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Advances in Marine Fisheries in India

18th to 23rd February 2019

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Advances in Marine Fisheries in India

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Chapter 01

Marine Fish Production in India - Present status

Somy Kuriakose and T.V. Sathianandan

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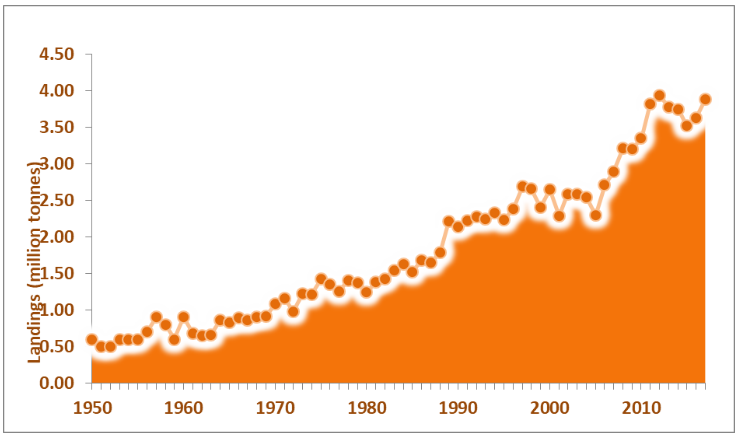
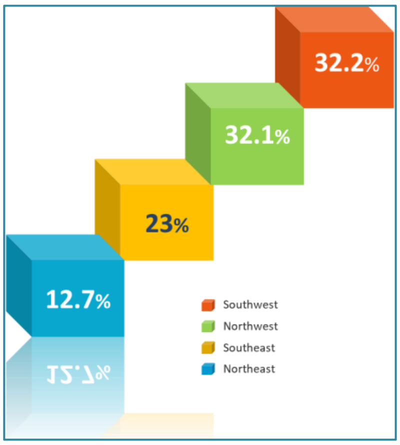
The fisheries sector in India, contributes significantly towards strengthening nutritional security, income, employment, foreign exchange earnings and livelihood opportunities. With a coastline of over 8000 km, an exclusive economic zone of over 2 million square kilometers and with extensive resource fisheries play a vital role. During the last six decades, Indian marine fisheries had made tremendous progress, with the annual fish production increasing from 0.5 million tonnes in 1950 to 3.83 million tonnes in 2017.



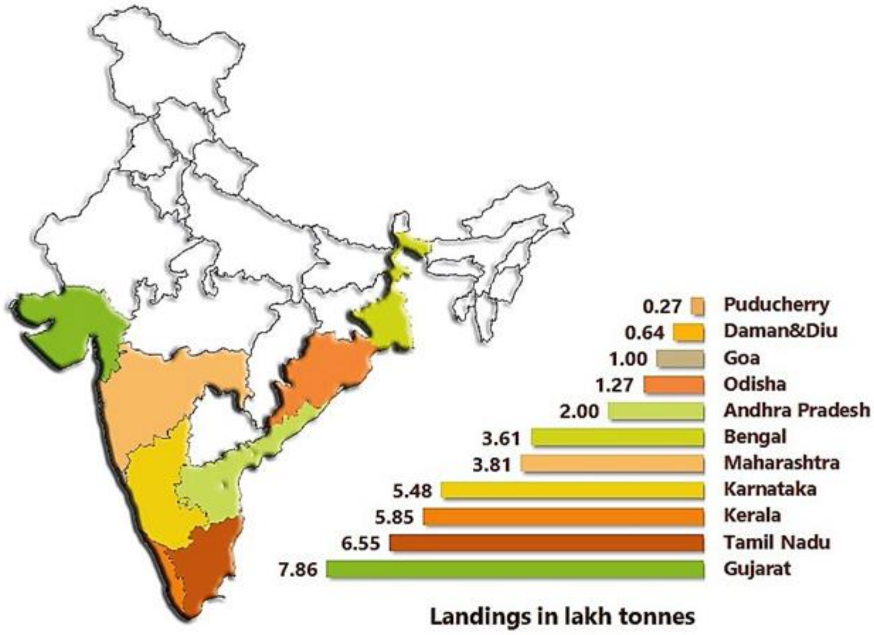
Compared to the estimate of 2016, an increase of about 5.6% was noticed in the marine fish landings of the country.

