the northwest coast is by trawlers. However, lobsters are exploited by both trawlers and indigenous gears such as bottom set gill net and traps along the southeast coast.



Species composition

Four littoral and one deep sea species of lobster contribute to the commercially important fishery in the country. The slipper lobster *Thenus orientalis* and spiny lobster *Panulirus polyphagus* constitute the fishery along the Gujarat coast whereas the latter species dominates the fishery along the Maharashtra coast. The fishery for *T. orientalis* from Mumbai waters declined from an average annual landing of 185 tonnes during 1978-85 to 3.6 tonnes during 1993-94 and nearly disappeared by 1994-95. The scalloped spiny lobster *P. homarus* is the dominant species in the shallow waters along the southwest coast. The ornate spiny lobster *P. ornatus* forms a fishery along the southeast coast. *P. homarus* and *T. orientalis* are also landed along the southeast coast. While *P. homarus* occupies 1-10 m depth, adult *P. ornatus* are seen at 40-50 m depth.

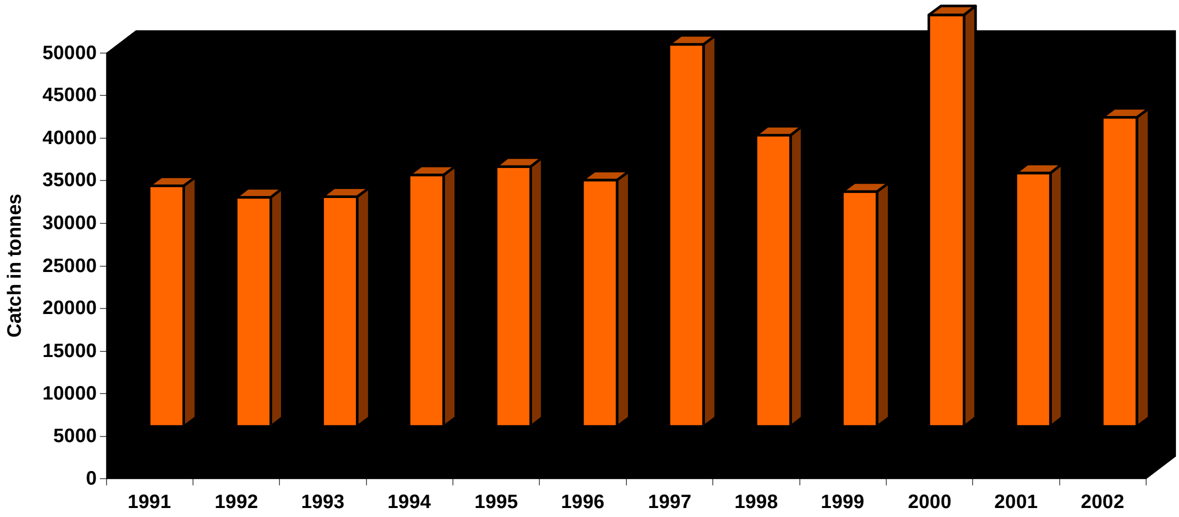
Biological characteristics

Studies on food and feeding habits of lobsters show that these animals generally feed on smaller crustaceans, molluscs and polychaetes. Growth, as in other crustaceans, is manifested by periodical shedding (moulting) of exoskeleton. The size of lobsters in the fishery generally ranges from 35 mm to 125 mm carapace length. *P. homarus* attains a total length of 320 mm, *P. polyphagus* 450 mm and *P. ornatus*, 500 mm. Fecundity in spiny lobsters ranges from 50,000 to 10,00,000 eggs depending upon the species and size of the lobster. *T. orientalis* is however, low fecund with shorter larval phase (45-50 days).

Crabs

Marine crab is a valuable seafood which is in good demand in the domestic market as well as export industry of the country. The commercially important species such as *Portunus sanguinolentus* (Spotted crab), *P. pelagicus* (Reticulate crab) and *Charybdis feriatus* (Cross crab) belong to the family Portunidae. The average annual catch in the country during 1975-2001 was about 26,000 tonnes. Exceptionally high landings were recorded during 1997 (45,000 tonnes), 1998 (34,000 tonnes) and 2000 (48,380 tonnes). On an average crabs formed 8% of the total crustacean landing in the country. The catches ranged from 2,383 tonnes to 20,923 tonnes in Gujarat, 8,851 tonnes t to 14,242 tonnes in Tamil Nadu, 2,256 tonnes to 5,144 tonnes in Andhra Pradesh and 2,030 tonnes to 10,438 tonnes in Kerala. Only small quantities of crabs are landed along the southwest coast during July-October.

Annaul crab landing during 1991-2002



Species composition

A centre-wise study of the marine crab fishery shows that *C. feriatus* predominates the edible crab fishery at Veraval and Mumbai. The dominant species at Mangalore, Calicut and Cochin is *P. sanguinolentus*. The dominant species of marine crabs at Tuticorin and Mandapam are *P. pelagicus* and at Chennai and Kakinada, *P.*

sanguinolentus. Large quantities of non-edible crabs are landed at Kakinada with *C. callianassa* as the dominant species.

Biological characteristics

Studies on the food and feeding habits of crabs show that they generally feed on smaller crustacea,s fishes and molluscs. Detritus, bits of plant and other organic materials are also noticed in the stomach contents. The mean monthly growth rate ranges from about 8 mm to 11 mm. Sizes upto 160-165 mm (carapace width) are available in the fishery. The 50 % level of maturity is generally at 90-105 mm carapace width in *P. sanguinolentus* and *P. pelagicus*. These crabs breed throughout the year with peak seasons and spawning may take place twice or more in a season. Peak breeding and recruitment seasons vary from region to region. The number of eggs on ovigerous females ranges from about 50,000 to over a million. Eggs are attached to the endopodite setae of the swimmerets of the abdomen. The eggs that hatch out pass through a number of zoeal stages.

Resource Management

Detailed study on the population dynamics and stock assessment of commercially important shrimps showed that the average annual yield of most of the commercial species has reached the MSY level. It was observed that increase in fishing effort may not result in much improvement in penaeid shrimps yield, and further it is not economically viable. Reduction in the number of fishing vessels being operated and increase in the cod end mesh size at least to 25 mm are the possible management measures which can be effectively implemented to safeguard the resource from over-exploitation as well as to get a sustainable yield of this valuable resource. Marine fishing regulations have earmarked areas of operation for different gears and vessels to safeguard the interest of different sectors. Trawling within 10 m area by commercial vessels and mini-trawls should be stopped in order to prevent exploitation of juvenile prawns.

The studies showed that MSY of non-penaeid prawns is 64,686 tonnes in Maharashtra and 76,550 tonnes in Gujarat together forming MSY of 1.41 lakh tonnes for the entire north west coat of India. In order to achieve this MSY, which is only 20% higher than the present annual average catch, the effort required would be more than double (1.3 times of the present level). Being single most important group of forage organisms along the northwest coast, the non-penaeid prawns support huge biomass of economically important fishes such as Bombay-duck, sciaenids, polynemids, ribbonfishes, carangids, penaeid shrimp and the cephalopods in the region.

Unlike the single species fishery of the sub-tropical and temperate countries, the lobster resources in India is multispecies and exploited by divergent gears involving both traditional and mechanised sectors. On the northwest coast nearly 90% of the lobster catch is landed by mechanised trawlers in which lobsters are incidentally caught and therefore optimizing the trawling effort for spiny lobster alone cannot be implemented. Therefore, the only management option is to persuade the fishermen to return the egg bearing lobsters and undersized lobsters back to the sea so that the spawning stock could be conserved. In February 2003 the Ministry of Commerce, New Delhi issued a Gazette Notification fixing Minimum Legal Size (MLS) for export of four species of lobsters based on the recommendation of CMFRI. However, there is no regulation on fishing and marketing of lobsters in domestic market as there is no ban on fishing. The MLS for fishing undersized lobsters is to be fixed by the respective State Governments.

MOLLUSCAN RESOURCES OF INDIA

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India is endowed with rich and diverse bio-resources and the molluscs are not an exception. Molluscs are a heterogenous group of animals both in shape and diversity and are represented by amphineura, gastropods, bivalves, cephalopods and scaphopods. Most of the molluscs inhabit the marine environment and very few dwells in the terrestrial and freshwater habitats. About 8,000-10,000 species of molluscs were recorded from the world over and a total of 3,271 species are reported from India (Subba Rao, 1991). They are represented in 220 families and 591 genera and the spectrum comprises 190 gastropods, 1,100 bivalves, 210 cephalopods, 41 polyplacophores and 20 scaphopods.

Molluscs were exploited for edible, industrial and ornamental purposes and the history of exploitation way back to the time immemorial. 28 species of bivalves, 65 species of gastropods (both the edible and ornamental) and 14 species of cephalopods are exploited at present in India. Various groups and the exploitation status are given in detail below.

CEPHALOPODS

Altogether eighty species of cephalopods are known and only a dozen species contribute to the fishery. Cephalopods comprise the squids, cuttle fishes and octopus and are exclusively marine. They have emerged as valuable resources in recent times due to their high demand in the export market.

Cephalopods make up only a small proportion (nearly 3%) of the world capture fisheries landings, but there have been substantial increases during the last three decades. According to the FAO, the total world landing of cephalopods was 1.6 million tonnes in 1982 and 3.4 million tonnes in the year 2001. The world production of the cephalopods is presented in Figure 1.

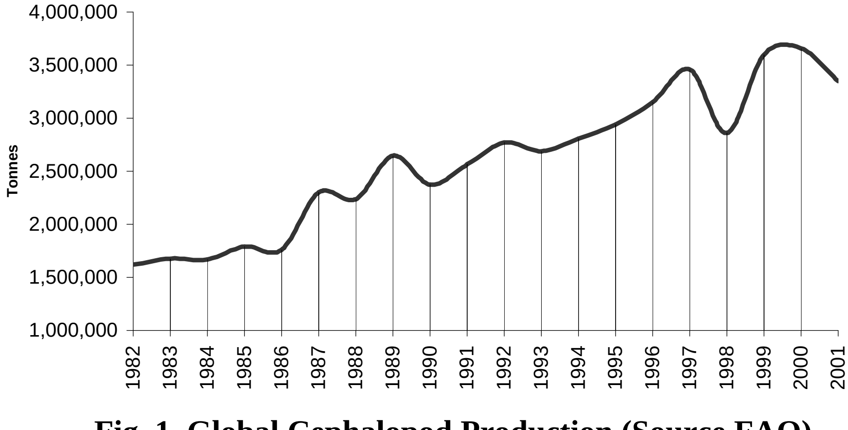

Fig. 1. Global Cephalopod Production (Source FAO)

The production of cephalopods increased from a mere 94 t in 1961 to 1, 11,534 t in 2000 along the Indian coast. However, the increase in production was not consistent and showed the following four phases during the four decades; (i) sharp increase from 94 t in 1961 to 10,786 t in 1976; (ii) marginal increase from 10,786 t in 1976 to 20,407 t in 1984; (iii) again sharp increase from 20,407 t in 1984 to 1, 16,753 t in 1995; and (iv) stagnation at around 1,10,000 t during 1996-2000. By, 2003, the total cephalopod landing is increased up to 1, 27,000t. Concurrent with this growth in production, the contribution by the cephalopods to all India marine fish production rose from 0.1% in 1972 to 4% in 1992.
Cephalopds are landed in all the maritime states in India and the production increased during 1961-1995. Kerala ranked first accounting for 37.70% of the total cephalopod landings followed by Maharashtra (28.98%), Tamilnadu (13.8%) and Gujarat (13.65%) during 1992. Region-wise analysis shows that there is an increase in the production from 83 t to 1,00,246 t along the west coast (1995) where as the increase was from 11t to 16,507 along the east coast. A break up in the production trends of different regions is presented in Table 1.

Table 1. Region-wise contribution (%) of cephalopods along Indian coast

Period	NE	SE	SW	NW	East coast	West coast
1961-1970	I	32	54	13	33	67
1971-1980	0	19	42	38	20	80
1981-1990	0	IS	39	45	16	84
1991-2000	0	13	41	45	14	86

Squids and cuttle fishes are the major groups contributing 52 and 48 % respectively to the cephalopod fishery. *Octopus* are landed in negligible quantities viz. 16t/year. *Loligo duvaceli, Sepia pharaonis* and *Sepia aculata* are the three main species contributing 42, 22 and 20% respectively to the cephalopod landing of the country.

The Indian squid, *Loligo duvaceli* is landed in all along the coast and Kerala accounts for 38% of this species, followed by Gujarat (22%) and Maharashtra (20%). Other squids with commercial importance but with restricted distribution are *Loligo uyi*, *Loliolus investigatris* and *Sepioteuthis lessoniana*. They contribute about6% of the total cephalopod landings. Bulk of the catch (87%) is landed by the trawlers which operates within 50m depth. The average catch per trawl unit per day was highest (96.9 kg) in Maharashtra and lowest (0.4 kg) in Orissa.

The all India production of cephalopods in India is estimated at 1,27,000 t during 2003. The production, estimates, percentage in all fish catch and percentage of squids, cuttle fishes and octopus are given in Table 2.

Table.2. Cephalopod production estimates, catch rate and group percentage from key centres during 2003

Landing Centre	Catch (t)	C/U (kg)	% in Trawl	Squids (%)	Cuttlefishes (%)	Octopus (%)
Mumbai	3860	176	6	58	39	3
Mangalore	7138	191	17	54	42	4
Malpe	4122	167	15	49	47	4

Calicut Puthiyappa	601	44	7	45	43	12
Cochin Cochin Munambam Vypeen Neendakara Sakthikulangara	 1196 1821 898 4973 6894	 136 94 44 128 165	 16 16 7 23 23	 21	 62	 17
Tuticorin Trawl net Hooks & lines	 541 162	 26 14	 4	 33 46	 67 54	 0 0
Mandapam Rameswaram Pamban	502 906 229	14 16 8	4 4 2	25 23 27	58 60 59	17 17 14
Chennai	2118	45	8	39	59	2
Kakinada	394	11	2	18	82	0
Visakhapatnam	820		2	9	91	0
Vizhinjam H&L (mech) H&L (Non-mech) Boat -Seine	 301 2 226	 6 1 9		 38 35 100	 62 64 0	 0 1 0
All India	127000					

POTENTIAL YIELD OF CEPHALOPODS

Various resources survey and estimations are available on the cephalopod resources of Indian Exclusive Economic Zone, continental shelf, neritc and oceanic sector. A brief summary is presented in Table 3.

Table 3. Estimated potential yield of cephalopods

Author	**Year**	**Estimated Potential yield**	**Sector/zone**
George et.,al	1977	1,80,000 t	EEZ
Chikuni	1983	50,000-1,00,000t	Bay of Bengal
Chikuni	1983	1,00,000-1,50,000 t	Eastern Arabian Sea
Silas	1985	50,000	Oceanic sector
Silas	1985	25,000-50,000 t	Neritic sector
Sudarashan	1990	20,600 t	50-300 m depth
Philip and Somavanshi	1991	49,100 t	Cuttlefish alone form the continental shelf
CMFRI	2002	92,604 t	

The cephalopod production has reached at an all time high of 1,27,000 t in 2003. This is higher than the potential estimated indicated by the above said authors. This higher production is attributed to various factors such as increased fishing efforts, and extension of trawl fishing beyond the 50m depth zone. And more over the above said authors have not taken into consideration of the availability of the cephalopod resources in the columnar, oceanic and pelagic zones (Narasimham, *et al*., 1993).

BIVALVES

The commercially important bivalves along the Indian coast are the clams, mussels edible oysters and pearl oysters. The bivalves were exploited for shell, meat, industrial purposes and for the pearl. The edible bivalves and ornamental shell became more popular and the average quantity of bivalve products exported per annum was 580 t during 1995-1999. The average annual production of bivalves during 1996-2000 was estimated as 1.52 lakhs tonnes. Clams and cockles form 73.8%, followed by oysters (12.5%), mussels (7.5%) and windowpane oysters (6.2%). The state-wise production of bivalves is given in Table 4.

Table 4. Details of bivalve fishery in the maritime states

State & main landing centers	Commercially Important bivalv resources	Average landing (t) (1996-00)
Kerala *(Vembanad and Ashtamudi Lakes)*	Vc, Pm, Mc, Mo, Cm, Sc, Pv, Pi	58763
Karnataka *Mulky, Udayavara*	Mc, Vc. Pm, Cm, Sc, Pv	12,750
Goa *(Nauxim Bay, Zuari, Mandovi* estuaries)	Mc,Vc, Pm,Cm, Sc, Pv	1,637.
Maharashtra *(Ratnagiri)*	Pm, Mc, Gb, Cg, Cr, Sc	2,035
Gujarat *(Gulf of Kutch)*	Cg, Cr, Sc, Pp, Pf	4,202
Tamil Nadu & Pondicherry	Mc, Mm, Cm, Sc, Pv, Pf, Pi,	2,098
Andhra Pradesh (Kakinada Bay)	Ag, Gb, Mc, Mm, Pm, Cm, Pv, Pp	70,705
Andaman & Nicobar Islands	Tc, Tm, Pmar, Pv,Pm	Na
Lakshadweep	Tc, Tm	Na

Ag-Anadara granosa, Cg-Crassostrea gryphoides, Cm-C.madrasensis, Cr-rivularis Gb-Gelonia bengalensis Mc-Meretrix casta, Mo-Marcia opima, Mm-Meretrix meretrix, Pf-Pinctada fucata, Pi-Perna indica, Pv-P.viridis Pm-Paphia malabarica, Pp-Placenta placenta, Pmar-Pinctada margaritifera, Sc-Saccostrea cucullata, Tc-Tridacna crocea, Tm-T.maxima, Vc-Villorita cyprinoides.

PERAL OYSTER

The Indian seas harbour six species of pearl oysters and among these, *Pinctada fucata and Pinctada margaritifera* are the two commercially important species. *Pinctada fucata* was dominant in the Gulf of Mannar and Gulf of Kutch and was contributing substantially for the pearl fisheries till early 60s. The latter is distributed in Andaman and Nicobar islands.

In the Gulf of Mannar, between Kanyakumari and Rameswaram there are about 65 pearl banks known as *Paars*. The *paars* are located at a distance 12-20 km away from the coast, at 12-25m depth. During 1663-1961, 38 pearl fisheries were conducted. The pearl fishery was conducted in India 1900, 1908, 1926 to 1928 and 1955 to 1961. The details of the 1956-1961 series of pearl fisheries in the Gulf of Mannar are given in Table 5.

Table 5. Details of pearl fishery during 1956-1961 in Gulf of Mannar

Year	No. oyster fished	Gross revenue
1955	3508967	146, 000
1956	2129058	45454
1957	1175214	168807
1958	21476514	474067
1859	16428298	874000
1960	16175839	215267
1961	15360928	288860

Due to several reasons there have been considerable decline in the fishery of pearl oysters. Shifting of the sand by bottom currents, colonization by the *Modiolus* on the pearl beds, over-fishing, over-crowding, diseases and predation by the gastropods, octopus, crabs and starfish are some of the explanations advanced for the decline of the resources.

In the Gulf of Kutch, there are about 42 important pearl oyster beds known as *Khaddas* in the inter tidal zone at distance ranging from 1 to 5 km from the coast. The total area is about 24,000ha from Sachana in the east and Ajad in the west. From 1950 to 1967, the average number of oyster fished per season was about 17,000 and the last fishery was held in 1966-67 yielded about 30,000 oysters. The highest value of pearls realized from the fishery was Rs. 61693 during 1943-44. Since 1968, there has been no improvement in the pearl fishery.

The CMFRI has developed the hatchery technology in 1981 for the spat production. To enhance the natural production, sea ranching was done in the Gulf of Mannar. During 1985-1990, a total of 1,025 300 spat of *P. fucata* has been sea ranched in 17 occasions. The average size of the spat ranged from 1.5 to 5.7mm.

WINDOWPANE OYSTER

Among the commercially exploited bivalves in India, the Windowpane oyster (*Placenta placenta*) occupies a prime position next to the clams in production. It occurs soft muddy bottom in shallow bays, estuaries and backwaters. It is reported to occur in Gulf of Kutch, Nauxim Bay (Goa) and Kakinada Bay. The oysters are handpicked at low tide without any diving aids.

In the Gulf of Kutch, Pindara bay is an important production center. The annual yield is 60 million oysters (Pota and Paterl, 1988). The standing stock at Goomara, Poshetra and Raida have been estimated at 9, 1.2 and 0.1 million windowpane oysters respectively (Varghese, 1976). The natural pearls from the oysters are collected and used in the indigenous pharmaceutical preparations. The shell accounts for 85% of whole weight and is used for lime based industries.

The Nauxim bay in Goa supports a minor fishery yielding 8,000-10,000 oysters/day throughout the year except the monsoon season (Achuthankutty *et al*., 1976). The annual production is estimated at 100t. The oyster meat is consumed locally and the pearls are not used.

Narasimham (1987) studied the windowpane fishery in Kakinda Bay. It occurs 40 km^2 area and the population density is low at 2-15 oyster/km^2. The annual production is 5,000t. The oysters are fished here for the shell only and the meat and pearls are discarded. The standing stock has been estimated at 12420 t in 1983.

In Tuticorin Bay, the windowpane fishery is done mainly for the extraction of the pearl. But in Vellapatti village, the exploitation is solely for the shells. During 2000, 150 tonnes of windowpane oysters were exploited and during 2001, about 60 tonnes of oysters were fished. The live windowpane oysters were purchased at the rate of 1.90/Kg from the fishers and Rs. 2.00/Kg to traders.

EDIBLE OYSTERS

Out of the seven species of edible oysters reported from India, *Crassostrea madrasensis, C. rivularis, C. gryphoides* and *Saccostrea cucculata* are commercially important. *C. rivularis* occurs along the Gujarat and Maharashtra coast. *C. gryphoides* is distributed along the north Karnataka, Goa, Maharashtra and Gujarat coast and is regularly exploited from several creeks and backwaters in Maharashtra. *S. cucculata* is found on the rocky substratum in marine environment in shallow coastal and intertidal areas throughout the mainland coast of India and also in the Andamans and Lakshadweep islands. At Worli and Bandra near Bombay 8.75 ha beds of this species have an estimated standing stock of 335.2t of oysters (Sundaram, 1988).

C. madrasensis is the mainstay of oyster fisheries of India. Dense populations are found and exploited along the east coast of India and exploited along the coast of Kerala, Karnataka and Maharashtra. It inhabits backwaters, creeks, bays and lagoons from the interridal region to 17m depth. Meat forms 5-10% of the total shell weight.

The studies conducted by CMFRI revealed that 11 water bodies in Andhra Pradesh the standing stock of oystes was about 1450 t in Tamil Nadu, 21 water bodies about 23,000t in Kerala in 13 water bodies at about 4,000t. The current annual production of oysters is about 2,000t.

MUSSELS

Along the Indian coast two species of mussels viz. the green mussel, *Perna viridis* and the brown mussel, *Perna indica* are commercially important. The former is found in small beds at several places along the east coast and extensively along the Kerala coast from Kollam to Kasaragod. It is also found in Karnataka, Goa, Maharashtra and the Gulf of Kutch along the west coast and also in Andamans. *Perna viridis* occurs from the intertidal zone to a depth of 15m. *P.indica* has restricted distribution and is found in the south west coast from Varkkala north Quilon to Kanyakumari and from there to Thiruchendur along the south-east coast.

Kerala state is aptly called as the "Mussel fishery zone of India" since extensive beds of both mussel species occur in the state. They account for the bulk of mussel production in the country. Kuriakose *et al.* (1988) described the mussel fishery in the state. In the major green mussel landing centers in Calicut-Canannore area about 325 full time and 336 part time divers and 340 canoes were deployed. The green mussel production from this area has been estimated at 3043, 3074 and 2579 t during 1981-82, 1982-3 and 1983-84 respectively. The catch per unit effort varied from 44.3 to 60.4 kg/canoe. The standing stock of the mussel has been estimated at 15887 t in 555 ha of mussel beds. The density varies from 2.25 to 4.5 kg/m^2. In the Majali-Bhatkal are of Karnataka during 1982-83, a total of 36.5 t green mussel were landed. The standing stock from 5 ha mussel bed in this area has been estimated at 206t. Appukkuttan et al. (2001) estimated an extent of 50675 m2 of mussel bed with 178t of biomass in Karnataka. In Kerala, the estimated extent of mussel bed was 5665300 m2 with 7954t mussel biomass.

Apukkuttan *et al.* (1988) described the brown mussel fishery based on the study conducted during 1982-84. The important fishing centers of *P. indica* are located between Kovalam and Muttom in the southern part of south-west coast of India. The annual production is estimated at 500t and the standing stock was estimated at 1586t. The population density of the mussel is 5-8kg/m^2.

CLAMS

Among the exploited bivalve molluscan resources of India calms are widely distributed and abundant. They form subsistence fisheries all along the Indian coast and fished by men, women and children from the inter tidal region to about 4m depth. They are hand picked.

The commercially exploited clams are *Villorita cyprinoides*, *Meretrix meretrix*, *M. casta*, *Paphia malabarica*, *Katelysia opima* and *Anadara granosa*. In the Andaman and Nicobar giant clams, *Tridacna maxima*, *T. squamos*, *T. crocea* and *Hippopus hippopus* occur. The former two species have been reported from Lakshadweep also. The state-wise production of the clams is given Table 6.

Table 6 . The state-wise production of the clams (source Narasimham, 1991)

State	Annual production (t)	%	Dominate species
Gujarat	NA	NA	NA
Maharashtra	1103	2.4	Mm, Ko
Goa	887	2.0	Vc, Mc
Karnataka	6592	14.5	Mc, Pm
Kerala	32927	72.5	Vc, Mc, Pm
Tamilnadu	1087	2.4	Mc
Andhra Pradesh	2816	6.2	Ag, Mm
Orissa	NA	NA	NA
West Bengal	NA	NA	NA
Total	**45412**		

Ag-Anadara granosa, Mc-Meretrix casta, Mm-Meretrix meretrix, Ko- Katelysia opima, Pm-Paphia malabarica, Vc-Villorita cyprinoides.

Kerala state stands far ahead of all maritime states in clam production with a catch of 32927 t which accounts for 72.5% of the estimated 45,412 t clam landings. The Ashtamudi and Vembanad lakes are the important production centers in Kerala. Karnataka ranks the second with 6592 t forming 14.5% of the clam production.

The extent of clam bed in Ashtamudi lake was estimated at 1200.78ha and it is dominated by *Paphia malabarica*, *Villorita cyprinoides* and *Meretrix casta*. About 61255 t of clam was estimated as the standing stock of Ashtamudi lake. The estimated biomass of *V. cyprinoides* is 36945t, *P. malabarica* 22672t and *M. casta* is 1638t (Appukuttan *et al*., 2002).

A few studies were conducted for the estimation of the standing stock of clams. In Karnataka, Rao and Rao (1985) estimated the standing stock of clams in 11 estuaries at 5345t. During 1984, the standing stock was estimated at 8027 t in 8 estuaries (Rao et al, 1989). In the Karnataka estuaries, Joseph and Joseph (1988) estimated the Y_{max} of *M. casta* in Nethravathi –Gurapur at 661 t, in Mulky at 2581t, Udyavara at 1592t and in Coondapur at 8110t.

In the Kakinada bay during March-May 1983, the standing stock of blood clam (*A. granosa*) has been estimated at 6895t and that of *M. meretrix* at 1082t.

The consumption of the clams generally limited to coastal communities. Export of frozen clam meat began in 1981 and in 1991, 1231.8 t valued Rs. 37.4 million was exported to 18 countries. Also 3t of dehydrated clam meat valued Rs. 8.72 million was exported in 1991.

EXPLOITATION OF SHELL DEPOSITS

The sub fossil deposits, also called lime shell are exploited for industrial purposes. The annual production from Karnataka estuaries is 62,000t, Vembanad lake in Kerala 148,000t, Pulicat lake in Tamilnadu 57,000t, Vaigai estuary in Tamilnadu 5500t and from other sources 5500t with a total of 278,000t. The estimated reserve of lime shell in Karnataka estuaries is 2135700t, suggesting vast scope to step up production.

Standing stock of Bivalves

Surveys were conducted in estuaries and coastal region of maritime states to study the standing stock of bivalve resources. The estimates by CMFRI are presented in Table 7.

Table 7. Standing stock and potential yield estimates of bivalves in tonnes

Resource	Est. standing stock	Av. Annual Before 1995	Landing 1996-2000	Potential Yield Estimate
CLAMS AND COCKLES				
Maharashtra	4000	770	1200	3000
Goa	1200	500	887	2000
Karnataka	8027	6592	8000	6823
Kerala	65000	32927	52537	55250
Tamil Nadu & Pondicherry	5770	950	1150	4905
Andhra Pradesh	58000	4000	49000	49300
TOTAL	**141997**	**45739**	**112774**	**121278**

OYSTERS				
Gujarat	1500	0	2.	1050
Maharashtra	335	0	55	235
Karnataka	450	0	190	315
Kerala	4200	50	1200	2940
Tamil Nadu & Pondicherry	19032	400	853	13322
Andhra Pradesh	23000'	0	16500	16100
TOTAL	**48517**	**450**	**18800**	**33962**
MUSSEL				
Maharashtra	1800	560	780	1260
Goa	1120	200	650	784
Karnataka	9800	37	4560	6860
Kerala	17473	3400	5026	12231
Tamil Nadu	350	0	95	245
Andhra Pradesh	1000	0	205	700
TOTAL	**31543**	**4197**	**11316**	**22080**
WINDOWPANE OYSTERS				
Gujarat	5000	4200	4200	3500
Goa	120	100	100	84
Andhra Pradesh	12420	5000	5000	8694
TOTAL	17540	9300	9300	12278
GRAND TOTAL	**239597**	**59686**	**152190**	**189598**

GASTROPODS

The shell of the sacred chank, *Xanchus pyrum* (Linnaeus) is extensively used in the bangle industry in West Bengal and exploited from time immemorial. The major resource occur in the Gulf of Mannar along the Ramanathapuram-Tuticorin coast. They are incidentally caught in bottom trawling along Tanjavur-Chingelpet coast, and in hook and lines along Vizhinjam coast. The average annual production in numbers shows that the catch from the Tuticorin coast as 877000, Ramanathapuram 300 000, Tanjavur-Chingelpet coast 40,000, Quilon-Vizhinjam coast 22,000, Gulf of Kutch 12,000 and Andaman and Nicobar Islands 5000. The overall production comes to 1,256,000 numbers. Devaraj and Ravichandran (1988) estimated the annual stock in the Gulf of Mannar at 2 million chanks and in the intertidal zone of the Gulf of Kutch at 25,000 chanks.
During 2003, about 116 tonnes of sacred chank were landed along the southeast coast mainly at Rameswaram, Mandapam, Keelakarai and Tuticorin. *Babylonia* sp., *Conus* sp. *Bursa* sp. and *Murex* sp were landed from Kakinada Bay and Thangaithittu (Pondicherry) and the annual landing came up to 893t.s

TOP SHELL AND TURBAN SHELL

The top shell, *Trochus niloticus*, and turban shell, *Turbo marmoratus* occur in Andaman and Nicobar island groups. These ornamental molluscs and the shells fetch lucrative price. The annual production ranges from 400 to 600t for top shell and 100 to 150 t for turban shell (Appukkuttan, 1977).

WHELK

The species *Babylonia* is widely distributed in the Indo-Pacific region. In India, this species is well represented on the Indian Peninsula at places such as Gulf of Mannar, Poompuhar, Nagapattinam, Madras and the waters around Andaman and Nicobar islands. *Babylonia* are commonly known as 'Whelk,' 'Spiral Babylon' and 'Puravumuttai chank' (Dove egg shell) in local parlance and 'Baigae' in trade. The total quantity of whelk trade during 1993-94 was 300 tonnes and it increased to 500-600 tonnes during 1995-96. *Babylonia* is a much sought after species and it fetch a good foreign exchange. It has been important food species in Indo-pacific region.

Annual landing of whelk during 2001 was 295 tonnes. It increased to 442t in 2002, whereas a decrease is observed in 2003 as 327t

ORNAMENTAL MOLLUSCS

Several ornamental gastropods and bivalves with trade value are distributed in the Gulf of Mannar, Palk Bay, Gulf of Kutch, Andaman and Nicobar islands and Lakshadweep. The important shells are *Xancus pyrum*, *Chicoreus* sp. *Babylonia, Cyprea, Conus, Cassis, Cymatium, Cymbium, Drupa, Fistularia, Hemifusus, Lambis, Mures, Natica, Nerita, Oliva, Pyrene, Strombus, Tonna, Tibia, Dentalium* sp*. Umbonium, etc*. They are regularly collected, cleaned and marketed and form the basic material for the shell craft articles. The annual production is estimated at 600 t in 1989, a total of 7.2 t ornamental shells valued at Rs. 0.464 million were exported (Alagaswami and Meiyappan, 1989).

Among edible gastropods whelks in the family Buccinidae is an important by-catch of shrimp trawlers along southern coasts and the fishery along off Kollam is supported by 2 species, *Babylonia spirata* and *Babylonia zeylanica* and have high demand in the international market. Similarly chanks *Xancus pyrum*, *Chicoreus ramosus, Cerethidae* spp. and *Hemifusus* spp. are other gastropods being exploited along the east and west coasts commercially. All others are landed as by-catches of the trawlers and used in the shell trade. Majority of the gastropods collected (approximately 70 species) are used in the ornamental shell trade. The rare gastropods collected include, *Conus milne-edwardsii* (endangered), *C. bengalensis*, *C. miles*, *C. striatus* and *C. geographus* from the family Conidae; *Strombus listeri* and *S. plicatus sibbaldi* (both endangered) from the genus strombus and *Lambis crocea, L. truncate and L. scropius* (three endangered) from the genus *Lambis* of the family strombidae, *Cypracassis rufa*, *Charonis tritonis*, *Trochus niloticus* and *Turbo marmmoratus* (all endangered). The species of *Tridacna* from Andaman and Nicobar islands are endangered.

Estimated *Xancus pyrum* landings were 4.2 lakh numbers caught by 52 divers during 2003-04. In addition to this there was 2 lakh numbers of elephant chank *Chicoreus ramosus* caught during this year. The landings of the ornamental shells in different states during 2003-04 are given in Table 8.

Table : 8

Resource	**Karnataka**	**Kerala**	**Tamil Nadu**	**Andhra Pradesh**	**Total**
Xancus pyrum	---	---	469.9	---	469.9
Hemifusus sp.	---	---	5.0	0.97	5.97
Cerethedea sp.	---	---	---	1133.3	1133.3
Telescopia sp.	---	---	---	134.5	134.5
Thais sp.	---	---	---	34.0	34
Chicoreus ramosus	---	---	172.5	---	172.5
Total Gastropods			**647.4**	**1302.77**	**1950.17**

CONCLUSION

Though cephalopod exploitation has crossed estimated potential yield, there is no sign of depletion of the stock so far. The bivalves and gastropod resources also are increasing year by year and exploitation in new areas are taken up in recent years. It is felt that closer monitoring of the stocks of mollusks and detailed studies on the population dynamics and systematic surveys of potential areas for assessment of stock are much essential for management of the much priced molluscan resources of India.

FISHERIES OCEANOGRAPHY – PROCESSES, PATTERNS & VARIABILITY

6

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Introduction

Oceanography is the scientific discipline concerned with all aspects of the world's oceans and seas, including their physical and chemical properties, their origin and geologic framework, and the life forms that inhabit the marine environment. Traditionally, oceanography has been studied under four separate but related branches: physical oceanography, chemical oceanography, marine geology, and marine ecology. Meteorology is another subject closely related to oceanography and inseparably linked to the physical processes of the ocean.

Fisheries oceanography (or hydrography) is essentially an interdisciplinary area of study focusing on the various factors and conditions of the sea determining the availability of fishery resources in time and space. The methods of fisheries oceanography relate the abundance (more exactly the patterns of behaviour) of species to the surrounding hydrological features and use the relationship for predictive purposes. In short, fisheries hydrography is an applied branch of oceanography, which integrates hydrographical knowledge and behaviour of species and technology of production so as to optimise the yield of commercially valuable species with minimum effort. Thus a prior knowledge of some sea conditions such as thermal structure could be used to locate the availability of certain species of fish and the fishing fleet targeting on the species can save significantly on searching time and fishing effort.

The earth system is fuelled by solar energy. The dynamic interaction among ocean, atmosphere and land, causes many events and mater/energy flows in the system to occur in a cyclic manner. The physical oceanic processes influence the chemical and ecological processes in the sea, which follow definite patterns. The dynamic nature of the system also causes temporal and spatial variability in the factors and dependent components.

The interrelations among various biotic and abiotic components in the ocean system are very complex. Researchers attempting to unravel the intricate relations have to face formidable challenges. A simple way to deal with this situation is to gain an understanding of the processes and underlying principles and then stud the small subsystems. Later this knowledge can be integrated to more complex systems. This approach to understand the processes and patterns in the dynamic ocean systems and associated responses in biological systems will pay rich dividends. This article attempts to provide the readers with glimpses of some important processes, phenomena, patterns and variability of fisheries oceanography in order to establish cause-effect linkages. This would help the readers to understand and intuitively analyse the various situations they encounter in the course of their learning. A list of further reading is also provided to help the readers to gain further knowledge on the subject.

Factors affecting fisheries

The different species in the sea have evolved to make the best use of the surrounding environment. Thus we find species adapted to even the most hostile environment and specialized to exploit every conceivable niche in the ocean. The survival strategies of many species are well tuned to the patterns and processes in the sea. For example, the spawning and seasonal migrations as well as larval drift of many species are well orchestrated with the circulation in the oceans.

Basically the presence of any organism in a particular place and time could be taken as an indication of the existence of some factors favourable (or some factors beyond the control) for the species in question. These factor(s) could be one or many of the following:

- Ambient environment (temperature, light, chemistry, currents)
- Abundance of dissolved gases (oxygen, carbon dioxide)
- Availability of food, shelter and substratum

Sometimes an anomaly in the system such as a change in the circulation pattern may transport certain species to certain localities. If the hydrological conditions most preferred by different organisms are known, it will be easier to relate their probable presence (absence) based on the conditions prevailing in a given location. For predicting potential areas for profitable fishing the following are required:

a) Optimum temperatures (and the optima of other environmental factors of all economically important species must be known.

b) Data from a sufficiently large number of hydrographical and meteorological observations to provide information on location of critical isotherms, sharp temperature gradients, eddies and currents.

c) Predictability of changes in the hydrological conditions.

In the following sections the oceanic processes controlling important hydrological factors and the behaviour of different species in response to these major environmental factors shall be discussed.

Temperature of Seawater

Temperature is one of the important factors affecting life in the ocean and is perhaps the most easily measured basic parameter in hydrographic studies. In fact the spatial difference in temperature (and consequently density and pressure) is the main factor controlling the multitude of processes that takes place in the earth system. There are a number of processes and factors influencing the thermal structure of the surface and sub-surface seawater (Table-1).

The surface waters receive most of the heat energy from the sun, which is not transmitted to the bottom beyond the mixing layer. The vertical profile of temperature measured using Bathythermograph (BT) generally show a mixed layer from surface to a certain depth (MLD) and then a zone of rapid decline called *thermocline* or *temperature discontinuity* *layer*. Thermocline may be permanent or seasonal and is generally observed between 10-200 m depth. Depending on the shape of the vertical temperature profile, different forms of thermoclines are identified (Figure.1). The normal thermocline is most common form and has a mixed layer near surface. On extreme case it may become a continuous density model with a uniform gradient.

Most of the cold-blooded animals prefer to be in ambient temperature for optimising their body functions and minimising the energy loss. Thermocline is an important thermal feature of the sea, which control the movement of fish. The different commercially important species of fish and shellfish prefer certain range of temperature to live (Table-2). It is worth noting that different species of tropical tunas occupy different positions with respect to the thermocline (Figure.2). The success of midwater trawling depends on the position of the mixed layer depth (MLD) nearer to the surface (Figure.3). For purse seining a shallow thermocline would prevent diving and escape of fish from the seine (Figure.4). Fishermen can use this knowledge to reduce their search time during fishing.

Temperature is also an important criterion in the energy budget of organisms. During winter baleen whales of southern hemisphere cease to feed and migrate to the tropics. Apparently the lower rate of body heat loss in tropical waters justifies energy expended for making 10000 km journey. The

Light in the sea

Light as the source of energy to the photosynthesis is the most important factor in the existence of life in the sea. In shallow areas light is available throughout the water column. In deeper regions surface and subsurface waters are well-illuminated (euphotic zones) supporting photosynthetic activity by plants and micro-algae. Absorption (more on the red side than on the blue side) and scattering (by mineral and particulate suspended matter) reduce the intensity of light in deeper layers. Thus Light becomes a limiting factor in deeper layers. Due to the influence of various processes the optical characteristics of seawater varies greatly (Table –3).

While planktonic production is associated with light, other organisms exhibit varying photo-tactic behaviour. Fishes are known to respond to light stimuli as low as 0.01-0.001 lux, but the lower light intensities, which bring about maximum response range between 50-200 lux. In sufficiently illuminated waters fishes can recognise colours and in turbid waters vision range is very low. Enhanced visibility in clear waters is not favourable for capture of fish in static nets such as gillnets. Attraction of different species (especially the hungry ones) to light is often used advantageously in different fishing techniques (e.g. squid jigging). Fishes tend to avoid high plankton production areas during daytime and remain down below. Fishes tend to actively swim during light period and passively drift during darkness. Mainly light and temperature together influences the common patters of diurnal vertical migration of fish:

- Pelagic species occurring slightly above thermocline during daytime migrate to surface layers at sunset and disperse between surface and thermocline during night.

- Pelagic species occurring below thermocline during daytime migrate through thermocline to surface layers at sunset and disperse between surface and bottom during night, with bulk occurring above thermocline.

- Pelagic species occurring below thermocline during daytime migrate into thermocline at sunset and disperse between thermocline and bottom during night.

- Demersal species occurring close to bottom shows migration and dispersal into the column below (sometime above) thermocline during sunset.

- Species, which are dispersed throughout the water column during the day, descend to bottom layers during night.

All the above species migrate back to their original position at dawn. It must be noted that there are many pelagic and demersal species without any distinct diurnal migration.

Chemistry of Seawater

Seawater contains almost all chemical elements in solution or in colloidal suspension. It is a complex aqueous solution of a variety of dissolved solids and gases. The absolute concentration of total dissolved solids varies from place to place (it may vary from 0 g kg^{-1} in freshwater influx areas to as high as 40 g kg^{-1} in Red sea), but the ratios between more abundant substances virtually remain constant. The composition of important ionic constituents in seawater (of 35 S) is given in Table-4.

Salinity is perhaps the most important parameter controlling the distribution of species. The coastal areas with river influx and the estuaries are of lower salinity and many species or life stages of some species prefer such areas. A large number other species prefer to be in higher range of salinity. All species show tolerance to varying range of salinity, though an abrupt change will have detrimental effect.

Micronutrients such as phosphates, nitrates, and silicates are the basic inputs for the primary production by plankton. Generally these nutrients flow in a cycle within the system with various physical processes and biological agents facilitating the different conversion process and transport. Silicates are generally abundant along coastal areas due to river discharge and interaction with land. Deeper water below thermocline may have phosphate concentration of 2-4 ?g.l^{-1}. In many places, especially the oceanic surface waters, the seawater is poor in phosphates, nitrates and they often become limiting nutrients in primary production. In addition various trace elements such as iron and cobalt, also important for plankton production, may at times become limiting factors in certain areas. Thus the chemical constituents of seawater will have an indirect impact on fisheries through primary production and the food chain.

Dissolved Gases

Oxygen (O_2), Nitrogen (N_2) and carbon dioxide (CO_2) are the three important dissolved gases in seawater. The concentration of gases in seawater is inversely related to temperature and salinity (Table-5). While carbon dioxide is the basic input for the primary production by plants and plankton in the sea, oxygen is indispensable to the maintenance of all organisms. Carbon dioxide is sufficiently abundant in seawater either as dissolved gas (replenished by excretion of living organisms and from atmosphere) or as a fixed constituent of the bicarbonates to meet the requirements of plants. Therefore CO_2 is never a limiting factor in the sea. Dissolved CO_2 is the main factor controlling the pH of seawater, which generally vary between 8.1 and 8.3.

The concentration of oxygen even in well-oxygenated seawater is very small (9 ml l^{-1}) compared to that present in the air (200 ml l^{-1}). Generally surface waters and surf zones are rich in oxygen due to mixing of atmospheric oxygen during wave action. Plants also release oxygen during photosynthesis. There is greater irregularity in the distribution of oxygen and in some instances sharp gradients can be observed. Within only 10 m the dissolved oxygen may range from 0 to 6.4 ml l^{-1}. In isolated and stagnant fjords the oxygen deficiencies are markedly reflected in the fauna.

A concentration of oxygen in the water column is controlled mainly by the atmospheric diffusion, temperature, salinity, primary production and consumption. At certain depth the rate of depletion may nearly equal replenishment. Fishes tend to avoid this layer of water having low oxygen known as *oxygen minimum layer*. The movement of fishes during upwelling is related to the movement of oxygen minimum layer (figure.5).

All marine organisms (except mammals and reptiles) need to absorb this small quantity of dissolved oxygen through the surfaces of their body or specialized organs such as gills. Thus obtaining adequate oxygen for metabolic needs is one of the major problems for marine organisms. As calorific return may be limited by either the amount of food ingested or by the amount of oxygen available to metabolise it, organisms may be compelled to trade off between availabity of oxygen and availability of food in the time space continuum.

The need for oxygen is more in the case of larger organisms since body volume increase at a greater rate than body surface area. As fish grow, retaining the geometric shape of the body, the gill’s surface area increases more slowly than the body volume. Therefore due to increased demand for oxygen, larger fishes tend to remain at relatively cooler deeper waters rich in oxygen. Tunas have very large heads (and gills) and shortened bodies to suit their high-energy life style. Even then, certain tropical tunas often are forced to dive down into deeper waters because they are unable to meet their need for oxygen in the warm surface waters. The tendency of many species of tunas to orient their position with respect to the thermocline is advantageous for the fishermen.

Food, Shelter and Substratum

Food is the most important factor for the survival of any organism. The marine organisms move vertically and horizontally in search of food. The sedentary organisms attach to suitable places where supply of food is ensured by the moving water. Successful of attachment of larvae to suitable substratum is a critical factor in the life of sedentary organisms. Plankton feeders flourish in places of high plankton production. Carnivores make a living in the proximity of prey population. Apex predators chase the prey over larger areas.

Many marine ecosystems share one striking aspect in configuration of their biological diversity. They typically contain a very large number of species at the lower trophic levels and a substantial number of species that feed (as adults) at apex or near apex level. However in many richly productive ecosystems of the world (upwelling areas) there is often a crucial intermediate trophic level, occupied by small, plankton-feeding pelagic fishes like sardine or anchovies. Because of the distribution of many species at top and bottom of trophic levels and few dominant species at the middle level, these ecosystems are often referred to as wasp-waist ecosystems (J. Rice as quoted in Bakun, 1996).

Different species flourish in different localities of the sea where conditions are favourable and individuals are protected from the vagaries of environment, including predation. Larval fish require very small food particles and thus feed at a lower tropic level and also protection from predators. The reason for many fishes having an estuarine larval form is obviously to avail the benefits of abundant food supply and protection from predators to ensure better survival. Reef ecosystems are also highly productive and provide abundant substratum and shelter for a rich diversity of species

In the featureless open ocean, the floating objects attract fish and other organisms. Sargasso Seas support a rich diversity of epifauna and serve as a spawning ground for many species. The tendency of fish to aggregate near floating objects is behind the development of Fish Aggregating Device (FAD).

Upwelling and tidal mixing

Having discussed some important oceanic factors having a significant role in the distribution of different species in time and space, it is appropriate to briefly discuss some important processes and which control other factors. Seasonal overturn of sweater is an important process, which brings the nutrient rich bottom waters to the surface areas. Tidal mixing and turbulence are frequent in shallow areas. *Upwelling* is an interesting process that takes place in many parts of the ocean.
The process of upwelling involves movement of subsurface water towards surface consequent to the displacement of surface waters by prevailing forces and may be of the following types:

- ✍ Coastal upwelling (most common)
- ✍ Shelf breaking upwelling
- ✍ Equatorial upwelling
- ✍ Vortex driven upwelling

In the case of coastal upwelling (as in the case of East Coast of India), the prevailing winds and currents running parallel to the coast and coriolis force causes surface water to drift away (Ekman's transport) from the coast. The deeper water raises up nearer to the coast to replace the drifting surface waters. Oceanic upwelling takes place near at the area of divergence where surface water move apart allowing deeper water to raise up. A converse process called *downwelling* or *sinking* also takes place in certain parts (as along the East Coast of India).

The significance of upwelling is that the process replenishes the nutrients in the surface waters and thereby enhancing the primary and secondary productivity. Highly productive upwelling areas are characterised by a dominant single species fishery (as Peruvian anchovy). As oceanic systems are subject to variability, the dependent fisheries collapse when the patterns and conditions vary. In other areas of upwelling, the oxygen minimum layer controls the movement of fish (Figure.5).

Currents

Ocean currents are the most important factor causing changes in the environmental properties of the sea over large areas. The great permanent currents (like the Gulf Steam) develop due to the horizontal density gradient by differential heating of oceanic water in different localities or are maintained by the trade winds. The major oceanic currents run along the continental boundaries and facilitate a number of coastal processes. In addition, short-tern currents, periodic tidal currents and advective movements also play an important role in the oceanic and coastal processes. The influence currents on the fishes may be direct or indirect. The following are some of the important aspects of fish behaviour related to currents.

- Currents transport fish eggs and fry from spawning grounds to nursery grounds and from nursery grounds to feeding grounds. Any variation in the pattern will affect the survival of the particular brood.
- Migration of adult fish could be affected by current, which serves as a means of orientation.
- Currents (especially tidal) may affect the diurnal behaviour of fish.
- Currents influence distribution of fish, especially at its boundaries, though direct effect as well as aggregation of food or bringing the favourable environmental boundaries (temperature).
- By affecting the properties of the environment, currents decide the geographic limits and boundaries of fish distribution.

Knowledge about the currents, thus, could be of immense use in the exploitation of fishery resources. Proper hydrogrpahic sampling focussing on changes in the patterns and abundance of eggs and larvae are very important for predicting the fishery yield.

Ecosystem Approach

Having understood the important factors determining the abundance of fish in the sea, it is appropriate to briefly discuss the different approaches to management fishery resource. The abundance of a species in a system is controlled by various environmental factors as well as the biological characteristics of the species itself. The models hitherto used for assessment of fisheries stocks often fail to explain many changes in the abundance of stocks as several important factors were not considered in deriving various parameters. The principal processes and interactions in the marine ecosystem are to be considered while developing models for fisheries management (figure.6).

Gary Sharp (1995) has voiced his concern that fisheries studies have simply ignored climate signals or have buried these and other environmentally mediated signals in mystical parameters. He called for truly interdisciplinary approaches to aquatic ecology and marine fisheries research and reincorporating of operational oceanography and climatology into fishery science. While observing that 'for some obscure reason, fisheries management has become welded to biomass as the principal measure of resource status', he points out that stock assessment tools need to be expanded to cope with ecosystem status. In fact Sverdrup (1952) had succinctly explained much earlier the practical aspects of fishery oceanography with respect to prediction of the availability and size of the stock of any exploited species of fish. These voices are reflected in the new approaches of fisheries management being evolved at various places.

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Table-1
Major causes that change sea surface temperature

Basic cause	**Processes and factors**
Advection	Permanent (gradient) flow, Wind currents, Inertia and tidal currents
Heat Exchange	Insolation (affected by clouds), Evaporation (affected by wind speed and e_w-e_a), Other heat exchange components
Mixing	Wave action, Convective stirring, Currents

Special causes	Upwelling and divergence/convergence, Precipitation, Runoff, Freezing and melting of Ice
Source: *Laevastu & Hela, 1970.*	

Table-2

The temperature (^{o}C) range in which some commercially important species prefer to live.

Species	***Distribution Range***	***Fishing range***
Cod	1-5	2-4
Pollock	0-8	2-5
Halibut	2-5	3-4
Herring	3-11	4-7
Salmon	4-11	6-8
Sardine	5-25	12-16
Squid	10-18	12-16
Pacific mackerel	12-18	14-16
Bluefin tuna	14-21	15-21
Bonito	12-25	15-22
Albacore	14-23	15-21
Bigeye tuna	11-28	18-22
Swordfish	13-27	19-22
Skipjack	17-28	19-23
Little tuna	17-28	18-23
Yellowfin	17-31	18-23

Source: adapted from Uda, M, (1952) and Monin, et al. (1977)

Table-3

Classification of sweater base on optical characteristics

Class	***Characteristics***
Oceanic clear	Clear oceanic waters in low productive areas especially in low latitudes. Water colour 0-2 (Forel scale).
Oceanic normal	Medium productive oceanic waters in medium and low latitudes. Water colour 2-5.
Oceanic turbid and coastal clear	High productive oceanic areas, especially during plankton bloom. Tropical coastal waters, especially over deep shelves. Water colour 5-8.
Coastal normal	Normal medium productive coastal waters and waters over shallow shelves. Water colour 8-10
Coastal turbid	Estuarine and coastal waters during intensive plankton bloom and waters close to the coast where wave action cause whirling up of sediments. Water colour 10
Source: *Laevastu & Hela, 1970.*	

Table-4

Ionic composition (g/kg) and percentage (of total salts) in seawater of practical salinity 35.0

Ion	*Symbol*	*Composition*	*Percentage*
Chloride	Cl^-	19.35	55.04
Sodium	Na^+	10.77	30.62
Sulphate	SO_4^-	2.71	7.71
Magnesium	Mg^{++}	1.29	3.68
Calcium	Ca^{++}	0.41	1.17
Potassium	K^+	0.40	1.14
Bicarbonate	HCO_3^-	0.12	0.33
Bromine	Br^-	0.07	0.19

Source: Based on Millero, F. J., 1974. *Ann. Rev. Earth Planetary Sci*., 2, 101

Table-5

Coefficient of saturation of atmospheric gases (C_s) in water (as ml l^{-1} in equilibrium with 760 Torr of designated gas)

Temperature	***0°***			***12°***			***24°***		
Chlorinity (°/oo)	***O_2***	***N_2***	***CO_2***	***O_2***	***N_2***	***CO_2***	***O_2***	***N_2***	***CO_2***
0	49.24	23.00	1715	36.75	17.80	1118	29.38	14.63	782
16	40.10	15.02	1489	30.60	11.56	980	24.80	9.36	695
20	38.00	14.21	1438	29.10	10.99	947	23.60	8.96	677

Source: Sverdrup et al., 1942

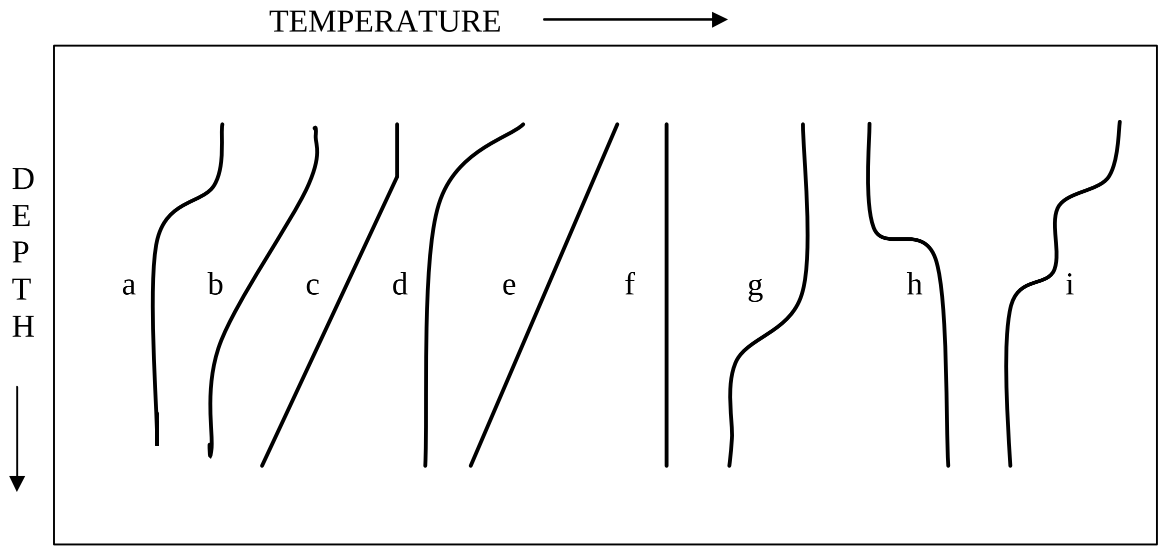

Figure.1. Different types of thermoclines: a) normal themocline, b) extended themocline, c) Epithermocline, d) Surface thermocline, e) Continuous density model, f) Homothermocline, g) Sub-thermocline, h) inverse thermocline, i) Double thermocline. (*Adapted from*: *Laevastu & Hela, 1970).*

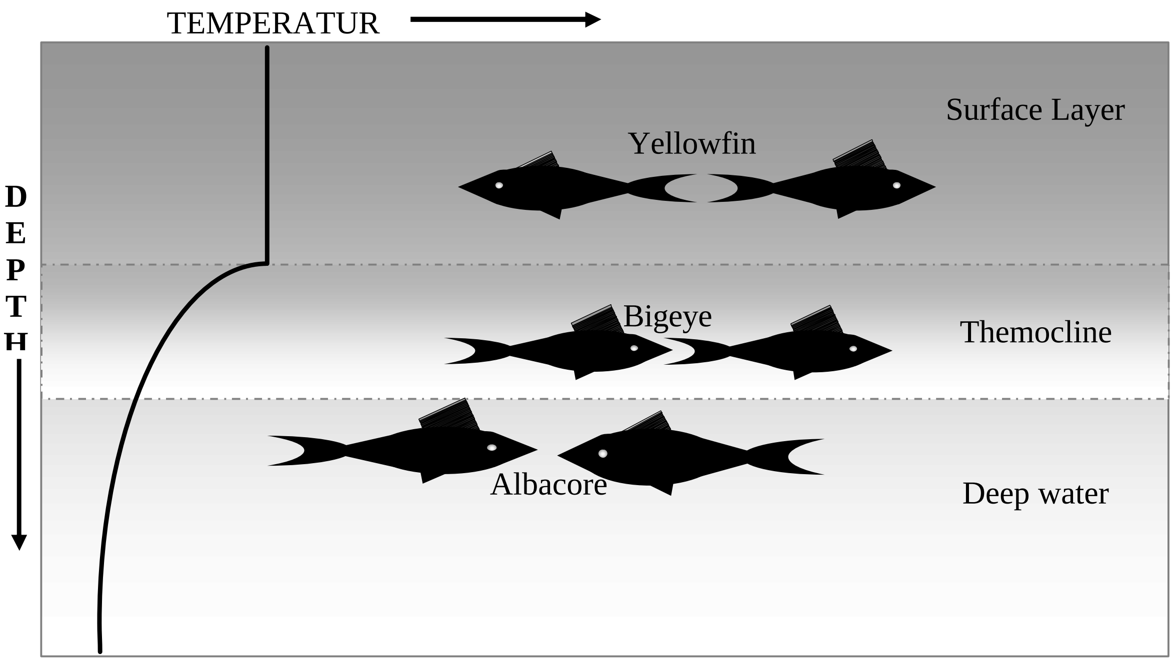

Figure-2. Schematic representation of temperature preference by different species of tuna in tropics (*Adapted from*: *Laevastu & Hela, 1970).*

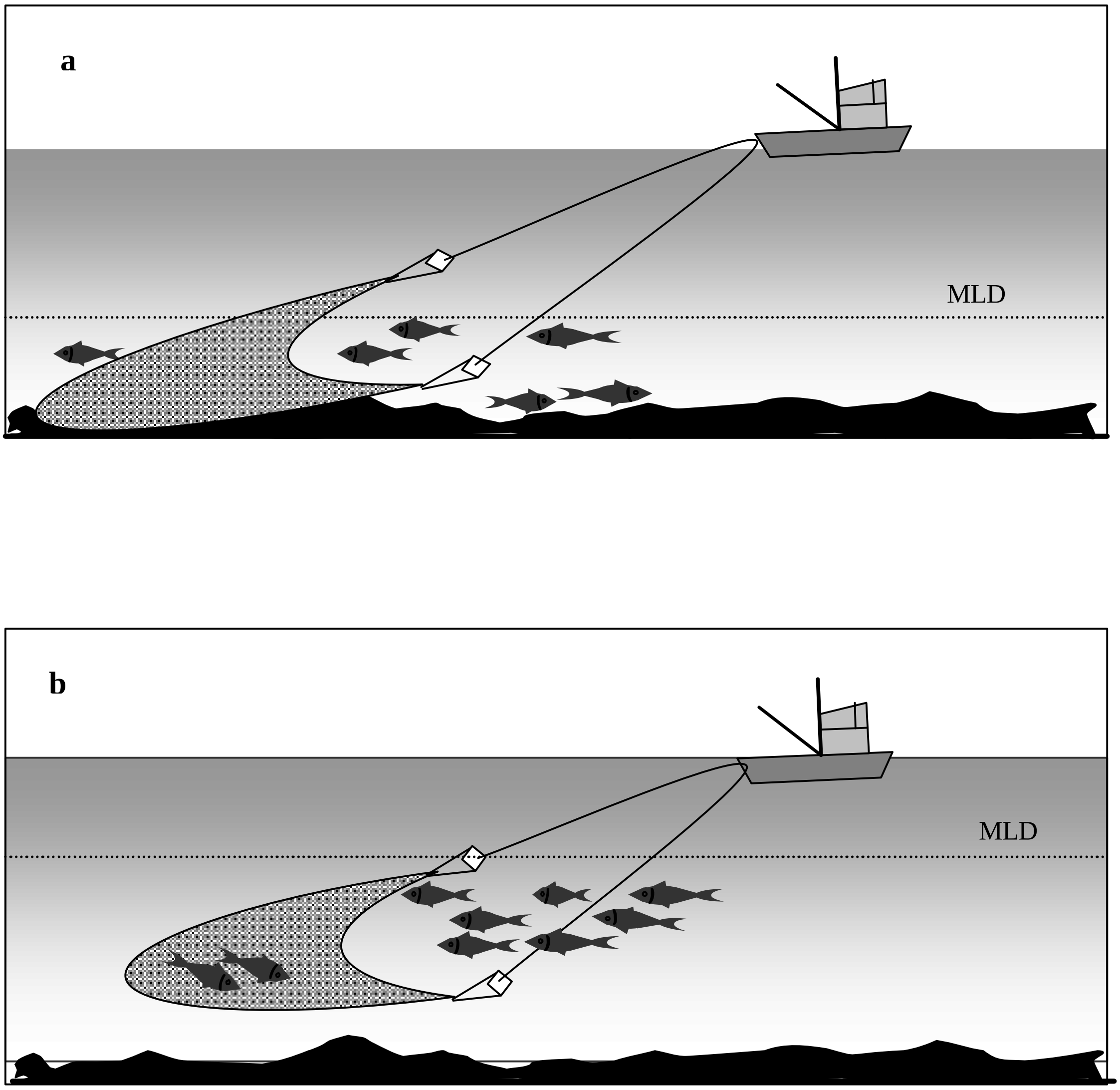

Figure.3. Fish behaviour and Trawling. (a) Deep MLD, fish schools too close to bottom, not favourable for mid water trawling, but may be good for bottom trawling; (b) Normal MLD, Fish schools (herring) below it good for mid water trawling (*Adapted from*: *Laevastu & Hela, 1970)*

SAMPLING DESIGN FOR ESTIMATION OF MARINE FISH LANDINGS

7

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India has a coast line of about 8129 km. Fishing is largely in the hands of a number fishermen and fishing is done by small mechanized and indigenous craft. Landings take place almost all along in the coast line throughout the day and sometimes during night. There are about 2000 fishing villages scattered along the coast line from where fishermen go for fishing and return to a landing centre which may be distinct from the fishing village. There are about 1300 landing centres scattered along the coastline of the main land. Under these conditions collection of statistics by complete enumeration would involve a very large number of enumerators and a huge sum of money apart from the time involved in collection of data. In this context a feasible solution for obtaining marine fish landings is the adoption of a suitable sampling technique for the collection of fish landing data.

To evolve a suitable sampling design, pilot surveys were organised by different organizations in India from time to time. The design of the present survey has been evolved on the basis of results obtained in these pilot surveys undertaken from time to time.

The sampling design adopted by the Central Marine Fisheries Research Institute (CMFRI) is based on stratified multi-stage random sampling technique, the stratification being over space and time. The stratification is made by dividing each maritime state into several zones on the basis of fishing practices and geographical considerations. The number of centres included vary from zone to zone depending on the topography. These zones have been further stratified into substrata, on the basis of intensity of fishing in a centre. There are zones which have only one centre, usually known as Single Centre Zone.

One zone and a calendar month are taken as the basis of space-time stratum. If in a zone, there are 20 landing centres, there will be 20 x 30 = 600 landing centre days in that zone for that month (of 30 days). For observation purpose, a month is divided into 3 groups, each of 10 days. From each group, a cluster of 6 consecutive days are selected systematically with a random start with a sampling interval of ten days: Thus fom the first five days of a month, a day is selected randomly, which together with the next 5 consecutive days (6 days in all) form the first cluster. The next 6 days each from the other groups follow systematically. For example, if for a zone, the observation starts from the 4th of a month and continue upto 9th, the next cluster will start from the 14th and the last cluster from 24th. As the days are selected as per the above procedure, three centres are randomly selected for observations over 6 days and each selected centre is observed for two consecutive days. The observation is made from 1200 hrs to 1800 hrs on the first day and from 0600 hrs to 1200 hrs on the second day, in a centre. The intervening period of these two days ie, data collected by enquiry from 1800 hrs of the first day of observation to 0600 hrs of the 2nd day of observation of a landing centre-day is termed as 'night landing '.

The `night landing' obtained by enquiry on the second day covering the period of 1800 hrs of the first day to 0600 hrs of the next day are added to the day landings so as to arrive at the landings for one day (24 hours). Thus in a 10 day period, data from 3 centre-days are sampled and consequently,in a month 9 landing centre-days are sampled .

Selection of units and recording of landings

It may not be practicable to record the catches of all boats landed during an observation period, if the number of boats/craft is large. A sampling of the boats/craft become essential. When the total number of boats landed is 15 or less, the total landings from all the boats are enumerated for catch composition and other particulars. When the total number of boats exceeds 15, the following procedure is followed to sample the number of boats :

Number of units landed	**Fraction to be examined**
Less than or equal to 15	100 %
Between 16 and 19	First 10 and the balance 50 %
Between 20 and 29	1 in 2
Between 30 and 39	1 in 3
Between 40 and 49	1 in 4
Between 50 and 59	1 in 5
and so on	

From the boats, the catches are normally removed in baskets of standard size. The weight of fish contained in these baskets being known, the weight of fish in each boat under observation is obtained.

Estimation procedure:

From the landings of the observed fishing units, the landings for all the units landed during the observation period are estimated. By adding the quantities landed during the two 6- hours periods and during the night (12-hours) the quantity landed for a day (24-hours) at a centre that is the landings for each centre day included in the sample is estimated. From these, the monthly zonal landings are obtained.

$$\hat{Y}_{ijk} = \frac{Nijk}{n} \sum_{i=1}^{n} Y_{ijkl}$$

where Yijk is the estimated landings for the k th month in the j th zone of the i th state, Nijk is the number of landings centre-days in the k th month for the respective zone, n is the corresponding number of centre days actually sampled and Yijkl is the estimated yield for the l th landing centre-day in the sample for the respective space-time stratum.

However, important centres such as Veraval, Sassoon Dock, Sakthikulangara etc. larger sampling coverage is ensured as they are treated as Single Centre Zones.

From the zonal estimates, districtwise, statewise and all India landings are arrived. The corresponding sampling errors are also estimated.

Determination of overall sample size and variance in different strata/states:

The sampling fractions at the level of the first stage units vary from 1.5 to 3% in different states. With the present sample size, the error in the estimated total annual landings in India is about 5%. The sample size allocated to each stratum (zone) is the same. As the variance is found to increase with the size of the landings, the good landing centres are given more chances of being included in the sample. This is done by sub-stratifying the landing centres of a zone on the basis of the intensity of landings. A statewise allocation of the sample size on the basis of the mean annual landings is found to be practical and close to the optimum allocation.

Observational errors their magnitude and control:

The estimated zonal landings are always compared with the previous year's survey figures,and if any discrepancy which cannot be explained is observed, the technique of interpenetrating sub-samples is adopted to detect observational errors. Observational errors are rarely confirmed and when confirmed, the field staff is either called back to the headquarters for giving intensive training or he is replaced.

Errors due to non-response, their magnitude and control:

Non-response occurs only when the regular field staff is not available to observe the centre-day included in the sample. Usually, arrangements are made to substitute the regular one by another on such occasions.

Sampling errors, methods for its estimation, statewise magnitude and control:

The sampling errors involved in sub-sampling the centre- day and the boats (units) are assumed to be negligible (Sukhathme et al., 1958). Therefore an estimate of the variance of the estimated landings (Yijk) of the k th month in the j th zone of the i th state ignoring the finite population correction factor is given by

$$\hat{V}(\hat{Y}_{ijk}) = \frac{N_{ijk}^2}{n} V_{ijk} \quad \text{where}$$

$$V_{ijk} = \frac{\sum_{l=1}^{n} y_{ijkl}^2 - \left(\sum_{l=1}^{n} y_{ijkl}\right)^2}{(n-1)}$$

The percentage errors at the states level vary from 5 to 20%. To control the error, the stratification (based on the intensity of landings) is made from time to time.

Plan of operation:

The survey staff immediately after recruitment undergoes a training course which lasts 10-12 weeks and is posted to the survey centres. Each survey centre is housed in 1-2 room rented apartment and each centre is provided with the necessary literature connected with the identification of fish, a reference collection of local fishes, crustaceans and molluscs, field note- books and registers. At the end of every month, the survey staff receives by post, the programme of work for the following month which includes the names of landing centres to be visited and details such as date and time of observations at each landing centre. The programme is carefully designed at the headquarters by the statistical staff. The field staff send the data collected during a month to the Institute's Headquarter before the end of the first week of the subsequent month where, they are scrutinised and processed by the statistical staff.

Supervision of scrutiny:

Surprise inspections are carried out at frequent intervals by the supervisory staff of the Institute and the enumerators are inspected while at work in the field and their field note-books and diaries are scrutinised and initialed. A survey staff is usually inspected twice in a month. The data received at the Headquarter are scrutinised carefully at every stage for finding it in order. The processed data are counter- checked for errors if any in the method of estimation. Usually only cross checks are made; but when discrepancies are detected the estimation procedures for any zone are scrutinized in detail.

Tabulation and processing

Different schedules are used to collect fishery survey data. Necessary coding of species were also done to process the data with the help of computer facilities at Headquarters.

FISH STOCK ASSESSMENT – AN OVERVIEW

8

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1.Introduction

During the last five decades there has been a tremendous increase in fish production, concomitant with the improved technologies in the harvest and post harvest operations, and the extension of fishing areas beyond the conventional grounds. In most of the countries, however, the production trends in respect of the commercially important fishery resources have been showing gradual decline. The situation is no different in India. The phenomenal increase in production triggered by market growth was achieved through adoption of modern methods for exploitation and extension of fishing from the traditional near shore waters to deeper regions. This has also brought in its wake regional and sectoral imbalances in the exploitation of the common resources. The artisanal sector is increasingly marginalized by the growth in mechanized and motorized sector. Many of the resources in different regions of our EEZ are reportedly over-fished. The catch rates of the commercially important resources were observed to be declining. Concerned with the dwindling catch rates, apprehensions of damage to the ecosystem and for ensuring sustainability of the exploited resources, the maritime states of India have imposed statutory regulations for fishing by imposing ban/restriction of fishing by certain gears and closure of fishery during specified periods. Although, the benefits accruing from such management interventions are a subject of considerable debate, it is significant that the fishery managers and stakeholders have realized that resources are limited and need appropriate harvesting strategies for long term sustenance and welfare of the coastal rural folk. Fish stock assessment thus becomes necessary for choosing appropriate harvesting strategies to realize sustainable yields without damage to the ecosystem and through the optimal utilization of the available infrastructure.

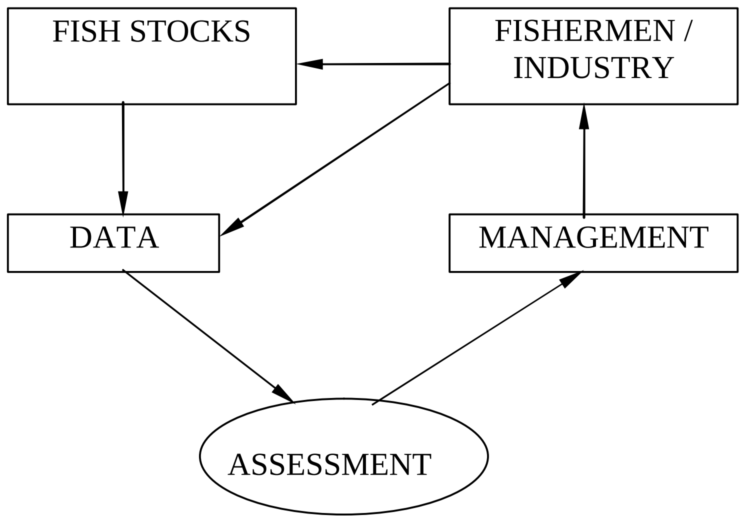
2. Stock assessment

2.1 What is stock assessment?

According to Hillborn and Walters (1992) stock assessment involves the application of statistical and mathematical calculations to relevant data in order to obtain a quantitative understanding of the status of the stock as needed to make quantitative predictions of the stock's reactions to alternative management choices. The direct impact of fishing on an exploited stock shall forms the essential basis for the more complex and realistic analysis of stocks dynamics. Techniques of stock assessment were developed initially addressing issues to single species and single gear systems for the temperate regions. Based on the experiences gained in such system, the assessment methods were generalized for more complex multispecies and multigear system using sophisticated computer intensive techniques. Models and methods arising out of such efforts are being currently used as basis for management of fisheries in many parts of the world. Relevance and direct application of such approaches in tropical resource assessment has been the subject of research in the recent part and the efforts are still continuing.

It is well recognized that stock assessment also involves understanding of the dynamics of fisheries. Modern stock assessment is not a mere exercise in predicting static equilibrium yields but involves forecasting about the time trends expected in response to policy change. It must also be realized that fishermen are an important and integral part of the dynamics of fisheries and stock assessment therefore also needs to take into account as to how they respond to the suggested interventions, if any.

A typical stock assessment process is illustrated below.



The objectives of stock assessment should address issues relating to the biological, technological, social and economic aspects of the fisheries. This involves collecting information on the indicators of the biological and technological status, economic performance and livelihood status of the dependent communities.

John A. Gulland categorized the main issues confronting fisheries administration as follows.

1. How big is the resource, and how many fish can be caught each year while maintaining the stock for the future?
2. Given the potential catch, how should this is to be used for the greatest benefit of the country?
3. What action needs to be taken to achieve these objectives?

There are two types of models that are employed in studying the dynamics of fish populations. The first type is the micro models or the analytical models (or methods) while the other type is the macro models or the global (surplus production) models. Models that can be solved in the closed form mathematically are called the analytical models. For such models it is possible to obtain a general solution, which is applicable to all the situations that the model can represent. In the analytical models we take into consideration the various components that affect the stock, namely, recruitment, growth, mortality, size or age at first capture etc. In the macro models we deal with only the observable inputs (say fishing effort) and the actual outputs (yield in weight) from a given population.

2.2. Data requirements

For assessment of status of the stocks and for evolving rational harvesting strategies several types of information are required. They include data on species composition, distribution and abundance data, biological data, environmental data, socio-economic data, besides fleetwise/sectorwise production data. To describe the effects of fisheries on fish stocks, it is necessary not only to know a great deal about the stocks but also to have an intimate knowledge of the fisheries themselves such as the quantities of each species removed, the time and location of removal and the size and age composition of the catch. For a proper evaluation of the stock, statistics of catch and effort along with the data on the relevant biological characteristics over time and space are very essential. Needless to say, the validity of resource evaluation depends largely on the precision of the database, which is governed by the scheme of data collection including the mode and frequency of data collection. Data types can be split into two groups, dependent or independent of the fishery. Fishery dependent data comprises of four usable types, the total catch, amount of fishing, (the combination known as) catch per unit effort (CPUE), age or size composition data. Catch data is essential for most stock production models, inaccurate or biased collection can have damaging long term effects.

When age data is sparse or the species cannot easily be aged, length based assessments are an alternative. Comparison between age and length structured yield-per-recruit models showed length structured techniques better incorporated information observed from fisheries, but age structured methods gave more precise and conservative estimates of yield-per-recruit. This is the main reason why age structured models are chosen from the conservation perspective in fisheries management. A potential strength of fishery science will be the adoption of multi-species models and ecosystem based models to fisheries that currently utilise single species methods.

2.3 Methods & Models

Having collected the required data for resource evaluation, the next step would obviously be to search for or explore an appropriate model (method) that would amply describe the underlying processes and estimate the parameters that govern the processes. This requires the application of mathematics and statistics. The use of mathematical models in fish stock assessment was established in the late 1950’s by Beverton and Holt. Building on this cornerstone, many fishery scientists, statisticians and mathematicians have developed various mathematical models which have greatly helped in understanding the system better. The application of mathematical models for the assessment of fish stocks forms the core of the resource evaluation activity. Model formulation is an important exercise in fish stock assessment. The purpose is not only to evaluate the magnitude and the variations in the various parameters of the fishery, but also to formulate the guidelines for the harvesting strategies for the rational exploitation of the stocks on a short term and long term basis. This calls for checking the validity of the chosen model from time to time. Similarly, there can be different manifestations of a model (which can be termed as 'derived forms') and one can choose an appropriate derived form depending upon the requirements. Thus, the exercise in model evaluation is an important aspect of resource assessment in judging its performance in respect of its ability to estimate the components of the underlying processes more precisely and provide meaningful predictions, if necessary. If the system is simple enough, it may be possible to derive analytical solutions to the parameter estimation. Traditionally, the approach to modeling in fisheries focused on the interrelationship of fishery dependent factors and the yield. The other factors are clubbed with 'random noises' or were assumed in the long run to cancel out each other. A simple approach is to ignore uncertainty and random fluctuations. Such an approach leads to static, deterministic models. Application of such models for highly dynamic fish populations living in a fluctuating environment may lead to hazardous results. Thus, it is imperative to consider the various sources of bias, and the variations in estimating the parameters of the model for a proper understanding of the system and how the model parameters and the functions of the parameters react to the 'noise' caused by the various sources of bias and variations.

The analytical models are developed as functions or individual components of the system such as the recruitment, growth, mortality, etc. Various approaches are followed in estimating these parameters either singly or in combinations. These parameters are vital to stock assessment and the harvesting strategies depend on the reliability of the estimates of the parameters. Various methods are applied to calculate estimates of recruitment, stock sizes, and age groups. It is apparent that stock assessment techniques are highly dependent on available data, whether long or short-term predictions are the aim, both strengths and weaknesses are influenced by the abundance of this information. For correct predictions many techniques require large inputs of unbiased data, therefore the strength of any stock biomass prediction will be influenced by the weakness of the available inputs; validating final modal estimates of a fishery.

2.4 A summary of models and methods commonly used

Method	**Description**	**Data required**	**Output**	**Remarks**
Production model (also known as global model, surplus production model or catch-effort model)	Method of estimation of the past and current level of biomass and the state of the stock, from the analysis of the relationships between effort and catch. It is based on a growth equation, the relationship	Historical series of catch-effort data (usually on an annual basis) of one species.	The three parameters of the production model are obtained: Carrying capacity (equivalent to Virgin Biomass), catchability and growth rate. These three parameters allow drawing	Gives a very general view of the current state of the fishery and its history. Easy to relate to sound reference points. Inapplicable to multi-species fisheries, mainly due to the difficulties of effort allocation. Not suitable when clear

	$F=q \cdot E$ and the catch equation $C=F \cdot B$ There are several dynamic (non-equilibrium) models.		the equilibrium curve in the catch-effort plane. If the observed path of the fishery is also drawn on the same graphic, a very general and useful view of the fishery's history is obtained. MSY and E_{MSY}	changes of catchability (although this parameter can also be modelled) or changes in selectivity. The only control parameter is the effort.
Yield per recruit (Y/R)	Computes the yield that produces one recruit given particular exploitation pattern (F vector) at different intensities of effort.	Fishing mortality vector (F) Natural mortality vector (M) Age-length key or parameters of the growth model	Equilibrium surface of yield as function of overall F (or effort) and exploitation pattern (selectivity). Y_{MAX}, F_{MAX}, virgin biomass. All these results are relative (it means "by recruit")	The output is very synthetic and gives a general overview of the state of the fishery. Easy to relate to reference points (maxima, current stock vs. virgin stock, etc.). With this method it is easy to detect growth overfishing and get the clues of management alternatives. Assumes steady state
VPA (Virtual Population Analysis). Also called Cohort Analysis (particularly when Pope's	From catch-at-age data and some parameters, VPA reconstructs the past history of stock in terms	Catch-at-age of several years by operational unit (this implies previous age estimations and length composition of	Numbers of individuals and biomass at sea by year and age (thus series of recruitment, total biomass at sea etc.)	The most efficient standard assessment method. Many parameters are needed, some of

approach is used)	of number of individuals and fishing mortalities. The VPA, and its variants, is the most standard and reliable method of stock assessment.	catches) *M* vector Terminal *F*s (this imply tuning, through surveys or CPUEs) Length-weight relationship (if biomasses are wanted in the output)	Fishing mortality by year, age and operational unit	them assumed (*M*). Tuning is required. It is difficult to get a general view of the resource.
LCA (length cohort analysis)	A modification of VPAEssentially is a VPA on a pseudocohort that can be run also on the length frequency distribution of the catch. Steady state is assumed	A length or age frequency distribution of the catch representing the pseudocohort. *M* vector Terminal *F*s (this imply tuning, through surveys or CPUEs) Length-weight relationship (if biomasses are wanted in the output) Total catch in biomass by operational unit	Numbers of individuals and biomass at sea by age (recruitment, total biomass at sea etc.) Fishing mortality by age or length and operational unit	With short data series (even one year) something can be said about the state of the stock Since the steady state is assumed (pseudocohort), important biases can be obtained if this hypothesis is far from reality.
Time series analysis	The standard ARIMA method is the analysis of a time series (usually monthly structured) which is split off into trend (including cycles), seasonality and noise. Some further	Series of data, usually catch, CPUE, effort, data on vessel characteristics, environmental etc.	Most frequently the trend and seasonality of the variable analysed are obtained. When additional information (i.e. environmental) is added, it is possible to relate the	Absence of underlying biological hypotheses has both pros and cons. It is a powerful method to reveal hidden structures in the data. Useful for short term forecasting, with due caution in its

	developments, as transfer functions, allow to associate these outputs with environmental or other external variables, or intervention analysis to detect anomalous events.		behaviour of the dependent variable to other variables, such as effects of environment. Short term forecasting.	interpretation. Mainly descriptive.
Ecological approaches	Multispecies modelling. Some approaches are straight expansions of the indirect (population dynamics) assessment methods taking into account the biological interaction between species (technical, or technological interaction??can be studied by the classical methods). Multispecies VPA or MSVPA belong to this group. Other recent development is the individualbased approach Ecological modelling	In addition to the single species analysis data needs, it requires the interaction factors, particularly the quantification of the predator-prey relationships, diet composition data etc.	Quantified pathways of matter and energy between the different species (in steady state).	It approaches much better the real ecological system than the single species does. Huge amount of biological information is required. The number of interaction parameters to be estimated grows with the square of species considered (hence the unknowns become more numerous than the equations)

	based on mass balance and food webs approach – ECOPATH & ECOSIM			
Bio-economic approach	Approach including the population dynamics and the economic structure of fisheries. There are two main kinds of approach: simulation and optimisation techniques.	All population dynamics parameters Economic parameters concerning all aspects of extractive activities and commercialisation (costs, profits, prices, etc.)	Depends on the type of methodology used. Conditions giving optima according different criteria (optimisation approach) or results	Since the economics is, an important aspect driving the fishing activities, bio-economic modelling is much more realistic than purely biological (or purely economic) approaches. Many parameters are needed, hence the complexity of the model increases its uncertainties.
Simulation	Indirect (population dynamics) method that reproduce in the computer the dynamics of a stock. Often with the aim to test the effects of different environmental situations or alternative management actions.	All population dynamics parameters A recruitment-stock relationship	Projection to the future of different variables (biomass, catch) and trends at short and medium term. In the case of stochastic models confidence intervals are provided. Several management scenarios.	Very useful to analyse and compare the possible results of alternative management measures at short and medium term. To understand complex natural systems. Uncertainties in the projection, particularly because of the stock recruitment relationship.

3. Conclusion

In tropical fisheries such as those existing in India, it is quite difficult to age many fishes and then age structured analysis is not found practical with the development of length based methods such as the ELEFAN and LFDA. During the mid eighties there was an urge in the tropical fish stock assessment. In recent years, application of such methodologies was subject of considerable research and the statistical validity of some of the length based methods has been mentioned. Inspite of dubious validity of such approaches, these methods are still in vogue and extensively used in estimating population parameters.

Of late, multispecies and ecosystem based approaches are gaining currency. Biomass dynamics models too are increasingly being used to derive management reference points. Therefore, there is an urgent need for concerted research effort to establish the validity of the above approaches for management of tropical fisheries and evolve appropriate management options. For the application of ecosystem models such as the ecopath, sufficient data is required for use in the model such as diet composition etc. need to be generated. Application of biomass dynamic models need to be critically investigated in the context of impact of seasonal closures on the fishery and the biomass of the exploited stocks. Besides, there is urgent need to understand the socio-economic dynamics of the fisherfolk and the stakeholders directly involved in fishery and the related activities.

There is a need of better understanding of the dynamics of fish populations to do a better job of managing them. In doing stock assessments, the idea is to bring in as many kinds of information to assess the health of the stock, including numbers of fish, age distribution, sex distribution, and size distribution, because all of those factors affect the population dynamics and determine how the stock will respond to fishing pressure. Moreover, there is a need for development of new techniques that can better accommodate incomplete and variable data and can account for the effects of environmental fluctuations on fisheries. Such techniques should allow the specification of uncertainty in key parameters (rather than assuming constant, known values), should be robust to measurement error, and should include the ability to show the risks associated with estimated uncertainty. Therefore, the stock assessments should

- Incorporate Bayesian methods and other techniques to include realistic uncertainty in stock assessment models.
- Develop better assessment models and methods to evaluate the impacts of the quality of data on stock assessments.
- Account for effects of directional changes in environmental variables (e.g., those that would accompany climate change) in new models; and
- Develop new means to estimate changes in average catchability, selectivity, and mortality over time, rather than assuming that these parameters remain constant.

It is quite obvious from the foregoing analysis that fish stock assessment is an important exercise in fisheries resource management. However, there is increasing focus now on the assessment of the status of the communities and ecosystems where individual stocks are mere components, for a greater understanding of the dynamics of the total system. In this approach, socioeconomic variables are also integrated appropriating to facilitate decision making leading to sustainable development of fisheries, ecosystems, fishing communities and the industry. Nevertheless, modelling will never be able to provide estimates that are as accurate as direct knowledge obtained by measurement and experimentation. Thus, if future stock assessments are to avoid some of the past problems, management agencies must devote the necessary resources to monitor and investigate fish populations in a stable research environment that fosters creative approaches.

New approaches to fisheries management must be explored. These approaches should necessarily take into account the perspectives of the stakeholders. This calls for co-operative research that should involve the stakeholders, scientists and administrators. It should attempt cooperative efforts in data collection, assessment of exploited resources and evolving appropriate management measures. Community based management approaches should be attempted on a priority basis. For efficient implementation of suggested management strategies, regional fishery management commissions with necessary statutory power need to be formed.

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9

CONCEPTS OF GROWTH & MORTALITY OF FISH STOCKS

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Knowledge of growth and mortality is essential for a meaningful assessment of the exploited stock. The parameters of growth and mortality are components of majority of the yield models used to explain the dynamics of the exploited stocks and the effect of fishing on them.

GROWTH

The most widely used growth model in fish stock assessment is the von Bertalanffy growth function (vBGF) and which has been shown to conform to the observed growth of most fish species. The mathematical model expressing the length, L, as a function of the age (t) of the fish, is given by:

$$L(t) = L? * (1 – \exp(-K*(t-t_o))$$

Where,
L? = the asymptotic (the limiting) length the fish can attain (or the average of the maximum lengths of the fish in the population),
K = the curvature parameter (also known as Brody’s growth coefficient or “shrinkage” factor) that determines how soon or fast L? is reached,
t_o = the age at which the fish has zero length.
The generalised functional form the growth and the one which incorporates seasonal growth are found in Sparre and Venema (1992).