Among the four regions of the Indian coast line, the south-west region and the North West region contributed almost equally towards marine fish landings in the country. Compared to the estimate of 2016, an increase of about 1.2 lakh tonnes was noticed in the south-west region. The next major contribution was from the Southeast region comprising the maritime states of Tamil Nadu, Puducherry

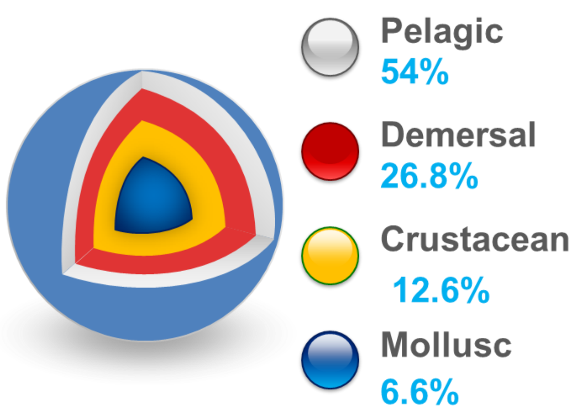


and Andhra Pradesh with 8.82 lakh tonnes which accounted for 23% of the total landings. The least landing was from northeast region with 4.88 lakh t.

Gujarat retained the top position among the states with 7.86 lakh t which is 20.5% of the total landings in India, followed by Tamil Nadu which landed 6.55 lakh t. Kerala and Karnataka are the other top states with contributions of 5.85 lakh t and 5.48 lakh t respectively. An overall increasing trend in catches has seen in all the maritime states except Tamil Nadu. The increase in landings is about 2.05 lakh t which is mainly due to increased landings in West Bengal by nearly 90,000 t, Maharashtra by 89,000 t and Kerala by 62,000 t.

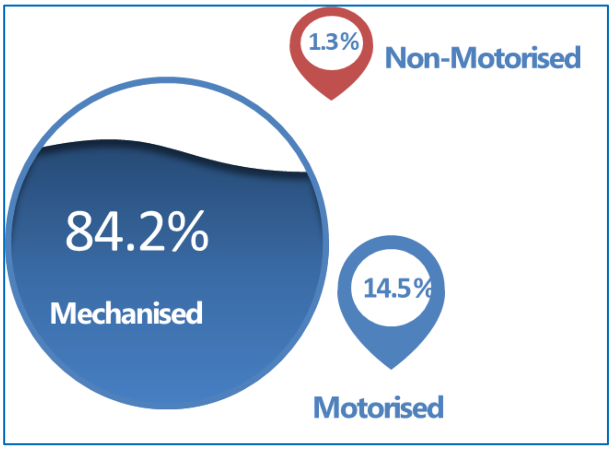


The total marine fish landings in the country comprised of 20.69 lakh tonnes of pelagic fishes, 10.28 lakh tonnes of demersal fishes, 4.83 lakh tonnes of molluscs and 2.54 lakh tonnes of crustaceans. Pelagic finfish contributed 54% of the total marine fish landings in 2017 with oil sardine, Indian mackerel and ribbonfishes top in the list. Indian oil sardine, mackerel, ribbon fish, lesser sardines and Bombayduck contributed almost 60% of the pelagic fish landings in 2017. Of this, the oil sardine alone accounted for 16.3%. Compared to the previous year, there was an increase in the landings of pelagic resources. Demersal



resources contributed around 26.8% of the landings with major contribution from bullseyes (*Priacanthus* spp.), threadfin breams, croakers, silverbellies and catfishes. Crustaceans include high value resources like prawns, crabs and lobsters and the contribution from this group was 12.6% and molluscan resources accounted for the remaining 6.6%.