The weight-based von Bertalanffy growth equation

Combining the von Bertalanffy growth equation

$$L(t) = L? * (1 – \exp(-K * (t – t_o))$$

with the length / weight relationship

$$W(t) = a * L^3 (t)$$

gives the weight of a fish as a function of age:

$$W(t) = a*L?^3 * (1 – \exp(-K*(t-t_o))^3$$

The “asymptotic weight”, W?, corresponding to the asymptotic length is given by,

$$W? = a*L?^3$$

The parameter, a, is called the “condition factor”. Thus, “the weight-based von Bertalanffy equation” can be written:

$$W(t) = W? * (1 – \exp(-K*(t-t_o))^3$$

Data required

To estimate the parameters of the von Bertalanffy growth model, the sources of data are,

1) Age reading and length measurements combined
    a) data from resource surveys with a research vessel
    b) data from samples taken from commercial catches
2) Length measurements only
    a) data from resource surveys with a research vessel
    b) data from samples taken from commercial catches
3) Mark-recapture (tagging) experiments, where two (or more) length measurements are obtained, viz. at the time of marking (usually on a research vessel) and the time of recovery (usually by the commercial fishery).

Estimation of growth parameters from length-at-age data

If the pairs of observations of age and length are available then the estimates of the parameters can be obtained by

1. Non-linear regression approach
2. Ford-Walford plot method
3. von Bertallanfy's plot method

If the data from tagging is available then Gulland-Holt plot method cane be used to estimate, $L_{?}$ and K.

The above estimation procedures described in Sparre and Venema (1992)

Growth as estimated from length-frequency data

The methods conventionally used for the analysis of length-frequency data have been introduced by Petersen and can be reduced to two basic techniques:

- the "Petersen Method", that is the attribution of relative ages to the peaks in a length-frequency sample, and
- the "Modal Class Progression Analysis", that is the linking up of the peaks of length-frequency samples sequentially arranged in time by means of growth segments.

With the first method, the problem consists of identifying those peaks representing broods spawned at known or assumed time intervals. The method generally involves the separation of the length-frequency samples into normally or otherwise distributed subsets by graphical methods, probability plots, parabola plot etc.

The "modal class progression analysis", on the other hand, has its major problems in the identification of those peaks which should be connected (by growth lines) with each other.

However, the need for a rapid, yet reliable and *objective* method for the analysis of length-frequency data led to a radical computer based approach known as ELEFAN (Electronic Length Frequency Analysis) in the analysis of length-frequency data, and such an approach was presented in Pauly and David(see Sparre and Venema (1992). Another such computer based approach is the Sheperd's Length Composition Analysis (SLCA).

ELEFAN I is based on the following steps:

- ? objective identification (definition) of the peaks and the troughs separating peaks of a (set of) length-frequency sample(s)
- ? attribution to the peaks of a certain number of positive "points"
- ? attribution to troughs separating the peaks of a certain number of negative
- ? "points"
- ? iterative identification of those growth parameters generating a growth curve
- ? which, by passing through most peaks and avoiding most troughs,
- ? accumulates the highest number of "points" and thus best explains the specific structure of a (set of) length-frequency sample(s).

Given the assumptions that the sample(s) used represent(s) the population investigated, and that the growth of the fish in question conforms to the vBGF, (seasonalized or not), the method can be used to derive growth parameters that are reproducible. Moreover, an estimator is given of the proportion of the peaks in a (set of) sample(s) that are "explained" by the growth parameters obtained at the end of the iteration process. This estimator is the ratio of a sum called "Explained Sum of Peaks", or ESP, referring to the number of "points" explained by a given growth curve, divided by another sum called" Available Sum of Peaks", or ASP, which refers to the total number of points "available" in a (set of) length-frequency samples).1 (See Sparre and Venema (1992) for details). The method which can be readily implemented on microcomputers, is fast, reliable, and objective.

MORTALITY

Total Mortality

A basic equation used in fishery biology for expressing the mortality of fish is

$$N_t = N_o e^{-Zt}$$

where N_o and N_t are fish numbers at time zero and t, respectively and where Z is the total mortality affecting the stock. Also, we have , $Z = F+M$,which states that total mortality is the sum of fishing mortality (F) plus natural mortality (M). If the age frequency data, meaning numbers caught by age are available, estimation Z is straight forward and the methods of estimation are described by Sparre and Venema (1992).

In tropical waters, where obtaining age-frequency data is rather difficult, the mortality is usually estimated from the length frequency data and assuming a suitable growth model for the length such as the von Bertalanffy growth model, with known parametric values.

One of the simplest methods employed to estimate the total mortality (Z) is from the mean length in the catch (Lbar) for a known length at first capture (Lc) or a known length (L') from which the fish are assumed to be fully vulnerable. The equation is given by Beverton and Holt (Gulland, 1983) where

$$Z = K^*(L_? - Lbar)/(Lbar - Lc)$$

and Pauly suggested using L’ instead of Lc in the equation. ($L_?$ and K have their usual meaning and are known). where L’ is “some length for which all fish of that length and longer are under full exploitation”. Note that L’ is the lower limit of the corresponding length interval.

One of the methods commonly applied in temperate waters to estimate total mortality is the “linearized catch curve method with constant time intervals”, which is given by

$$Ln(Ct) = a - Z^*t$$ (Ct is numbers caught of age t)

Typically, a catch curve will have an ascending left limb and a descending right limb and Z is estimated from the regression of ‘Ln(Ct)’ on ‘t’ from the points of the right limb.

The linearized catch curve based on length composition data

It is often referred to as the “length-converted catch curve” or the “linearized length-converted catch curve”. What is actually done is to convert length data into age data, using the inverse von Bertalanffy growth equation and the equation used is

$$Ln (Nt/?t) = a - Z^* t^{bar}$$

Where, Nt is the number caught in given length class,
?t is the time taken to grow from the lower limit of the length class to the upper limit of the length class and
t^{bar} is the average of the relative ages corresponding to the lower and upper limit of the given length class.
The plot of the curve obtained from above equation will resemble the one of the age based catch curve, and Z is estimated from the regression of ‘Ln(Nt/?t)’ on ‘t^{bar}’ from the points on the descending right limb. The procedure of deriving the length catch curve and the estimation of Z is explained in detail by Sparre and Venema(1992).

Another method of estimating Z using length data is by Jones and van Zalinge, which is popularly called the “cumulative catch” curve method.
The “Jones and van Zalinge equation” is:

$$Ln\ C(L, L?) = a + Z/K ^*Ln (L? - L)$$

Where, C(L, L?) is the cumulative catch from L onwards (L is the lower limit of the length class).

Natural mortality

Natural mortality (M) is a parameter that is generally extremely difficult to estimate, and typically, natural mortality estimates of tropical fish have been obtained from estimates of total mortality in stocks known, or assumed to be unfished.. In a few cases, however, it has been possible to obtain time series of values of Z from the same stock, and to plot these against their corresponding values of effort, with M being obtained from the intercept of the line fitted to these data. The natural mortality is the mortality created by all other causes than fishing, e.g., predation including cannibalism, diseases, spawning stress, starvation, and old age. Predation and starvation mortalities and several others are linked to the ambient ecosystem. The same species may have different natural mortality rates in different areas dependent on the density of predators and competitors whose abundance is influenced by fishing activities. As direct measurements of M are often impossible to obtain, it has been attempted to identify quantities which can be assumed proportional to M and which are easier to measure (or estimate).

Longevity can be considered more closely related to mortality than K, L? or ambient temperature. Alagaraja (1984) suggested another way of illustrating the concept of the mortality coefficient. He tentatively defined the natural life span of fish species (or the longevity) as the age at which 99% of a cohort had died if it had been exposed to natural mortality only (i.e. if Z = M). if Tm stands for longevity and M1% stands for the natural corresponding to a 1% survival, then:

$$M1\% = \ln(0.01)/Tm$$

Pauly (1980) made a regression analysis of M (per year) on K (per year), L? (cm) and T (average annual temperature at the surface in degrees centigrade), based on data from 175 different fish stocks, and estimated the empirical linear relationship.

$$\ln M = -0.0152 - 0.279 * \ln L? + 0.6543 * \ln K + 0.463 * \ln T$$

Srinath (1998) has derived a simpler empirical equation to estimate M, for the fishes in the temperature range of 26? to 28? C , which represents, in general, mean annual temperature range obtained in the tropical waters. The equation which has better predictability than the one derived by Pauly(1980) is given by

$$M = 0.4615 + 1.4753 * K$$

Rikhter and Efanov (1976) showed a close association between M and Tm50% the age when 50% of the population is mature (also called “the age of massive maturation”):

$$M = 1.521 / (Tm50\%^{0.720}) - 0.155 \quad \text{per year}$$

Tm50% should be equal to the “optimum age” defined as the age at which the biomass of a cohort is maximal.

Fishing mortality

Fishing mortality is the most important parameter that should be known in order to assess the effect of fishing on the exploited stocks and also to estimate the rate of exploitation.

Of the various methods used to estimate fishing mortality, four may be listed here:

- tagging/recapture studies
- subtraction of M from Z
- swept-area method in the case of trawlable demersal stocks
- Virtual Population Analysis (VP A) or Cohort Analysis

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MACRO ANALYTICAL MODELS - SURPLUS PRODUCTION

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Surplus production models are an important approach to the study of harvested populations' dynamics. Such models are based on quite simple equations where both the state of the population and fishing activity are each described by a single variable. These models take into account only the interrelationship between observable inputs such as fishing effort and observable output which is the yield obtained from the fishery. In surplus production models the stock is considered as a single unit of biomass and modeling is not based on any age structure, length structure or dynamics of the population in terms of growth and mortalities. Instead, in these models the entire stock, the fishing effort and the total yield obtained from the stock are studied and a relationship between these are established without considering any micro level details such as growth, mortality, age at first capture, mesh size effect etc. The objective here is to obtain optimum levels of effort, which gives the maximum yield that can be sustained over a long period. These models do not demand much data for the analysis and for this reason these models more popular. When reasonable estimates are available for the yield and corresponding fishing efforts over a period of time these models can be used for obtaining optimum levels of effort and corresponding yield estimates.

Production models are classified into two major groups namely Macro / Global / Synthetic models and Micro Analytical Models. Surplus production models are Macro analytical models.

Change in biomass depends on recruitment, growth and mortality. This can be represented by the following equation

$$B_{t?1} ? B_t ? R_t ? G_t ? Z_t$$

where B_t is the biomass at time *t*, R_t is the weight of the new recruits into the fishery, G_t is the total increase in the weight of the animals due to growth and Z_t is the weight of the animals died during the period. Then production is given by

$$P_t ? B_{t?1} ? B_t ? R_t ? G_t ? Z_t$$

The population is in equilibrium when production is zero.
When

$P_t ? 0$, population is in equilibrium.

$P_t ? 0$, population is in surplus

$P_t ? 0$, population is in depletion

The population may collapse when P_t goes beyond some values. Here biomass is a point time concept and yield or production is a period concept.

At given time *t*, under fishing activity f_t and population state B_t, the change in B_t is assumed to depend on population state and fishing activity. Hence the equation used commonly to define surplus production models is

$$\frac{dB_t}{dt} = g(f_t, B_t)$$

Different versions of this model are given by different workers, such as

1. Pella and Tomlinson

$$\frac{dB_t}{dt} = r\,B_t \left[1 - \left(\frac{B_t}{B_0}\right)^{m-1}\right] - q\,f_t\,B_t$$

2. Graham Schaefer's model

$$\frac{dB_t}{dt} = r\,B_t \left[1 - \left(\frac{B_t}{B_0}\right)^{2}\right] - q\,f_t\,B_t$$

3. Exponential model

$$\frac{dB_t}{dt} = r\,B_t \left[1 - \ln\left(\frac{B_t}{B_0}\right)\right] - q\,f_t\,B_t$$

Here B_0, r, m and q are parameters of the model which have to be estimated using data on yield and fishing effort.

In surplus production model the rate of increase in biomass is taken as a function of biomass itself so that the relative change is given by the equation

$$\frac{1}{B_t}\frac{dB_t}{dt} = f(B_t) - F_t \quad \text{where } F_t = q\,f_t$$

and F_t is the reduction in biomass due to fishing. When the production is surplus the relative change in biomass will be positive and it will be zero when the population is in the state of equilibrium and hence $f(B_t) = F_t$ at equilibrium.

Graham-Schaefer Model: In this model the first order differential equation is used to describe the rate of change of stock biomass B_t due to production. In the absence of fishing the rate of change in the biomass is assumed to be a function of current population size only. That is

$$\frac{dB_t}{dt} = rB_t - \frac{r}{K}B_t^2$$

where B_t is the biomass at time *t*, *K* is the carrying capacity beyond which the population can not grow and *r* is the intrinsic rate of increase in stock per unit time. When fishing mortality is added to this model it becomes,

$$\frac{dB_t}{dt} ? (r ? F_t)B_t ? \frac{r}{K}B_t^2$$
$$? ?_t B_t ? ? B_t^2$$

where $?_t ? (r ? F_t)$, $? ? \frac{r}{K}$ and F_t is the instantaneous rate of fishing mortality.

For a short period $(t ? h, t ? h ? ?)$ during which the instantaneous rate of fishing mortality F_t is constant, the solution of the differential equation is

$$B_{h??} ? \begin{cases} \dfrac{?_h B_h e^{?_h ?}}{?_h ? ? B_h e^{?_h ? ?1}} & when\ ?_h ? 0 \\ \dfrac{B_h}{1 ? ? ? B_h} & when\ ?_h ? 0 \end{cases}$$

and yield during the same period denoted by Y_h is

$$Y_h ? \int_{t?h}^{t?h??} F_t B_t \, dt$$

and solution of this integral yields

$$Y_h ? \begin{cases} \dfrac{F_h}{?} \ln[1 ? \dfrac{? B_h (1 ? e^{?_h ?})}{?_h}] & when\ ?_h ? 0 \\ \dfrac{F_h}{?} \ln[1 ? ? ? B_h] & when\ ?_h ? 0 \end{cases}$$

The estimated average biomass during this short period $(t ? h, t ? h ? ?)$ is given by

$$\overline{B}_h ? \frac{Y_h}{F_h}.$$

The surplus production during this period $(t ? h, t ? h ? ?)$ is

$$P_h ? B_{h??} ? B_h ? Y_h$$

When yield is equal to surplus production, the population is in equilibrium.

Parameter Estimation: It is assumed that the yield Y_t at equal time periods *t=1,…,T* are available. The following notations and assumptions are made for estimation purpose.

B_t : Population biomass at start of time *t*

Y_t : Yield in biomass during time *t*

P_t : Surplus production during time *t*

F_t : Fishing mortality rate during time *t*, assumed to be proportional to fishing effort rate.

f_t : Fishing effort rate during time *t*

q : Catchability coefficient

$F_t ? q\, f_t$

$?_t ? r ? F_t$

Parameters to be estimated are *r, K, q* and the initial biomass B_1.

Algorithm for estimation: The estimation procedure is by minimizing an objective function. With some starting guess estimates of the parameters compute the initial biomass and project through time estimating the yield for each time point *t=1,…,T*. The procedure is then iterative leading to the general function minimization procedure with the function to be minimized is

$$f(r, K, q, B_1) ? \overset{T}{\underset{t?1}{?}} [\log(Y_t) ? \log(\hat{Y}_t)]^2$$

where Y_t is the actual yield and $\hat{Y}_t$ is the corresponding yield estimated according to the model. Fishing mortality can also be estimated from recorded yield using the equation

$$F_t ? \begin{cases} \dfrac{? \ Y_t}{\ln[\dfrac{? \ B_t e^{?_t ?1}}{?_t} ? 1]} & when\ ?_t ? 0 \\ \dfrac{? Y_t}{\ln(1 ? \ ? B_t)} & when\ ?_t ? 0 \end{cases}$$

<u>Pella and Tomlinson's Model</u>: One problem with the Graham-Schaefer model is that the maximum sustainable yield *MSY* always occurs when the biomass is half the carrying capacity *K*. This is a direct consequence of the parabolic relationship between $\frac{dB_t}{dt}$ and B_t, which in turn follows from the linear relationship between per capita productivity and population size. Pella and Tomlinson (1969) proposed an alteration to the model for which uncouples B_{MSY} from *K*. One form of this model is given by

$$\frac{dB_t}{dt} ? \begin{cases} a\ B_t^n ? b\ B_t & for\ 0 ? n ? 1 \\ b\ B_t ? a\ B_t^n & for\ n ? 1 \end{cases}$$

Simple forms

1. The simple representation of Schaefer model is

   $$(Y_t / f_t) ? a ? b\, f_t$$

   For this model the catch per unit effort is considered as a linear function of effort and the linear relationship has negative slope and positive intercept. Under this model the catch per unit effort will be maximum when

$$f_t \; ? \; \frac{? \, a}{b}$$

The maximum sustainable yield (*MSY*) for the model is

$$MSY \; ? \; \frac{? \, a^2}{4b}$$

and the corresponding effort is

$$f_{MSY} \; ? \; \frac{? \, a}{2b}$$

When we have time series data on catch and effort by a linear regression of catch per unit effort (CPUE) on effort, we can estimate the coefficients *a* and *b* and calculate MSY using this estimates.

2. In the model suggested by Fox, exponential relationship between *CPUE* and effort is assumed. The model is given by

$$Y_t / f_t \; ? \; e^{c \, ? \, d \, f_t}$$ or equivalently

$$\ln(Y_t / f_t) \; ? \; c \; ? \; d \; f_t$$

This function will have maximum value for the yield when

$$f_t \; ? \; \frac{? \, 1}{d}$$

and the maximum value of yield (*MSY*) is given by

$$MSY \; ? \; \frac{? \, 1}{d} e^{c ? 1}$$

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MICRO-ANALYTICAL MODELS – RELATIVE YIELD PER RECRUIT

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Beverton and Holts yield per recruit model is a steady state model. A model that describes the state of the stock and yield when the fishing pattern has been the same over a long period so that all recruited fish alive are exposed to fishing is termed as a steady state model. The Beverton and Holts model makes the following assumptions.

1. Recruitment is constant
2. All fish belonging to a cohort are born on the same day
3. Recruitment and selection are knife-edged
4. Fishing and natural mortalities are constant through out the phase after recruitment
5. There is complete mixing within the stock
6. Growth in weight is isometric. That is $b ? 3$ in $W_t ? a L_t^b$

At the age at recruitment t_r of the cohort, numbers recruited is

$$R ? N_{t_r}$$

Number of survivors at age t_c, age at first capture, is

$$N_{t_c} ? R e^{? M (t_c ? t_r)}$$

because only natural mortality operates on the cohort between age t_r and t_c.
Number of survivors of the recruited cohort at age *t* is give by the equation

$$N_t ? N_{t_c} e^{? (M ? F)(t ? t_c)}$$

$$? R e^{? M (t_c ? t_r) ? (M ? F)(t ? t_c)}$$

The fraction of the recruits surviving up to age *t* is given by

$$\frac{N_t}{R} ? e^{? M (t_c ? t_r) ? (M ? F)(t ? t_c)}$$

The numbers caught between a very small interval $(t, t ? ?)$ is given by

$$C(t, t ? ?) ? ? F N_t$$

To obtain the yield we have to multiply this with the weight of the animal and hence we get the expression for yield from the cohort during this short period as

$$Y(t, t ? ?) ? ? \; F \; N_t \, W_t \text{ where } W_t \; ? \; a \, L_t^3$$

The relative yield is then obtained as

$$\frac{Y(t, t ? ?)}{R} ? ? \; F \, \frac{N_t}{R} W_t$$

which is the relative yield from the recruited cohort during the period $(t, \; t ? ?)$.
To obtain the total relative yield from the cohort during the entire life span of the cohort we have to add such quantities from age t_c onwards. The expression for the total relative yield then is

$$\frac{Y}{R} ? \sum_{i?1}^{n} \frac{Y(t ? (i ? 1)? , t ? i?)}{R}$$

where n is choosen sufficiently large to cover the entire life span of the cohort. The above sum finally reduce to the following form after a set of substitutions and simplifications.

$$\frac{Y}{R} ? \; F \, e^{?M(t_c ? t_r)} \, W_? \; ?\frac{1}{Z} ? \frac{3S}{Z ? K} ? \frac{3S^2}{Z ? 2K} ? \frac{S^3}{Z ? 3K} ? \text{ where}$$

$$S \; ? \; e^{? K(t_c ? t_0)}$$

$K, t_0, W_?$ are Von Bertalaffy growth parameters

t_c : age at first capture

t_r : age at recruitment

F : fishing mortality

M : natural mortality

$\frac{Y}{R}$: the yield per recruit in grams per recruit.

It is important to note that t_c and F are the two parameters over which the fishery managers have control. Fishing mortality F is proportional to effort and t_c is a function of gear selectivity which in turn is related to mesh size. Hence $\frac{Y}{R}$ can be considered as a function of F and t_c, and often $\frac{Y}{R}$ values are calculated for varying inputs of F and plotted for finding optimum value of F. This curve is known as yield per recruit curve and it often has a maximum that corresponds to the Maximum Sustainable Yield (MSY). This maximum changes as the value of t_c used is changed. By varying F and t_c simultaneously we can obtain a combination of F and t_c which gives the highest value for MSY. The above model is based on age of the cohorts. A similar version based on length of the cohort is given below.

When growth is isometric Beverton and Holt obtained the relation

$$\left(Y/R\right)' = E\,U^{M/K}\left[1 - \frac{3U}{1+m} + \frac{3U^2}{1+2m} - \frac{U^3}{1+3m}\right] \qquad (1)$$

where

$$m = \frac{1-E}{M/K} = \frac{K}{Z}$$

$$U = 1 - \frac{L_c}{L_\infty}$$

$E = \frac{F}{Z}$ is the exploitation rate (fraction of deaths due to fishing).

K, L_∞ : Von Bertalanffy growth parameters

F : Fishing mortality coefficient

M: Natural mortality coefficient

The relation between relative yield per recruit and $\left(Y/R\right)$ is

$$\left(Y/R\right) = W_\infty\, e^{M(t_r - t_0)} \left(Y/R\right)' \qquad (2)$$

Using the above relation the Maximum Sustainable Yield can be obtained in the following steps.

- For the present level of exploitation (the estimated F which corresponds to the present level of exploitation, $E = \frac{F}{Z}$) calculate the quantity $\left(Y/R\right)'$ using equation (1).
- Calculate corresponding $\left(Y/R\right)$ using equation (2).
- This will be the yield per recruit for the present level of exploitation and since we know the present yield Y (catch) we can obtain the recruitment R by dividing yield by yield per recruit.
- Estimate $\left(Y/R\right)'$ for different levels of exploitation rates E and from the plot of $\left(Y/R\right)'$ against E or other wise find the maximum sustainable value of $\left(Y/R\right)'$, say MS $\left(Y/R\right)'$.
- Calculate MS $\left(Y/R\right)$ using equation (2) corresponding to the value of MS $\left(Y/R\right)'$.
- To get MSY multiply MS $\left(Y/R\right)$ by R.

Jones Modified Method of Yield Per Recruit:

The major flow in Beverton and Holts method is that it requires isometric growth. Jones (1957) suggested a general procedure for estimating yield per recruit as follows.

The instantaneous rate of yield when $W_t\ ?\ aL_t^b$ is

$$\frac{dY_t}{dt}\ ?\ F\ N_t\ a\ L_?^b\ [1\,?\,e^{?K(t?t_0)^b}\,]$$

Jones obtained by transformation and integration that

$$\frac{Y}{R}\ ?\ \frac{F}{K}\,a\ L_?^b\ \ e^{?M(t_c?t_r)}\ \ e^{(F?M)(t_c?t_0)}\ \ ?e^{?K(t_c?t_0)}\ x^{\frac{F?M}{K}\,?\,1}\ (1\,?\,x)^b\,dx$$

The integral part in the above equation is in the form of an incomplete beta function given by

$$?\,(z;p;q)\ ?\ ?_0^z x^{p?1}\ (1\,?\,x)^{q?1}\ dx$$

where $p\ ?\ \frac{F\ ?\ M}{K}\ ?\ \frac{Z}{K}$, $q\ ?\ b\,?\,1$ and $z\ ?\ e^{?K(t_c?t_0)}$. Values of beta function are tabulated and will be available in statistical tables.

MICRO-ANALYTICAL MODELS – VIRTUAL POPULATION ANALYSIS, THOMPSON & BELL

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The most methods currently used in temperate fisheries stock assessments rely on catch-at-age data an among them virtual population analysis (VPA) or cohort analysis is the most common method that calculates stock size based on catches with no underlying statistical assumptions. Virtual population analysis (VPA) calculates past stock abundances based on past catches. Once stock sizes are calculated, fishing size-selectivity as well as changes in vulnerability over time can be determined. The stock size estimates, which include recruitment estimates for each year, can be used for stock and recruitment analysis. VPA, also known as cohort analysis, is one of the most powerful techniques available for the analysis of fisheries data and forms the heart of many current assessment methods where catch-at-age data are available. Virtual population analysis or VPA is basically an analysis of the catches of commercial fisheries, obtained through fishery statistics, combined with detailed information on the contribution of each cohort to the catch, which is usually obtained through sampling progrmmes and age readings. The word "virtual", introduced by Fry is based on the analogy with the "virtual image", known from physics. A "virtual population" is not the real population, but it is the only one that is seen. The idea behind the method is to analyse that what can be seen, the catch, inorder to calculate the population that must have been in the water to produce this catch.

VPA therefore looks at a population in an historic perspective. The advantage of doing a VPA is that once the history is known it becomes easier to predict the future catches, which is usually one of the most important tasks of fishery scientists.

Virtual population analysis calculates the number of fish alive in each cohort for each past year. It is also called cohort analysis because each cohort is analysed separately. VPA relies on a very simple relationship for each cohort. If we knew the initial cohort size, and the natural mortality rate, we could use the equation to calculate the number alive each year. Unfortunately, we rarely if ever know the initial number alive; this is in fact one of the things we want cohort analysis to tell us.

The basic equation for VPA is

Number alive		Number alive		Catch		Natural
At Beginning	=	at beginning	+	this	+	mortality
Of this year		of next year		year		this year

If we are willing to assume that at some age there are none alive (or that we know the number alive at some terminal age) and that we know the natural mortality rate, we can use above equation to iteratively calculate the number alive each year, starting from the oldest ages and moving backward to the youngest.

Age-based cohort analysis (Pope's cohort analysis)

As derived from the catch equation, the VPA implied the solutation by some numerical techniques (some trial and error method). This is a minor technical problem when one has access to a computer. However, the problem can be circumvented in an easy way, so that VPA can also be carried out on a pocket calculator. The version of VPA suitable for pocket calculators is the "cohort analysis" developed by Pope (1972).

Cohort analysis is conceptually identical to VPA, but the calculation technique is simpler. It is based on an approximation, illustrated which shows the number of survivors of a cohort during one year. The catch is taken continuously during the year, but in cohort analysis the assumption is made that all fish are caught on one single day..

Consequently in the first half year the fish suffer only natural mortality so the number of survivors becomes:

$$N (y, t + 0.5) = N (y, t) * \exp (-M/2)$$

Then, instantaneously, the catch is taken and the number of survivors becomes:

$$N (y , t) * \exp (-M/2) – C (y, t, t + 1)$$

This number of survivors then suffers further only natural mortality in the ssecond half year and finally the number of survivors at the end of the year is:

$$N (y+1, t+1) = (N (y, t) * \exp (-M/2) – C (y, t, t+1)) * \exp (-M/2)$$

For convenience of calculation this equation is rearranged as:

$$N (y, t) = (N (y + 1, t + 1) * \exp (M/2) + C (y, t, t+1)) * \exp (M/2)$$

Note that the F that caused computational problems in the VPA equation does not occur here.

Jones' Length-based cohort analysis

Keeping in view the difficulty in determination of ages for certain resources and also the fact that it is rather difficult to obtain age-frequency data for most of the tropical fish, cohort analysis described above is modified to make use of the length frequency data (length composition data for the total fishery are available for one year or the average length composition for a sequence of years). According to Sparre et.al () the name "length-based cohort analysis" is somewhat misleading, as we are nor dealing with real cohorts in the present analysis. The real cohort is replaced by a "pseudo-cohort" which is based on the assumption of a constant parameter system. Thus, it is assumed that the picture presented by all length (or age) classes caught during one year reflects that of a single cohort during its entire life span.

To convert the cohort analysis equation into a length-based version, only the term exp (M* ? t /2) has to be changed.

It is convenient to use a symbol instead of this complicated term, therefore we introduce the symbols:

N(L1) = N (t (L1)) = the number of fish that attain length L1
= the number of fish that attain age t (L1)
(also called the number of survivors)
N(L2) = N (t (L1 + ? t) = the number of fish that attain length L2
= the number of fish that attain age t (L2)
(= t (L1 + ? t)
C (L1, L2) = C (t, t + ? t) = the number of fish caught of lengths between L1 and L2
= the number of fish caught of ages between t (L1) and t (L2)

Now equation can be rewritten using these length-based symbols, as:

N (L1) = (N (L2) * H (L1, L2) + C (L1, L2))) * H (L1, L2)

The calculation procedure of equation is similar to that of the age-based cohort analysis. We start with the last group and use the length-based form of the catch equation

C (L1, L2) = N (L1) * C/Z * (1 – exp (- Z* ? t)

Thompson and Bell model

The first predictive model developed much earlier than the Beverton and Holt model was by Thompson and Bell (1934). The Thompson and Bell model is the exact opposite of the VPA and cohort analysis. It is used to predict the effects of changes in the fishing effort on future yields, while VPA and cohort analysis are used to determine the numbers of fish that must have been present in the sea, to account for a known sustained catch, and the fishing effort that must have been expended on each age or length group to obtain the numbers caught. Therefore, VPA and cohort analysis are called historic or retrospective models, while the Thompson and Bell model is predictive.

The Thompson and Bell model is a very important tool for the fishery scientist to demonstrate the effect that certain management measures, such as changes in the minimum mesh size, decreases or increases of fishing effort, or closed seasons will have on the yield, the biomass and the value of the catch. Since a large number of calculations is required, it is essential to use computers.

An important aspect of the Thompson and Bell model is that it allows for the incorporation of the value of the catch. Therefore, the model has become the basis for the development of so-called bio-economic models, which are extremely useful for the provision of predictions needed for management decisions.

Age based model

The Thompson and Bell method consists of two main stages: 1) Provision of essential and optional inputs and 2) the calculation of outputs in the form of predictions of future yields, biomass levels and even the value of the future yields.

1) Provision of inputs: The main input is a so-called “reference F-at-age-array”, an array of F-values per age group. In principle any F-array could be used as input, but, of course, not just any F-array will produce results which are related to the real situation of a fishery. Therefore, it is customary to use an F-array that has been obtained from an analysis of historical data, in other words from a VPA or a cohort analysis

   Another important input parameter is the number of recruits, which may also be obtained from VPA or cohort analysis. This input is needed to obtain predictions of yields etc. in absolute quantities. However, if this input is not available the Thompson and Bell model can still be used to provide relative figures as output, for example, in th4e form of units “per 1000 recruits”.

   The model further requires a “weight-at-age-array”, the weights of individual fish per age group. For economic analyses the model also requires inputs of value, usually in the form of the price per kg by age group. (For the length-based Thompson and Bell model the same type of input is required per length group).

2) Outputs: The output of the model is in the form of predictions of the catch in numbers, the total number of deaths, the yield, the mean biomass and the value, all pr age group, related to values of F for each age group. New values of F can be obtained by multiplying the reference F-array as a whole by a certain factor, usually called X, or by applying such factors only to a part of the reference F-array. The latter is applied, for example, in the case of a change in the minimum mesh size, or to separate the effect of fleets with different characteristics (e.g. artisanal and industrial) on a particular stock. By carrying out a whole series of calculations with different values for X (F-factors), graphs can be drawn that illustrate clearly the effects of changes in F on the yield, the average biomass and the value of the catch.

The “length-based Thompson and Bell model” takes its inputs from a length-based cohort analysis. The inputs consist of the fishing mortalities by length group, the F-at-length-array, the number of fish in the smallest length group, the growth parameter K and the natural mortality factor H by length group, which must be the same as the ones used in the cohort analysis. Additional inputs are the parameters of a length-weight relationship (or the average weight of a single fish or shrimp by length group) and the average price per kg by length group.

The outputs are the same as for the age-based model, viz., for each length group the number at the lower limit of the length group, N(L1), the catch in numbers, the yield in weight, the biomass multiplied by ?t, i.e. the time required to grow from the lower limit to the upper limit of the length group and the value. Finally, the totals of the catch, yield, mean biomass * ?t and value are obtained. The calculations are repeated for a range of X values (F-arrays) and the final results (totals) are plotted in graphs. The principle is the same as that described above for the age-based models, only the formulas are slightly different. They can be derived from those used for Jones' length-based cohort analysis.

Since the length-based Thompson and Bell analysis is derived from Jones' length-based cohort analysis which in turn is based on Pope's age-based cohort analysis, the length-based Thompson and Bell method has the same limitations as Pope's age-based cohort analysis. The approximation to VPA in the predictive mode is valid for values of F* ?t up to 1.2 and of M* ?t up to 0.3 (Pope, 1972, as quoted by Sparre and Vemema, 1992). If the F's are high, nonsensical results will come out of the analysis, such as negative stock numbers. If that is the case, smaller length groups and hence, smaller ?t values, are required.

For further reading:

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FISHERIES MANAGEMENT TECHNIQUES

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Introduction

Marine living resources are by no means inexhaustible, although some of them are extremely rich. In India, the production of marine fish increased by about 5.5 times in 55 years, from 0.5 million tonnes in 1948 to 2.7 m t in 2003. However, the catch rate is on the decline in many centers, and the scope for further increase in catch from the inshore waters is limited. To sustain marine fish production, a consistent fisheries management policy and implementation of management measures are needed. In recent years, considerable time and effort have been spent, discussing the need for and modalities of marine fisheries management involving the fisheries scientists, politicians, managers and fisherfolk.

Fisheries management is a dynamic resource allocation process where ecological, economic and institutional resources of a fisheries exploitation system are distributed with value to the society as the overall goal (Silvestre and Pauly, 1997). As the coastal fisheries are set in a variety of natural and human conditions, a wide diversity of specific objectives need to be pursued for their management. Multiplicities of issues confront the fisheries sector in achieving the management objectives. Devaraj and Vivekanandan (1999) identified the following major issues in coastal fisheries: increasing population of fisherfolk, increasing fishing intensity, inappropriate exploitation pattern, use of destructive gears, fish stock decline, biodiversity decline, inefficient marketing system, inadequate handling and processing of the produce, discards and postharvest losses, sectoral conflicts, poverty, illiteracy and poor hygiene among the artisanal fisherfolk, inadequate fisheries policies, resistance by the fisherfolk to follow fishing regulations, and low financial resource allocation for the fisheries sector.

Objectives of fisheries management

The need to manage fisheries arises from two conditions. First, there is a need to limit the harvest to what the fish stocks can sustain. Second, property rights to fish stocks are difficult to establish, leading to intersectoral conflicts. The central idea to keep in mind about the management of fisheries is that the problems encountered in fish production are unique compared to any other commercial sector industry. The limited but renewable nature of the resources and the ownership conflicts have no parallel in other sectors. When any other area of the economy collapses, there is a chance that it could be rebuilt, but if a fish stock depletes, it is a very difficult task, though not impossible, to rebuild.

Fisheries represent one of the best examples of the exploitation of the natural resources. One of the most important characteristics of capture fisheries is that the resources are a common property, the access to which is free and open. Irrespective of the type of exploiters: artisanal fishers or large fleet owners or joint venture operators, their operation will not be limited until the zero profitability threshold is reached. Hence, there is a need for a manager to intervene and regulate their activity.

The general objectives of fisheries management are to achieve nutritional security, maintain sustainability of the resources, and ensure gainful employment and economic benefits. To achieve this, a multidisciplinary approach involving biological, environmental, social, economic and administrative instruments is necessary (Silvestre and Pauly, 1997).

Principles of fisheries management

Management should be an integral part of any developmental activity. Fisheries development also should have effective management plans as integral part of the developmental strategy. The principle of fisheries management is to follow the model, which gives the best relationship between fishing effort and production. The generally observed relationship is that when the effort increases, the catch also increases initially almost proportionately. Later, the increase in catch slows compared to that of the effort (Fig. 1) with the result there is a progressive decrease in the catch rate (Fig. 2). If there is no management, the fishery will progress and reach the maximum yield and realise maximum value initially (point A in Fig. 3). It will progress further and reach point B, when the yield (or value) is equal to the cost of fishing. It is only at this stage, the need for management is felt, and the government compensates in the form of aids and subsidies and makes attempts to continue the profitability. Exhausting all other possibilities, the fishery will not progress beyond point C when only the running costs like fuel and labour are met with by both the fish yield value and the government aids (Gulland, 1972). Once arriving at this point of development, it is obvious that the crisis cannot be solved without stringent action, which may lead to socioeconomic upsets. Hence, it is preferable that management intervenes during the early phase itself in the development of a fishery. It is much easier to slow down expansion in the earlier phase than to reduce exploitation levels when the situation reaches a crisis.

The development of a fishery over the time scale can be categorised as (i) predevelopment phase, (ii) growth phase, (iii) full exploitation phase, (iv) overexploitation phase, and eventually (v) collapse phase, and may be, (vi) recovery phase (Csirke, 1984). In a well-planned fishery, effort is controlled during growth phase and catches are sustained at the level of full exploitation over a long period with no apparent risk of collapse, unless adverse environmental conditions occur. The principles and techniques of management vary during the different phases of a fishery. When the fishery is in the predeveloped phase, it has to be promoted; when it is in growth or fully exploited phase, it should be maintained; and when it is in an overexploited phase, attempts should be made to recover the fishery (Table 1).

In an uncontrolled fishery, on the other hand, the passage from the fully exploited phase to the overexploited phase occurs very rapidly, and if not controlled in time, leads to collapse. Coastal marine fisheries in India remained in a predeveloped phase till 1962 (premechanisation period; annual production: <0.8 m t) and on a prolonged growth phase till 1988 (mechanization period; increase in the number and efficiency of fishing vessels; annual production: 0.8 to1.8 m t); this is followed by the fully exploited phase, which lasted for 15 years till 2003 (exploitation of underexploited coastal areas and further increase in effort; annual production: 1.8 to 2.6 m t). The effort (in terms of fishing effort and fisher population) increased steadily throughout the three phases of development, more so in the fully exploited phase. Unless effective management measures are implemented, there may be a severe drop in the production in the future years.

The present fully exploited phase of the coastal fishery can be continued if the area of exploitable fishing grounds is increased in proportion to the increase in fisherfolk population and number of craft. Presently, only about 20% of the total fishing effort is in areas >50 m depth. Extending about 50% of the total fishing effort to 50-200 m depth may prolong the fully exploited phase.

Promoting an underdeveloped fishery

In most fisheries, their different constituents are usually in various stages of development. For instance, in spite of the transition of the Indian coastal fisheries entering the fully exploited phase, a few specific fishery groups like the pelagic sharks, tunas, bullseye, deepsea prawns and a few other deepsea fish stocks are still in the underexploited phase. The management for these stocks should aim at creating proper fishing opportunities in terms of appropriate fleets, postharvest value addition and training the interested groups of fisherfolks and entrepreneurs in the relevant technologies. There should be greater focus on investments in the types of craft and gear and equipments best suited for exploiting the identified stocks and processing them into products of demand. Prudent planning is extremely important to prevent risks of collapse, if the fishery becomes successful, but left without control.

Maintaining a developed fishery

The approach to maintain a developed fishery should be different from that of promoting an underdeveloped fishery. Information on the fish stock and the socioeconomic state of the fisherfolk is essential for managing this phase of the fishery. Based on this information, a decision has to taken, as the first step, whether to restrict or promote or just maintain the fishery. In case of a decision in favour of restrictions, proper methods of restriction have to be identified and adapted. Alternative fishing activities or occupations may have to be designed. The social acceptability of the restrictions and the socioeconomics of the fisherfolk have to be given priority at this stage. During this phase, the prospects of the stock in the future are more important than its current status. Today's Indian trawl fishery is a good example of a fishery in its developed phase.

Rebuilding a depleted fishery

For rebuilding a depleted fishery, the cause for depletion, environmental or fishing, should be investigated. If it is due to fishing, corrective action based on past experiences is necessary. The management approach could be either restriction of fishing or total ban depending on the severity of the problem. Alternative employment opportunities should be opened up for the fisherfolk well before imposing a ban. In many instances, depletion may not be wholesome, affecting all the constituent fisheries of a given area, but species-specific. For instance, the depletion of the stocks of the whitefish *Lactarias lactarias*, which is one among the many stocks, exploited by the trawl fishery (especially along the southeast coast), is a classical case of species-specific depletion. Management of the whitefish stock alone in a multispecies fishery becomes extremely difficult. In this type of depletion, the bionomic characteristics of the stock such as stock-recruitment and population fecundity should be closely monitored and steps (e.g., searanching) taken to prevent them from crossing danger levels.

Existing fishing regulations

Closure of fishing seasons

One of major problems in fisheries management is to regulate the fishing effort, which is increasing in spite of decline in the fish stocks. Fishing effort is a composite of many parameters, particularly fishing duration and fishing efficiency. The restriction of fishing effort could take various forms such as restriction on the number of vessels, number of days at sea, fishing days/hours, engine power, length of net (in the case of gillnet), fish holding capacity of vessels etc. Restriction of the number of days of fishing during the monsoon and fish spawning seasons is the most common method followed in India. The maritime state governments take year-to-year decision on the period and duration of closure of fishing operation by the mechanised vessels, normally prior to or during the onset of the southwest monsoon. On the west coast, Gujarat observes seasonal closure for 140 to 150 days/year during May-September for the last 25 years and Kerala for 45 to 60 days/year during June-August for the last 15 years. The other states along the west coast also observe seasonal closure for 30 to 60 days. Along the east coast, Andhra Pradesh and Tamil Nadu initiated 45 days' closure during April-May since 1999 and 2001, respectively. In addition to this, the government of Tamil Nadu has regulated the fishing activity in the Gulf of Mannar, wherein the mechanised vessels are permitted to undertake fishing three days/week (Mondays, Wednesdays and Fridays) and the artisanal craft on the other 4 days in a week. The objective of seasonal closure is to reduce the annual fishing effort of mechanised vessels, particularly the effort of the trawlers during the spawning season of fishes, and thereby replenish the stocks.

The positive effects of seasonal closure on the replenishment of fish stocks are yet to be proved. Seasonal closure of trawling/mechanised fishing is implemented with the general belief that most of the fishes, prawns and cephalopods undergo peak spawning during the monsoon seasons. Though tropical fishes spawn throughout the year with almost equal intensity, closure during the monsoon seasons helps the escape of the spawning population at least during the period of closure.

Demarcation of fishing areas for mechanised and artisanal sectors

In the context of persistent conflicts between the artisanal and mechanised vessels in the inshore waters, most of the maritime state governments promulgated their respective Marine Fishing Regulation Acts. Under these Acts, the areas of operation of the artisanal and mechanised vessels have been delineated. In general, the mechanised vessels have been banned from operating in the inshore areas (extending to a distance of 5 to10 km from the shore), which have been assigned exclusively to the artisanal craft. The mechanised vessels are classified according to the size of the vessels and the area/depth of operation is delineated accordingly. As the density of fish biomass is generally related to the depth of water, there are complaints of bias in demarcating the areas of fishing based on the distance from the shore. At a distance of 5 km from the shore, the depth may be only 20 m in certain areas like the Gulf of Mannar but 100 m in certain other areas (for e.g., off Cuddalore in the Coromandel coast). In order to remove this bias, some of the state governments incorporated the depth factor in their Acts in addition to distance from the shore. For instance, the Kerala Marine Fishing Regulation Act, 1980 divides the coastline into two sectors, a southern sector of 78 km coastal length and a northern sector of 512 km length. In the southern sector, distances from the shore up to the 32 m depth and in the northern sector distances from the shore up to the 16 m depth have been reserved exclusively for the artisanal craft. In the 32 to 40 m depth zone in the southern sector and the16 to 20 m depth zone in the northern sector, only motorised craft are permitted to operate. The small mechanised vessels (<25 GRT) are allowed to operate between 40 and 70 m depths in the southern sector and between 20 and 40 m depths in the northern sector. Larger vessels (>25 GRT) are supposed to operate beyond the 70 m and 40 m depths in the southern and northern sectors, respectively.

Regulation of mesh size

The purpose of controlling the mesh size, especially in the codend of the trawls, is to permit the escape of juveniles hoping that their growth would largely compensate the loss and increase the exploitable biomass, which might be available to the fishery later. Minimum mesh sizes are often emphasized as essential by the scientists as there is general agreement that protection of young fish is necessary. It is often argued that if fishing on immature fish is intense, the abundance of the species may be so reduced before it approaches maturity that there would be insufficient adult fish surviving even if there is no fishing on them. It is also postulated that long term yields would increase by permitting the faster growing immature fish to attain sexual maturity before exploitation, primarily because growth is most rapid in young fish. Under these assumptions, the biomass of a cohort maximizes at about the age at first maturity.

The codend mesh size (CEMS) of the trawls prevalent in India is uniformly very small (generally about 10 mm stretched knot to knot; but quite often, much less than this). Most fishery scientists have suggested a minimum stretched mesh size of 30 mm. Kalawar *et al*. (1985) advocated a compulsory mesh regulation by legally imposing a minimum stretched CEMS of 35 mm, that would help protect significant number of juvenile fishes as well as shrimps. According to Garcia and Le Reste (1981), mesh regulation would be useful for shrimps in the long term due to the following reasons: (i) Since shrimps have a short life span and rapid growth, the possible annual increase would be obtained before the completion of the first annual cycle. (ii) Increasing the mesh size leads to an increase in age and individual average weight and price/kg. The possible increase in value would be proportionately greater than the increase in tonnage.

Nevertheless, the regulation of CEMS is difficult to enforce. In countries where there are mesh size regulations, there is either noncompliance or the fishermen often get round the law by any of the following ways: (i) by lining the codend outside or inside with a finer mesh; (ii) by superimposing two layers of the legal mesh size so that the apertures are about half the original mesh size; (iii) by attaching a weight to the end of the codend so as to obtain maximum stretching of the net, thus decreasing the opening.

For a biological management system to be effective, monitoring, control and surveillance are necessary to enforce the regulations. This is one of the reasons why the biological management is considered to be very expensive. In Canada, where fisheries management includes quotas, restrictive licenses, seasonal closures and gear limitations, surveillance is done on the shore and at the sea by using ships and aircraft. The entire surveillance system is able to sustain itself financially through licensing and fines or through redistribution of funds from other sources. According to Arnasson (1994), the biological fishery management measures, although well suited for sustaining fish stocks, are useless from an economic point of view.

Prospective fishing regulations

Finding the existing fishing regulations inadequate to meet the increasing fishing intensity in the coastal waters, different government and non-government agencies have suggested various kinds of management measures for a sustainable fishery.

Overcapitalisation and limited entry

An assessment of the state of health of fisheries cannot be confined to changes in production but must also include an evaluation of costs and revenues. The coastal fisheries can ill afford the economic losses resulting from overcapitalisation and overfishing.

Under this situation, fishery management approach should involve the rationalisation of capital investment on fishing. To avoid overcapitalisation and dissipation of economic rent, the aggregate gross tonnage and/or horsepower of fishing vessels operating in an area should form the basis upon which the number of licensed vessels has to be regulated. In determining the number of vessels to be licensed, the total capital investment has to be evaluated and distributed by the size-class of vessel. Technical innovations could be permitted so long as the size of vessel remains unchanged. If the vessel size is to be enlarged, extra tonnage could be purchased only if a vessel is condemned. To ensure that the total operational efficiency of a fishery does not exceed the prescribed ceiling, plans for the enlargement of vessel size have to be carefully coordinated. In this way, the overall fishing effort could be controlled and overinvestment could be prevented, and at the same time, the fishing industry can improve the efficiency of the fleet. To implement this method of limited entry on the fishing capacity, a strict licensing system is required. At present, the mechanised vessels are licensed mainly for the purpose of revenue earning. The priority of licensing should be shifted from mere revenue earning to a system of preventing overcapitalisation and regulating the fishing effort (Vivekanandan, 2001).

Marine fisheries in India are common property, characterized by free access in almost every sense. There is no accountability of the effort expended and the catch realised. The only responsibility of the mechanised boats is to obtain licences from the state government authorities and observe the time-to-time restrictions, if and when imposed. There are several instances of vessels operating without any license and also not following the restrictions. There is no licensing for the artisanal craft. As there is no proper marketing system, the catch and the revenue realised are totally unaccounted. There should be a beginning to introduce logsheets for the fishing vessels and to insist on submitting details regarding fishing effort, catch, area of operation, sale proceedings etc. Predictably, the fishers will not provide reliable information. The mechanism of monitoring and verifying the declared information would not be impossible, but will be very expensive. Nevertheless a beginning should be made to inculcate responsible fishing among the fisherfolks.

Kalawar *et al.* (1985) suggested that the mechanised boats could be registered according to ports and prior permission of authorised officers made obligatory for vessel movement from one port to another. Licensing scheme could be extended to cover the entire fishing industry including the artisanal sector to help monitor fishing effort and optimisation of inputs. It is necessary to constitute scientific committees for resources estimation, prescription of total allowable catches and for rendering advice on various fisheries management issues. District level advisory committees with presidents of fishermen cooperative societies as members could be formed to help the government in framing or modifying rules governing fishing regulations. The revenue departments could also be involved in the enforcement of fishing regulations. A system in which the fisheries officer and the presidents of the fishermen cooperatives serve as the enforcement personnel, the tahsildar (administrative head of a tahsil or subdistrict) as the adjudicating officer and the district magistrate as the appellate board, would facilitate quick decisions on which the judgement given by the appellate board would be final.

Total allowable catch

The most common fisheries management method followed in many countries is to impose an upper limit on the total allowable catch (TAC). Setting an upper limit on how much can be caught, most fish stocks in the northeast Atlantic are now controlled. This is a typical biological management measure designed to protect fish stocks. If adhered to, the TAC restrictions are well suited for conserving the fish stocks. Under this system, the fishery biologists recommend the TAC for each stock for the ensuing fishing season. These recommendations are usually based on the criterion that fishing mortality should be at the level that allows MSY or related criteria. Once the TAC is set, it is divided among vessels, depending upon the type and efficiency of the vessels. For the purseseine fleet, for instance, the TAC for each of the pelagic stocks such as the herring, capelin and mackerel is divided on the basis of the licensed cargo capacity of the vessels. When the fishing capacity of the fleet is greater than the TAC, the activity of the fleet will have to be constrained to prevent its catches from exceeding the TAC. The catch of each vessel is reported to the concerned authorities through the fish marketing organisations. The TAC system is reported to be largely successful. In the case of Barents Sea capelin, the TAC system averted the collapse of the stock. The stock was severely depleted in the early 1980s and the TAC was introduced from 1986 to 1990. In 1991, the stock recovered sufficiently (Hannesson, 1994).

This example of successful management notwithstanding, the system also has shortcomings. Fishers and boat designers circumvent regulations on fishing vessels by increasing fishing capacity through new designs that satisfy the restrictive rules, and by including new fish finding devices and efficient gears. To overcome this, the US government amended the Fisheries Act of 1986, a regulatory device called individual transferable quota (ITQ), which is now being implemented in many countries. Under this device, the TAC quotas for each species and each vessel are transferable. The transferability ensures that the least efficient fishing vessels will not be used, as their quotas can be bought by the owners of more efficient vessels at a price that benefits both the buyer and the seller. If the ITQs are defined as shares of the TAC, the catch quotas of individual vessel will fluctuate in proportion to the TAC, and the boat owners will have to make a well educated guess as to how the TAC will fluctuate and how much they can expect to be allowed to fish in the future (Hannesson, 1994).

The debates on fisheries management around the world, and the novel methods being tried elsewhere, originate from the simple fact that open access is totally inadequate for managing marine fisheries resources. Open access is certain to lead to the depletion of stocks, possibly beyond recovery as evidenced in the case of many fisheries elsewhere. Access to fish resources must be limited by any of the restrictive methods though all of them have undesired side effects (Table 2).

In spite of the shortcomings, of all the fisheries management systems, it is believed that the TAC and the ITQs on catch are capable of biologically managing fisheries and deliver the full potential economic benefits of fisheries. In many countries, a consensus has emerged among the fishery economists that the ITQ system, because it essentially eliminates the basic common property problem of fisheries, offers the most promising general approach to managing marine fisheries. Unfortunately, the present marine fisheries management system in India could not adopt the TAC or the ITQ system, as there is no practice of reporting the catch to any authority by any commercial vessel, whether mechanised or artisanal. It is necessary, as the first step, to introduce reporting of the catch and revenue realised by the commercial mechanised vessels through logsheets.

Ecosystem-based fisheries management

As far back as half a century ago, the UN Technical Conference on the Conservation of the Living Resources of the Sea recognized the importance of an ecosystem approach to fisheries management in 1955. However, the impetus to this approach was given only in 1995 in the FAO Code of Conduct for Responsible Fisheries. Since then, several developed countries have begun the process of adopting the ecosystem-based fisheries management. Unlike the single species models in fisheries management, an ecosystem approach is an effective tool since it takes into account the complexity of the marine and coastal ecosystems and it is now believed that such an approach could provide a lasting solution to the problems of declining aquatic biodiversity and fish stock biomass. An ecosystem-based approach to fisheries management, according to the NMFS (1999), should take into account the following four aspects: (i) the interaction of a targeted fish stock with its predators, competitors and prey species; (ii) the effects of weather and hydrography on the fish biology and ecosystem; (iii) the interactions between fish and their habitats; and (iv) the effects of fishing on fish stocks and their habitats, especially how the harvesting of one species might have an impact upon the other species in the ecosystem. The National Research Council of the USA has advocated one more aspect to this approach, i.e., recognizing humans as components of the ecosystems they inhabit and use, thereby incorporating the users of the ecosystem in the approach (NRC, 1999).

An ecosystem approach could help manage fisheries in the following ways (Mathew, 2001): (i) Conservation of fisheries resources, protection of fish habitats, and allocation to fishers are the three most important considerations in fisheries management. The vantage point to start from is the fishing gear group, because without its cooperation, it would not be possible to adopt effective conservation measures and protect fish habitats from fishery-related stress. The ecosystem models estimate the carrying capacity of the ecosystems and the biomass at each trophic level by taking into consideration the weather and hydrography of the ecosystem and fish biology. It also quantifies the number of craft and gears required for sustainable harvest from the given ecosystem. It helps bring about a greater control over large scale operations of nonselective fishing gears. (ii) The approach can facilitate a better understanding of the trophodynamics in an ecosystem, and also the impact of fishing gear selectivity on marine living resources. Programs designed to conserve marine mammals and turtles may become counterproductive when these resources multiply in large numbers and compete with fish stocks as well as fisheries. The fishermen of the Lakshadweep Islands complain about the proliferation of marine turtle population, which not only predate on fishes, but also cause damages to the fishing gears. Along the north Peru coast, squid jiggers complain about predation on squids by sea lions and dolphins. It is estimated that the annual damage caused by the sea lions is about 64 million US $ along the north Peru coast (Manuel, 1997). (iii) The ecosystem approach can be applied to understand and to prevent land-based sources of pollution that have an adverse impact on plankton, which constitute the mainstay of the food of the small pelagics. In addition, reduction of nursery grounds from destructive activities like construction and reclamation in coastal areas, mangrove deforestation, destruction of coral reefs, as well as the loss of marine biodiversity are the other vital issues that need to be dealt with seriously and effectively in the tropical waters. (iv) It would be helpful to understand the impact of the natural factors such as weather and hydrographic factors on fish stocks. In the Pulicat backwaters (southeast coast of India), for example, the mullet and shrimp stocks perish if the salinity exceeds that of the sea due to evaporation, zero exchange of water (as a result of mud formation at the mouth), and zero discharge into the lagoon from rivers (due to upstream dams). Under such conditions, conservation of the mullet and shrimp stocks is not possible just by refraining from fishing. The *padu* system, a system of rotational access to the fishers to shrimping grounds, practised in the Pulicat, does not mitigate the pressure on shrimp stocks because different groups, in a rotational basis, incessantly harvest the stocks.

The fisheries prevailing in about 150 marine ecosystems around the world have already been assessed based on ecosystem models. It appears that this approach may totally replace the dependence on the conventional single species stock models in the near future. Developing the ecosystem approach would be ideal for a country like India, which is characterized by multispecies, multigear and multicultural marine fisheries. However complex it might be, the ecosystems models need to be built up by knitting together all the relevant historic data, and involving in the process, the training and education of the fishermen towards the adoption of ecosystem approach to fishing.

No-fishing zones (Marine Protected Areas)

In the early 1990s, Canada’s Atlantic cod fishery collapsed and thousands of people were put out of work. None of the conventional methods such as the (i) restrictions on the season’s total catch, (ii) controls on the number of days or weeks of fishing, and (iii) regulations on the kind of craft and gear that can be used, did not have the desired effect on the stocks. Therefore, a group of scientists proposed a radical and surprising idea. If all forms of fishing in certain areas are banned altogether, the overall catch can be increased in a sustainable way. Since then, a plethora of studies have convincingly demonstrated that the creation of no-fishing reserves allows the rapid build-up of fish spawning stock biomass (Roberts and Polunin, 1991; Dugan and Davis, 1993; Allison *et al*., 1998). The idea behind reserves is simple. If the fish are protected from fishing, they live longer, grow larger and produce an exponentially increasing number of eggs. It is observed that adult fishes tend to remain in the protected areas while their larvae help replenish adjacent fisheries. Overall (multispecies) levels of biomass per unit area can double in two years and quadruple in ten years of closure. In the Californian reserves, reproductive output of two rockfish species was estimated to be two to three times as great as in the fished areas. On the west coast of the USA, the reproductive output of the longcod in a reserve in Puget Sound was 20 times greater than outside, and for the copper rockfish 100 times greater (Palsson, 1998). These reserves showed average increases of 91% in the number of fish, 31% in the size of fish and 23% in the number of fish species present (Roberts, 1999). These increases occurred within two years of starting the protection scheme. Crucially, the beneficial effects spilled over into areas where fishing was still permitted. In St.Lucia, for example, a third of the country's fishing grounds were designated no-fishing areas in 1995. Within three years, commercially important fish stocks had doubled in the seas adjacent to the reserves.

No-fishing reserves will work well for migratory species also if the reserves are put in the right places. Reserves placed in nursery and spawning areas will protect the migratory species during critical life stages. For example, spawning haddock and groupers are protected in the Georges Bank and Virginia Islands, respectively as the spawning aggregations were fished to extinction. Some reserves will primarily benefit fisheries, some others conservation, but most will benefit both simultaneously.

There are strong evidences to suggest that reserves will work even better in the tropics. However, there is no direct experience of reserves in India barring the marine sanctuaries in the fragile coastal zones to protect coral reefs and mangroves. Considering that the concept of no-fishing zone is a good strategic tool, fisheries managers in India should start working on the questions about how much of the fishing grounds should be placed in reserves, how many are needed, and where should they be. There seem to be three principles, which govern no-fishing zones. According to the first principle, both biological and economic benefits can be maximized through closures ranging between 20 and 40% of fishing grounds. Recently the American Association for the Advancement of Science (AAAS), along with about one hundred scientists called for 20% of the world's oceans to be declared for no-fishing by the year 2020 (Roberts, 1999). The second principle is based on the expectation of maximization and equitable distribution of benefits through a subdivision of the 20% reserve area to represent both biogeographic and ecological diversities within the reserves. The third principle stems from the question whether the derivation of maximum benefits is from the permanent or rotational reserves. Considering the location of fishing villages close to each other along the Indian coast, the selection of areas for no-fishing and the logistical, economic and social implications of dislocating and rehabilitating the fishers to fishing areas away from the reserves call for extreme care in planning.

Social issues

The components of fisheries management encompass more than resource management. Fisheries management, through the control of fishing activities, aims not merely to ensure the most favourable stock conditions for achieving the MSY or the maximum economic yield (MEY), but also on the social upliftment of the fisherfolks.

A review of the historical development of Indian fisheries reveals that in the earlier stages when the resources were abundant and management was not a serious concern, there was no dispute over the utilization of fishing grounds. The steady decline in the catch in the traditional sector has created great apprehension among the artisanal fisherfolk, who generally accuse the trawlers for the decline in the fish stocks. Competition for space is also believed to be a major factor for the setback in the catches in the artisanal sector. As a large number of trawlers crisscross the limited inshore waters (traditionally exploited by the artisanal fisherfolks), both day and night, there are complaints of stationary artisanal gears such as the gillnets and longlines getting damaged by them. Moreover, the artisanal fisherfolks are of the view that trawling is detrimental to the shrimp stocks.

Fisheries management deals with multiple stakeholders, and sustaining a fishery or fisheries requires the participation of all the stakeholders, who should discuss, agree upon and implement the management plans. The fishermen in India are generally organised through their cooperative societies. However, the societies are effective only in very few areas. In Gujarat, for example, these societies play a very important role in managing the fishery. They act as the managing agencies and take decisions on the suspension of trawling every year. Any violation of the decision by an individual fisher is dealt with seriously by the society/community. Representatives from the various levels of the societies are members of the local and regional fishery coordination bodies. This sort of democratisation greatly helps in improving the fishery or fisheries. Participatory and negotiated fisheries management is the most effective way to manage fisheries.

Other management options

For sustaining marine fish production, the management plan should explore the possibilities of (i) dispersing the existing fishing intensity in the inshore waters to the farsea, (ii) providing support to the fisherfolk by locating potential fishing zones through remote sensing, (iii) increasing the productivity of the coastal waters by installing artificial fish habitats and searanching, and (iv) providing alternate employment opportunities such as mariculture.

Thus there are multiplicities of issues with objectives such as resource enhancement, environmental integrity, distributional equity, economic realization and organizational effectiveness. All these generic elements should be considered in advancing marine fisheries management options for the resolution or mitigation of the issues. The issues are interconnected with cross-reinforcing tendencies, for example, increasing fishermen population leads to increase in fishing effort, overfishing, stock depletion, habitat degradation and conflicts within the fishing communities. The management interventions are also interconnected, for example, the limited entry of fishing vessels will result in effort reduction, stock enhancement and shift the priorities in capture fisheries. The management interventions call for biological, ecological, social, administrative, legal and political actions at the community, state and national levels. Much of the success depends on organizational capabilities for implementing the interventions to achieve the overall objective of sustainable marine fisheries development.

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Table 1. Management techniques for different phases of a fishery		
Pre-developed fishery	**Developed fishery**	**Depleted fishery**
Promote	Maintain	Recover
Identify the resources	Assess the stock status	Investigate the causes
Provide economic incentives	Decide on promotions/ restrictions	Correct the earlier mistakes
Develop suitable craft, gears & equipments	Consider socioeconomics of fishers	Stock-recruitment relationships to be closely monitored
Train the fishers	Future prospects of tocks to be given priority	Decide the levels of restrictions and strictly enforce them; Searanching may help; Alternate employment oppurtunities to be opened for fishers

Table 2. Methods of biological fisheries management		
Methods	**Desired effects**	**Undesired side effects**
Restriction on effort	To relieve fishing pressure on the stock	Fishers overcome restrictions by enhancing fishing efficiency; fishing becomes expensive; artisanal fishers affected.
Closed areas and/or seasons MPAs	Protection of spawning stocks	Fishing intensity increases outside closed areas/seasons; fishing cost increases.
Minimum mesh size	Protection of juveniles; increase in stock biomass	Instant decrease in catch not acceptable to fishers; uniform minimum mesh size not possible in multispecies fishery; effects could not be verified.
Total allowable catch	Decrease of fishing mortality; rebuild of stocks	Overcapacity of fleets; tendency to increase fishing efficiency.
Individual transferable quotas	Decrease of fishing mortality; rebuild of stocks	Favours a few large companies

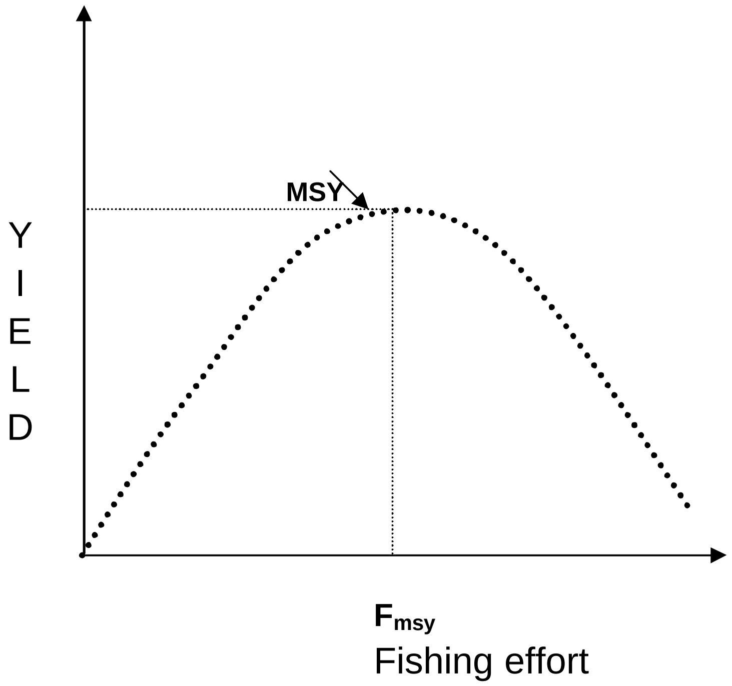

Fig. 1. Decrease in yield with increasing fishing effort

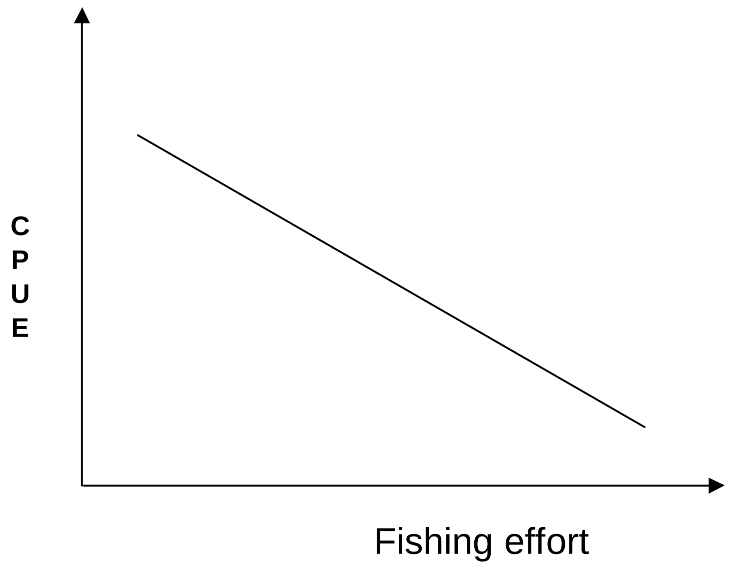

Fig. 2. Decrease in catch per unit effort (CPUE) with increasing effort

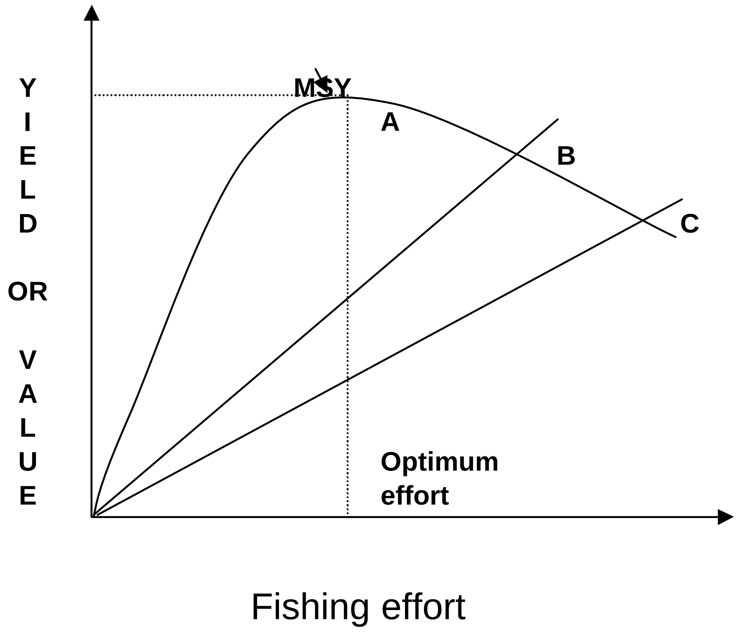

Fig. 3. Relationship between effort and yield/value; A : maximum yield/value; B : yield = cost of fishing; C : no further progress in fishery

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FISHERIES ECOLOGY - CONCEPTS

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Introduction

In nature, organisms can survive only in appropriate environments, interact with each other and are influenced by the whole complex of environmental factors. Ecology is the interaction of organisms with their environment, studied usually by trying to understand the distribution and abundance of organisms. An understanding of the ecological principles is needed for the sustainable use of resources, and to evolve strategies, for the mitigation of environmental problems.

In a natural environment, all organisms depend upon plants, which use light energy in the process of photosynthesis to convert carbon dioxide and water into sugars and other essential compounds, and accomplish the manufacture of organic molecules. Plants are the most familiar of these organisms, but many bacteria can also manufacture organic substances with the aid of light or chemical energy. Plants are consumed by herbivores, and these are, in turn, consumed by carnivores.

Primary productivity is the amount of living material produced in photosynthesis, per unit area per unit time. In contrast, secondary productivity refers to the production of plant consumers, or herbivores, per unit area per unit time. The productivity of carnivores, or consumers of herbivores, is tertiary productivity. In general, primary production is greater than secondary production, which in turn is greater than tertiary production.

Productivity is to be distinguished from **biomass**. Productivity is the amount of living material produced per unit area per unit time (e.g., g/m^2/year), and may be expressed in units of body mass or in terms of the carbon content of the organisms. On the other hand, biomass is the mass of organisms present in a defined area or volume (expressed in units such as g/m^2).

The levels of biological organization of interest in fisheries ecology are: organism-population-community-ecosystem. This involves a series of processes from individuals to ecosystems.

Population

Population is a group of individuals of the same species, inhabiting the same area. For example, all individuals of the oil sardine in a given area constitute its life cycle and experience a similar ecological process at a particular stage of the life cycle. Populations have a number of attributes. Different populations can be compared by measuring these attributes. A population has characteristics like density, birth rate, death rate, dispersal, age distribution, biotic potential and growth.

The size of the population is represented by its density. Density is expressed as the total number of individuals present per unit area or volume at a given time. For instance, 10,000 individuals of oil sardine may occur in one sq. km, which may also be expressed as 1 tonne/km^2. The size of the population is determined by available resources like food at a given time and other characteristics such as birth and death rates and age structure. The increase in the number of individuals in a population is possible due to **birth**. The loss of individuals due to death in a population is termed **mortality**. It is expressed as mortality rate, indicating the number of individuals dying over a time period. Fish populations are affected by two types of mortality, i.e., **natural morality**, which is due to predation, disease and senescence; and **fishing mortality**, which is due to fishing.

Distribution of age groups in a population influences the population growth. Populations with more juveniles grow rapidly while the declining populations have a large proportion of older individuals. Majority of fishes disperse at one time or the other during their life cycle. The individuals move into (**immigration**) and move out (**emigration**) of the population, and these movements influence the size of the population. Migratory fishes like tunas are examples of dispersal.

The inherent maximum capacity of an organism to reproduce or increase in number is termed **biotic potential**. Biotic potential is realized only when the environmental conditions are non-limiting, so that birth rate is maximum and mortality rate is minimum. Under these conditions, population size increases at the maximum rate. If a pair of oil sardine is allowed to reproduce and grow unchecked, the oil sardine population may occupy the oceans in a few years. However, the environment has a check on population size, or its biotic potential. The environmental resistance represents the limiting effect of abiotic (e.g., temperature, salinity, depth, light) and biotic factors (e.g., food, competition) that do not allow the fish to attain their biotic potential and keep the population size at a much lower level.

Generally, the population size stabilizes with time, with some fluctuations around the upper limit. The maximum number of individuals of a population that can be sustained indefinitely in a given habitat represents its **carrying capacity**.

Community

Populations of a different species occurring in a habitat is called community. The community can be recognized and named through features like dominance, stratification and species interactions. Community analysis involves qualitative (species) and quantitative (frequency, density, biomass) analysis of species present in the community.

The members of the community are interdependent for food and protection. Organisms living together may benefit each other (mutualism), or one way benefit without affecting the other (commensalism). Sometimes, one organism (predator) may adversely affect the other (prey). Parasitism is the relation in which the smaller organism (parasite) adversely affects the larger host.

The community is dynamic and undergoes changes with the passage of time. These changes are sequentially ordered and constitute **succession**. Succession involves replacement of one community by the other. Ultimately, succession leads to a dominant community, which remains stable as long as the environment remains unchanged.

Ecosystem

An ecosystem is a group of interdependent biological communities in a geographic area, capable of living nearly independently of other ecosystems. Ecosystems are parts of nature where living organisms interact among themselves and with their physical environment. An ecosystem includes biological community integrated with its physical environment. Ecosystems can be recognised as self-regulating and self-sustaining units. Human activities such as fishing and dredging may modify and affect the marine ecosystems.

An ecosystem has two basic **components**: abiotic and biotic. Abiotic components comprise of inorganic materials such as carbon, nitrogen, oxygen, CO_2 etc, and dead organic matter contain protein, carbohydrates, lipids, etc. The climatic parameters like solar radiation and temperature determine the abiotic conditions within which the organisms carryout life functions. Biotic components include producers, consumers and decomposers.

Biotic and abiotic components are physically organized to provide a characteristic **structure** of the ecosystem. Important structural features are species composition and stratification. Some ecosystems (e.g., the coral reef ecosystems) show very high species richness whereas, deepsea ecosystem shows fewer species and extensive bare patches of water.

Within the ecosystem, nutrients recycle between organisms and the environment. Some of the species (e.g. plants) manufacture organic molecules using only solar energy and inorganic chemical sources and the system can continue independently of other systems. Under this definition, a large lake and its immediate drainage comprise an ecosystem, because the organism in the lake can survive indefinitely. A coral reef and its immediate surrounding water also qualify as an ecosystem, because no import is necessary to sustain the system. In reality, all ecosystems exchange nutrients with other ecosystems. It is crucial, therefore to determine the boundaries of an ecosystem and the places where losses and gains may occur.

Another way to depict the ecosystem structure is through food relationships. Ecosystems possess a natural tendency to persist. This is made possible by a variety of **functions** (activities undertaken to ensure persistence) performed by the structural components. For instance, phytoplankton function as sites of food production; herbivores like the oil sardine perform the function of utilizing part of phytoplankton, and in turn, serve as food for carnivores. Decomposers carryout the function of complex organic materials into simpler inorganic products, which can be used by the producers.

In many marine ecosystems, most of the plant material produced is never consumed by herbivores; rather, much of it falls to the seafloor and is decomposed by bacteria and fungi producing dissolved nutrients. The dissolved nutrients are then available for primary producers. This pathway is known as the saprophyte cycle. Knowledge at the rates per which these processes occur in the ecosystem is necessary to understand the interrelationship of ecosystem structure and function.

Energy flow is the key function in the ecosystem. The storage and expenditure of energy in the ecosystem is based on the two **laws of thermodynamics**. The first law states that energy is neither created nor destroyed, but can be transferred from one component to another, or transformed from one state to another. Accordingly, energy of sunlight can be transformed into energy of food and heat. The second law of thermodynamics states that no energy transformation occurs spontaneously unless energy is degraded or dissipated from a concentrated to a dispersed form. Thus, in ecosystem, transfer of food energy from one organism to another leads to degradation and loss of major fraction of food energy as heat due to metabolic activities, with only a small fraction being stored in living tissues or biomass. While energy in food is in concentrated form, heat energy is highly dispersed. It must be understood that, in any system all changes in energy forms can be accounted.

A food chain is a set of connected feeding levels of primary, secondary and tertiary sources of productivity. An example of a simple food chain is:

→ Seaweed → gastropod → fish shore bird

In more complicated systems, a simple chain cannot be constructed, and a more complex food web is a better description. A food chain is a linear sequence that reveals which organisms consume which other organisms in an environment. A food web is a more complicated diagram of feeding interactions that shows the overall pattern of feeding among organisms.

Each organism in the above food chain (seaweed, gastropod, fish and bird) represents a **trophic** (food) **level**.

A simplified representation of energy flow through ecosystem has been made in Figure1. The energy flows in one way i.e., from producers to herbivores to carnivores. It cannot be transferred in the reverse direction.

Not all the production from one trophic level is transferred perfectly to the next. To estimate the potential production at the top of a food chain such as fish production, the losses at each trophic level should be determined. Losses result from the following two factors:

(i) Unconsumed: Some proportion of a given trophic level evades consumption through escape, unpalatability or unavailability. Phytoplankton with large spines or toxins are avoided by zooplankton. Phytoplankton cell size may be too small, or too large, to permit ingestion.

(ii) Inefficient conversion: Some portion of the food that is ingested is not converted for growth.

A budget for consumed food can be constructed as follows:

$$C = E + R + G$$

Where C is the amount consumed, E is the amount egested as faeces and nitrogenous waste, R is the amount spent in respiration, and G is the amount used in growth. G can be partitioned between somatic growth and reproduction. This budget is usually constructed in terms of energy units, i.e., calories or joules.

The energy lost in respiration is not available to the next trophic level. The respiration cost increases sharply along successive trophic levels. On an average, respiration of producers consumes about 20% of its gross productivity. Herbivores consume about 30% of assimilated energy in respiration. The proportion of assimilated energy consumed in respiration rises to about 60% in carnivores. Because of this tremendous loss of energy at successive higher trophic levels, the residual energy is decreased to such an extent that no further trophic level can be supported.

Trophic structure in ecosystem can be represented by comparing **standing crop** (either number of individuals or biomass) or energy fixed per unit area at different levels. Graphical representation of the trophic structure is done by drawing ecological pyramids, where the basal, mid and top tiers show the parameter values for producers, herbivores and carnivores in the ecosystem (Fig. 2). It emphasizes that the total biomass or energy flow at successive trophic levels always decreases, compared to the preceding trophic levels.

Animal that have no immediate predators also contribute nutrients to the food web. Marine mammals and turtles, while not specifically targeted for consumption, do produce waste. The waste may be either excretions from digestive processes or dead tissue. It is eventually broken down by decomposers, i.e., primarily bacteria, in a process that releases nutrients that plants can use to start the whole cycle again.

Organisms higher up the food web tend to be larger in size and fewer in number than those at lower levels. This is partly a function of the many trophic steps required to meet advanced energy needs. Because the efficiency rate at each trophic level is only about 10%, each succeeding level supports a smaller total biomass to compensate for the 90% loss of food value.

The incompleteness of transfer up a food chain can be estimated in terms of **ecotrophic efficiency**, EE, defined as the amount of energy extracted from a trophic level divided by the amount of energy supplied to that trophic level. EE is often in the range of 10%. However, high latitude planktonic systems may have higher EE.

EE can be used to estimate the potential fish production at the top of the food chain. If B is the biomass of phytoplankton and n is the number of links between trophic levels, then the production P of fish is: $P = B * EE^n$ (Levinton, 2001). Using this concept, Gulland (1972) estimated the global potential annual yield of fishes as 100 m t. However, even a minor a change in EE, for instance, from 0.1 to 0.2, would magnify the estimate of fish production by 16 times at the fifth tropic level, and hence, may lead to serious potential errors in the estimates. Due to this reason, these estimates are considered as arbitrary.

According to the classifications of Ryther (1969), marine planktonic food chains can be classified into three basic systems (Table 1). The oceanic system has five trophic levels, with a low annual primary production of about 50 g C/m^2/year. The coastal system has three trophic levels, and the primary production is about 100 g C/m^2/year. The upwelling system occurs in areas such as the Kerala coast, and has only two trophic levels. Upwelling provides higher and more continuous material supply, leading to a primary productivity of about 300 g C/m^2/year. The high potential of upwelling systems is enhanced by a greater EE, which is related to the case of consumption and assimilation of large diatoms by planktivorous fishes. Low primary productivity and large number of trophic levels greatly reduce the fishery potential of the oceanic systems.

Temporal environmental stability and stable water column may increase the number of trophic levels and promote the survival of complex food webs. In nearshore and upwelling systems, strong temporal changes in environmental parameters would on the other hand, tend to collapse a complex multilevel food web.

Interaction between species

Most of the commercial fish are first or second stage carnivores, and the order of volume of production corresponds quite closely to the order of closeness of the fish to the primary production. On the other hand, predators at the top of food webs are fewer in numbers, but may exert strong effects on entire ecosystems if there are strong interactions between trophic levels. A predator at the top of a food web exerting strong effects is known as **keystone species**. When linkages among trophic levels are strong, changes in abundance of the top predator causes a **trophic cascade** through the trophic levels.

Ecosystem impacts of fisheries

Fish populations do not live by themselves. Rather, they are embedded in ecosystems where they perform their roles as consumers and prey of other organisms, including larger fishes. For describing the ecosystem impacts of fisheries, it is necessary to concentrate on the impacts fisheries have on food webs, i.e., on the net work of flows of matter (= biomass), which in ecosystems, links the plants with herbivores, and the latter with their predators. These networks of flows are affected directly by fishing, which removes predatory fish, or competes with them for their preys, in either case affecting the web within which predators and preys are embedded.

Figure 3 gives an example of a simplified food web, and defines the various elements of such webs (functional groups), the flow between them, the trophic levels, which indicate the position of each functional group within the web.

Here, the plants have a definitional trophic level of 1, as does dead organic matter (detritus), while exclusive plant or detritus feeders (herbivores or detritivores) have a trophic level of 2. Carnivores feeding exclusively on herbivores and/or deritivores have a trophic level of 3, and so on. Carnivores do not necessarily have trophic levels of exactly 3 or 4, but are more likely to have intermediate values, reflective of the mix of preys they consume. For example, a pelagic shark that should have a trophic level of 5.0 because it feeds on small pelagics such as whitebaits with a trophic level of 3.0 will end up having a trophic level of 4.0 if it feeds, equally, on a low level carnivore or herbivore like the sardines with a trophic level of 2.0-2.5.

Because of this effect of mixed diets, top predators in marine ecosystem rarely have trophic levels in excess of 5. Such high values occur only in killer whales, which, by feeding exclusively on marine mammals (which prey on piscivorous fish), can reach trophic levels much higher than those reached by fish. While some fish reach trophic levels in excess of 4.0, the overwhelming bulk of them have trophic levels between 3 and 4.

The trophic level of consumers can be estimated based on the weighted average of the prey's trophic level. A consumer eating 40% plants (with trophic level 1) and 60% herbivores (with trophic level 2) will have a trophic level of $1 + (0.4 * 1 + 0.6 * 2) = 2.6$.

The 1 at the beginning of this equation is the definitional trophic level of producers and detritus. The trophic level is a dimensionless index.

However, the approach to assign numeric trophic level to each species, is an oversimplification due to the following reasons:

? The trophic levels change during ontogeny of fishes. Larvae, which usually feed on herbivorous zooplankton (trophic level = 2.0). Consequently have a trophic level of 3.0. Subsequent growth enables the larvae to consume larger, predatory zooplankton and small fishes or benthic invertebrates. This leads to an increase in trophic level often culminating in values around 4.5 in purely piscivorous, large fishes.

? The role of fishes within ecosystems is largely a function of their body size. Small fish are more likely to have a vast array of predators than very large ones.

? Opportunistic feeders may eat larval forms of their predators. For example, squids feed on juvenile threadfin breams, but small squids are predated by adult threadfin breams.

? Opportunistic feeders may eat their own larval forms. For example, the bombayduck, lizardfish and ribbonfish are cannibalistic and trophic level assigned to cannibalistic fish would be only an arbitrary value.

Fisheries impacts on marine ecosystems

Fishing is one of the oldest human activities, and it developed gradually, when our ancestors moved from the collection of plants and animals they happened to find, to the extraction of organisms, using tools and weapons. The tools were shaped, first of stone, later of wood, bone, ivory etc. The oldest fishing implements so far identified are harpoons, found in the territory of Congo, and dated about 90,000 years (Stergiou, 1999). Well–preserved fishing tools from the Neolithic and Bronze Age (1700-800 BC) indicate further technical improvements. In the Alps region, these included dugout canoes, and curved hook made of bronze and iron and nets made of hemp and flax with mesh size from 5 to 45 mm knot to knot. During 900-800 BC, various fishing methods relying on hooks, nets and harpoon were used. All these early and later developments up to about a century ago indicate that fisheries tended to use highly selective gear. Moreover, their effect on ecosystems, being highly localized, probably resembled the effect of natural predation.

The fishing pressure exerted by modern fleets differs radically from natural predation, due to the combination of direct and indirect effects. The direct fishing effort of reducing the abundance of various exploited populations is often enough for them to collapse. There are also strong reductions of mean size in the species landed, reflecting similar reductions of size in the ecosystems. These changes imply changes in the life history of the species concerned, through changes of their age at first maturity and of their sex ratio.

A strong indirect effect of fishing on ecosystem is through habitat alteration. Trawling is a major culprit as far as sea bottom is concerned, while dredging and explosives destroy the coral reefs, which support the fish species, and their prey.

The ecosystem consideration of effect of fishing is gaining importance and has become a thrust area of investigation in the assessment of exploited stocks. It is increasingly realized now that changes in ecosystems could be due to ecological and exploitation parameters either singly or in combination, and hence, assessment of stocks need to be tuned accordingly. Pauly et al (1998) examined the FAO capture fisheries production database for 1950-1994 in terms of trophic levels of the catch and showed that landings from global fisheries have shifted from large piscivorous fishes toward small invertebrates and planktivorous fishes, a process now called “fishing down marine food webs”. They estimated that the trophic levels of fisheries landings declined at a rate of about 0.1 per decade. One concern about this trend is that fishing may cause large and vulnerable predatory fish to be replaced by other species lower down the food web. This may not only affect the value of fisheries, but may cause significant problems in the structure and function of marine ecosystems.

Pauly and Christensen (1995) estimated how much primary production was required to sustain the global fisheries in 1988-1991. The results showed that, globally, 8% of aquatic primary production was appropriated by the fisheries, and that there was considerable variation between resource system types: for open ocean fisheries, only 2% was required, while upwelling, shelves and freshwater systems required 25-35% of total primary production. When this is added to arrive at the total requirement of primary production, it may be concluded that the available primary production of the oceans is fully utilized by the humans, since over half of the total primary production can be expected to fall out to the sediment. It appears that humans can be expected to use one third of the total primary production through fisheries. For terrestrial systems (which in general are more fully exploitable and exploited), the global average is that 35-45% of the primary production is appropriated by humans, directly or indirectly.

Natural changes in the ecology of the oceans

Not all ecological changes are anthropogenic. Natural conditions in the oceans fluctuate greatly and sometimes suddenly on time scales that extend for decades to millennia. An important example of the potential magnitude of natural change comes from annually layered sediments of the Santa Barbara Basin (Baumgartner et al., 1992). Abundance of fish scales of anchovies and sardines preserved in these sediments fluctuate more than an order of magnitude and exhibit nine major collapses and recoveries in over 1700 years. Perhaps a parallel may be drawn for the oil sardine abundance along the southwest coast of India.

Another example of nature-driven ecological change is the catastrophic mortality of the western Atlantic coral reefs in the 1980s (Jackson, 2001). The principal cause of coral mortality was overgrowth by macroalgae that exploded in abundance after an unidentified pathogen caused mass mortality of the enormously abundant grazing sea urchin *Diadema antillarum* in 1983-1984. Increasing frequency of coral disease and bleaching were also major factors. Mass mortality of *Diadema* was also caused by overfishing of major fish predators of the sea urchin and of large herbivorous fishes that competed with the urchin for algal food. Thus there were no large grazers remaining to consume the algae, which caused mortality of the coral reefs.

Ecosystem maturity

Odum (1969) proposed the term **ecosystem maturity** to define the stability of the ecosystem. He considered that the stability of the ecosystem is high if the energy flow of the network is high. The complex trophic organization of a community is more stable than a simple one. A more diverse ecosystem has the potential of becoming more complex and possessing more choice than a less diverse one. An ecosystem attains maturity after several ecological successions, and hence development and maturity of an ecosystem stand in opposition to each other. A mature ecosystem has the capacity to withstand perturbations caused by human beings or nature more than an immature ecosystem.