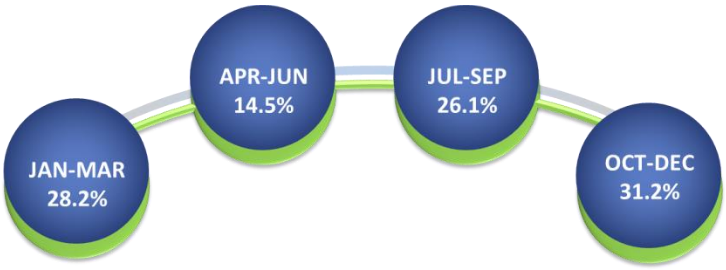
Among the three different categories of crafts used for fishing the contribution by mechanized, motorised and artisanal sectors were 84.2%, 14.5% and 1.3%, respectively. Different gears which contributed to the mechanised sector were trawlnets, bagnets, seines and gillnets. In the motorised sector, ring seines contributed the major share.



Oil sardine was the major component of landings during 2017 and it accounted for 3,37,390 tonnes. Considerable improvement in the landings of Oil sardine was noticed. Among the other major resources, fishery of Indian mackerel, penaeid prawns, Cephalopods, Ribbon fishes, other sardines, non-penaeid prawns etc. recorded increase in landings whereas marginal decline in the landings of Threadfin Breams, *Stolephorous,* Hilsa shad, Tunnies and Lizard fishes. The estimated landings of major resources for 2017 are given in the table.

Species/ Group	Landings (lakh tonnes)	Major contributing state	Percentage contribution from the state
Oil sardine	3.37	Kerala	38
Indian mackerel	2.88	Karnataka	42
Ribbon fishes	2.39	Gujarat	48
Cephalopods	2.31	Tamil Nadu	25
Lesser sardines	2.27	Tamil Nadu	49
Penaeid prawns	2.08	Kerala	21
Non-penaeid prawns	2.02	Gujarat	73
Threadfin breams	1.57	Kerala	34
Croakers	1.50	Gujarat	30
Bullseyes	1.43	Karnataka	44

During 2017, most productive season was found to be October-December, contributing nearly 31.2 % of the landings followed by 28.2% January-March. Cyclone Ockhi was devastating and affected the fishing days in the coastal States of Kerala and Karnataka, reducing the landings in the fourth quarter considerably during this year. When examined at month level the maximum landings (11.6%) was in December and the least was in June.



Chapter
02

Status of Commercially Exploited Demersal Fishery Resources of India

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Demersal finfishes are grouped, based on their depth-wise distribution, as finfishes occupying the neritic areas in the continental shelf. In deep waters, they are found on or near the continental slope or along the continental rise. Demersal fishes can be divided into two main types: strictly benthic fish which can rest on the sea floor, and benthopelagic fish which can float in the water column just above the sea floor. Benthic fish, which are rest on the sea floor, sometimes called groundfish. World catches of demersal species increased rapidly during the first three-quarters of the 20th century. Demersal finfishes are one of the major components in the marine fish landings along the Indian coast. The demersal fisheries in India have exploited many major fish groups of different biological characteristics occupying a variety of ecological niche. The major gear which exploit the demersal finfish resources in India are bottom trawlnets. Large species are mainly caught by bottom set gillnets. Some demersal finfishes are taken as a by-catch in Indian trawl fisheries. Demersal fish though generally occupy the seafloor; feeding on the benthic organisms and detritus, perform vertical and horizontal migration in search of their feeding and breeding grounds. Hence, the day and night catches in bottom trawl show differences, eg. catfish, rays, eels etc. In the inshore fishing activities below 50 m depth, occurrence of pelagics in bottom trawl and catfish, perches and penaeid prawns in pelagic net is common. Trawl catch consists of 76% demersal (finfish 38% and inveretebares-38%) remaining pelagic or column water fishes.

Proper exploitation of the demersal finfishes in India has been initiated only three decades ago (Bensam, 1992). With the introduction of mechanized bottom trawling from the late fifties, the exploitation of demersal finfishes attained a threefold increase during late eighties.