To assess the maturity of an ecosystem, Odum (1971) suggested indices, which were modified to suit fisheries ecosystem by later researchers. Some of the indices for determining the maturity of an ecosystem are as follows:

(i) **Respiration / assimilation ratio** can be more than 1. For top predators the ratio is close to 1 since the production is low. For organisms with low trophic level, the ratio is lower, but the value is positive.

(ii) **Production / respiration ratio** is always less than 1.

(iii) **Respiration / biomass ratio** takes a positive value and depends on the activity of the ecological group; higher the activity, higher the ratio.

(iv) **Primary production / respiration ratio** is > 1 in the early developmental stages of an ecosystem. In mature system, the value is around 1, but in polluted system, the ratio is < 1.

(v) **Primary production / biomass ratio** is < 1 in immature system since the biomass accumulates.

(vi) **System throughput** is the size of the entire ecosystem in terms of flow (consumption + export + respiration + flow to detritus). The value can be compared with the throughput of other ecosystems.

(vii) **Biomass / throughput ratio** increases to a maximum for the most mature stages of a system.

(viii) **Net system production** is the difference between total primary production and total respiration. In immature system, the production is large, but in mature systems, it is close to zero.

(ix) **Efficiency of the fishery** is the relationship between sum of all fisheries catches and total primary production. The global average efficiency of the fishery is 0.0002. The value is high for systems with a fishery harvesting fish low in food web (e.g., upwelling fishery), and the value is low for the systems that are underexploited or where the fishery is concentrated on apex predators.

(x) **Connectance index** is the ratio of the actual links to the number of possible links in a given food web. Food chain structure changes from linear to weblike as systems mature.

(xi) **System omnivory index** is a measure of the feeding interactions that are distributed between trophic levels.

(xii) **Ascendancy** is a measure of knowledge on the location of a unit of energy and where it will flow next. The upper limit of ascendancy is the developmental capacity. Ascendancy = Total system throughput * Information flows.

(xiii) **System overhead** is the difference between the capacity and the ascendancy. It reflects the system's strength in reserve from which it can draw energy to meet unexpected perturbations.

(xiv) **Cycling index** is the fraction of an ecosystem's throughput that is recycled. This index normally takes the value around 0.2%. It is strongly correlated with system maturity, resilience and stability.

(xv) **Primary production required** is an important quantification of the primary productivity required to sustain fisheries harvest by humans. It is estimated mainly from the trophic positions of the various organisms harvested.

(xvi) **Mixed trophic impact** is an assessment of the effect of the changes in the biomass of a group that will have on the biomass of other groups in a system. For example, tunas have a negative impact on their prey, the sardines, but have positive impact on their prey's prey, the phytoplankton. Moreover, the sardines may have a marginal positive impact on phytoplankton since the sardines also feed on zooplankton, which are consumers of phytoplankton.

The question is whether ecology can help in managing fisheries. The two basic answers could be:

(i) Ecology may help in finding out what is the carrying capacity of the ecosystem. This carrying capacity, measured as the sum of all the possible fluxes in the ecosystem, represents the available energy from which maximum can be diverted as fish catch. It is also possible to arrive at a limit of what one can get from an ecosystem.

(ii) Ecology may help by characterizing the space and time where the valuable species should be protected. However protection should not be extended only to a few species. Also, species that have an ecological impact on the valuable species should find protection in space and time, and ecology can elucidate what those species are.

(iii) Recently, ecology and ecosystem analysis are used to interpret the effects of natural and human influence on fisheries, and this analysis is helpful for recommending ecosystem-based fisheries management options.

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Table 1. Characteristics of three principal types of marine food chains (after Ryther,1969)

Type of system	Primary productivity (g C/m^2/year)	Number of trophic levels	Ecotrophic efficiency (%)	Potential fish production (mg C/m^2/year)
Oceanic	50	5	10	0.5
Shelf	100	3	15	340
Upwelling	300	2	20	36,000

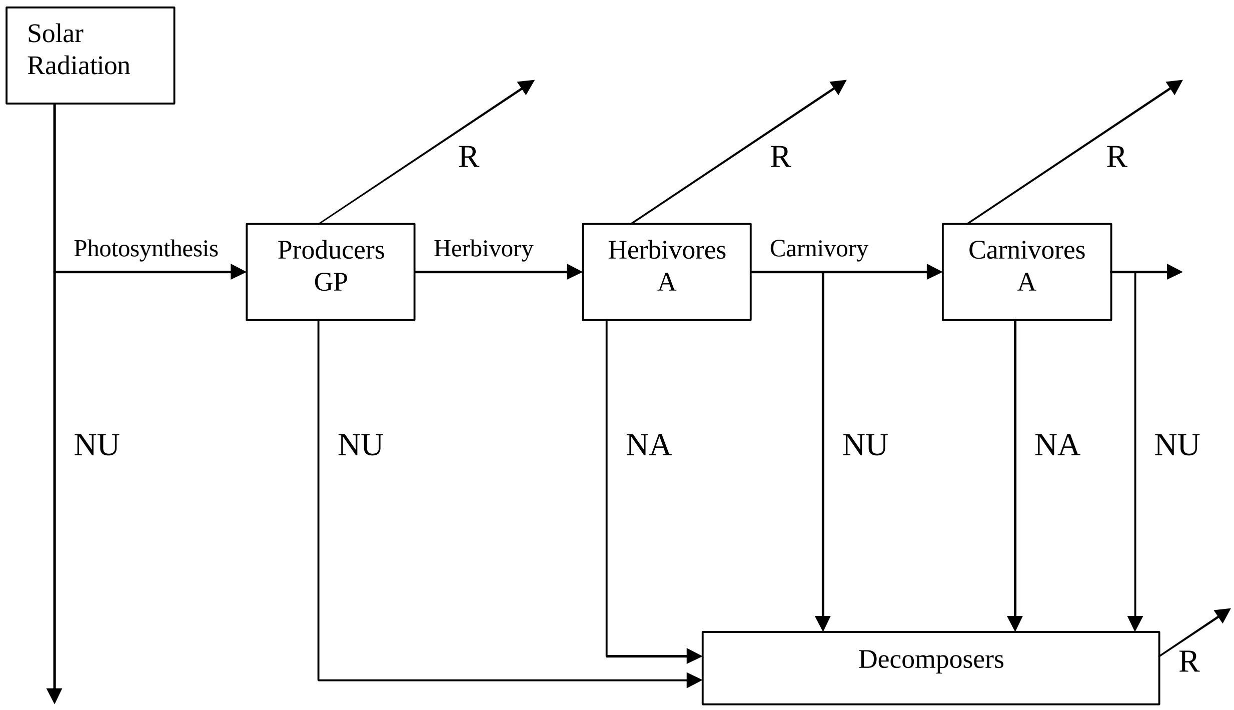

Fig. 1. A generalised energy flow model of ecosystem. Boxes represent biotic components and the arrows show the pathways of energy transfer; Sr, Solar radiation; GP, Gross primary productivity; A, Assimilation; R, Respiration; NU, Not utilised; NA, Not assimilated

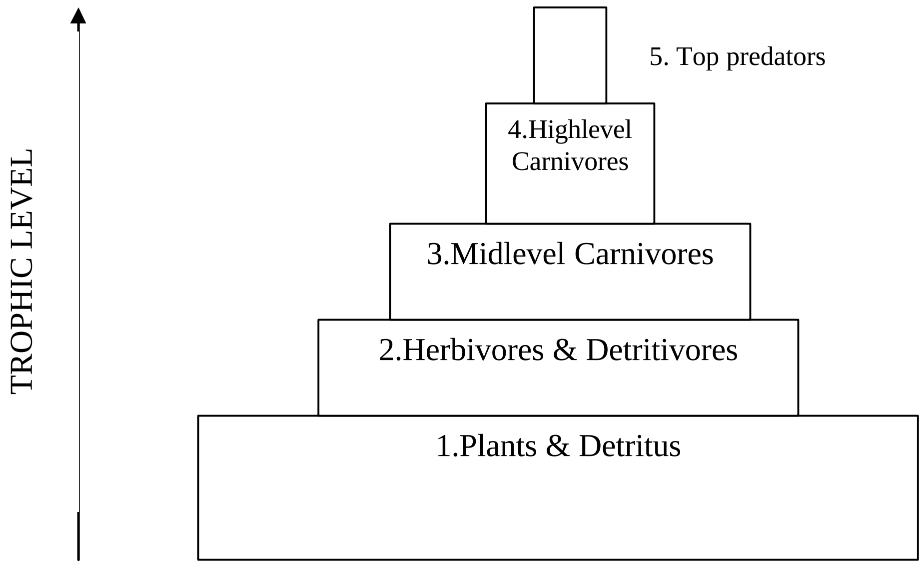

Fig. 2. Typical trophic structure in a marine ecosystem; the boxes represent number of individuals or biomass or energy at each trophic level

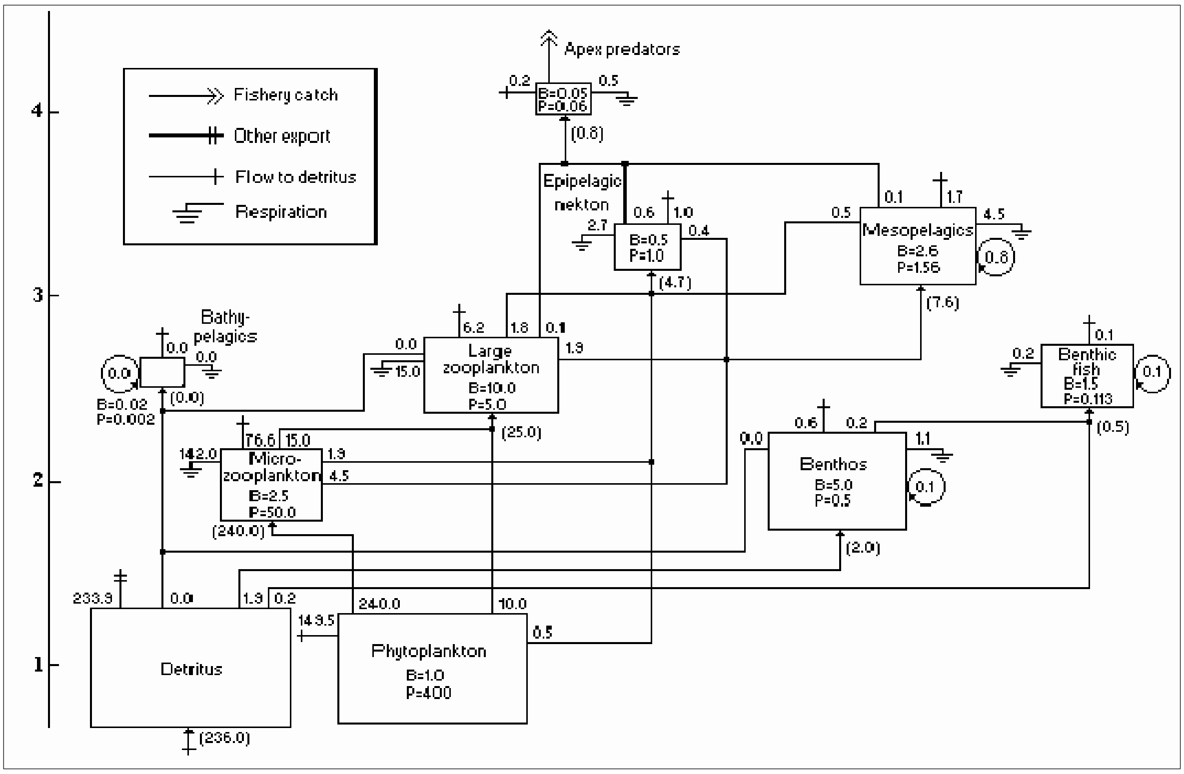

Fig. 3. A simplified food web in the marine ecosystem

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ECOSYSTEM BASED FISHERIES MANAGEMENT

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INTRODUCTION

A lot of attention has recently been directed at assessing the impacts of fisheries on whole marine ecosystems (ICES, 1998, 2000; Frid et al., 1999b; Hall,1999a,b).This has in part been driven by the need to ensure conservation of biological diversity and sustainable use of the biosphere, key provisions of the convention agreed at the UN Rio summit (Tasker et al .,2000).The utilization of sound ecological models as a tool in the exploration and evaluation of ecosystem health and state, has been encouraged and endorsed by the leading bodies in ecosystem-based fisheries research and management (NRC,1999; ICES, 2000). The potential of the available dynamic ecosystem models to make measurable and meaningful predictions about the effects of fishing on ecosystems has not however been fully assessed.

ECOLOGICAL FACTORS

Harvesting alters ecosystem structure in ways that are only beginning to be understood. It is argued that long-term heavy commercial harvesting is likely to shift the ecosystem to high-turnover species with low trophic levels (Pitcher and Pauly, 1998). The biological mechanism underlying species shifts is that the relatively large, long-lived fishes which have low mortality rates are more strongly affected by a given fishing mortality rate than are smaller fishes which are part of the same community. A second shift-inducing biological mechanism is habitat degradation caused by various fishing gears, especially bottom trawls. Here, the effect is through destruction of bottom structure, depriving benthic fishes of habitats and prey.

Thirdly, the above and the fishery induced reduction of predatory pressure by benthic fish, may then lead to an increase of small pelagic fish and squids which becomes available for exploitation. This may mask the decline in catches of the demersal groups. In the Gulf of Thailand, in Hong Kong Bay and other areas of the South China Sea, extremely heavy trawl pressure has resulted in a shift from valuable demersal table fish such as croakers, groupers and snappers to a fishery dominated by small pelagics used for animal feed and invertebrates such as jellyfish and squids.

These mechanisms almost often lead, through a positive feedback loop, to a fourth biological mechanism: harvesting small pelagic fish species at lower trophic levels reduces the availability of food for higher trophic levels, which then decline further, releasing more prey for capture by a fishery that finds its targets even lower down the food web, a process now occurring throughout the world (Pitcher and Pauly, 1998). Some examples of such documented species shifts in exploited multispecies fish communities are shown in table.

Table: Examples of documented shifts towards smaller, high-turnover species in exploited multispecies communities (modified from Pitcher and Pauly, 1998)

Fishing grounds/ Stocks (period)	**Documented species shift**
Gulf of Thailand Demersal stocks (1960-1980)	Overall biomass reduced by 90%; residual biomass dominated by trash fish
Philippine shelf Small pelagics (1950-1980)	Gradual replacement of sardine-like fishes by anchovies
Carigara Bay, Philippines All fish (1970-1990)	Fish replaced by jellyfish, now an export item
Black Sea	Small pelagics and jellyfish replace large table fish
North Sea	Halibut and small sharks extinct; cod and haddock threatened; demersal omnivores and small pelagics favoured
Humboldt Current, Chile	Large hake depleted, small pelagics favoured
North Pacific	First marine mammal depletions, followed by huge trawl fisheries: Pollock favoured
South China Sea, Hong Kong	Croakers and groupers almost extinct; small pelagics bulk of fishery

It has also been observed that fishes evolve or change their life histories in response to selective fishing mortality, for e.g, halving of the size of mature Chinook salmon. In this semelparous species early maturity means less time at risk of being caught and therefore, higher fitness. This species has been intensively managed for over 80 years using the best that single species quantitative science can offer, and yet Chinook salmon are on decline.

SOCI-ECONOMIC FACTORS

One of the main socio-economic mechanisms which contribute to species shift is increasing prices, both for traditional high-value species and for trash species. Such price increases are effective in masking the economic consequences of fishing at lower trophic levels.

SINGLE SPECIES ASSESSMENTS

The tools developed for single species population dynamics are an essential part of any new methodology. Detailed information on growth, mortality and recruitment schedules and their associated errors and uncertainties are essential for the implementation of the ecosystem approach advocated in the Rio summit.

When considering the management of single components of the ecosystem, such as the target fish stocks, it is possible to set target and limit reference points for particular measurable properties of the species. For example, the implementation of precautionary fisheries management in the North Atlantic has progressed through the setting of reference points for various measures of the status of the exploited species, e.g. the spawning stock biomass (SSB).Two types of reference point are considered - a limit reference point and a target reference point (Fig.1). Management measures are aimed at achieving the target reference point in the medium term and ensuring that the limit reference point is never exceeded.

In theory, it should be possible to apply reference points to any or all taxa in the ecosystem. ICES (2000) have contended that even if this was practical for a significant number of taxa, it may not ensure adequate protection of all the ecosystem components at risk. There is a need, therefore, to develop reference points for system level emergent properties as a measure of ecosystem health (Hall, 1999a; Gislason et al., 2000).

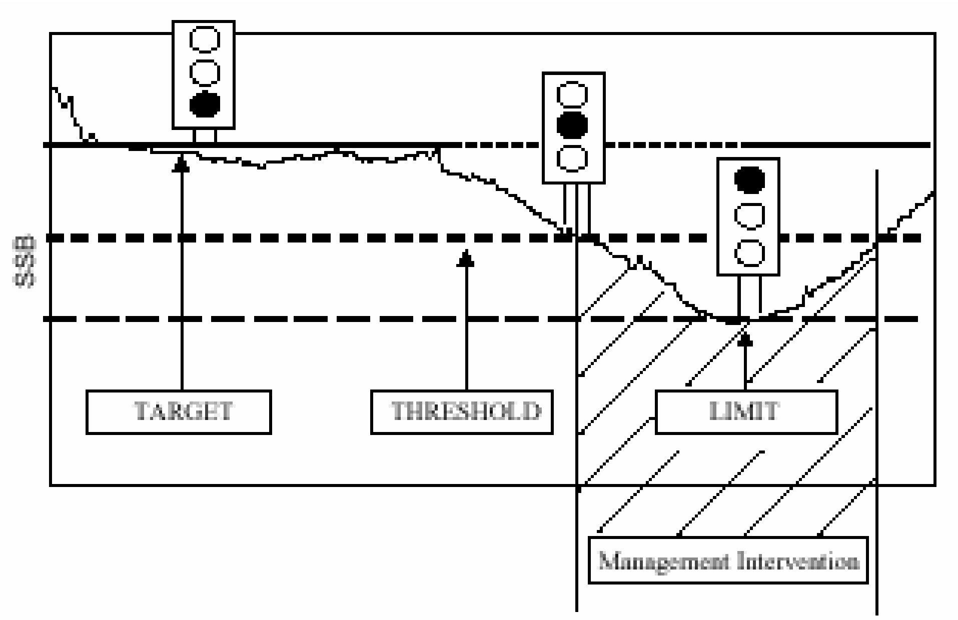

Fig.1. Illustration of target, threshold and limit reference points with regard to spawning stock biomass (from Hall and Mainprize, 2004)

ECOSYSTEM MODELLING

There are many recent developments in building of trophic models of aquatic ecosystems. Such modelling can now be performed more rapidly and rigorously than ever before, providing a basis for viable and practical simulation models that have real predictive power (Christensen and Pauly, 1993; Walters et al., 1997). This was made possible by the development of ECOPATH (Polovina, 1984; Christensen and Pauly, 1992), for construction of mass-balance models of ecosystems, based mainly on diet composition, food consumption rates, biomass and mortality estimates.

Such ecosystem models can describe the biomass flows between the different elements of the exploited ecosystems, and can provide answers to ‘what if’ questions regarding the likely outcome of alternate fishing policies. The ECOPATH suite of software has now been modified (Walters et al., 1997, 2000) to include ECOSIM (simulation module) and ECOSPACE (spatial module). These new routine have not only increased the quantitative power of the approach, but have also allowed qualitatively new questions to be asked.

Ecopath applications to ecosystems, ranging from low latitude areas to the tropics, and from ponds, rivers, and lakes to estuaries, coral reefs, shelves, and the open sea, but all using the same metrics, allowed identification of several general features of aquatic ecosystems:

Multivariate comparisons demonstrated the basic soundness of E. P. Odum’s (1969) theory of eco-system maturation (Christensen, 1995b), including a confirmation of his detailed predictions regarding ecosystems near carrying capacity (Christensen and Pauly, 1998). Conversely, this theory can now be used to predict the effect of fisheries on ecosystems, which tend to reduce their maturity, as illustrated by the comparison of Ecopath models for the Eastern Bering Sea in the 1950s and early 1990s (Trites *et al*., 1999a, b), and to guide ecosystem rebuilding strategies implied in ‘‘Back to the Future’’ approaches (Pitcher, 1998; Pitcher *et a*l., 2000).

The importance (relative to fishing) of predation by fish and marine mammals within marine ecosystems as suggested by complex models in a few areas (North Sea – Andersen and Ursin, 1977; North Pacific – Laevastu and Favorite, 1977) was confirmed globally by Ecopath models (Christensen, 1996; Trites *et al*., 1997).

Identification of trophic levels as functional entities rather than as concepts for sorting species (Lindeman, 1942; Rigler, 1975) implied the use of non-integer values (computed as 1+ the mean trophic level of the preys, as proposed by Odum and Heald, 1975) that express degree of omnivory (Christensen and Pauly, 1992a), i.e., the extent to which feeding occurs at different trophic levels (Pimm, 1982). Also, trophic level estimated from analyses of stable isotopes of nitrogen has been shown to correlate well with estimates from Ecopath models (Kline and Pauly, 1998).

Estimates of transfer efficiencies between trophic levels (Christensen and Pauly, 1993b; Pauly and Christensen, 1995), previously a matter of conjecture usually pertaining to single-species populations or even to studies of a few individual animals (Slobodkin, 1972), differed radically from earlier guesses by ecosystem types (Ryther, 1969) used for inferences on the potential yields of fisheries (Pauly, 1996), even though the mean was unsurprising (about 10%; Morowitz, 1991).

PERFORMANCE MEASURES

It is generally agreed that reductions in single species fishing mortality levels is perhaps the most significant step one could take towards ensuring the persistence of marine ecosystems (Hall and Mainprize, 2004). It is also clear that ecosystem based fisheries management is still in its formative years, although substantial developments have been seen in some countries and regions. Among these, North America, Antarctica, Europe, Australia and New Zealand are the most notable.

Table 2. The six principles for an ecosystem based fisheries management approach (adapted from Inter-agency Marine Fisheries Working Group, 2002)

Principle	**Description**
Ecosystem identification	The ecosystem that fisheries will be managed within need to be defined on the basis of the main physical, biological and human dependency relationships
Clear objectives	Objectives for fisheries management shall have regard to local and national needs, and management should be decentralized to the maximum extent possible
Long term benefits	Ecosystem based management should aim for long term benefits – management should look to restore stocks to levels that are capable of delivering optimal yields over the long term; and achieving such yields should not compromise other marine species and habitats. Management should also aim to support biological biodiversity
Incentives aligned with and ecosystem based approach	Incentives should be realigned to support aims of the ecosystem based approach – incentives and financial support needs to be redirected from fisheries that aim at increasing fishing efficiency to those that make concerted efforts to those that promote the restoration of fish stocks to optimal yield levels and which support responsible fishing practices in sensitive marine areas
Easily assessed information and alternate management options	Information necessary to implement the ecosystem based approach should be made available to all. Where information is insufficient, adaptive management and the precautionary approach should be followed. If the outcome falls short of what was intended the management decisions should be suitably altered – proactive management

Unfortunately, despite the legislative imperative and clearly articulated principles (Table 2), arriving at an operational framework for an ecosystem based approach to fisheries management is fraught with difficulties. This difficulty is due, not only to the inherent challenge in establishing and quantifying the effects of fishing at an ecosystem level, but also due to the social and political dimensions associated with harvesting fisheries at an environmentally sustainable level.

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SYSTEM ANALYSIS

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When addressing an issue in fisheries we may have to consider many interacting biological, economic, social and legal factors. Management plans ignoring one or other of these and concentrate on the remaining will fail when executed. Systems analysis is both philosophical approach and a collection of techniques developed explicitly to address complex problems. Its origin can be traced to Second World War by the military to deal with complex logical problems. It was later successfully applied in the fields of engineering, industrial dynamics, business management, economics and recently in biology, ecology and renewable natural resource management. Systems analysis emphasizes a holistic approach to problem solving and use of mathematical models to identify and simulate important characteristics of complex systems. In systems analysis complex problems are quantitatively addressed.

What is a system?

There are several different definitions of system in current use:

- A system is an organized collection of interrelated physical components characterized by a boundary and functional unity.
- A system is any set of objects that interact.
- It is a collection of "communicating" materials and processes that together perform some set of functions.
- A system is an interlocking complex of processes characterized by many reciprocal cause-effect pathways.
- Dictionary definition: An organized or connected group of objects.
- A set or assemblage of things connected, associated, or interdependent, so as to form a complex unity.
- Any phenomenon, either structural or functional, having at least two separate components with some interaction between these components.
- A more general definition is "any object whose behaviour is of interest". (Here, what affects the system, but lies outside its limits, is part of the system's environment.)

The principal attribute of a system is that we can understand the system only by viewing it as a whole. A system is chosen for a particular purpose like "to answer a question", "to demonstrate a theory", "to classify part of the natural world" etc. In ecology examples of system are communities, ecosystems, populations, individuals and even part of a body like rumen of a deer.

The two most useful properties that systems have are:

1. Systems may be nested
2. Systems at the same level of resolution may overlap.

For example, an individual is a part of a population; a population is a part of a community and so on. A system that we define to study the population dynamics of a fish species will overlap with the system that we define to study the population dynamics of another fish species if they posses pray-predator relationship. For a problem at hand we must take great care to define the boundaries of the system of interest. The philosophy of studying the total behaviour of some complicated system is termed **Holism**. The general systems theory is based on the idea that complex systems have characteristics in common that make them an independent object of scientific inquire. Knowledge of individual processes and elements is not able to explain vital phenomena. It is necessary to discover the laws of biological systems at the different levels of organization.

Systems around us

1. The heating system of this building.
2. The ignition system of an automobile.

Each of these systems has components that themselves could be considered as systems: e.g. a thermostat or a spark plug. Each of these systems is a part of a larger system, i.e. the building, or the engine (which in turn is part of the automobile). Thus any particular system that we may wish to study is part of a hierarchy of other systems. It is up to us to choose the level that we work with, and our first order of business is to define the spatial, temporal, and conceptual limits that we wish to address. We are mostly concerned with the larger systems of nature, including the ways that man interacts with nature. Such systems are normally called ecological, sociological, or economic, and they display the same types of interactions and generalities of scale as physical systems display.

mouse: nervous system interacts with circulatory system, etc.
population: many mice
community: mice population + other animals + plants + microorganisms
ecological system: community + nonliving associates:
ecosystem: Generally for a unit of landscape (e.g. ponds)
biome: very large ecosystems of subcontinental dimensions and strong biotic continuity. (e.g. the boreal forest)

Ecosystems tend to be a convenient level to study some environmental problems. It is usually necessary to consider levels of complexity above and below the main level of interest: ‘each level of complexity finds its explanations of mechanism in the levels below, and its significance in the levels above.

Complexity

Complexity increases with the number of components conforming a system, however, there are other factors of great importance. Systems are classified into three:

1. simple systems of small-numbers,
2. simple systems of large-numbers, and
3. middle-number systems.

The first ones can be adequately handled using differential equations. The second ones can be handled by replacing the individual entities by their mean using a statistical approach. However, when complexity increases none of these two approaches is useful: the parts are too few or too different to reliably average them, but too many to represent each one with an equation. Middle-number systems require the viewpoint provided by the general systems theory.

Systems Analysis: Systems analysis can be defined as the application of the scientific methods to problems involving complex systems. It is a body of theory and techniques for studying, describing and making predictions about complex systems, which often is characterized by use of advanced mathematical and statistical procedures by using computers. The goal of systems analysis in fisheries management is to promote good decision making in practical situations. Systems analysis is the formalized study of any system, or of the general properties of systems.

What is a model?

A model is an abstraction of reality. It is the formal description of the essential elements of a problem. A model for systems analysis can be thought as a formal description of the system of interest. The description can be physical, mathematical or verbal. A **mathematical model** is a set of equations, which describes the inter-relationships among system components. By solving these equations we can mimic, or simulate the dynamic (time varying) behavior of the system.

A very general definition of model, from the viewpoint of its relation to reality is: "An object 'A' is a model of an object 'B' for an observer 'C', if the observer can use 'A' to answer questions that interest him about 'B'. This definition can be applied equally well to mathematical models, scale models, and simulators (machines like flight simulators). Implicit in the definition is the fact that there is a goal in modelling (given by questions that interest the observer). As reality is complex, every model is a partial projection of the reality on a domain of interest, taking into account the state of knowledge of the modeller.

A model is an incomplete representation of reality

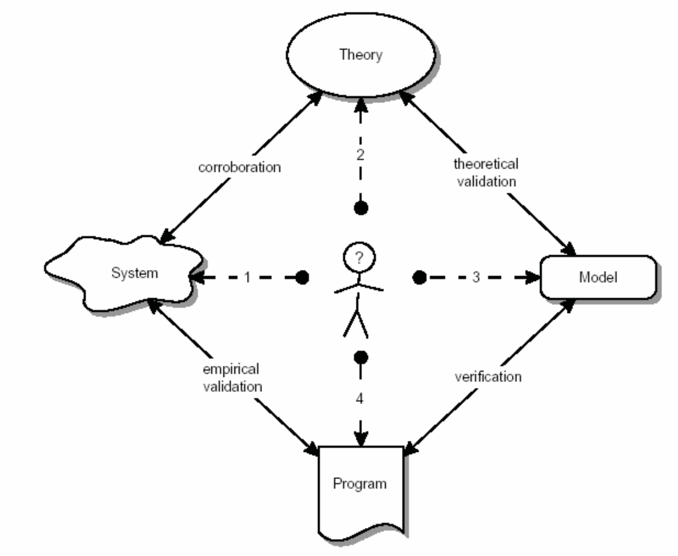
- because we have a goal and strive for simplicity
- because we are ignorant and brain capacity has limits

In systems analysis, a model is thought as a collection of variables and relations between them.

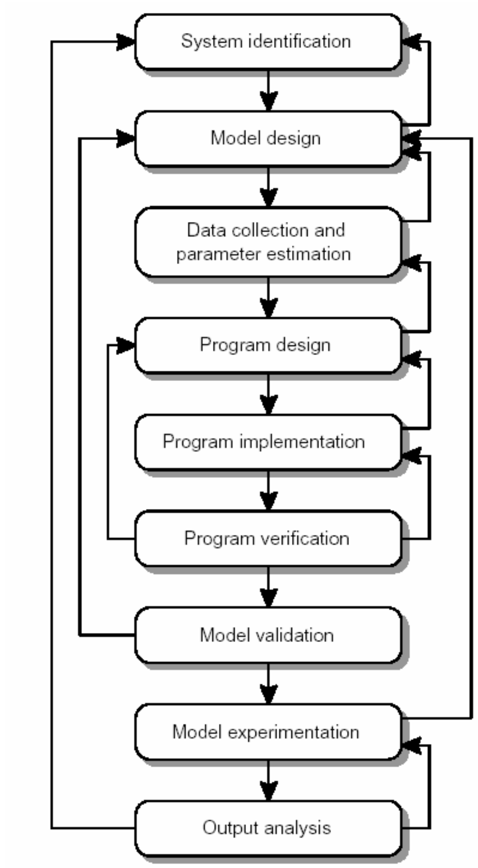
- ✍ A parametric model is a functional relationship, with the values of the parameters unspecified: it gives the structure of the model.
  For example: $y = f(x) = a \cdot x$, where a is a parameter.
- ✍ A mathematical model is a parametric model plus a set of values for the parameters.
  For example: $y = f(x) = 2.35\ x$, with $a = 2.35$.
- ✍ Simulation is to do experiments with a model.
- ✍ Experimental frame is the subset of all the experiments doable with the real system that can be reproduced with the model.
- ✍ Experimental condition is the set of conditions within an experimental frame, which defines a particular experiment.
- ✍ The specification of an experiment consists in the specification of an experimental frame, plus a parametric model, plus a set of values for the parameters.

Modelling as a mental activity

1. system identification
2. system representation
3. model design
4. model coding



Life cycle of a model



The boundaries of a model: System identification consists in defining the boundaries of the system to be modelled.

Patterns (of behaviour, in time)

- ✍ Linear growth
- ✍ Linear decay
- ✍ Exponential growth
- ✍ Exponential decay
- ✍ S-shaped growth
- ✍ Overshoot
- ✍ Overshoot and collapse
- ✍ Oscillation

Steps in modeling

1. Draw a graph of how an important variable changes with time.
   This is the "reference mode".
2. List policies that might improve the performance of the system.
3. Think about key variables and their interconnections.
4. Always remember that we should leave out unimportant factors and keep the important ones.

Classification of models: Models can be classified in different ways

<u>Physical model Vs Abstract model</u>: Physical models are physical replicas of the objects under study on a reduced scale. Ex.: A marine aquarium is a physical model of a marine ecosystem. A scaled down architectural model used to help us visualize floor plans and space relationships is a physical model of multi-floored building. Abstract models use symbols rather than physical devices to represent the system. The symbols can be written languages, verbal description or a thought process. A mathematical model is a special type of abstract model written in the language of mathematics. Since mathematical notation is more specific than language, mathematical models are less ambiguous than word models.

<u>Dynamic model Vs Static model</u>: A dynamic model describes a time varying relationship. Simulation models are dynamic so also some regression models involving time as independent variable. A static model describes a set of relationships that do not change with time. Regression models with out time component are static.

<u>Empirical model Vs Mechanistic model</u>: Empirical models are developed primarily to describe and summarize a set of relationships, without regard for appropriate representation of processes or mechanisms that actually are operating in the real system. The goal of empirical models is prediction and not explanation. Another term used for empirical models is correlative model. Ex.: A model predicting metabolic rates of an animal solely as a function of body size, surplus production models in fish stock assessment. Mechanistic models, otherwise known as explanatory models, are developed primarily to represent internal dynamics of the system of interest. Here the goal is explanation through representation of the casual mechanisms underlying system behavior. A model representing metabolic rate of an animal as a function of body size, level of activity, environmental temperature, wind and length of exposure to ambient conditions is an example of mechanistic model.

<u>Deterministic model Vs Stochastic model</u>: A model is deterministic if it contains no random variable. Predictions using deterministic models under a set of conditions are always exactly the same. Ex: Model developed relating energy requirements of an

individual (in kcal/day) to ambient temperature (in ?C) given by *y = 100 – 2 x* is a deterministic model. A model is stochastic if it contains one or more random variables. Stochastic model predictions under a specified set of conditions are not always exactly the same, because random variables within the model can take different values each time the model is solved. Choice between deterministic and stochastic models depends on the specific objectives of modeling. Deterministic models are easier to build, as it does not require specification of the distributions for the random variables. Prediction for a given situation need to be made only once for deterministic models where as stochastic model predictions must be repeated sufficiently to obtain the average response for a given situation.

Analytical model Vs Simulation model: Models that can be solved in closed form mathematically are analytical models. A general solution that is applicable to all situations can be obtained for analytical models. Regression models, differential equation models, models of standard theoretical statistical distributions etc. are analytical models. The analytical model for population growth given by the formula $N_t = N_0 e^{rt}$ is an analytical model. Here N_t is the population size at time *t*, N_0 is the initial population size and *r* is the intrinsic rate of population increase. Models for which a general analytical solution is not possible must be solved numerically using a specified set of arithmetic operations, for each particular situation the model can represent. Such models are known as simulation models. Most of the ecological models are simulation models. In ecological modeling, the choice between analytical model and simulation model is based on whether we sacrifice ecological realism to obtain analytical model or sacrifice mathematical power to include more ecological realism.

Different Phases of Systems Analysis: There are several aspects of problem definition that always should be considered before application of systems approach.

I. Conceptual Model Formulation
Model formulation consists of a) Bounding the system of interest b) Categorizing components within the system c) Identifying relationships between components and d) Formally representing the conceptual model.
II. Quantitative Specification of the Model
Quantitative specification of the model is composed of a) Choosing the general quantitative structure for the model b) Choosing functional forms of model equations c) Choosing the basic time unit for simulations and parameterizing model equations and d) Formally presenting and computer coding model equations and executing the baseline simulation.
III. Model Validation: The components of model validation are a) Examining capability of the model to address the problem of interest b) Examining reasonableness of model structure and individual model mechanisms c) Examining qualitative reasonableness of overall model behavior d) Examining quantitative correspondence between overall model behavior and real system behavior and e) Sensitivity analysis of the model
IV. Model Use: Model use is the final part of system analysis and it involves a) Identifying management policies or environmental situations to be evaluated and representing them in the model b) Developing the experimental design for simulations c) Analyzing and interpreting simulation results and d) Further examining selected types of management policies or environmental situations.

ESTIMATION OF PRIMARY PRODUCTIVITY

17

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The primary production can be defined as the amount of organic materials, which by the activity of organisms in unit time is synthesized in a unit volume of water by the phytoplankton using the solar energy and extending from the sea surface to the bottom of the euphotic zone. The micro algae remove dissolved carbon dioxide and micro nutrients from the water and using solar energy convert them into complex organic compounds of high potential energy with the help of photosynthetic pigments, the chlorophylls. The primary productivity will be confined practically entirely to that brought about by phytoplankton. The growth and distribution is controlled by many factors which may be physical factors like light, temperature, currents etc., chemical factors like salinity, dissolved oxygen content, pH, nutrients such as nitrite, nitrate, phosphate and silicate and trace elements, organic minerals etc., biological factors like grazing and reproduction, hydrological events like upwelling, sinking, turbulence etc., and seasonal variations like winter, summer, spring and autumn.

The word 'production' is synonymously used for standing crop as well as primary production, which is basically a measure of the photosynthetic activity of the micro algae. Various methods, both direct and indirect, are employed for estimating the productivity of an area. Of the direct methods, which are used in the measurement of primary production, the light and dark bottle oxygen technique (Gaarder and Gran, 1927), ^{14}C technique (Steemen Neilsen, 1952) and chlorophyll estimation (Strickland and Parsons, 1972) are the most popular.

Oxygen Technique

In this technique, samples are collected from various depths in reagent bottles with glass stoppers. Three samples are required from each depth. First bottle (IB) has to be fixed with Wrinkler A & B, second bottle (LB) has to be kept for incubation along with the third bottle (DB) which has to be covered with black paper or black rexene cloth. Both light and dark bottle has to be incubated at least 3 hrs/4hrs/6hrs or 12 hrs depending on the convenience. After the incubation, both the bottles have to be fixed with Wrinkler's solution. All the three bottles have to be titrated against Sodium thiosulphate in a burette, starch will be the indicator and estimate the oxygen content of each bottle. In the dark bottle, only respiration takes place while in the light bottle, both photosynthesis and respiration take place. The oxygen content in the light bottle minus that in the dark bottle represents the gross production. The oxygen content of the light bottle minus that of the initial bottle represents the Net production. The oxygen content in the initial bottle minus that in the dark bottle represents the respiration of all the organisms present.

$$\text{Production (mg C)} = \frac{O_{2\,(ml/l)} \times 0.536}{PQ} \quad \text{or} \quad \frac{O_{2\,(mg)} \times 0.375}{PQ}$$

where, PQ (Photosynthetic Quotient) is taken as 1.25.

Carbon-14 Technique

This technique was introduced by Steemen Neilsen in 1952 on board the Danish research vessel GALATHEA is the most suitable technique for the measurement of primary production in water bodies where the rate of production is very low. Besides, the practical application of the technique in fieldwork is relatively simple. A solution with a definite quantity (1 ml) of $NaH^{14}C0_3$ in sealed ampoules is pippeted out and added to water samples (60 ml) collected from different depths before an experiment. The total CO_2 content of the water has to be estimated. One light and dark bottle of each depth has to be collected and an ampoule of ^{14}C added. After the exposure of samples for a definite period *(in situ* or simulated *in situ* conditions) the samples are filtered in to Millipore or membrane filters. The filters are dried over silica gel and counted in a Geiger Muller Counter. The counts are converted into the carbon equivalent using the formulae,

$$\frac{\text{Activity of the filter (cpm)}}{\text{Activity of the Ampoule (cpm)}} \times \frac{\text{Total } CO_2}{\text{Hrs of incubation}} \quad \frac{12}{44} \quad \times 1.06 \quad = \text{mgC/l/h}$$

By integrating the values for the different depths, production for the water column in $gC/m^2/day$ can be calculated.

Estimation of chlorophylls

Since Chlorophyll *(a, b,* c) are the photosynthetic pigments in phytoplankton, its abundance will give a measure of the presence of primary producers and hence the productivity of an area.

One litre of seawater can be collected from the surface or required depth with the help of a sampler and filtered through Millipore/Sartorius/GFC filter paper (47 mm) and the filter paper is dissolved in 90 % acetone. If the GFC filter paper is used for filtration, the acetone has to be centrifuged and the clear solution is poured to the cuvitte of a Spectrophotometer. In a cuvitte, 90 % acetone is poured for being used as standard and measurement was taken in different wavelengths (630,645,665 and 750). For the estimation of chlorophyll a the below mentioned formulae can be used.

$$\textbf{Chl a (mg/m}^3\textbf{)} = \frac{26.7\,(665_o - 665_a) \times v}{V \times l}$$

Where,

665_0 = before acidification
665a = After acidification

v = volume of acetone added (10 ml)
V = volume of water filtered
I = length and path of the cuvitte

However, Parsons et *al* (1984) has given a revised formula for the estimation of chlorophylls.

Chlorophyll a = 11.85 $_{E664}$ - 1.54 $_{E647}$ - 0.08 $_{E630}$
Chlorophyll *b* = 21.03 $_{E647}$ - 5.43 $_{E664}$ - 3.66 $_{E630}$
Chlorophyll *c* = 24.52 $_{E630}$ - 1.67 $_{E664}$ - 7.60 $_{E647}$

Primary production in special ecosystems

There is great amount of seasonal and spatial variations in the magnitude of primary production in special type of ecosystem such as mangroves, prawn culture fields and sea grass beds.

Mangroves are highly specialised ecosystem in the coastal zone and are the breeding grounds of most of the aquatic organisms. The productivity of the mangroves is very high due to the high quantity of litterfall and organic detritus. Usually mangroove waters are having an average production of 2 - 3 gC/m^3/day depending on the area and season. Mangrooves existing in the island ecosystem are found to be highly productive with an average of 3 - 3.5 gC/m^3/day, especially in the Andaman Nicobar Islands.

The prawn culture fields existing in the estuarine and backwater regions of Kerala indicated moderate to high rates of primary production, ranging from 1 - 3 gC/m3/day depending on the abundance of micro algae. Usually the backwaters and estuaries will have moderate rates of primary production, ranging from 1 - 2 gC/m^3/day during the monsoon season and less than 1.5 gC/m^3/day during the pre and post monsoon periods.

Similar to the mangroves, the sea grass ecosystem occurring in the coastal areas is also found to be highly productive. The productivity of the sea grass beds alone ranges from 3 - 4 gC/m^3/day and when the other primary producers such as benthic and epiphytic algae are included, the daily production may be over 6 - 8 gC/m^3/day revealing that sea grass ecosystem is highly productive in the coastal zone.

Indian Seas

The shelf areas of the Indian seas, which sustain the bulk of the fish production at present, are on the whole having a high rate of primary production. Because of the constant replenishment of nutrients in the surface layers, the shallow waters are generally productive. An average rate of 0.5 to 1.0 gC/m^3/day is observed in the shallow areas most of the time. Rates exceeding 2 gC/m^3/day are found during the southwest monsoon.

In the eastern Arabian Sea, towards the coast of India, the average rate within 50 m depth is about 1.2 gC/m^2/day and for the outer shelf region, the rate is 0.5 gC/m^2/day. The net production (taken as 60% of the gross) from the shelf area on the west coast of India upto 50 m depth has been computed as 30 x 10^6 tonnes of Carbon. Between 50 - 100 m, the net production was only 17 x 10^6 tonnes of Carbon. Thus for the whole continental shelf area on the West Coast, the annual net production is computed as 47 million tonnes of

Carbon. The rate of primary production for the East Coast are 0.65 $gC/m^2/day$ outside the shelf and the annual estimate of net production is 17 x 10^6 tonnes of Carbon (Table 1) totaling 64 million tonnes of Carbon from the entire coastal area, within 100 m depth of the Indian Seas (Nair and Pillai, 1983).

In recent years, various projections of potential yield have been made from the estimates of primary production. The optimum yield from organic production generally varies from 0.3 - 0.4% (in terms of Carbon - 10% of the wet weight 50% of the protein content), the potential exploitable resources for the whole Indian coast is about 3.5 million tonnes. Actually we are exploiting about 1.4 million tonnes only from the coastal region, there is vast scope for further exploitation of the resources.

In view of the declaration of 200 miles Exclusive Economic Zone, having a total area of 2.02 million Sq. km., it would be worthwhile to compute the annual production rate of this area (Fig. 1). The different gradients for the shelf and outside when integrated give a total production of 283 x 10^6 tonnes of Carbon (Gopinathan, 1981).

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In view of the distance involved and the sparseness of distribution, a minimum possible exploitation of 0.2% could be expected from the entire EEZ of India. Therefore the exploited yield of the living resources from the EEZ would amount to 5.5 million tonnes, both pelagic and demersal (Nair and Gopinathan, 1981). Since the present yield from the Indian Seas is only 2.7 million tonnes and exploitable potential yield based on catch statistics is 3.92 million tonnes, there is still vast harvestable resources is available in the Indian EEZ, based on the estimates of phytoplankton production.

Indian Ocean and World Oceans

The magnitude of primary production in different areas has been estimated by various authors during different Research Cruises and Expedition Reports. The potential production of the entire Indian Ocean has been computed as 4.1 x 10^9 tonnes of Carbon, which is about 1/5 of the world Oceanic production (Koblanztz Mishke et *al,* 1970). The potential yield from the Indian Ocean has been estimated by various workers which ranges from 14 - 18 million tonnes (Prasad et *al,* 1970; Gulland, 1970).

Based on the different Expedition reports and cruises conducted around the world, the World Oceanic production of phytoplankton in terms of Carbon was estimated as 2.5 - 3.0 x 10^{10} tonnes (Koblanztz Mishke *et al,* 1970). If we apply the optimum conversion efficiency of just 0.1%, the potential yield of harvestable resources will be about 300 million tonnes. The latest reports indicated that the present exploitation from the World Ocean is less than 100 million tonnes. There is still vast scope for further exploitation of the living resources.

TABLE -1

GENERAL LEVEL OF PRIMARY PRODUCTION IN VARIOUS ECOSYSTEMS

Estuaries, backwaters & prawn culture fields	1-3 gC/m^3/day
Mangroves, seaweed & seagrass ecosystems	3-5 gC/ m^3/day
Inshore and coastal areas	1-2 gC/ m^3/day
West coast of India upto 50m	1-2 gC/ m^3/day
West coast of India upto 100 m	0.53gC/m^2/day
East coast of India upto 50 m	0.68gC/m^2/day
East coast of India upto 100 m	0.20gC/m^2/day

Annual Gross Production

West coast upto 50 m	30xl0^{6}T. of C
West coast upto 100 m	17xl0^{6}T. of C
East coast of India upto 50 m	10xl0^{6}T. of C
East coast of India upto 100 m	7xl0^{6}T. of C

Total production of the Indian Seas:
West coast = 47 m.T. plus East coast = 17 m.T.

Indian seas upto 100 m	60 m T. of C
Exclusive Economic Zone of lndia (2.02 m.Sq.km)	283xl0^{6}T. of C

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ESTIMATION OF SECONDARY PRODUCTION & BENTHOS

18

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Marine organisms can be categorized as benthic, planktonic or nektonic depending on their physical habitat and their mode of motility. Planktonic organisms are those that live suspended in the water column and that are sufficiently small and/or slow so as to be incapable of directed swimming. Thus, their distribution is considered to be controlled by physical processes, such as water currents and turbulent mixing. In addition, plankton can be divided further based on their nutritional modality. Autotrophic phytoplankton depends on light and chlorophyll to fix carbon dioxide into organic molecules, whereas heterotrophic zooplankton ultimately depends on the phytoplankton for their dissolved or particulate foodstuffs.

Detectable changes in the abundance or species composition of mesozooplankton may reflect fundamental changes in the ocean environment affecting phytoplankton. In turn, because zooplankton are eaten by larger animals, some of which are of commercial importance, changes in zooplankton communities can provide early indications of imminent changes in the food conditions for fish, birds and mammals.

Plankton are tiny open-water plants, animals or bacteria. The name, like the word *planet*, is derived from a Greek root that means, "wanderer." These organisms range in size from microscopic bacteria and plants to larger animals, such as jellyfish. Plankton generally have limited or no swimming ability and are transported through the water by currents and tides. Plankton communities serve as a base for the food chain that supports the commercial fisheries.

Plankton can be divided into three major size classes:

? **phytoplankton**–microscopic plants and bacteria
? **zooplankton**–microscopic animals
? **macrozooplankton**–larger fish eggs and larvae and pelagic invertebrates

Plankton are often used as indicators of environmental and aquatic health because of their high sensitivity to environmental change and short life span. Phytoplankton are useful indicators of high nutrient conditions due to their propensity to multiply rapidly in the right conditions. Zooplankton are useful indicators of future fisheries health because they are a food source for organisms at higher trophic levels, such as finfish.

1. Phytoplankton

Like land plants, phytoplankton fix carbon through photosynthesis, making it available for higher trophic levels. The major environmental factors influencing phytoplankton growth are temperature, light and nutrient availability. Phytoplankton growth is usually limited to the *photic zone*, or the depth to which sunlight penetrates the water.

Phytoplankton can undergo rapid population growth or "algal blooms" when water temperatures rises in the presence of excess nutrients, which typically occurs near the coastal waters. While increased phytoplankton populations provide more food to organisms at higher trophic levels, too much phytoplankton can harm the overall health of the ecosystem. During these blooms, most of the phytoplankton die and sink to the bottom, where they decompose. This process depletes the bottom waters of dissolved oxygen, which is necessary for the survival of other organisms, including fish and crabs.

Phytoplankton are being used as indicators of environmental conditions because their populations are especially sensitive to changes in nutrient levels and other water quality conditions. A good picture of the current conditions in the sea can be derived by looking at phytoplankton indicators such as chlorophyll, primary production rates, biomass and species composition.

2. Zooplankton

Zooplankton are planktonic animals that range in size from microscopic rotifers to macroscopic jellyfish. Their distribution is governed by salinity, temperature and food availability. The smallest zooplankton can be characterized as recyclers of water-column nutrients and often are closely tied to measures of nutrient enrichment. Larger zooplankton are important food for forage fish species and larval stages of all fish. They also link the primary producers (phytoplankton) with larger or higher trophic-level organisms. The zooplankton community is composed of both primary consumers, which eat phytoplankton, and secondary consumers, which feed on other zooplankton.
Zooplankton can be classified into three size classes:

- **Microzooplankton**–(protozoans and rotifers) are usually less than 200 microcrons in size.
- **Mesozooplankton**–(including copepods and invertebrate larvae) are between 200 microns and 2 millimeters in size.
- **Macrozooplankton**–(including amphipods, shrimp, fish larvae and gelatinous zooplankton or jelly fish)are greater than 2 millimeters in size.

Zooplankton, like phytoplankton, make excellent indicators of environmental conditions, because they are sensitive to changes in water quality. They respond to low dissolved oxygen, high nutrient levels, toxic contaminants, poor food quality or abundance and predation. A good picture of the current conditions in the sea can be derived by looking at zooplankton indicators such as their biomass, abundance and species diversity.

Feeding habits of zooplankton

- Heterotrophs - Organisms that live off carbon fixed by primary production.
- Herbivores - Direct users of the primary producers, i.e. the phytoplankton.
- Detritivores - Consumers of dead organic matter produced by the senesence of pytoplankton, egestion of material from other zooplanktors (fecal material), or the remains of other zooplankton.
- Carnivores - Predators feeding on other zooplankton.

- Omnivores - Zooplankton that use a combination of food sources.

There are a variety of feeding stratagies in the zooplankton. Some such as copepods feed through a range of methods including setting up feeding currents with their legs that then pull phytoplankton cells past their mouths. Chaetognathas or arrow worms typically stay still in the water column and then lunge at a passing copepod to capture it with their sharp grasping spines. These saber-like spines are driven into the copepod during the ambush. Other organisms filter feed by pumping water through themselves or by the construction of large amounts of mucus upon which particles (phytoplankton, microzooplankton and detritus) become stuck. An example is the chordate salps that produce lots of mucus.

3. Benthic organisms

Studies on the benthic system are important in evaluating the health and productivity of the marine environment. Benthic macro invertebrates are the dominant groups in the marine sediments from the intertidal areas to the deep sea. Benthos is vital to the dynamics and health of the marine environment. Benthic organisms help in the deposition, breakdown and turn over of organic matter in the seabed and facilitate the recycling of nutrients. These organisms provide a key link in marine food webs. There exists a relationship between the benthic standing crop and the production of exploited demersal fishes and crustaceans.

The benthos is an aggregation of organisms living on or at the bottom of a body of water. The name *benthos* is derived from the Greek, meaning "depths of the sea." The benthic community is composed of a wide range of plants, animals and bacteria from all levels of the food web.

Benthic organisms can be divided into three distinct communities:

- **Infauna:** Plants, animals and bacteria of any size that live in the sediment.
- **Epifauna:** Plants, animals and bacteria that are attached to the hard bottom or substrate (for example, to rocks or debris); are capable of movement; or that live on the sediment surface.
- **Demersal:** Bottom-feeding or bottom-dwelling fish that feed on the benthic infauna and epifauna.

Benthic organisms link the primary producers, such as phytoplankton, with the higher trophic levels, such as finfish, by consuming phytoplankton and then being consumed by larger organisms. They also play a major role in breaking down organic material. Benthic algae and submerged aquatic vegetation (SAV) provide ideal habitat for juvenile fish. Benthic invertebrates are among the most important components of estuarine ecosystems and may represent the largest standing stock of organic carbon in the sea. Many benthic organisms, such as hard clams, softshell clams and bottom-dwelling fish, are the basis of commercial fisheries. Other bottom-dwelling organisms, such as polychaete worms and crustaceans, contribute significantly to the diets of economically important fish.

Infaunal benthic communities often are considered to be "just worms." In reality, however, these groups that inhabit the sediment include animals from all trophic levels–the primary producers, such as diatoms, and primary consumers, such as mollusks and worms; secondary consumers, such as worms and crustaceans; and "decomposers," such as bacteria and flagellates.

Benthic invertebrate communities are used as prime indicators of environmental conditions because:

- they have limited mobility and thus are unable to avoid adverse conditions;
- they live in sediments where they are exposed to environmental stressors, such as chemical contaminants and low dissolved oxygen levels;
- their life spans are long enough to reflect the effects of environmental stressors; and
- their communities are taxonomically diverse enough to respond to multiple types of stress.

Epifaunal Benthos

Epifauna are the most familiar of all the benthic organisms. They include the plants and animals one sees while wading in tidal pools or among pilings or rocks. These communities include seaweeds, oysters, mussels and barnacles; and snails, starfish and crabs. They also include animals that span a wide evolutionary range, from primitive sponges to early vertebrates (for example, tunicates, such as sea squirts). These varied organisms share an important characteristic: they live either attached to the hard substrate or move on the sediment surface.

The demersal community includes some of the most economically valuable fish. In order to adapt to life on the bottom, benthic fish have developed some of the most diverse physical characteristics found in any fish community. Soft-bottom fish include the flounders, puffers, searobins and cownose rays. Hard-bottom fish include those found near reefs, such as the oyster toadfish and the goby, which, when stationary, resemble rocks.

4. Sample collection

There are various methods for collecting samples for plankton and benthos analysis, depending on whether a quantitative or qualitative analysis is desired. With all methods, samples should be preserved soon after collection and where possible, live samples should also be examined. The methods for collecting samples are available in standard marine ecology text books.

5. Estimation of biomass

Biomass can be estimated either in wet weight or dry weight basis. While estimating wet weight, samples should be weighed immediately after blotting with tissue paper and for dry weight, samples should be dried using a hot air oven.

Zooplankton:

All zooplankton are delicate and easily damaged, so sample handling should be as gentle as possible. Since the zooplankton samples may not be counted for some time after they are returned to the laboratory, and since we hope these samples serve as a long-term, archive of national and international importance, the long-term maintenance of all of the organisms in each sample is a high priority. We recommend identifying and counting the samples under a dissecting microscope with dark-field illumination. Therefore, staining is not routinely required.

If one wants to know the total number of species in each sample, then the entire sample should be examined. If only a subsample will be analyzed, for abundance determination for example, there are a number of acceptable sample splitting routines one can follow. Recommended sub-sampling devices are the Folsom plankton splitter and the Motoda box splitter (Omori and Ikeda, 1984).

Biomass has commonly been expressed by settled volume, displacement volume, wet weight, dry weight, ash-free dry weight (organic weight), or carbon weight. The usual measure after fixing a sample has been its settled volume, displacement volume, or wet weight. The term biomass is often inappropriately used synonymously with the wet weight. In most cases, however the biomass is measured to determine the productivity and nutritional condition of the species in question and to assess the role of the species in the food web. In this sense biomass is expressed as settled volume, displacement volume, or wet weight is not always adequate because considerable variation occurs in these values due to manner of treatment and the composition of organisms. Furthermore, the measurement includes ash and other materials of low nutritive value.

In **settled-volume measurement** the sample is poured into a graduated cylinder or sedimentation tube of 50-100ml in volume, gently stirred with a glass rod, allowed to settle for 24 hr, and settled volume read. In case of **displacement-volume measurement**, the volume of the total water containing the plankton sample is first measured, after which the water is removed and its volume measured separately. The difference in volume is due to plankton. The above two methods not only include the absolute volume of the plankton but also the water between the organisms.

In case of **wet weight**, the weight of plankton is determined after eliminating as much surrounding water as possible. The water can be eliminated by vacuum filtration and by blotting the sample with filter paper (the filter paper is replaced when no more water can be absorbed by the paper). Care should be taken not to compress the plankton and damage the specimens to rush dehydration. The plankton sample without the adhering water is then weighed. The value is expressed as mg/m^3.

In case of **dry weight**, live specimens should always be weighed with this measurement, as the changes in the dry and organic weights as well as chemical composition of formalin- preserved specimen are considerable. The dried and weighed sample could not be used for species identification, in such case you have to go for duplicate samples. In case of preserved samples, samples not more than a month is used.

Procedure: A pyrex holder for membrane filters or similar filtration unit may be used to drain the water. A glass fiber (GF) filter with smaller or same mesh size of that of plankton net is weighed and then moistened on the filter holder with distilled water. The sample is added and sucked dry at about 250mmHg. When no more water can be eliminated, salt contained in any water remaining between specimens is eliminated with an isotonic ammonium formate (6.0 – 6.5 % W/V) rinse, which is also removed by suction. For specimens with harder outer covering (Crustaceans) sea salt can be eliminated with quick rinse with distilled water (prolonged rinsing will lead to loss of body fluids and dry weight). The specimens are large; it can be put in a bag of nylon plankton gauge and immersed for a short time in isotonic solution. After removal of rinse, the specimens are dried to a constant weight in an oven at 60°C.

In case of dry **organic weight (Ash-free dry weight)**, a known weight of the dry sample is ashed to a constant weight in a crucible at 450-500°C in an electric furnace. After it is completely ashed, the material is cooled in desicator and then weighed. The dry organic weight is obtained by subtracting the ash weight from the dry weight.

Benthic biomass:

The benthic organisms collected should be washed in seawater and sieved over five and one millimetre screens with round holes. The five-millimetre fraction should be sorted by hand, all fauna and biogenic structures were collected and preserved in 4% buffered formalin in seawater for later identification in the laboratory. The one millimeter fraction should be preserved without sorting. All calcareous poriferans should be preserved in 96 % ethanol.

In the laboratory, the organisms should be sorted and transferred to 80% ethanol. They should be later identified to the lowest possible taxonomic level, counted and weighed. Since marine macro-benthos seldom has great lipid stores they lose relatively little biomass during storage and biomass loss is therefore expected to be relatively evenly distributed in all samples. Weight should be measured by picking up the respective animals, removing excess water using paper tissue and then weighing. All individuals of the same species from one station should be weighed in one group. Animals with shells can be weighed with their shell. Biomass should be expressed in g/m^2.

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METHODS OF STOMACH CONTENT ANALYSIS OF FISHES

19

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The study of the feeding habits of fish and other animals based upon analysis of stomach content has become a standard practice (Hyslop 1980). Stomach content analysis provides important insight into fish feeding patterns and quantitative assessment of food habits is an important aspect of fisheries management. Lagler (1949) pointed out that the gut contents only indicate what the fish would feed on. Accurate description of fish diets and feeding habits also provides the basis for understanding trophic interactions in aquatic food webs. Diets of fishes represent an integration of many important ecological components that included behavior, condition, habitat use, energy intake and inter/intra specific interactions. A food habit study might be conducted to determine the most frequently consumed prey or to determine the relative importance of different food types to fish nutrition and to quantify the consumption rate of individual prey types. Each of these questions requires information on fish diets and necessitates different approaches in how one collects and analyzes data. Here, we outline qualitative and quantitative techniques used to describe food habits and feeding patterns of fishes. For a better understanding of diet data and for accurate interpretation of fish feeding patterns, time of day, sampling location, prey availability and even the type of collecting gear used need to be considered before initiating a diet study or analyzing existing diet data.

Stomach contents can be collected either from the live or fresh died fish. Regardless of the method, investigators should ensure that the removal technique effectively samples all items in the gut. Other wise data will be skewed toward items that are more easily displaced from the stomach. Alternatively, live fish can be sacrificed and stomach contents removed for analysis. If fish are to be sacrificed, they should be preserved immediately either by freezing or by fixing in formalin. Stomach contents will continue to digest, rendering rapid preservation of the fish or removed contents necessary to prevent loss of resolution. As in most fish groups feeding behavior of juveniles and adults vary distinctly attention should be taken to encounter more samples which will include all size groups of the particular fish. The specimens either from live or preserved should be measured to its total length to the nearest 1mm and weight to the nearest 0.1 g. Cut open the fish and record the sex and maturity stage of the fish. Remove the stomach and preserve them in 5% neutralized formalin for further analysis. For the analysis, a longitudinal cut must be made across the stomach and the contents are transferred into a Petri dish. The contents then keep for five minutes to remove excess formalin and then examine under binocular microscope. Identify the gut content up to the genus and if possible up to species level depending up on the state of digestion. Various taxa digest at different rates. As such, all recently consumed taxa may be present in the foregut but only resistant items remain in the hindgut. To avoid bias when both easily digested prey and resistant prey are present, only the immediate foregut (e.g., stomach) should be sampled.

Prey items in fish stomachs are often not intact. Hard parts such as otoliths, scales, cleithra or backbones have diagnostic, species specific characteristics useful for identifying prey. Alternatively, partially digested prey may be identified using unique biochemical methods such as allozyme electrophoresis, or immunoassays. An important fact assessed by the examination of the stomach is the state or the intensity of feeding. This is judged by the degree of distension of the stomach or by the quantity of food that is contained in it. The distension of the stomach is judged and classified as ‘gorged or distended’, ‘full’, ‘3/4full’, ‘1/2full’ etc by eye estimation.

Fish diets can be measured in a variety of ways. Methods of gut contents analysis are broadly divisible into two, *viz.*, qualitative and quantitative. The qualitative analysis consists of a complete identification of the organisms in the gut contents. Only with extensive experience and with the aid of good references it is possible to identify them from digested, broken and finely comminuted materials. Quantitative methods of analysis are three types, *viz.*, numerical, gravimetric and volumetric. All these types of analysis are widely employed by different workers. The following outline of methods is based mainly on the reviews by Hynes (1950), Pillay (1952), Windell (1968), Hyslop (1980) and Chipps *et a*l (2002).

1) Numerical methods

The numerical methods are based on the counts of constituent items in the gut contents. The numerical methods have been adapted in different ways to assess the relative importance of food items and these can be classified under four distinct heads, viz., a) Occurrence, b) Dominance, c) Number and d) Point (Numerical) methods.

a) Frequency of Occurrence. Stomach contents are examined and the individual food organisms sorted and identified. The number of stomachs in which each item occurs is recorded and expressed as a percentage of the total number of stomachs examined.

$$\text{Frequency of Occurrence, } O_i = \frac{J_i}{P}$$

Where, J_i is number of fish containing prey **i** and P is the number of fish with food in their stomach.

This method demonstrates what organisms are being fed upon, but it gives no information on quantities or numbers and doest not take in to consideration the accumulation of food organisms resistant to digestion. For instance, three organisms in a stomach, say, prawn, rotifers and diatoms, present in the ratio of 1:200:2000 would all be treated by this method as 1:1:1 with reference to the stomach in question. This method holds good even when there is differential distribution of various food organisms in the water for the same reason that it is not biased by size or numbers of organism comprising the food. Many have used this method as an indicator of inter-specific competition while some utilized this method to illustrate the seasonal changes in diet composition.

b) Number method. The number of individual of each food type in each stomach is counted and expressed as a percentage of the total number of food items in the sample studied, or as a percentage of the gut contents of each specimen examined, from which the total percentage composition is estimated.

$$\text{Percent by number, } N_i = \frac{N_i}{\sum_{i=1}^{Q} N_i}$$

Where, N_i is the number of food category **i**

This method has been employed successfully by several workers in studies on the food of plankton feeding fishes where the items can be counted with ease. In the basic number method, no allowance is made for the differences in size of food items. So in the studies on the food of fishes other than plankton feeders, the number method has very limited use. The counting of comminuted plant matter in the stomach of fish is impracticable and will not yield correct evaluations. So also in the analysis of the gut contents of a carnivore which may consist of only one large sized fish and a couple of small larvae, the counting are of little value computations. These are summed to give totals for each kind of food item in the whole sample, and then a grand total of all items. The quotient of these gives the percentage representation, by number, of each type of food item.

c) Dominance method. Essentially the dominance method is a partial improvement of the occurrence method, *viz*., the lack of consideration of the quantities of the food items present in the stomach, sought to be remedied. The stomach contents comprising the main bulk of the food materials present, is determined and the number of fish in which each such dominant food material is present is expressed as a percentage of the total number of fishes examined. The percentage composition of the dominant food materials can also be expressed by this method as in the occurrence method.

Though in an analysis of dominance the bulk of the food material is taken in to account, it can yield only a very rough picture of the dietary of a fish. More over, items which are less dominant due to environmental reasons may escape notice. Though this defect can also be remedied to a certain extent by the examination of large samples spread over a long period of time, a system of assay that takes in to account the relative importance of food constituents will obviously be more suitable in gut content analysis.

d) Points (Numerical) Method. The points method is an improvement on the numerical method where consideration is given to the bulk of the food items. The simple form of points method is the one in which the counts are computed falling a certain organisms as the unit. In a more modified form, the food items are classified as 'very common', 'common', 'frequent', 'rare', etc., based on rough counts and judgments by the eye. In this arbitrary classification the size of the individual organisms is also given due consideration. The contents of all stomachs are then tabulated and as a further approximation, different categories are allotted a certain number of points and the summations of the points for each food item are reduced to percentages to show the percentage composition of the diet. This method is essentially a numerical one; the volume being only a secondary consideration and it is only in the counts that a certain amount of accuracy can be claimed.

2) Volumetric methods

Many workers consider the volume as a more satisfactory method for quantitative analysis of gut contents. As Hynes (1950) pointed out, volume forms a very suitable means of assessment, this is especially so in the case of herbivorous and mud feeding fishes where the numerical methods “become meaningless as well as inaccurate”. Even in cases where the numerical methods are suitable, volume has been considered as an essential factor to be reckoned with, and in all improved numerical methods the volume of the food items is taken in to consideration in some way or other. The chief methods that are employed in assessing the volume of food items in the gut contents of fishes are:

a) Eye estimation method: - This is probably the simples and easiest means of determining the volume of food constituents. In this method the contents of each sample is considered as unity, the various items being expressed in terms of percentage by volume as estimated by inspection. This method of analysis is subjective in nature and the investigators personal bias is likely to influence the results very greatly. This defect can be minimized to a great extent by the examination of large samples conducted over a long period.

b) Points (Volumetric) method: - This method is a variation of the eye estimation method. Here instead of directly assessing the volume by sight as in the previous method, each food item in the stomach is allotted a certain number of points based on its volume. Certain workers have taken into account both the size of the fish and the fullness of the stomach in the allotment of points. The diet component with highest volume was given 16 points. Every other component was awarded 16, 8, 4, 2, 1 and 0 points depending on the volume relative to the component with the highest volume. Percentage volumes within each subsample were calculated as:

$$? = \frac{\text{Number of points allocated to component } ?}{\text{Total points allocated to sub sample}} \text{ X } 100$$

Where,

? is the percentage volume of the prey component ?

This method is quite useful for analyzing omnivorous and herbivores where measuring volumes of microscopic organisms such as diatoms and filamentous algae are very difficult.

c) Displacement method: - The displacement method is probably the most accurate one for assessing the volume. The volume of each food item is measured by displacement in a graduated container such as a cylinder with the smallest possible diameter for accuracy. This method is eminently suited in the estimation of the food of carnivorous fishes. But the differential rate of digestion of the food items may sometimes affect he accuracy of the observations. However, if the collections are made when the fish are on feed, this defect can be easily overcome. A knowledge of the volumes of the different size groups of the food items ay be of great help in estimating the volume of the whole item form the semi digested fragments

3. Gravimetric method

The gravimetric method consists of the estimation of the weight of each of the food items, which is usually expressed as percentages of the weight of the total gut contents as in other quantitative methods.

$$\text{Percent by weight, } W_i = \frac{W_i}{\sum_{i=1}^{Q} W_i}$$

Where, W_i is the weight of the prey **i**

Generally the wet weigh of the food after removing superfluous water buy pressing it dry between filter papers is taken for this purpose. Dry weight estimation is more time consuming and is usually employed where accurate determinations of calorific intake is required. The limitation of weight as a criterion of analysis has already been referred in the consideration of the method of assessing the condition of feed. Besides these, the accurate weighing of small quantities of food matter is extremely difficult and impracticable in studies of large collections. This method is, therefore generally employed only in conjunction with other methods to demonstrate seasonal variations in the intensity of feeding.

Food analysis indices

A. Simple indices

1) Index of fullness. This is measured as the ratio of food weight to body weight as an index of fullness, which is very widely employed. (The ratio of corresponding volume can also be used.) This index can be applied to the food in the stomach, or to that in the whole digestive tract. It is usually expressed as parts per 10,000 (%00, or parts per decimile); that is:

$$\text{Fullness index} = \frac{\text{weight of the stomch contents x 10,000}}{\text{weight of fish}}$$

2) Index of consumption. Some authors have used not the actual weight (or volume) of the stomach contents, but their reconstructed weight: i.e. their estimated weight at time of ingestion. When reconstructed weights are used in the formula above, the index obtained has been distinguished as the index of consumption

$$\text{Consumption index} = \frac{\text{reconstructed weight of stomach contents x 10,000}}{\text{weight of fish}}$$

Reconstructed weights are estimated form the lengths of relatively indigestible parts of the organisms consumed- for example shells, chitin, bones, otoliths, scales or stomachs. For accuracy it is necessary to make systematic measurements on whole specimens of various sizes, for each of the food species consumed.

3) Index of selection or forage ratio. Most fishes have a scale of preference for the organisms in their environment, so that some are consumed in large numbers, others moderately, some not al all. A quantitative index of such differences called as the forage ratio. A study of the quantities of different organisms available to the fish is made, and also of the various items in their stomachs; then;

Selection index = forage ratio = $\frac{s}{b}$

Where, s = percentage representation by weight, of a food organism in the stomach and b = percentage representation of the same organism in the environment. The lower limit for this index is 0; its upper limit is indefinitely large.

4) Index of electivity, Ivlev (1961) proposed a somewhat different quantitative measure of selection which has been widely used as mean of comparing the feeding habits of fishes and other aquatic organisms with the availability of potential food resources in natural habitats. The relationship is defined as

Electivity index = E = $\frac{s - b}{s ? b}$

The index has a possible range of -1 to +1, with negative values indicating avoidance or inaccessibility of the prey item, zero indicating random selection form the environment, and positive values indicating active selection.

5) Manly-Chesson index

When given a variety of prey types, most fishes select some food categories over others. To measure this selectivity, a variety of indices have been developed that incorporate measures of prey use and prey availability. While prey use can be easily determined from gut content analysis, accurate description of prey availability can be problematic. What we quantify as prey availability may be quite different than what fish perceive under natural conditions. Furthermore, because different prey can occupy different habitats, a single sampling technique may not adequately quantify the relative abundance of different prey items in the environment. This is important because we cannot use volumetric estimates of zooplankton abundance (e.g. no/L) and area densities of benthic invertebrates (e.g., no/m^2) as a simultaneous measure of prey availability. Only in cases where prey is collected with the same gear type, such as open water zooplankton, can we begin to compare use versus availability.

Like diet and overlap indices, there is much controversy over which index is best. Comparisons of different indices have revealed that the Manly-Chesson (Chesson 1983) and the Linear index (Strauss 1979) are good choices for quantifying prey preference. The Manly-Chesson index is frequently used to quantify prey preference and can be calculated for two scenarios

a) Constant prey abundance – used when the number of prey eaten is very small relative to its total population or when prey is replaced as in laboratory studies. The equation for the Manly-Chesson index under constant prey abundance is,

$$?_i ? \frac{r_i}{n_i} \frac{1}{? (r_j / n_j)}$$

Where $?_i$ = Manly's alpha for prey type i

r_i, r_j = Proportion of prey type **i** or j in the diet

n_i, n_j = Proportion of prey type **i** or j in the environment
m = Total number of prey types

Values of $?_i$ are normalized so that $\overset{m}{?} \; ?_i = 1.0$

Prey preference is indicated when $?_i$ values are greater than 1/m. Conversely, $?_i$ values Less than 1/m imply that prey species **i** is avoided in the diet because it is used in lower proportion than its availability in the environment.

b) Variable prey abundance – used when the number of prey eaten is large relative to its total population in the environment or, in experimental studies, when prey are not replaced after being eaten. The Manly-Chesson index for variable prey populations is calculated using the equation,

$$?_i = \frac{\log p_i}{\overset{m}{\underset{j?1}{?}} \log p_j}$$

Where $?_i$ = Manly's alpha for variable prey populations
p_i, p_j = Proportion of prey i or j remaining at the end of the experiment (= ei/ni)
Where,
ei = Number of prey type i remaining at the end of experiment
ni = Number of prey type i at the beginning of the experiment
m = Total number of prey types

In practice, indices such as the Manly-Chesson can be used to test for differences in prey selectivity providing important information about preferred (or vulnerable) prey types.

Compound indices

In an attempt to consolidate the desirable properties of individual diet measures (e.g., Ni, Wi. Foi), compound indices were developed that combine two or more measures into a single index. The belief is that compound indices capture more information than do single component measures (Chipps et al 2002).

1) Index of Preponderance: - (Natarajan and Jhingran, 1961)

This index gives a summary picture of frequency of occurrence as well as bulk of various food items. It provides a definite and measurable basis of grading the various food elements. The bulk of food items can be evaluated by 1) Numerical 2) volumetric and 3) Gravimetric methods. As the numerical method is not suited to the index with the frequency of occurrence it magnifies the importance of smaller organisms which may appear in enormous numbers. Therefore either volumetric or gravimetric are best to assess the food items quantitatively. If we V_i and O_i are the volume and occurrence index of food item i. then,

$$\text{Index of preponderance } I_i = \frac{V_i O_i}{?\ V_i O_i} ?\ 100$$

Example: The 'Index of Preponderance' of food items of *Catla catla* (Ham.) is given in the table 1 with rankings in brackets.

Index of Preponderance (Natarajan and Jhingran, 1961) of adult Catla

Food items	Percentage of occurrence (O_i)	Percentage of volume (V_i)	$V_i O_i$	$\frac{V_i O_i}{?\ V_i O_i} ?\ 100$
Crustaceans	24.5	57.1	1398.95	64.50 (1)
Algae	27.3	24.0	655.20	30.06 (2)
Plants	6.4	8.2	52.48	2.41 (3)
Rotifers	10.8	2.4	25.92	1.19 (4)
Insects	3.6	6.0	21.60	0.99 (5)
Protozoa	0.6	0.3	0.18	0.01 (8)
Molluscs	….	….	……	…...
Polyzoa	….	….	……	. ….
Detritus	10.0	1.3	13.00	0.60 (6)
Sand and mud	16.8	0.7	11.76	0.54 (7)
?	100	100	2179.09	100

According to the index crustacea and algae constitute 1 and 2 ranks in *Catla catla*. While third, fourth and fifth places are held by plants, rotifers and insects. In grading the food elements accidental and incidental inclusions like sand, mud, etc., may be left out of consideration.

2) Index of Relative Importance (IRI):- Leo Pinkas et al (1971)

This index is an integration of measurement of number, volume and frequency of occurrence to assist in evaluating the relationship of the various food items found in the stomach. It is calculated by summing the numerical and volumetric percentages values and multiplying with frequency of occurrence percentage value.;

$$\text{Index of relative importance, } IRI_i = (\%N_i + \%V_i)\ \%O_i ,$$

Where, N_i, V_i and O_i represent percentages of number, volume and frequency of occurrence prey **i** respectively.

Example:. Index of Relative Importance of pelagic preflexion summer flounder, *Paralichthys dentatus* larvae (Grover, 1998).

Prey	$\% N_i$	$\% V_i$	$\% O_i$	$(\% N_i + \% V_i)\ \% O_i$	%IRI
Tintinnids	28.7	3.3	37.6	1203.2	19.3
Copepod nauplii	20.0	10.2	41.2	1244.24	20.0
Copepodites	16.0	61.4	30.0	2322	37.3
Calanoids	0.6	4.9	2.0	11	0.2
Cyclopoids	0.6	2.0	2.4	6.24	0.1
Copepod eggs	16.0	1.2	34.8	598.56	9.6
Bivalve larvae	12.1	14.8	28.0	753.2	12.1
Invertebrate eggs	3.7	0.9	11.6	53.36	0.9
Other	2.3	1.3	9.2	33.12	0.5

In pelagic preflexion summer (*Paralichthy dentatus)* larvae, copepodites composed the bulk of the diet (61.4% Vol, 37.3 % IRI) and formed the most important prey. Copepod nauplii, the second most important prey, composed 20.0% (N and IRI). Tintinnids, despite being the most abundantly ingested prey (28.7% N); ranked third in importance at 19.3% (IRI). Bivalve larvae and copepod eggs were the only other prey that accounted for >1% of the diet, and together they composed 21.7% (IRI).

Diet overlap indices

Niche overlap indices tabulated in the form of matrices are often used to measure the magnitude of resource overlap among different species. Although sometimes used to infer competition, we should recognize that high resource overlap between two species may not indicate competitive bottlenecks. Rather, it may be indicative of high resource abundance such as seasonal peaks in prey availability.

a) Morista's index

When stomach data are represented in prey numbers or only prey numbers are available, Morista's index has been recommended as the most robust index.

Morista's index is calculated using the equation,

$$M = \frac{2\sum p_{ij}\, p_{ik}}{\sum^{n} p_{ij}\left[(n_{ij}-1)/(N_j-1)\right] + \sum^{n} p_{ik}\left[(n_{ik}-1)/(N_k-1)\right]}$$

Where, M =Morista's index of niche overlap between species *j* and *k*

p_{ij} =Proportion resource *i* is of the total resources used by species *j*

p_{ik} =Proportion resource *i* is of the total resources used by species *k*

n_{ij} =Number of individuals of species *j* that use resource category *i*

n_{ik} =Number of individuals of species *k* that use resource category *i*

N_j, N_k =Total number of individuals of each species in sample

b) Horn's index

If stomach data are not expressed as prey numbers (e.g., biomass or volume), then Horn's index is recommended and is calculated as,

$$H ? \frac{? (p_{ij} ? p_{ik}) \log(p_{ij} ? p_{ik}) ? ? p_{ij} \log p_{ij} ? ? p_{ik} \log p_{ik}}{2 \log 2}$$

Where H =Horn's index of overlap between species j and k

p_{ij} =Proportion resource *i* is of the total resources used by species j

p_{ik} =Proportion resource *i* is of the total resources used by species k

c) Schoener's index

Basically this index was used to study the diet overlap of terrestrial animals. Later many fishery biologists have used this index to compare the dietary overlap of the two fish species or of the two size/age categories or of the two different habitats. Percentage values of weight of the prey or Index of Relative Importance can be used to compare the diets.

$$S_{io} = 1\text{-}0.5 \overset{n}{\underset{j?1}{?}} \left| p_{xi} ? p_{y_i} \right|$$

Where,

p_{xi} = the proportion of the prey i in the diet of fish species x (or size class x);

p_{y_i} = The proportion of prey i in the diet of two species y (or size class y);

and j = the numbers of prey categories.

An overlap value of S_{io} ? 0.6 (Schoener, 1970) is considered as biologically significant.

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OVERVIEW OF COMPUTER SIMULATIONS

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Computer simulation is the discipline of designing a model of an actual or theoretical physical system, executing the model on a digital computer, and analyzing the execution output. Simulation embodies the principle of ``learning by doing'' - to learn about the system we must first build a model of some sort and then operate the model. The use of simulation is an activity that is as natural as a child who role-plays. Children understand the world around them by simulating (with toys and figurines) most of their interactions with other people, animals and objects. As adults, we lose some of this childlike behavior but recapture it later on through computer simulation. To understand reality and all of its complexity, we must build artificial objects and dynamically act out roles with them. Computer simulation is the electronic equivalent of this type of role-playing and it serves to drive synthetic environments and virtual worlds.

Simulation definitions:

- A representation of an item of equipment, device, system, or subsystem in realistic form. Simulation enables the learner to experience the operation of the target item without possibility of destroying it.
- "The process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system".
- The process of conducting experiments with a model (an abstraction or simplification) of an item, within all or part of its operating environment, for the purpose of accessing its behavior under selected conditions or for evaluating various strategies for its operation within the limits imposed by developmental or operational criteria.
- "a simulation is a software package (sometimes bundled with special hardware input devices) that re-creates or simulates, albeit in a simplified manner, a complex phenomena, environment, or experience, providing the user with the opportunity for some new level of understanding. A simulation is based on some underlying computational model of the phenomena, environment, or experience that it is simulating.
- The imitative representation of the functioning of one system or process by means of the functioning of another.
- A technique for solving complex problems that is not amenable to solution using formal analytical techniques. Essentially simulation consists of a representation of a system or organization by means of a model and then analyzing the behavior of the system under various possible operational conditions or assumptions through repeated manipulation of the model.
- The use of a model system, e.g., a mathematical model or an animal model, to approximate the action of a real system, often used to study the properties of a real system.

- ✍ The use of models and logic tools to test the outcomes of a proposed group of inputs and processes, prior to or in place of their implementation in a live system.
- ✍ A simulation is an experiment run as a model of reality. The simulations are run on a computer using mathematical models. They are also stochastic, that is they involve input generated to follow probability distributions.
- ✍ The examination of a problem often not subject to direct experimentation or analytical solution- most often by the use of a computer.
- ✍ The technique of representing the real world by a computer program; "a simulation should imitate the internal processes and not merely the results of the thing being simulated".
- ✍ The act of imitating the behavior of some situation or some process by means of something suitably analogous (especially for the purpose of study).

Within the overall task of simulation, there are three primary sub-fields: model design, model execution and model analysis. To simulate something physical, you will first need to create a mathematical model, which represents that physical object. The next task, once a model has been developed, is to execute the model on a computer - that is, you need to create a computer program which steps through time while updating the state and event variables in your mathematical model. There are many ways to ``step through time." You can, for instance, leap through time using event scheduling or you can employ small time increments using time slicing. You can also execute (i.e., simulate) the program on a massively parallel computer. This is called parallel and distributed simulation. For many large-scale models, this is the only feasible way of getting answers back in a reasonable amount of time.

Simulation of a system can be done at many different levels of fidelity so that whereas one reader will think of physics-based models and output, another may think of more abstract models, which yield higher-level, less detailed output as in a queuing network. Models are designed to provide answers at a given abstraction level - the more detailed the model, the more detailed the output. The kind of output you need will suggest the type of model you will employ.

Why do Simulation?

You may wonder whether simulation must be used to study dynamic systems. There are many methods of modeling systems which do not involve simulation but which involve the solution of a closed-form system (such as a system of linear equations). Simulation is often essential in the following cases:

1) the model is very complex with many variables and interacting components;
2) the underlying variables relationships are nonlinear;
3) the model contains random variates;
4) the model output is to be visual as in a 3D computer animation.

The power of simulation is that, even for easily solvable linear systems, a uniform model execution technique can be used to solve a large variety of systems without resorting to a ``bag of tricks" where one must choose special-purpose and sometimes-arcane solution methods to avoid simulation. Another important aspect of the simulation technique is that one builds a simulation model to replicate the actual system. When one uses the closed-form approach, the model is sometimes twisted to suit the closed-form nature of the solution method rather than to accurately represent the physical system.

Simulating Random Variables: In any area of research the variable we are interested in will be mostly of stochastic in nature. These variables, known as random variables, will follow some probability distributions such as Binomial, Poisson and Normal. The first two are of discrete type and the last is continuous type. When we study two related variables together, we may have to use bivariate normal distribution for generating these random variables together. In simulation studies we will have to simulate such random variables – other wise known as sampling from a known probability distribution. Different methods are available for simulating such random variables and one method each is given below for these probability distributions.

Uniform Random Number Generation: Random number generation is a vital part of any simulation experiment. We may have to generate random variables having specified probability distributions with known parameter estimates. The basis for generation of such random variables is mostly on uniform random number generation especially that between 0 and 1. Wichmann and Hill (1982) presented an algorithm for generating Pseudo-random numbers between 0 and 1 and this is described below.

1. Use three random seeds between 1 and 30,000 say S_1, S_2 and S_3 (to be used only once).
2. Recalculate these values as

$$S_1 \;?\; 171 ? \mathrm{mod}(S_1, 177) \;?\; 2 ? \mathrm{int}(\frac{S_1}{177})$$

$$S_2 \;?\; 172 ? \mathrm{mod}(S_2, 176) \;?\; 35 ? \mathrm{int}(\frac{S_2}{176})$$

$$S_1 \;?\; 170 ? \mathrm{mod}(S_3, 178) \;?\; 63 ? \mathrm{int}(\frac{S_3}{178})$$

3. When the recalculated values are negative, reset them as

$$S_1 \;?\; S_1 ? 30269$$
$$S_2 \;?\; S_2 ? 30307$$
$$S_3 \;?\; S_3 ? 30323$$

4. Compute the random number as

$$R \;?\; \frac{S_1}{30269} ? \frac{S_2}{30307} ? \frac{S_3}{30323}$$

5. The required uniform random number between 0 and 1 is then obtained as
$X \;?\; R \;?\; ?R?$
6. Repeat steps 2 to 5 for generating another indepentent uniform random number between 0 and 1.

Simulating Binomial random variable: There are many methods available in literature for the generation of binomial random variables. The geometric method given by Devroye and Naderisamani (1980) is as followed.

Suppose n and p are the known parameters using which we have to generate a binomial random variate.

1. Set $y ? \; 0, \quad x ? \; 0$ and $c ? \; \ln(1 ? p)$
2. If $c \;?\; 0$ then the generated variate is $x \;?\; 0$
3. Generate a uniform random number u between 0 and 1.

4. Set $y ? \; y ? \left?\frac{?\ln(u)?}{? \; c \; ?}\right? ? 1$ where the notation $?s?$ denotes the integer portion of *s*.
5. If $y ? n$, set $x ? \; x ? 1$ and go to step 3.
6. Return the generated random variate *x*.

Simulating Poisson random variable: To simulate a Poisson random variable with known parameter $?$, one of the methods is as followed.

1. Set the counter $n ? \; 0$
2. Set the product $Z ? \; 1$
3. Generate an independent uniform random number u_n between 0 and 1.
4. Set the counter $n ? \; n ? 1$
5. Update the product $Z ? \; Z ? u_n$
6. Compare the product $Z ? e^{?}$ and if it is true go to step 3.
7. Return the random variable as $X ? n ? 1$

Simulating Normal random variable: To generate a Normal Random Variable with specified mean $?$ and standard deviation $?$ the procedure is as followed.

1. Generate two independent uniform random numbers u_1 and u_2 between 0 and 1.
2. Compute the quantities *X* and *Y* as given below which will be distributed as independent standard normal variates

   $X ? ?2\ln(u_1)\, Cos(2? u_2)$

   $Y ? ?2\ln(u_1)\, Sin(2? u_2)$
3. Generate the required normal random variate as

   $Z ? ? ? X?$ or

   $Z ? ? ? Y?$

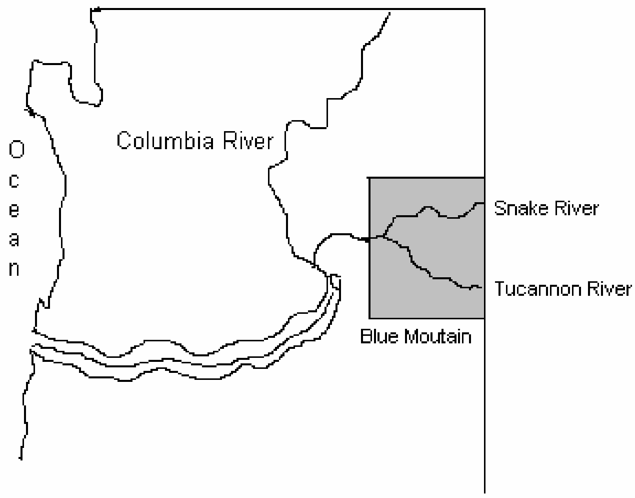
Simulating Bivariate Normal random variables: To generate random varaiates with bivariate normal distribution having specified mean vector and dispersion matrix the procedure is as followed.

1. Suppose $? ? \begin{matrix} ?? _1 ? \\ ?? _2 ? \end{matrix}$ is the required mean vector for the bivariate random variable and $? ? \begin{matrix} ? \; ? _1^2 & ?? _1? _2 ? \\ ??? _1? _2 & ? _2^2 \; ? \end{matrix}$ the dispersion matrix where $?$ is the correlation coefficient between the variates x_1 and x_2 and $? _1, ? _2$ the respective standard deviations.
2. Generate two independent standard normal variates $?z_1, z_2?$.
3. Compute the required quantities x_1 and x_2 having bivariate normal distribution as

   $x_1 ? ? _1 ? ? _1 z_1$ and

   $x_2 ? ? _2 ? ? _2 [? z_1 ? (1 ? ?) z_2$

Example (Systems analysis & Simulation): The system considered here is the Chinook salmon population in Tucannon river.



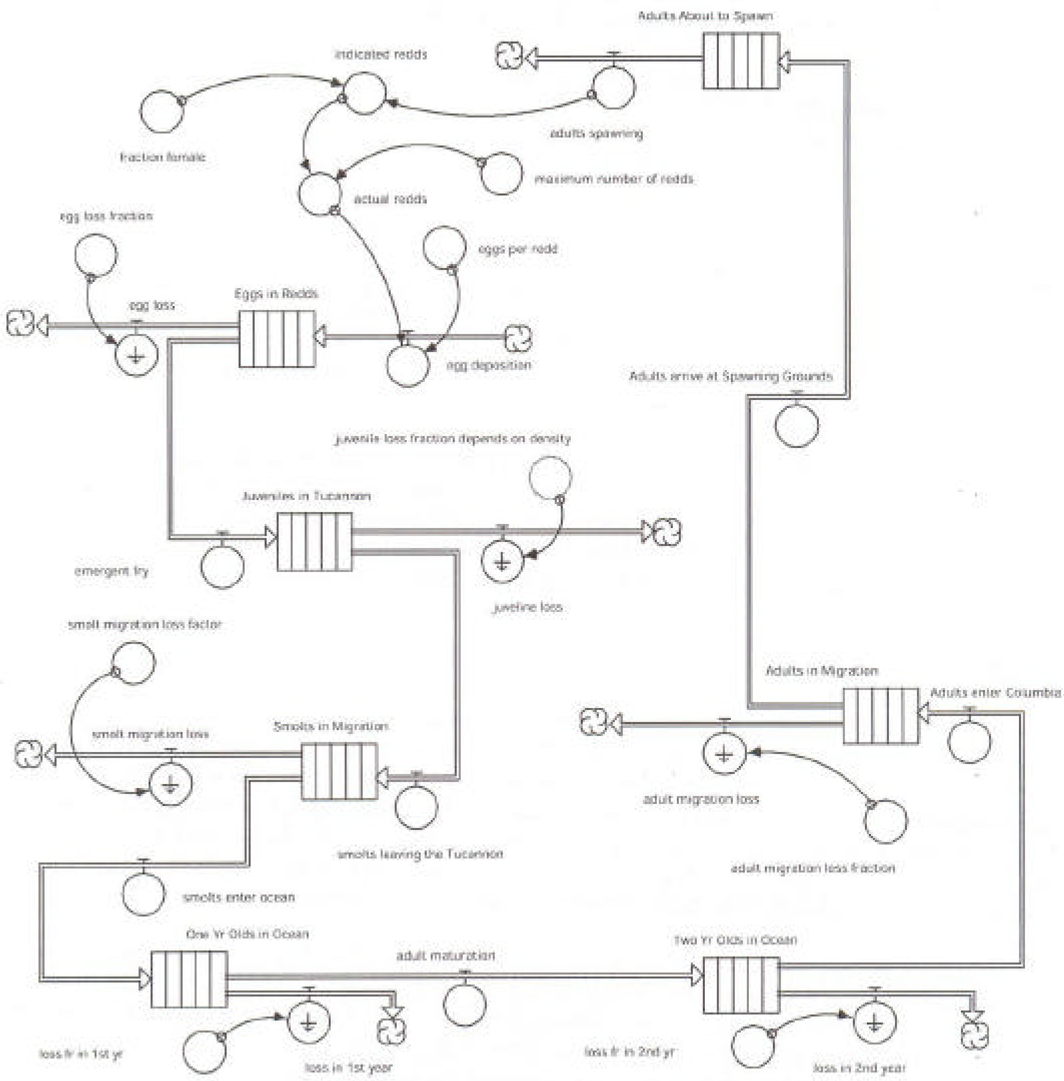
Background: Tucannon river rises in the Blue Mountains and flows towards the snake river. This 50 miles of stretch is suitable for Chinook salmon habitat and each mile supports around 65 redds (spawning nest formed in the gravel). Each redd contains thousands of eggs that hatch in the spring and the hatchlings live for a month or more on nutrients stored in yolk sacs. Juveniles of salmon spent one year in Tucannon river competing for food after which they undergo smoltification that triggers migration urge. Smolts migrate about 50 miles to reach the Snake river and then about 400 mile through the Columbia river to reach the ocean. They spent two years in the ocean and then return to the Columbia river mouth in the spring of the final year. They migrate up the Columbia and Snake rivers to reach the mouth of Tucannon. They reach the spawning grounds in the fall to build redds for the next generation.

Objective: Study the long term trends in the Salmon population over several decades by analyzing the system, developing a model and then simulating the system. Knowing the fundamental pattern, the primary objective is to develop a model to simulate the growth in salmon population under the pre-development conditions.

Model design: The model design consists of seven components to keep track of the population in various phases of it s life cycle. Salmon move through these phases in tightly controlled patterns.

The life cycle of Chinook salmon begins in the fall when spawners build the redds. The seven phases (sub-systems) in the life cycle of Salmon are:

No.	Phase	Duration (Months)	Parameters	Estimate
1	Adults about to spawn	1	Female fraction	0.50
2	Eggs in redds	6	Eggs per redd	3900
3	Juveniles in Tucannon	12	Egg loss fraction	0.50
4	Smolts in migration	1	Smolt migr. loss fr.	0.90
5	One year olds in ocean	12	Loss fr. for 1st year	0.35
6	Two year olds in ocean	12	Loss fr. for 2nd year	0.10
7	Adults in migration	4	Adult migr. loss fr.	0.25



A model of the salmon life cycle.

Simulation calculations: With the assumption of 2000 adults about to spawn in the beginning we make the following calculations.

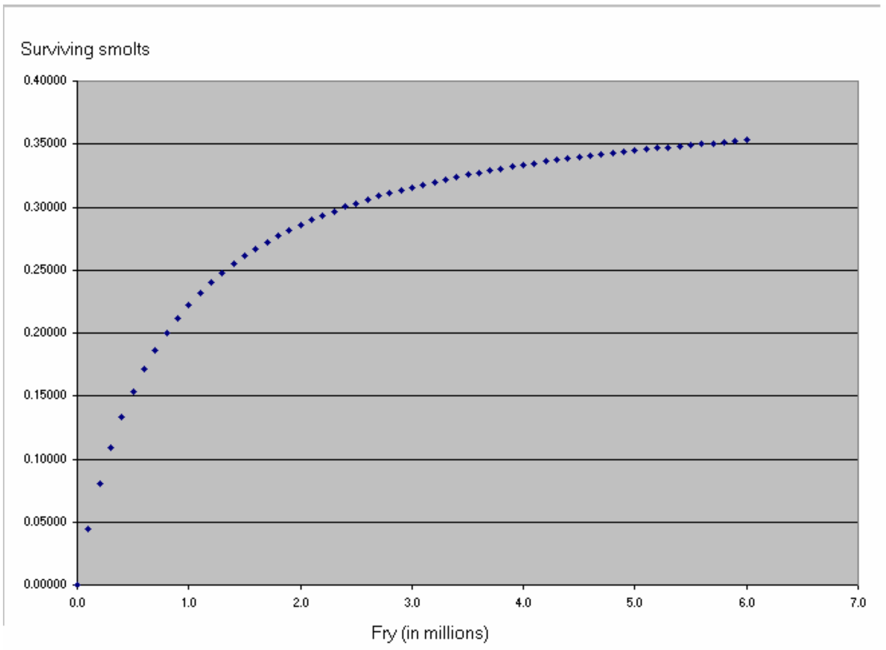
Phase		Population size	Remarks
i. Adults about to spawn	=	2,000	
ii. Adult females about spawn	=	1,000	2000 × 0.50
iii. Number of redds in Tucannon	=	1,000	1000 ×1
iv. Eggs in redds	=	3,900,000	1000 ×3900
v. Fry emerging from eggs	=	1,950,000	3,900,000 × 0.50
vi. Juveniles in Tucannon	=	1,950,000	

But there are limits to the number of juveniles that can survive their first year in Tucannon river. In summer they have to compete for limited feeding sites and in the falls they compete for limited amount of cover. These facts will constrain the juvenile population and juvenile survival heavily depends on juvenile population density. That is juvenile loss fraction depends on density. No matter how many fry emerge, there can never be more than a fixed number of smolts (say 400,000 smolts) one year later which is the carrying capacity of the Tucannon river.

The relationship between emergent fry and surviving smots is non-linear and this relationship is given by Beverton and Holts as

$$Surviving\ smolts = \frac{fry}{\frac{fry}{CC} ? \frac{1}{S}}$$

Fry: number of emergent fry (in millions)
CC: carrying capacity
S: slope of the curve at the origin.



Assuming 4,00,000 smolts as the carrying capacity and 0.50 as the slope of the curve survival of juveniles can be worked out.

	Phase		Population size	Remarks
vii.	Juveniles surviving the first year of life in Tucannon	=	280,000	$\frac{1,950,000}{\frac{1,950,000}{400,000} ? \frac{1}{0.5}}$

These are the smolts that migrate to the ocean in the following spring

viii.	Smolts migrating and reaching the ocean	=	28,000	280,000 × 0.10
ix.	One year olds in ocean	=	18,200	28,000 × 0.35
x.	Two year olds in ocean	=	16,380	18,200 × 0.90

They migrate to the mouth of Columbia river

xi. Adults reaching the spawning ground	=	12,285	16,380 × 0.75

There can be limits at different phases. For example the maximum number of redds that can be built in the river, when we assume @ 65 redds/mile, is 3250 redds. Also, randomness can be introduced into the model in different phases.

FISHERIES ECONOMICS – CASE STUDIES

21

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Economics is the study of how human beings in a society go about achieving their wants and desires. It is also defined as the study of allocation of scarce resources to satisfy individual wants or desires. The latter is perhaps the best way to broadly define the study of economics in general. Economists analyse questions and issues on the basis of trade off i.e. they compare the cost and the benefits of every issue and make decisions based on those costs and benefits. Broadly, economics may be divided into macroeconomics and microeconomics. Macroeconomics as the name suggests is the study of the overall economy and its aggregates such as Gross National Product, Inflation, Unemployment, Exports, Imports, Taxation policy etc. Microeconomics deals with individual actors in the economy such as firms and individuals. Further the market is perhaps the most important and complex institution playing a vital role in the decision making process of any economy. The major point is that firms operate in different types of markets and use the well-established principles of managerial economics to improve profitability. Managerial economics draws on economic analysis for such concepts as cost, demand, profit and competition. It attempts to bridge the gap between the purely analytical problems that intrigue many economic theorists and the day-to-day decisions that managers must face. It offers powerful tools and approaches for managerial policy.

The application of economic principles is highly essential to take rational policy decisions in marine fisheries for optimum exploitation, equitable distribution, efficient marketing and evolving alternate management strategies. The monetary returns of fishery enterprises depend on the economic efficiency of resource use in production. Cost minimisation and profit maximisation are the inter related twin objectives of any productive venture to increase the economic efficiency. The welfare of the people should be taken into consideration and an equitable distribution of benefits to the entire society should be assured in all developmental strategies. The economic impact of alternate, management strategies on the primary and secondary sectors vis-a-viz Socio-economic status of the people also requires proper assessment for the implementation of fishery policies. Fishery Economics in India is gaining importance in recent years due to its high applicability for evolving appropriate fishery polices and management decisions

Some cost concepts

Cost concepts are not important for decision making but the accounting approach nor is the economic approach completely acceptable when decision making is involved. Costs must be considered in various ways, depending on the decision at hand. All the cost concepts need to be considered in such a way so as to help make sound decisions. The decision maker should try to discover the "relevant" costs by asking what cost are relevant to a particular decision at hand, and the decision maker is not necessarily bound by traditional concept constructed for other purposes. Some of the important cost concepts that are relevant for managerial decision are briefly discussed below

Actual costs and opportunity costs

Actual cost are those costs, which a firm incurs while producing or acquiring a good or service like raw materials, labour, rent etc. Suppose, we pay Rs/150 per day to a worker whom we employ for 10 days, then the cost of labour is Rs. 1500. Sometimes the actual costs are also called acquisition costs or outlay costs.

On the other hand, opportunity cost is defined as the value of a resource in its next best use. In other words the next best alternative use of any factor of production is known as its opportunity cost. For example Mr. X is currently working with a firm and earning Rs. 2 lakhs per year. He decides to quit his job and start his own small business. Alth0ugh, the accounting cost of Mr. X's labour to his own business is 0, the opportunity cost is Rs. 2 lakhs per year. therefore, the opportunity cost is the earnings he foregoes by working of his own firm. One may ask you that whether this opportunity cost is really meaningful in the decision making process. As we see that the opportunity cost is important simply because, if Mr X cannot recover this cost from his new business, then he will probably return to his old job

Opportunity cost can be similarly defined for other factors of production. For example, consider a firm that owns a building and therefore do not pay rent for office space. If the building was rented to others, the firm could have earned rent. The foregone rent is an opportunity cost of utilising the office space and should be included as part of the cost of doing business. Some times these opportunity costs are called as alternative costs.

Explicit and implicit costs

Explicit costs are those costs that involve an actual payment to other parties. Therefore, an explicit cost is the monitory payment made by a firm for use of an input owned or controlled by others. Explicit costs are also referred to as accounting costs. For example, a firm pays Rs. 100 per day to a worker and engages 15 workers for 10 days, the explicit cost will be Rs. 15,000 incurred by the firm. Other types of explicit costs include purchase of raw materials, renting a building, amount spent on advertising etc.

On the other hand, implicit costs represent the value of foregone opportunities but do not involve an actual cash payment. Implicit costs are just as important as explicit costs but are sometimes neglected because they are not as obvious. For example, a manger who runs his own business foregoes the salary that could have been earned working for someone else as we have seen in our earlier example. This implicit cost generally is not reflected accounting statements, but rational decision-making requires that it be considered. Therefore, an implicit cost is the opportunity cost of using resources that are owned or controlled by the owners of the firm. The implicit cost is the foregone return, the owner of the firm could have received had they used their own resources in their best alternative use rather than using the s recourses for their own firm'' production.

Private costs and social costs

A further distinction that is useful to make –especially in the public sector- is between private and social costs. Private costs are those that accrue directly to the individuals or firms engaged in relevant activity. Social costs, on the other hand, are passed on to persons not involved in the activity in any direct way (i.e, they are passed on to society at large). Consider the case of a manufacturer located on the bank of a river who dumps the waster in to water rather than disposing it of in some other manner. While the private cost to the firm of dumping is zero, it is definitely harm full to they society. It affects adversely the people located down current and incur higher costs in terms of treating the water for their use, or having to travel a great deal to fetch potable water. If these external costs were included in the production costs of a producing firm, a true picture of real, or social costs of the output would be obtained. Ignoring external costs may lead to an inefficient and undesirable allocation of resources in society.

Fixed and variable costs

Fixed costs are that part of the total cost of the firm which does not change with output. Expenditures on deprecation, rent of land and building, property taxes, and interest payment on bonds are examples of fixed costs. Given a capacity, fixed costs remain the same irrespective of actual output. Variable costs, on the other hand, change with changes in output. Examples of variable costs are wages and expenses on raw material.

However, it is not very easy to classify all costs into fixed and variable. There are some costs, which fall between these extremes. They are called semi variable costs. They are neither perfectly variable nor absolutely fixed in relation to changes in output. For example, part of the depreciation charges is fixed, and part variable. However, its very difficult to determine how much of depreciation cost is due to the technical obsolescence of asset and hence fixed cost, and how much is due to the use of equipments and hence variable cost. Nevertheless, it does not mean that it is not useful to classify costs into fixed and variable. This distinction is of great value in break-even analysis and pricing decisions. For decision-making purposes, in general, it is the variable cost, which is relevant and not the fixed cost.

To an economist the fixed costs are overhead costs and to an accountant these are indirect costs. When the output goes up, the fixed cost per unit of output comes, down, as the total fixed cost is divided between larger units of output.

Total average and marginal costs

Total cost (TC) of a firm is the sum-total of all the explicit and implicit expenditures incurred for producing a given level of output. It represents the money value of the total resources required for production of goods and services. T.C. = TFC + TVC

Average cost (AC) is the cost per unit of output. That is, average cost equals the total cost divided by the number of units produced (N). If TC = Rs. 500 and N -= 50 then AC = Rs.10

Marginal cost (MC) is the extra cost of producing one additional unit. At a given level of output, one examines the additional costs being incurred in producing one extra unit and this yields the marginal cost.

The total cost concept is useful in break-even analysis and finding out whether a firm is making profit or not. The average cost concept is significant for calculating the per unit profit. The marginal and incremental cost concepts are needed in deciding whether a firm needs to expand its production or not. In fact, the relevant costs to be considered will depend upon the situation or production problem faced by the manager.

Production function and Economic efficiency

Production process involves the transformation of inputs into output. The input could be land, labour, capital, entrepreneurship etc. and the output could be goods or services,. In a production process managers take four types of decisions: (a) whether to produce or not, (b) how much output to produce, (c) what input combination to use, and (d) what type of technology to use. In general a given output can be produced with different combination of inputs. A production function is the functional relationship between inputs and output. It shows the maximum output which can be obtained for a given combination of inputs. It expresses the technological relationship between inputs and output of a product. In general, we can represent the production function for a firm as:

$$Q = f(x_1, x_2, \ldots\ldots x_n)$$

Where Q is the maximum quantity of output, x_1, x_2,……..x_n are the quantities of various inputs, and f stands for functional relationship between inputs and output

Economic Efficiency and Technical Efficiency

A firm is technically efficient when it obtains maximum level of output form any given combination of inputs. The production function incorporates the technically efficient method of production. A producer cannot decrease one input and at the same time maintain the output at the same level without increasing one or more inputs. When economists use production function, they assume that the maximum output is obtained from any given combination of inputs. That is, they assume that production is technically efficient.

On the other hand, we say a firm is economically efficient, when it produces a given amount of output at the lowest possible cost for a combination of inputs provided that the prices of inputs are given. Therefore, when only input combinations are given, we deal with the problem of technical efficiency; that is, how to produce maximum output. On the other hand, when input prices are also given in addition to the combination of inputs, we deal with the problem of economic efficiency; that is, how to produce a given amount of output at the lowest possible cost.

One has to be careful while interpreting whether a production process is efficient or inefficient. Certainly a production process can be called efficient if another process produced the same level of output using one or, more inputs, other things remaining constant. However, if a production process uses less of some inputs and more of others, the economically efficient method of producing a given level of output depends on the prices of inputs. Even when two production processes are technically efficient, one process may be economically efficient under one set of input prices, while the other production process may be economically efficient at other input prices.

Special features of fish marketing and marketing efficiency

1. Greater uncertainties in the production of fish and hence in the supply of fish
2. High perishability of fish
3. Assembling of fish form too many coastal landing centres.
4. Too many species and too many demand patterns
5. Wide seasonal and spatial variations in price.
6. Disequilibrium of demand and supply
7. Difficulty in maintaining the quality of fish
8. Lack of preservation and storage.
9. Lack of minimum facilities at marketing centres.
10. Lack of transportation facilities.
11. Seasonal abundance and scarcity of different varieties of fish
12. Lack of information on price and production.

Measures of marketing efficiency

1. Price spread
2. Marketing cost
3. Marketing margin
4. Producer's share in the consumer's rupee

Economic feasibility and efficiency analysis

Many methods are used - some are better than others in certain context. They are only tools for decision making and cannot be substituted for judgement of facts that cannot be quantified. The measures mainly used are

I. profit

The profit is the difference between the revenue and total cost

= Total revenue – Total cost

II. Net operating income

= Total revenue – variable cost

III. Capital turnover ratio

This ratio is used to measure the rate at which income is generated per rupee of capital invested. This ratio is calculated as follows

$$= \frac{\text{Gross income}}{\text{Capital Investment}}$$

A ratio of 40 would indicate that for every rupee invested 40 paise in income was generated Generally higher the turn over the greater the net income

IV. Pay back period

The time required to recover the initial investment out of the expected earnings from the investment before any allowance for depreciation

T = C/E

Where T = The Pay back period (Year)
C = Initial investment cost
E = Profit before depreciation.

V. Rate of return

The average annual return of an investment is measured by this method

$$\frac{\text{Annual profit + Interest}}{\text{Initial Investment}} \times 100$$

If the rate of return is higher than the opportunity cost of capital investment then the money is utilised efficiently in this investment

There are several uses of applying the above tools and production function depending on their specific needs. It can be used to compute the least-cost combination of inputs for a given output or to choose the input combination that yields the maximum level of output with a given level of cost. There are several feasible combinations of input factors and it is highly useful for decision-makers to find out the most appropriate among them. The production function is useful in deciding on the additional value of employing a variable input in the production process. So long as the marginal revenue productivity of a variable factor exceeds it price, it may be worthwhile to increase its use

Model Question:

A farmer engaged in giant freshwater prawn culture in a 5 hectare farm incurred a capital investment of Rs. 5 lakhs. He can have two crops in an year. He will be incurring an operating expense of Rs. 2lakh towards seed, Rs. 2 lakh towards feed, Rs.50,000/- towards labour charges and another Rs. 50,000 towards miscellaneous expenses per crop. The farmer gets an avenge yield of 2.5 tonnes of *M. rosenbergii* per crop fetching a price of Rs. 300 per kg. Whether the prawn farm is running on (I) profit or loss or (iii) No profit no loss basis. Justify.

Answer

I		**Capital Investment**	= Rs. 5,00,000
II		Average Fixed Cost (Annual)	
	i.	Depreciation lease value of land (a. 10% of the capital cost)	= Rs. 50,000
	ii.	Interest (a. 15%of investment)	= Rs. 75,000
		Total fixed cost (TFC)	= Rs. 1,25,000
III.		**Average variable cost (crop)**	
	i.	Seed	= Rs. 2,00,000
	ii.	Feed	= Rs. 2,00,000
	iii.	Labour charges	= Rs. 50,000
	iv.	Misc. Expenses	= Rs. 50,000
		Total	= Rs. 50,00,000
IV		**Total Variable Cost (TVC)** (Annual –5,00,000 x 2)	= Rs. 10,00,000
V		**Total Cost (T.C) = {TFC + TVC}**	= Rs. 1,25,000
		+	Rs. 10,00,000
			= Rs. 11,25,000
VI		**Revenue**	
	i.	Yield per crop	= 2.5 tonnes of, *M. rosenbergii*
	ii.	Price per Kg	= Rs. 300
	iii.	Gross revenue per crop (2500 x 300)	= Rs. 7,50,000
	iv	Total Revenue (TR) {Annual –7,50,00 x 2}	= Rs. 15,00,000
VII		**Total profit (T.P) {T.R. – T.C.}** (15,00,000 – 11.25.000)	= Rs. 3,75,000

Pay back period = $\dfrac{5,00,000}{3,75,000 + 50,000}$ = 1.2 years

Rate of return = $\dfrac{3,75,000 + 75,000}{5,00,0000}$ X 100 = 90%

The farm is running on high profit. Since the acquisition cost of Rs. 5 lakh incurred for fixed expenditure is only the prevailing interest rate of about 10% and the business is earning higher rate of return than this, it is advisable to continue

IMMEDIATE EFFECT OF TRAWLING ON SEA BOTTOM & ITS LIVING COMMUNITIES ALONG KERALA COAST

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Introduction

Otter trawling, the most widely used towed bottom fishing gear, is known to have a wide range of impact on benthos. Seabed disturbance by mobile bottom fishing gear has emerged as a major concern related to the conservation of essential fish habitat (DeAlteris *et al.,* 1999). Several studies have been conducted on the impact of trawling on sea bottom and its living communities (Walting and Norse 1999,Churchill, 1989, Gibbs *et al*., 1980), however no concerted attempt has so far been made to assess its real impact on the sea bottom ecology along Indian coast. Trawl fishing with more than 5000 units, is the most widespread method of capturing marine fishes and invertebrates in Kerala, the southernmost state of India with a coastline of 590 Km (Raveendran, 2001). Menon (1996) reported that incessant trawling operations in a climatically limited coastal habitat slowly resulted in disproportionate destruction of non – target groups too along with juveniles /sub adults of homogeneous species of commercially important fishes and shell fishes and a wide spectrum of benthic organisms. Benthos representing the secondary level of the benthic productivity forms the major food resource of demersal fishery resources represented by prawns, bottom dwelling fishes and other marine invertebrates thereby serving as an inevitable link in the benthic food chain (Mohammed, 1955). Benthic animals also have a role in releasing nutrients back into the water column and aid in the stability of sediments. The distribution of macrofaunal species on the sea bottom is closely related to salinity, water movement, sediment grain size and organic content of the sediment (Duineveld *et al*., 1991). Availability of benthos at a region can be an indicator of demersal fishery potential since they form an important food reserve for crabs and fishes (Varshney *et al*., 1988). This paper deals with the results of the experimental bottom trawling conducted along the Cochin coast with a view to bring out the extent to which trawling operations are responsible in altering the physico-chemical parameters of the soil, water and the living communities of the sea bottom.

Materials and methods

Experimental trawling was conducted along Cochin –Munambam area (Long. 75º 56'00 to 76º10' 94" and lat. 9º58' to 10⁰10') in the south west coast of India (Fig: 1) at depth ranging from 0-50m during December 2000- November 2002. Bottom trawling operations were carried out at predetermined depth zones such as 0-10, 10-20,20-30,30-40 and 40-50m using a 39 m statutory trawl net of 35mm cod end with the help of a commercial trawler of 30-40ft OAL. Trawling was conducted for one hour during daytime starting from 8 am to 6 pm in all stations. The physical and chemical parameters of water observed were temperature, salinity, dissolved oxygen turbidity, pH, nitrite nitrogen and inorganic phosphate, both before and after trawling operations conducted at selected depth zones. Bottom water was collected from sites using horizontal water sampler (Hydro Bios, West Germany). Salinity was determined following Knudsen's method, dissolved oxygen was determined using standard Winkler's method, and pH was measured using pH meter, temperature by a mercuric thermometer and turbidity by Nephaloturbidity meter. Nitrite and phosphate concentrations were estimated following standard procedures (Grasshoff, 1983). Pipette analysis (Carver, 1971) was performed to understand the texture of sediment while the sediment organic matter was analysed using El Wakeel and Riley (1959). Macro and meiofauna were sorted and analysed using Holme and McIntyre (1975). ANOVA was performed to establish the level of significance of the data followed by t test, both before and after trawling.

Results & Discussion

The physico-chemical parameters like temperature, salinity, pH and dissolved oxygen play vital roles in the high production of pelagic fishes and other living organisms (Suresh *et al*., 1978). Lower temperature was recorded during July and August at Cochin harbour (Ramamirtham and Jayaraman, 1963). Ramesh Babu *et al.* (1980) also pointed out the lowering of salinity (< 34 ‰) in the coastal waters of Kerala under the influence of summer monsoon.

A slight decrease of pH values was registered in monsoon months. Rivonker *et al.* (1990) also pointed out trifle variation in pH during their study conducted along the west coast of India. Jayaraman *et al*. (1959) registered the distribution of dissolved oxygen at surface and sub surface layers upto 50 meters and were of the opinion that there exists more or less uniform oxygen content in the coastal waters of Kerala. In general, inshore waters were well aerated during major part of the year except during the southwest monsoon season.

Turbidity showed inverse relationship to oxygen throughout the stations. High turbidity values were noticed during monsoon, which could be the result of increased river and land run off and the churning action of the sea. Highly turbid waters were noticed at the near shore waters, which may be due to the rise of clayey soil by the action of currents and waves as well as the river flow into the sea.

Nutrients are essential to life in the sea and among them nitrogen and phosphorus are the most important elements (Tyrrell, 1999; Naqvi and Jayakumar, 2000). The distribution of nitrite-nitrogen and phosphate phosphorus observed in the present study strongly agrees to that in the previous studies conducted in the Kerala waters (Damodaran, 1973; De Sousa *et al.*, 1996). Distinct seasonal variations were noticed with high nitrite and phosphate concentrations in the monsoon period while postmonsoon and premonsoon periods showed comparatively lower values. Subramanyan (1958) recorded high nitrite and phosphate during southwest monsoon in Kerala coast. The depletion of nutrients in the closing stages of postmonsoon period can be attributed to the planktonic productivity as reported by Sankaranarayanan and Qasim (1969). Damodaran (1973) recorded the surface phosphate phosphorus in the range 0.03 - 3.37 μ ML^{-1} and between 0.03 and 5.39 μ ML^{-1} at the bottom. In the present study, the surface and bottom phosphate concentrations ranged between 0.02 - 3.44 and 0.04 - 5.83 μ ML^{-1} respectively which strongly corroborate to his findings. Nitrite-nitrogen recorded in bottom waters showed lesser values than that of phosphate phosphorus recorded at the study area, ranging from 0.01 - 3.9 μ ML^{-1} in the samples collected before trawling which also agrees to the earlier findings of Rivonker *et al*. (1990) and Lakshmanan *et al.* (1987). Rittenberg *et a*l. (1955) opined that in marine condition, the major source of nutrients is the run - off from terrestrial environs. High phosphate and nitrite concentrations observed in the near shore waters in the present study also agree to this.

The results of the natural sediment structure computed from the study area before trawling were corroborated to the earlier reports (Bhosle *et al.*, 1978; Hashimi *et al.*, 1978). In the present study, the distribution of sediments were in the silty clay/ clayey silt range up to the 30 m depth and silty/ clayey sand between 30-40 m however, it turned into sandy above 40 metres depth. Seasonal variations of organic matter reported in the present study also agree with the previous studies (Nair and Balchand, 1992). The high organic matter observed during the postmonsoon and monsoon months are due to the heavy river runoff and surface productivity as reported by Subrahmanyan and Sarma (1965).

Towed gears in contact with the seabed will disturb it physically and cause resuspension of fine particles and relocation of stones and boulders (Gislason, 1995). Of the five major physico– chemical parameters studied, both dissolved oxygen and turbidity showed wide variations in the trawled grounds when compared to the samples collected before trawling. Salinity, temperature and pH did not exhibit any noticeable changes due to bottom trawling while dissolved oxygen concentration was found reduced after trawling. During bottom trawling trawl net scrape the sea bottom leading to the rise of sediments of few centimeters to the water column (De Groot, 1984; Redant, 1987). Trawling pressure is more in the months of August and September in the inshore waters (<100 meters). Besides the low dissolved oxygen concentration during monsoon, intense trawling operations during this period may create a persistent hypoxic condition in water, which may destroy the eggs, larvae and juveniles of fish and other living organisms as discussed by Morgan *et al*. (1983) and Newcombe and MacDonald (1991). Oxygen level decreased significantly after dredging / trawling probably because of mixing of reduced products such as methane and hydrogen sulphide and/ or because the resuspended particulate material like bacteria attached to sediments exerting an increase in oxygen demand in the water column (Riemann and Hoffmann, 1991). Dredging and trawling causes high oxygen demand that has the potential to form a barrier which may hamper the movement of migratory fishes (Eliott *et al.*, 1988).

Trawling on muddy grounds generate heavy sediment clouds in the water column (Ganz, 1980; Main and Sangster, 1981). High turbidity values recorded immediately after trawling in the present study also agree to this. Churchill *et al.*, (1994) also discussed the adverse effect on shellfish and other benthic organisms due to the rise of turbidity plumes during trawling. In the present study average four - fold increase of turbidity was noticed after trawling. Turbidity of bottom water nutrients at bottom waters was reported to be increasing during dredging in Cochin harbour (Thressiamma *et al.,* 1998). They also reported a two – three fold increase in the phosphate phosphorus and nitrite concentrations immediately after the dredging at the Cochin port. In the present study almost all stations showed steep increase in turbidity after trawling. The incessant bottom trawling during the monsoon season, and the upwelling periods in southwest coast of India by all means poses a threat to the growth of marine animals.

Nitrite-nitrogen and phosphate phosphorus recorded in the samples collected after trawling was conspicuously high when compared with that of samples collected before trawling. German researchers noted significant remobilization of nutrients from pore water as a result of disturbance to surface sediment layers (ICES, 1989). During dragging along the bottom, the churning action of otter boards and heavy trawl net raise the sediments into the water column along with nutrients and minerals (de Groot, 1984). Gislason (1995) stated that the bottom trawling cause physical disturbance and resuspension of sediments as well as increase the exchange of nutrients and pollutants between the sediment and the water column. The high concentration of nutrients observed in the present study, immediately after trawling also points to the same fact. The nitrite has showed average of two – three fold increase in the after trawling samples; whereas phosphate recorded average four fold increase in values as observed by Reimann and Hoffmann (1991).The more perceptible variations in the phosphate concentrations recorded after trawling than that of nitrites also strengthens the view that the phosphate content is more at the sea bottom than nitrite especially in the coastal waters (Qasim 1977).

Rasheed (1997) noticed an increase of nutrients in the surface waters due to the dredging activities in the Cochin port. The results of the present study also highlights the heavy transport of the nutrients into the water column due to bottom trawling. Bottom trawling directly affect physical properties of sea floor by increasing turbulence and by altering grain size distribution, sediment porosity and chemical exchange process (McConnaughey *et al.*, 2000). Various observations have revealed that turbulence in the wake of trawl doors and big nets often generate large and highly turbid clouds of suspended sediments (Main and Sangster, 1981; Wardle, 1983 ; Churchill, 1989). Bottom trawling causes abnormally high nutrients levels in the ocean by stirring up the sediments and this could increase noxious phytoplankton production notorious for the mass fish kills and shift the balance of plankton populations which would in turn could shift the balance of the fish and other marine life that feed on them as reported by Collie (2000); Gordon *et al*. (1998) and Rogers *et al*., (1998). Morrison *et al*. (1998) noticed the high algal production at the coastal upwelling zone due to the heavy nutrient concentration. Messiah *et al*. (1991) opined the possible effect of a sudden release of nutrients or contaminants from sediments due to trawling. Heavy nutrients observed in the bottom waters in the present study reveals the significant disturbance occurring at the sea bottom due to trawling.

Though the nutrients may increase the productivity of water column the possible rise of lethal gases such as ammonia, methane and hydrogen sulphide will adversely affect the living organisms in water (Churchill *et al*., 1988). Abnormal bloom formation due to the presence of nutrients and minerals at the surface would deplete dissolved oxygen (De' Sousa and Singbal, 1986).

Bottom trawling causes severe damage to the upper sediment layers. Sediments are dispersed off into the subsurface water column due to the scrapping of heavy otter boards and nets (Messiah *et al*., 1991). In the present observation, sand and silt fractions were found to be increasing in the trawled grounds after trawling. This may be due to the quicker settlement of the heavier sand and silt particles when compared to the lighter clay particles. The latter on the other hand, showed drastic decline at the trawled grounds. It can be surmised that clay fractions being lighter, gets removed from the sediment due to the dispersion along with the current created in the wake of passage of nets. The predominance in silt proportion after trawling at the stations 1 – 6, where sand proportion was minimal, clearly depict the loss of clay content during trawling. Moreover, wide changes occurred in the percentage distribution of sediments at stations 4, 5 and 6 where the pattern of sediment changed from silty clay to clayey silt after trawling, manifesting a severe loss of clay fraction during trawling. The increased sand, silt concentrations and subsequent decrease in clay content in the samples collected after trawling are attributed to resuspension as opined by Shelton and Rolfe (1972); Caddy (1973) and Langton and Robinson (1990). Rapid resettling of the heavier particles also has a major role in the coarsening of sediments, with the finer fraction remaining suspended for some time. The incessant perturbations on the substratum may leave the seabed in an altered condition (Eleftheriou and Robertson, 1992; Black and Parry, 1994) with permanent sediment clouds in the water column as noticed by Schwinghamer *et al*. (1996) and Currie and Parry (1996).

Many studies conducted in the west and east coasts of India especially along the shelf waters reported the dominance of polychaetes in the infaunal macrofauna (Damodaran 1973; Harkantra *et al.*, 1982). Parulekar and Ansari (1981) also reported that polychaetes were the most important group (70%) in the macrobenthic assemblage in the Andaman Sea. In the present observations, high abundance of polychaete were noticed at the sandy stations, which also corroborate to the findings of Harkantra (1982) and Sunil Kumar (1995). Bottom layers of sand with a mixture of silt or clay form ideal substrates for polychaete and bivalves (Parulekar and Wagh, 1975). In the present study, highest abundance and biomass was recorded during post monsoon period followed by premonsoon and monsoon. Harkantra and Parulekar (1994) reported the replenishment of benthic fauna with high species diversity after southwest monsoon. The present findings show very strong agreement with the above view. However, a second peak was observed in July, during the trawl ban period along the Kerala coast imposed by the Govt. of Kerala. It appears that the polychaetes get an opportunity for their recoupement and regeneration as the sea bottom is totally free from any sort of disturbance due to the imposition of ban for bottom trawlers.

During the study, the number and biomass of the polychaetes were found increased in the samples collected immediately after trawling. This increase in abundance may be attributed to their exposure due to the removal of top sediment layer associated with the settlement of dispersed organisms after trawling. Polychaetes showed high abundance after beam trawling in an experiment conducted by Bergman and Hup (1992). Most of the polychaetes observed throughout this study were small in size and this was due to the fact that communities become dominated by juvenile stages where extensive and repeated fishing disturbance are prevalent (Sainsbury 1988; Eleftheriou and Robertson,1992). These organisms do not get the opportunity to grow into larger size because of the continuous trawling disturbance at the bottom.

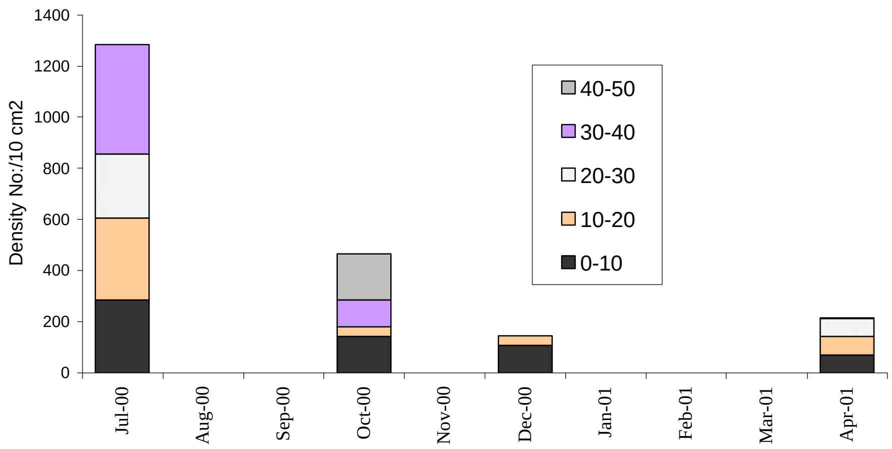

Fig. Pattern of variations in polychaetes in different depth zones along Cochin- Munumbam area during Dec-2000 April 2001

Nematodes have been found to be among the most dominant groups in the composition of meiofauna in various studies of meiofaunal distribution (Heip *et al* 1990; Bell and Sherman 1980; Harkantra and Parulekar, 1989). Particulate organic matter serves as food source for many meiobenthic organisms (Coull, 1973). More nematodes were found in the inshore regions characterised by silty nature of sediment which can be corroborated to the studies of Harkantra and Parulekar, 1989 and Desai and Krishnankutty, 1967. The premonsoon and monsoon months harbored more nematodes, while post monsoon seasons manifest a decline in abundance, during the successive years of study. Thus it can be inferred that there is destruction of meiofauna throughout the post monsoon season, which can be attributed to the lift of monsoon ban on trawling during this season. On the other hand, studies on the meiofauna of this region indicate that postmonsoon is the phase of proliferation of these organisms (Damodaran, 1973; SunithaRao and RamaSarma, 1990).

During bottom trawling, the trawl net and otter boards penetrate the top few centimeters of the sediment layer (Caddy 1973), exposing the fauna immediately below it leading to an increase in the after trawling samples. Thus there is a progressive reduction in the nematode abundance during each sweep of the trawl gear, and several studies have come out with the conclusion that the mobile fishing gear can cause reduction in abundance of some fragile infaunal species (Bergman and Hup, 1992). Most of the nematodes are found at depths 0-10 cm, (Damodaran, 1973) and thus are well within the reach of the trawl gear. Thus bottom trawling perturbs the benthic environment by displacing the nematodes from its natural niche and altering the habitat characteristics. Though their reproductive abilities are high, their recolonisation is gradual but steady process.

In summary, bottom trawling had a strong and immediate impact on the marine milieu. Variations in the major physico-chemical parameters due to human intervention in the form of bottom trawling activities are highly deleterious so as to inflict irreparable perturbations in the marine ecosystem. Considering the results obtained in the study, it is clear that bottom trawling alter seafloor habitat, reduce habitat complexity, and may lead to increased predation on infaunal species which affect stability of the ecosystem as a whole.

IMPACT ASSESSMENT OF BOTTOM TRAWLING ON THE MARINE BIODIVERSITY ALONG KERALA

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Introduction

The introduction of mechanised trawlers to exploit the demersal resources beyond the traditional fishing grounds of Kerala in the early fifties was an important event in the marine fisheries of Kerala and due to its high returns it became widespread all along the trawlable coastal grounds. As it is found as the most efficient method for the exploitation of shrimps and therefore, its number has shown an exponential increase along the coastal waters of Kerala. Among the mechanised boats operating along Kerala coast more than 90% belong to bottom trawl specifically aimed for the exploitation of shrimp resources of the inshore waters (Ravindran and Baiju, 1998). Kurup and Radhika (2003) enumerated the number of bottom trawlers operated from 11 major and minor fisheries harbours of Kerala as 4960.Bottom trawling being a non selective fishing gear, it hauls up all the organisms dwelling at the sea bottom and therefore, its destructive effect to the non target organisms of the sea bottom is a matter of grave concern on a global basis (Jennings and Kaiser, 1998). Discards are bycatch organisms that are trapped in the trawl net during its path of tow and most of them are thrown back to the sea because of various reasons such as they are non-edible and poisonous nature of the species, not marketable, inferior quality and also due to lack of storage space on board (Clucas, 1997). Saila (1983) estimated that 6.72 million tonnes of biota were discarded back to the sea while Andrew and Pepperal (1992) estimated a total global discards of 16.7million tonnes from shrimp fisheries alone. Commercial bottom trawling globally has been estimated to produce 27 million tonnes of discards and this represent more than half of all fish produced annually from marine capture fisheries for direct human consumption (Alverson *et al.*, 1994). Quantification of discards have been made based on discards landed at the harbour (Rao, 1998; Bensam *et al.*, 1994) but no concerted attempts have been made to quantify the discards by collection data onboard the bottom trawlers operated along Kerala coast. Therefore in the present study a pioneer attempt was made to quantify the discards from the bottom trawlers of Kerala.

Materials and methods

The quantification of discard on board the trawlers were done on the basis of data generated from fishing operation of 375 bottom trawlers operated from 6 major fisheries harbours such as Sakthikulangara Neendakara, Cochin, Munambam, Beypore and Puthiyappa (Fig.1) during April 2000 to March 2002. Besides, the trawl catch composition were analysed from 100 boats beyond 100 m on the basis of samples collected from the last haul and preserved in tubs. The trawl catch composition was also examined by collecting samples from 120 boats during trawling operations carried out in the regular fishing grounds with the help of a hired boat during the study period. Data during second half of June and full month of July could not be collected due to the ban imposed for bottom trawling along Kerala coast. The units of bottom trawlers for monthly onboard participation from various harbours were selected following Alagaraja (1984). The fishing endurance of the selected units varied from 1-3 days. The number of hauls in each voyage varied from 1-8 depending on the endurance and availability of fish. The catches from individual hauls were examined separately and the components were sorted in to target, non-target and discards following McCaughran (1992) and species /group level identification was done following FAO, (1984), Munro (2000) and Dance (1977). The marketable fraction of the catch was sorted out and packed in trays of 20kg and the number of boxes was counted to compute the total weight. The discards were also sorted group/species wise, weighed and 10% of the assorted sample was taken for detailed analysis in the laboratory. Details such as cruise time, facilities on board, OAL, cod end mesh size, fishing endurance and actual fishing hours together with the number of hauls, number of units operated in the vicinity and details of crew, duration and number of hauls performed, depth of fishing, fishing ground, etc. were also collected and entered on to proforma. The daily discarded fraction from the trawl catch was computed by multiplying the average catch arrived at from individual units multiplied by total units operated from the harbour on a daily basis. The monthly catch was estimated by multiplying the daily landings with actual fishing days of each month. The number of trawlers operated from different fisheries harbours agrees with that of Kurup and Radhika (2003). The discards were categorized under finfishes, Soles, Crabs, Gastropods, Shrimps, Cephalopods, Jellyfish, Stomatopods, eggs, juvenile shrimps and Snakes. The effort in terms of fishing hours was worked out on the basis on actual time spent for fishing following Kurup and Radhika (2003). The catch per hour and catch per unit of the discards were computed following Scariah *et al.* (1999). The data was processed with the help of Microsoft excel package at the School of Industrial Fisheries as part of the DOD-OSTC project.

Results

1. Species composition of discards

From the discards, during the study period, a total of 120 species of finfishes, 65 species of gastropods, 12 species of bivalves, 12 species of crabs among them 3 are only commercially important, 8 species of shrimps in the form of advanced post larvae and juveniles, 3 species of echinoderms, 2 species of Stomatopods, and 5 species of cephalopods were identified . During the first year (2000-01) the Finfishes (37.13%) were the dominant groups in the discards followed by Crabs (28.46%), Stomatopods (8.13%) and Gastropods (9.94%). Shrimps formed 1.96%, Jellyfish accounted for 0.85% while cephalopods and Soles contributed to 1.50 and 1.17% of the discards respectively (Fig.2). The contribution of eggs and echinoderms were to the tune of was 0.40 and 0.51% respectively. The year 2001-02 also showed a similar trend with Finfishes dominating the discards (42.08%) followed by Crabs (27.31%), Stomatopods (15.08%) and Gastropods (7.79%). The share of Shrimps, Cephalopods, Soles and Echinoderms were to the tune of 2.51, 1.61, 1.32 and 1.01% respectively.

2. Quantification of onboard discards

The annual discarded quantity during 2000-01 was computed at 2.62 lakh tonnes and that of the second year (2001-02) was 2.25 lakh tonnes. During the first year 0.97 lakh tonnes of finfishes of both edible and non-edible categories were found to be discarded back to the sea. Crabs discarded were mostly of non-edible species which accounted for 0.74 lakh tonnes, where as stomatopods were more or less dominated by *Oratosquilla nepa*, (0.47lakh tonnes). The quantity of gastropods was around 0.25 lakh tonnes while other major groups of discards were Soles (0.03 lakh tonnes), juvenile cephalopods (0.02 lakh tonnes) , juvenile shrimps (0.051 lakh tonnes) and jelly fishes (0.039 lakh tonnes).

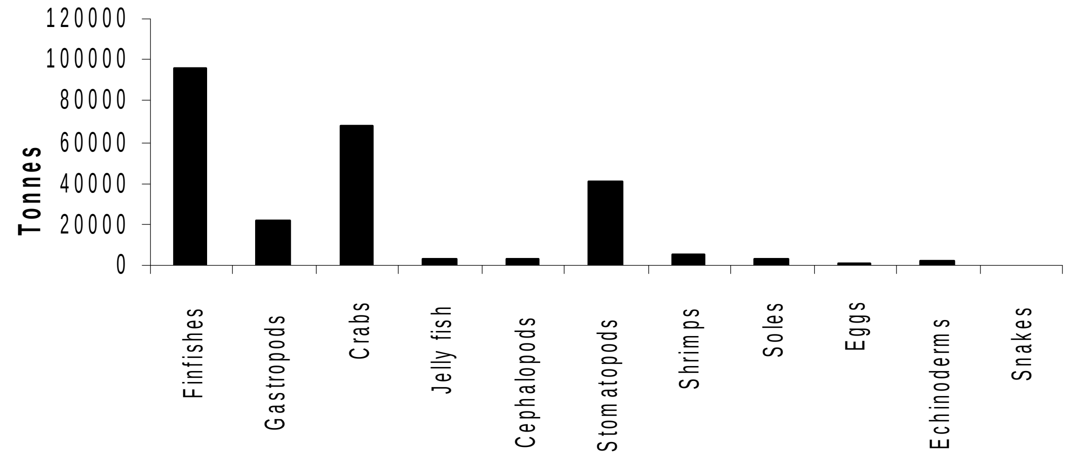

Fig: Average estimated quantity of discards (Major groups) April 2000- March

During the year 2001-02, Finfishes accounted for 0.95 lakh tonnes followed by Crabs (0.61 lakh tonnes), Stomatopods (0.34 lakh tonnes), Gastropods (0.17 lakh tonnes) and Shrimps (0.56 lakh tonnes). The share of Cephalopods, Soles and Echinoderms were to the tune of 0.036, 0.03 and 0.02 tonnes respectively. The contributions from Eggs (0.007 lakh tonnes) and Jellyfish (0.02 lakh tonnes) were relatively low when compared to preceeding year (Fig. 3).

3. Major groups

The percentage compositions of edible and non-edible biota in the onboard discards during first year is shown in Fig. 4. During 2000-01 edible biota was worked out to be 0.87 lakh tonnes which accounted for 33.33% of the discards while the non-edible fraction formed 66.67 % with 1.74 lakh tonnes .

Even though the trend during the second year was similar, a slight increase in the edible quantity was observed which contributed to 35.54 % (0.80 lakh tonnes) while the non-edible one formed 64.45% with 1.45 lakh tonnes.

3.1 Edible Finfishes

Edible finfish component during 2000-01 accounted for 28.45% of the total discards. Highest quantity of discards were registered in the month of September 2000 (19600 tonnes), which was predominated by juveniles of *Nemipterus japonicus* and *Decapterus russelli*, contributing to 37.04% and 36.52 % respectively of the total edible finfishes discarded in this month. An increase in the discarded quantity in this month can be attributed to the hectic fishery of Nemipterids during the post monsoon periods. Nempterids having length below 12cm lengths were found discarded onboard itself since it do not fetch a good price in the market. The edible fishes were found lowest in December 2000 (1273.02 tonnes) in the discarded fraction. In 2001-02 too similar trend was observed, with highest contribution in September 2001(10369 tonnes), where both the Nemipterids and Decapterids contributed to 37.08 and 25.14 % respectively Fig. 5. Decapterids were found discarded along Cochin and Sakthikulangara regions, mostly due to their vulnerability to easy spoilage within very short time, which would in turn deteriorate the quality of other commercially important fishes stored along with it. It appears that edible finfishes were discarded more during the pre monsoon and monsoon periods while these contribution in the discarded fraction was insignificant during post-monsoon periods.

During the second year Nemipterids contributed to 23.28% among the discarded edible finfishes followed by silver bellies and Carangids registering 19.4 and 17.9% respectively. The share of the perches (e.g. *Epinephelus tauvina* and *E. diacanthus)* and sciaenids (e.g. *Johnius* and *Otolithes spp)* were 15.28 and 15.21% respectively while ribbonfishes, Priacanthids, other clupeids and anchovies accounted for 3.31, 1.91, 1.47 and 1.41% respectively of the edible finfish discards.

Nemipterids showed the dominance in the discarded finfish group during 2001-02 also as in the preceding year, registering 25.33%, followed by perches (19.86%) and Carangids (18%). However, the contribution of silver bellies and sciaenids showed a reduction to 9.41 and 10.80% respectively. Interestingly when compared to the first year, the percentage contribution of the Ribbonfishes, Anchovies and Sardines increased to 6.39, 4.66 and 2.99% respectively when compared to the previous year Fig. 6.

3. Non-edible fin fishes

The percentage contribution of the non- edible fishes to the total discards during 2000-01 and 2001-02 was arrived at 8.69 and 12.83 % respectively. Discards of this category during 2000-01 was found to be very high in September (5319 tonnes) during when *Rogadis asper* (2713 tonnes) emerged as the dominant species which accounted for 51% while it was least in December (357 tonnes). However, in 2001-02 maximum quantities of discards was observed in May (5472 tonnes), which was dominated by *Lagocephalus inermis* 45.51% followed by *Apogonychthys* spp. 41.34%. while the former species is discarded due to its poisonous nature, ,latter is thrown due to its smaller (5-8 cm) size. Quantities of discards were lowest in December 2001(186.16 tonnes) during when *Lagocephalus* dominated the non-edible finfish catch (91.45%). Species composition of the non-edible fin fishes in the total discards category is given in Fig 7. *Lagocephalus inermis* (30.85%) was the dominant species followed by *Diodon spp* (21.61%) and *Rogadius asper* (19.57%). The contribution from *Apagonychthys molutrix, Platycephalus niger* and *Synodus indicus* were to the tune of 5.57, 3.77 and 3.55% respectively.

The trend in discarded fraction during the second year was same with the dominance of *Lagocephalus inermis* (26.31%) followed by *Diodon spp* (24.95%), *and Rogadis asper* (13.96%). *Apagonychthys molutrix* (5.57%), *Platycephalus niger* (3.77%) and *Synodus indicus* (3.55%) were also contributed insignificantly.

5. 5.3 Edible crabs

The contribution of crabs having edible value in the total discards during 2000-01 and 2001-02 was 0.54 and 0.42 % respectively. During the first year, April recorded highest quantity (1052 tonnes) during when *P.sanguinolentus* was the dominant species (858 tonnes). It was lowest during October (21.24 tonnes), however during August this group was not represented. On the contrary, during the second year, highest quantity was recorded in May 2001 (1331 tonnes) while during October it was least registering the lowest catch (35.74 tonnes). Interestingly, during August, December, January, February and March this group was totally absent. Of the total edible crabs discarded, *C.cruciata (*57.26%) appeared as the dominant species followed by *P. sanguinolentus (39.89*%) while *P. pelagicus* contributed insignificantly. However, during 2001-02, *P. sanguinolentus (*62.15%*)* emerged as the dominant species followed by *C.cruciata (*37.56%). The share of *P. pelagicus (*0.29%) was more or less negligible Fig. 8.

4.Non-edible crabs.

Of the total onboard discards, non-edible crabs contributed to 26.96 % with apportioning of the first and second years were 14.75 and 12.21% respectively. During the first year (2000-01), highest quantity of non-edible crabs were discarded in August (28098 tonnes) followed by September (18239 tonnes). During these months the most predominant species was the swarming crab *Charybdis smithii* that accounted for 54.67 % of the total discarded non-edible crabs. *C.smithii* was found all along the coast with highest abundance off Cochin region at the depths 70-180 m. The peak abundance of this species recorded during August and September corroborated with the findings of Joice and Kurup (2000), who reported this species in the inshore waters of Kerala during August with a CPUE in the range 120-200kg. Least quantity of non-edible crabs discarded was found during May (722 tonnes). Of the total non-edible crabs *Charybdis smithii* (54.68%) dominated the discards followed by *Charybdis granula* (34.77%). The contributions from *Callapa lophosa, Doclea gracelepis* and *Phyllyra coralicola* were 2.95, 2.49and 1.96% respectively. Even though similar trends of high discards were observed during the second year in August (17343 tonnes) and September (15711 tonnes), the discarded quantity during these months was lower when compared to 2000-01. Availability of non-edible crabs was lowest in May 02 (405 tonnes). The species composition of non-edible crabs is shown in Fig.9. *Charybdis smithii* contributed to 45.81 % while that of C.granula was 36.11 %, whereas *Calapa lophosa* formed only 11.07 % of the total discarded non-edible crabs.

5. Cephalopods

During 2000-01, Cephalopods formed 0.85% of the total discards, while during 20001-02, it formed 1.61%. The highest discards during 2000-01 were recorded in March (929 tonnes) where the juveniles of Octopus *dolfusi* (477 tonnes) showed the dominance while lowest was in December (5.91 tonnes). May (1319 tonnes) accounted for the highest quantity of discards in 2001-02 due to the glaring dominance of *S. pharoanis* (1172 tonnes). The high occurrence of cephalopod in the discards during May is due to the intensification of fishing for cephalopods along the shelf waters of Kerala. Majority of the discarded cephalopods fall in 5-7cm average mantle length. It appeared only in very stray numbers in November (26.65 tonnes) where as in December virtually no specimens of cephalopods were found in the discarded category. The percentage composition of cephalopod species in discards for the year 2000-01 is shown in Fig 10. *Loligo duvaceli* formed the dominant species with 52.10% followed by *Sepia pharoanis* with 30.96 % while *S.brevimana* formed only 13.22 % whereas the contributions from *Octopus dolfusi* was least with 3.72 % of the total discarded quantity of cephalopods. Although a similar trend was observed in the second year the percentage contribution of Sepia *pharoanis* (42.80%) showed an increase, in contrast *S.brevimana* (*4.98*%) and *Octopus dolfusi* (0.59%) showing an inversing trend .

6. Shrimps

Discarding of juvenile shrimps is another matter of grave concern. It was observed that a total of 5110 (2000-01) and 5662.06 tonnes (2001-02) of juvenile shrimps were discarded during the study period accounting for 1.95 and 2.51% of the total discards respectively of the two years. During the first year, the highest discarded quantity was observed in March (1248 tonnes) where *P.stylifera* (871 tonnes) was the dominant species. The contribution of shrimp species to the total discards (2000-01) is shown in Fig.11, where the dominance of P.stylifera (66.34 %)is clearly discernible followed by *M. dobsonii* (33.02%). Interestingly ,during the second year, discarding of shrimps were nil during March, however a maximum of 2813 tonnes was recorded in May mainly comprised *P.stylifera* (2238 tonnes) and *M.dobsonii* (575 tonnes). During this period, *P.stylifera* accounted for 64.22 % while *M.dobsonii* formed 33.68 % whereas the share of *Plesionika spp*. was 2.10 % of the total shrimps being discarded onboard .

7. Gastropods

Gastropods are mostly inedible or accommodate hermit crabs in them and hence are being discarded.During 2000-01, Gastropods contributed to 9.91 % of the total discards. During this period highest quantity of gastropods discard were recorded in September (12122 tonnes) whereas it was very low in October (499 tonnes). However unlike the first year, the discards in August were very low during the second year. The contribution of Gastropods (2001-02) to the total discards were 7.67%. Highest quantity was (3471 tonnes) recorded during February. In 2001-02 *Turritella maculata* (16.73%) dominated the discards, followed by *Tibia maculata* (13.47%), and *Babylonia zeylandica* (10.59%) with significant contributions from *Turritella spp* (10.29%), *Tibia fucus* (10.10%), *Babylonia spirata* (9.70%), *Harpa spp* (8.77%) *and Murex spp* (7.25%). On the other hand, in 2001-02, *Murex* spp. dominated with 26.65 % followed by *Babylonia spirata (16.89%)* and *Tibia fucus* (14.54 %). The share of *Murex retrirostris* , *Harpa spp,* and *Turritella maculata* were found to the tune of 6.51, 5.16 and 4.82% respectively (Fig.12).

8 .Jellyfish.

Jellyfish accounted for 1.49% of the total discards during 2000-01 whereas the corresponding figures for the second year was 0.96%. The highest quantity of jellyfish discarded in the first year (1006 tonnes) and second year (712 tonnes) was found in August. Their abundance was registered during monsoon season, which can be correlated with heavy fresh water influx from the rivers. They showed a decreasing trend after monsoon,however increased during premonsoon period of 2000-01. In contrast this trend was not observed in 2001-02. They clog the gear thus increasing the resistance of tow.

9. Echinoderms

During 2000-01 and 2001-02, the respective quantity of echinoderms under discarded fraction were 1338 and 2284 tonnes. The highest discards of echinoderms was registerd during September (510 tonnes) during 2000-01 while during 2001-02 it was in April (1388 tonnes). These groups were found absent during August 2000, January 2001, February 2001, August 2001 and December 2001. While the lowest quantity discarded was in January 2002(11.04 tonnes) interestingly , there was practically no echinoderm discards during August 00, 01and December 01.

10. Stomatopods

Stomatopod discards, depicted were represented by one species, *Oratosquilla nepa* that was found abundant along the entire coast with predominance along northern zone, when compared to the other two zones. The quantity of this group even reached up to 300-400kg/haul with a cpue of 88.5 kg/ hr. During 2000-01 they accounted for 18.08% of the total discards, however its share in the year 2001-02 declined to 15.07%. Its hare among the discards during the first year was highest in March (11870 tonnes) while during the second year April registered the maximum discards of stomatopods (10939 tonnes) and thenceforth a decreasing trend was observed till March 02. However, this species was not found in September. The lowest was recorded in March 2002 with 418.87 tonnes.

11 Eggs

The quantity of Squid eggs discarded during 2000-01 and 2001-02 was 1041 and 735 tonnes respectively. Squid eggs were encountered in the trawl catches especially during August and September. The highest quantities of both the years was registered in September with 428 and 285 tonnes respectively. Eggs were totally absent in the trawl catches of late pre- monsoon and early monsoon months.

Temporal variations of Discards

During 2000-01, the discards were found highest in September (0.57 lakh tonnes) followed by March (0.45 lakh tonnes) and August (0.44 lakh tonnes). During this period least quantities discarded were registered during November (0.072 lakh tonnes). In 2001-02 maximum discards were recorded in September (0.32 lakh tonnes) followed by May (0.31 lakh tonnes). An increase in discards during May can be attributed to high fishing effort exerted for *M.dobson*ii before the introduction of fishing holidays. Quantity of discards during this period was least during December with 0.058 lakh tonnes. High quantity of discards recorded in April and May were due to the emergence of a non-edible crab *Charybdis granula* and *Oratosquilla nepa*. Discards in August was dominated by yet another non-edible swarming crab, *Charybdis smithii* which showed dominance in the catches during the monsoon periods and contributed to 63.03% of the total discards in these months. A highest of 1200 kg /haul was recorded off Cochin, while Sakthikulangara recorded 600kg/haul, in contrast this species was not recorded from Ponanni and Puthiyappa in such huge quantities. Among the finfishes, scianeids and Nemipterids were the major groups in discards. The scianeids fishery co-existed with that of *P.stylifera* since juvenile scianeids feed on them, as reported by Bhaskari (1977). During the last weeks of October, November and December, discards were found very less when compared to the preceding months and the reason can be attributed to the semi pelagic type of trawling operations being carried out aiming at resources like *Trichurus savala* and *Stolephorus spp.* With the help of bottom trawl, which was rigged with more floats so enabling the gear not to touch the sea bottom unlike shrimp trawling and as result there were very fewer discards. The trawl nets used for fishing of *Trichurus* spp. is characterized by big mesh size so as to reduce the resistance imparted by the water flow and thus retaining the trawling speed at 4-4.5 knots. In contrast, in shrimp trawling the trawling speed cannot be maintained more than 3.5 knots. The bigger mesh size also facilitated faster towing thus enabling catching of ribbonfishes, which are generally characterized by its fast moving. Hauls with practically no discards were also encountered in November. In January ,the discards were comprised mainly of Silver bellies, represented by 5 species, accounting for 11.51 (2000-01) and 8.75 %(2001-02) of the total edible finfish discards respectively.

Seasonal Variations in Discards

The discards of the pre-monsoon period was predominated by *Charybdis granula* which was found distributed all along the coast up to 75 m followed by *Oratosquilla nepa* which also was found all along the coast with highest abundance in northern area, with highest of 400kg/haul recorded off puthiyappa during March 2001. On the contrary, the discards in the monsoon were dominated by *Charybdis smithii* with a catch up to 1200kg/haul off Cochin (August 2000). The cpue of discards during the monsoon period was much higher during both 2000-01 and 2001-02 where the average cpue were 75.33 and 83.39 kg/hr respectively, when compared to that of pre and post monsoon seasons (Fig. 13). Post monsoon periods registered the lowest cpue both in 2000-01(26.64 kg/hr) and 2001-02 (36.48 kg/hr).

Depth wise variation of discards

The total area was divided into 5 zones viz 0-20, 21-40,41-60, 61-80 and 81-100 m for the purpose of assessing the quantity of discards fro various depths, their species composition etc. Discards were encountered from all the depth zones surveyed. Highest discards were observed in the 21-40 m depth zone during the first and second years of study, contributing to 53.37 and 48.87% respectively of the total discarded fraction for 0-100 m depth(Fig.14). Depth zone 0-20 m was the next highest contributor with 15.475 in the former year and 17.35 during the latter year while 81-100m accounted for13.93 and 13.34% respectively during the first and second years respectively.

Recommendations:

1. On an annual basis, around 2.4 lakh tones of discards are thrown back in to the sea from bottom trawlers operated along Kerala waters due to their non edible nature, wrong species and size, lack of storage facilities onboard, low market value, etc. It is found imperative to initiate urgent steps for their effective utlisation for the preparation of protein rich fishery products, byproducts and value added products for local and export markets. With back up of these materials, Govt.of Kerala can plan for the setting up of high quality fishmeal manufacturing plant either under Govt. or public sectors.
2. The edible portion of the discards is worked out to be around 0.85 lakhs tones per annum and therefore, steps may be taken to make available this fraction of the discarded catch for consumption. This may be possible by improving the storage facilities in the bottom trawlers. The discarding of edible finfishes are mostly due to relative market price prevailing during different months.
3. The magnitude of destruction of eggs and juveniles of commercially important fin and shellfishes along Kerala waters due to bottom trawling is a matter of grave concern. The results of the present study revealed that, on an average annually around 2500 tonnes of cephalopods, 5000 tonnes of shrimp juveniles and 700 tonnes of squid eggs were destroyed due to bottom trawling. This may incur a loss to the marine fisheries wealth of Kerala by at least to the tune of one lakh tones per annum. It is recommended that this situation can only be ameliorated by a reduction of trawl fishing pressure during February to May and a definite improvement in the cod end mesh size used in the bottom trawlers.
4. The exploited marine fishery of Kerala need to be revalidated on the basis of the pioneer data generated on discards. This data base shall be given adequate attention while framing any policies and legislation on conservation and management of marine fisheries of Kerala.
5. The present study revealed that 94% of the bottom trawlers operated along Kerala coast are having a cod end mesh size of 18 mm and below against the statutory mesh size of 35 mm imposed by the Govt, of Kerala vide KMFRA (!980). This situation calls for an effective implementation of KMFRA regulation.
6. 232 organisms were found killed and discarded in to sea in varying proportions from the bottom trawlers. This disproportionate destruction of non-target organisms would brought about serious biodiversity degradation in the coastal waters of Kerala. The wanton killing of some of the uneconomic but key occupants in the

marine food chain may affect the life supporting system in the long run. The trawl net and accessories presently used cause heavy damage to the seabed by penetrating into it and dispersing off the top layer of sediments. So it is found essential to make necessary technical modification in the design and operation of trawl gears such as rigging with separate panels, sorting grids, square mesh cod ends, square mesh panels or windows, bycatch excluder devices, provision for electrical stimulation device at the footrope and release holes at the cod ends, rigging with more floats, dispensing with the tickler chain, etc. to make bottom trawling more ecofriendly in order to minimize mortality and devastation of benthic organisms.

7. It has been observed that the survival of crabs, stomatopods ,echinoderms, gastropods, sea snakes, etc are quite long among the discards while the post fishery survival of fishes and shrimps are almost negligible. This may lead in to the proliferation of the former group of organisms in the fishing ground. This amounts to the transformation of the mature ecosystem in to an immature and inefficient ecosystem over a period of time and would ultimately leads in to the ecosystem over fishing as defined by Pauly (1983). The increase of gastropods and crabs observed during the second year in the present study also corroborate with this view. So it is recommended that the invasion of the above unwanted species in the fertile fishing grounds shall be prevented either by killing them onboard itself or bringing them to the shore for their effective utilization.
8. Vide Kerala marine Fisheries Regulation Act(KMFRA), up to 30 m between Kollemoode to Paravoor and upto 20 m from Paravoor to Manjeswar along Kerala coast are earmarked exclusively for the artisanal fishermen. The present study revealed that there is infringement by the trawlers in to these areas as this depth zone contribute to 17% of the total discards from the bottom trawls .

9. Establish “no trawling zones” in selective region of continental shelf and slope ecosystems along Kerala coast as a measure to recoup the benthic communities for the sustenance of demersal fishery. Marine Protection Areas (MPAs) may also be established for the protection of benthic habitats and conservation of marine fishery.

10. Since the ban imposed on bottom trawling during June -July for a period of 45 days was found very effective for the regeneration and recoupement of benthic communities, it is recommended that the fishing holidays may be increased to 65 days in consonance with the uniform ban being proposed for the west coast states by the Govt. of India. Furthermore, the high CPUE of discards were also observed during the monsoon periods and therefore, the quantity of discards can be reduced by regulating the fishing effort during these months

11. It is recommended that research need to be pursued on post fishery survival of discards in general and juveniles of fin and shell fishes in particular. Based on the results so compiled, the survival rate of discards can be improved by keeping them in short term rearing facilities to be equipped in the trawlers and their subsequent release in to the sea. This facility shall be made mandatory for the bottom trawlers operated along Kerala coast vide Kerala Marine Fisheries Regulation Act(KMFRA).

12. Minimum landing size (MLS) system should be fixed and implemented to curb landings of juveniles and young ones. Holding, selling, processing and exporting of

under sized shrimps, crabs, squids, cuttle fishes and other commercially important fin and shellfishes shall be fully banned. This will be most useful as a conservation measure and minimizing the magnitude of juvenile fishery.

13. The fishing pressures from bottom trawlers along coastal waters of Kerala is very high when compared to any other maritime states of the country and therefore, it is recommended that there is an urgent need for the regulation of fishing effort. At present around 4900 bottom trawling units are operated from the nine coastal districts of Kerala. The number of bottom trawlers may be regulated to 3000.The mesh size regulation may be limited to 30 mm for making it much more practical.

14. The present study revealed that the discards from multi day fishing trawlers are higher when compared to single day fishing trawlers. It is recommended that cold storage facilities in the former category of vessels shall be proportionately increased in consonance with their endurance.

15. Mass awareness programmes shall be conducted among fishermen engaged in bottom trawling, boat owners, auctioneers, and middlemen, workers engaged in peeling sheds, processing factories etc. about the impact of bottom trawling on sea bottom and its living communities. Definite programmes for the conservation and management of discards and for the protection and preservation of marine habitats shall be formulated by giving due participation to the fishermen who are actively involved in trawl fishing. Effective conservation and utilization of discards can be undertaken under the aegis of local bodies. Strengthen the co management activities with the participation fishermen for mitigating the wanton killing and discarding of the non target organisms in to the sea.

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GLOSSARY OF TECHNICAL TERMS

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a	multiplicative term in a length/weight relationship
abiotic	referring to non-living structures, substances, factors, environments, etc
apex predator	a fish at the top of the food chain, relying on smaller fishes for food.
A_r	aspect ratio of caudal fin of fish. $A_r = h^2/s$ where h, height of caudal fin of fish and s, surface area
AS	artisanal Gear, operated mainly during monsoon season (indigenous) fishing undertaken by peoples native to an area.
ascendancy index	information content of an ecosystem. The product of total system throughput (T) times an index of the average mutual information.
asymptotic length	length the fish in a stock would attain if they were to grow for an infinitely long period. Not the largest observed size of a species.
asymptotic weight	a parameter of the von Bertalanffy Growth Function, q.v., expressing the mean weight the fish in a stock would attain if they were to grow for an infinitely long period.
b	exponent of a length-weight relationship
benthos	organisms which live on the bottom of a water body, in it or near it.
benthic infauna	benthic animals living in the soft bottom or substrate
biomass	or standing stock. The total weight of a group (stock) of living organisms in an area at a particular time
bloom	a rapid and localized increase in the density of plankton resulting from a nutrient-rich habitat. The nutrients may come from upwelling, mixing or pollution and the bloom can kill fish populations through toxins or oxygen depletion.
cannibalism.	eating members of one's own species
catch	the number or weight of fish caught by a fishery, by fishing gear or by angling. May be the total amount caught, only the amount landed, or not kept but released. Usually expressed in terms of wet weight.

combination vessel	a vessel capable of more than one type of fishing, e.g. longliner/trawler, midwater trawler/purse seiner, bottom trawler/purse seiner.
connectance index	for a given food web, the ratio of the number of actual links to the number of possible links.
continental shelf	the area of gently sloping sea bottom from the shore to a depth of 200 metres. It may be only a few kilometres offshore where the sea floor descends rapidly to great depths or may be extensive and form an accessible habitat for many commercial fishes.
continental slope	the steeply sloping sea bottom from 200 to 2000 metres (or 100-300 m to 1400-3200 m) and 3-6°C. Average angle of slope is 4° with a maximum about 20° near the upper margin.
density dependence	the dependence of a factor influencing population dynamics (such as survival rate or reproductive success) on population density. The effect is usually in the direction that contributes to the regulative capacity of a stock
detritus	debris, disintegrated material or particulate material that enters into an aquatic system. If derived from decaying organic matter it is organic detritus.
DGN	drift gill net
discard	the part of a fish catch that is thrown overboard, but which may be of important ecological or commercial value. Also the act of throwing fish overboard. The discard typically consists of "non-target" species, damaged specimens or undersized specimens. The fish may be alive or dead, whole or in parts. Estimates of discards are made by observers and logbook records. Also called discarded catch. Discarding lower value fish to increase the value of a catch is called high grading.
dynamic pool model	analytical yield-per-recruit types of fisheries models describing how growth, recruitment and mortality interact, resulting in biomass and yields.
E	exploitation rate; $E = F/Z$
ecotrophic efficiency	= EE - The ratio between what flows into it and what flows out of it Is that part of production that is exported from or is eaten within the system ($t \cdot km^{-2} \cdot year^{-1}$)
electivity	express the food preferences of consumers. Electivities scale from -1 (total avoidance) over 0 (non-selective feeding) to 1 (exclusive feeding). The electivity is calculated as standardized forage ratio.
ecosystem	the complex of living organisms and environmental conditions that function as a unit. Biocenosis plus biotope.

ecosystem maturity	a number of statistics describing an ecosystem as a whole which can be of use for assessing the status of an ecosystem, e.g., to express its state of maturity
effort	the total fishing gear in use for a specified period of time; when two or more kinds of gear are used, they must be adjusted to some standard type before being added.
equilibrium	when fishing and natural mortality, exploitation pattern, growth and recruitment do not change from year to year; when such factors have been in effect long enough to affect all ages for the whole exploited life. Also called steady state.
equilibrium yield	the yield in weight taken from a fish stock when it is in equilibrium with fishing of a given intensity, and (apart from effects of environmental variation) its biomass is not changing from one year to the next (Ricker, 1975). Also called sustainable yield, equivalent sustainable yield. No stock is really in balance with fishing effort because effort cannot be maintained at the same level and the stock is always changing in response to environmental variables.
productivity/ primary productivity	a measure of the capacity of a biological system, the amount of fish supported or produced by a given area in a given time. Also used as a measure of the efficiency with which a biological system converts energy into growth and production. A highly productive stock of fishes has high birth, growth and mortality rates resulting in high turnover and production to biomass ratios. Such a stock can be exploited fully and can recover more easily if depleted.
exports	sum of fishery catches plus migration to/from adjacent ecosystems
exploitation rate	the proportion of a population at the beginning of a given time period that is caught during that time period (usually on a yearly basis). A catch in a year of 10 fish out of a stock of 100 is a 10% exploitation rate. Also the ratio of fish caught to total mortality (= F/Z when fishing and natural mortality take place concurrently (Ricker, 1975)). Also called rate of exploitation. Abbreviated as E.
F	Instantaneous rate of fishing mortality (mortality due to fishing)
fishing effort	effective fishing effort, abbreviated as f or *f* (Ricker, 1975).
fishery model	a representation of a fishery, usually simplified and may be mathematical.
flow diagram	graphical representation of trophic flow from one group to another in an ecosystem model
Fmax or F_{max}	the rate of fishing mortality for a given exploitation pattern, rate of growth, and natural mortality that results in the maximum yield per recruit; the point that defines growth overfishing. This mortality would give the maximum catch year after year. $F_{0.1}$ is often preferred as F_{max} is difficult to estimate.

FMSY or F_{MSY}	the fishing mortality rate which, if applied constantly, would result in maximum sustainable yield. Can be estimated from simple biomass-aggregated production models or from age-structured models that include a stock-recruitment relationship. Reality applies, however, and as the ocean conditions change a constant fishing mortality of F_{MSY} would give varying catches and eventually overfishing would result. A $2/3F_{MSY}$ is used to avoid overfishing. Fishing at this level means fishermen use only two-thirds of the effort needed to achieve maximum sustainable yield but they catch 80-90% of the MSY. Their catch rate is higher.
forage	the diet of a fish species.
F_{opt}	optimum (effective) fishing effort corresponding to fMSY, Used as biological reference point
generation time	T_g, the average age of parents at the time their young ones are born. In most fishes L_{opt} is the size class with the maximum egg production $t_g = t_0 - \ln(1 - L_{opt}/L_8) / K$.
GN	Gill net
gonadal products	the products by sexual organs, ovary and testis, producing the primary sexual products (eggs and sperm).
gross efficiency of the fishery	ratio between the total catch (landing + discards) and the total primary production in the system. Value will be higher for systems with fishery harvesting fish low in the food chain than fisheries concentrate on apex predators
growth model	a mathematical description or representation of the size of a living organisms at its various ages, e.g. the Von Bertalanffy growth model.
habitat	the place a species lives, defined by necessary biological and physical parameters, e.g. tidal pool, marsh, reef, continental shelf
K	curvature parameter of the VBGF (increase in weight of a fish per year, divided by the initial weight).
km	kilometre (0.621 mi).
L-25	length at which 25% of the fish will be vulnerable to the gear (left hand selection)
L-50	length at which 50% of the fish will be vulnerable to the fishing gear
L-75	length at which 75% of the fish will be vulnerable to the fishing gear
L_8	asymptotic length, i.e., the (mean) length the fish of a given stock would reach if they were to grow forever

L_c	mean length of fish at first capture; equivalent to L_{50}
L_m	mean length first maturity (or massive maturation)
L_{max}	maximum length reached by the fish of a given stock, may also be predicted from the largest specimens of several samples using the extreme value theorem
L_{mean}	mean length of fish computed from L' upward in catch curve
L_{opt}	the length class with the highest biomass in an unfished population, where the number of survivors multiplied with their average weight reaches a maximum (Beverton 1992)
L_r	mean length at first recruitment
landings	the weight of a catch as fish or fish products brought to a wharf or beach. Also called landed weight. Note that the catch is different and may include discards.
length Frequency	a breakdown of the different lengths of a kind of fish in a population or sample
length-weight relationship	mathematical formula for the weight of a fish in terms of its length. When only one is known, the formula can be used to determine the other.
linear relationship	used to described the variation of one variable as a liner function of another variable, e.g., total length and body weight of a fish
M	Instantaneous rate of natural mortality, i.e., due to all causes except fishing
maturity	fish of a given age/size capable of reproduction; attainment of first spawning
mechanised fishing sector	organized sector which uses crafts fitted with in-board engines, such as purse siener, trawler; mechanized fishing is banned during monsoon season.
MDF	multi-Day Fishing Fleet, Trawlers which undertake voyages lasing two days or more
mortality rate	the rate at which the numbers in a population decrease with time due to various causes. The proportion of the total stock (in numbers) dying each year is the annual mortality rate. To facilitate calculations, mortality is expressed as an exponential rate (called instantaneous rate) thus Nt/N0 = e-Z = e-(M+F) in which Nt/N0 is the survival rate, M the natural mortality rate, F the fishing mortality rate, and Z the total mortality rate (of deaths due to predation or disease).
n	number of items in a sample

nekton	organisms of relatively large size which have fairly strong locomotory powers (as compared to plankton) and swim in the water column independent of currents, e.g. most adult fishes.
net system production	or yield is the difference between total primary production and total respiration. System production will be large in immature systems and close to zero in mature ones.
niche overlap	an overlap in resource requirements by two species; is an overlap index which explains how a single prey (food) is shared between two predators
overhead	the difference between development capacity (C) and ascendancy (A). provides limits on the increase in ascendancy and reflect the strength in reserve from which it can draw to meet unexpected perturbations.
over-capitalization.	where the amount of harvesting capacity in a fishery exceeds the amount needed to harvest the desired amount of fish at least cost. Too many boats, too much fishing effort. May be addition of new technology rather than new boats
over-exploitation	rate of exploitation where the resource stock is drawn down below the size that would, on average, support the long term maximum potential yield of the fishery.
P/B	equivalent to total mortality under steady state, when von Bertalanffy growth and exponential mortality are used
pelagic season	the September-November season when pelagic fishes like sardine and mackerel are exploited by gears specially designed to harvest them (eg., purse seine)
population dynamics	the study of fish populations and how fishing mortality, growth, recruitment, and natural morality affect them over time.
potential yield	the yield of fishes estimated to be available for exploitation.
	the yield in weight taken from a fish stock when it is in equilibrium with fishing of a given intensity, and (apart from effects of environmental variation) its biomass is not changing from one year to the next (Ricker, 1975). Also called sustainable yield, equivalent sustainable yield. Abbreviated as YE or Y_E. No stock is really in balance with fishing effort because effort cannot be maintained at the same level and the stock is always changing in response to environmental variables
primary consumer	a fish that feeds on the lowest level of a community's food web, namely plants. Also called first-level consumer.

production model	a population model that describes how biomass changes from year to year or how biomass changes in equilibrium as a function of fishing mortality. Three or four simple parameters are used in a deterministic model. Production models are used primarily in simple data situations where total catch and effort data are available but age-structured data is unavailable or less reliable
PS	purse seine- a seine used to encircle a school of fish in open water. It is set at speed from a large, powered vessel and the other end is anchored by a small boat. A purse line at the bottom of the net allows it to be closed like a purse.
Q/B	ratio of consumption over biomass where consumption is the intake of food by a group over the time period expressed as /year
r	product-moment correlation coefficient
recruit	an individual fish that has moved into a certain class, such as the spawning class or fishing-size class through growth, migration, etc.
R_n	goodness of fit index of the ELEFAN I routine ($=10^{ESP/ASP}/10$)
resilience	capacity of a natural system such as a fish community or ecosystem to recover from heavy disturbance such as intensive fishing.
respiration	a flow (flows) of mass or energy that is not directed toward, nor could be used by any other box (es). When Carbon is used as currency respiration appears as CO_2
Schaefer model	the basic form of production model in which the relation between yield and effort takes the form of a symmetric parabola.
SDF	single-Day Fishing Fleet, Trawlers which make daily trips
SL	starting length; one of two coordinates used to locate a growth curve in the ELEFAN I routine
size-at-first-maturity	length or weight at maturity. Maturity is defined as minimal size attained at maturity or the size at which 50% of the fish at that size are mature.
spawning stock biomass (SSB)	the total weight of the fish in a stock that are old enough to spawn; the biomass of all fish beyond the age or size class in which 50% of the individuals are mature. May be used instead of measuring egg production.
SS	starting sample the other coordinate used to locate a growth curve in the ELEFAN I routine

standing stock	biomass; weight of a stock. May apply to a part of the stock such as spawning fish, fish in a particular area or at a particular time stochastic = having components affected by random variability, e.g. future recruitments in a fishery are projected with a stochastic component (random variables) to allow for unexplained effects.
steady state population	is a theoretical construction never occurring in reality. Can be approximated by averaging time series data over longer periods if there are no major changes in biomass or size
stock	the part of a fish population which is under consideration from the point of view of actual or potential utilization; stock (noun) = a distinct genetic population, a population defined by movement pattern, part of a population potentially harvestable, i.e. an assessment or management unit, or a quantity of fish from a given area; usually isolated from other stocks of the same species
summer monsoon	the south-west monsoon occurring during the June-September period
surplus production model.	an estimate of the catch in a given year and the change in stock size. The stock size could increase or decrease depending on new recruits and natural mortality. A surplus production model estimates the natural increase in fish weight or the sustainable yield
sustainable yield	the yield (in weight or number) taken from a fish stock when it is in equilibrium with fishing of a given intensity, and (apart from effects of environmental variation) its biomass is not changing from one year to the next. Also called equilibrium yield, equivalent sustainable yield.
system omnivory index	average omnivory index of all consumers weighted by the logarithm of each consumer's food intake, is a measure of how the feeding interactions are distributed between the sexes.
t	abbreviation for tonne (metric ton, 1000 kg, 2204.62 pounds (lb), 0.984 long tons)
total length	length from the anterior-most part of the head to the tip of either lobe of the caudal fin when that fin is normally splayed.
total system throughput (T)	sum of all flows into and from the boxes in an ecosystem including imports and exports of usable materials or energy (i.e., catches or emigration) expressed as t./km^2/year
t_0	the age the fish would have had at length zero if they had grown always according to the VBGF
t_c	mean age at first capture, corresponding to l_c
t_{max}	longevity, approximate maximum age that fish of a given population would reach. $t_{max} = t_0 + 3/K$
trophic	pertaining to nutrition.
trophic level	(Troph),Classification of organisms or natural communities

	according to their place in the food web, trophic = 1+ mean troph of the food items
upwelling	an upward movement of cold, nutrient-rich water from the ocean depths, often associated with great production of fish and fisheries. For fisheries, the most important types are wind-induced coastal upwelling where the upward movement is a consequence of wind stress (along shore) and Ekman transport (offshore).
virtual population analysis	an algorithm for computing historical fishing mortality rates and stock sizes by age or length, based on data on catches, natural mortality, and certain assumptions about mortality for the last year and last age group. Essentially reconstructs the history of each cohort or year class over its life in a fishery, assuming that the observed catches are known without error. Abbreviated as VPA. Also called cohort analysis.
winter monsoon	The North-East monsoon which occurs during November-January period
W_8	asymptotic weight, i.e., the (mean) weight the fish of a given stock would reach if they were to grow forever
yield	catch in weight. Catch and yield are often used interchangeably. Amount of production per unit area over a given time. A measure of production. The sustainable yield is the quantity of fish which can be taken from a stock (usually on an annual basis) without severely depleting or eliminating that stock
yield-per-recruit analysis	analysis of how growth, natural mortality, and fishing interact to determine the best size of the fish at which to start fishing them, and the most appropriate level of fishing mortality. The yield-per-recruit models do not consider the possibility of changes in recruitment (and reproductive capacity) due to change in stock size. They also do not deal with environmental impacts.
Z	Instantaneous rate of total mortality (the sum of natural and fishing mortalities)
F '	phi-prime, i.e., length based index of growth performance (F '= $\log_{10}$ (K) + $2\log_{10}$ (L_8)
B_i	Biomass of group (i)
C_i	Catch of group (i) UNIT $time^{-1}$
DC_{ij},	The fraction that prey j constitutes in predator i's food intake; is weighted over species, sizes and seasons included in a box. UNIT $time^{-1}$
DC (N1,i)	Diet composition of detritus box, Dimensionless
EE_i	Ecotrophic Efficiency is production that goes to predation and

	catches (including exports); same as (1 - other mortality)
GE_i	Gross efficiency (of food conversion); Dimensionless
E_i	The coefficient for other exports than fishery, $time^{-1}$
MO_i	Other mortality coefficient; $time^{-1}$
$M2_i$	Predation mortality of (i); $time^{-1}$
P/B	Production/biomass ratio of (i). Equals the total mortality; $time^{-1}$
P_i	Production rate of (i). UNIT time-1
PP_i	Proportion of production of (i) that is attributed to primary production 0 PP 1 >0 for consumers; Dimensionless
Q_i	Consumption rate of (i); UNIT $time^{-1}$

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REPRINTS OF KEY ECOPATH PAPERS