With the large-scale introduction of mechanized trawling, several environmental problems and stock-recruitment hazards to inshore fisheries have come up. Demersal fish groups such as the sharks, groupers, snappers, threadfins, pomfrets and Indian halibut are commercially valuable and contribute substantially to the economy of Indian marine fisheries. Some of these groups, especially of large-size, are targeted by the fishermen by using different craft and gear combinations. However, several other demersal finfishes are not targeted, but are landed as bycatch by shrimp trawlers (Vivekanandan, 2011). Recent changes in the ecosystem due to climate change coupled with intensive fishing pressure necessitates the formulation of policy measures to harvest the demersal fishery resources of the country at sustainable levels. However, compared with the pelagic, the demersal fishes are less affected by the environmental changes namely, temperature, currents and so on.

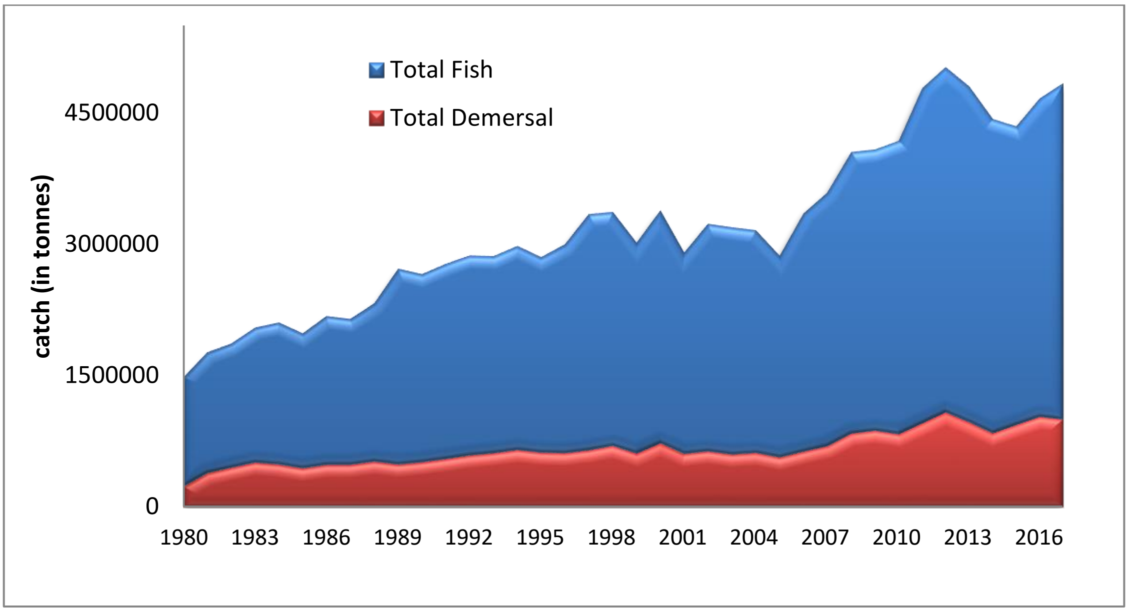

Fig. 1. Trends in the landings of demersal finfishes in India during 1980-2017.

The landings of demersal finfishes India during 1980-2014 period shows that the catch is increasing steadily over the years from a meagre of 2,34,408 tonnes to nearly 10,76,789 tonnes in 2012, and thereafter declined to 8,42,199 tonnes in 2014. However, the catch share of demersal finfishes during the last 35 years indicate that the contribution of demersal finfishes to the total Indian marine landings are decreasing over the years. The maximum share was reported in 1983 with 33% contribution and the lowest share (21.7%) was in 1989. The region-wise average share of demersal finfishes along the Indian coast shows that the northwest region comprising of Gujarat and Maharashtra contributes the highest share, followed by southwest coast comprising Kerala and Karnataka and southeast coast comprising Tamil Nadu and Andhra Pradesh. The share of demersal finfishes to all India marine landings of India in 2017 was 26%.

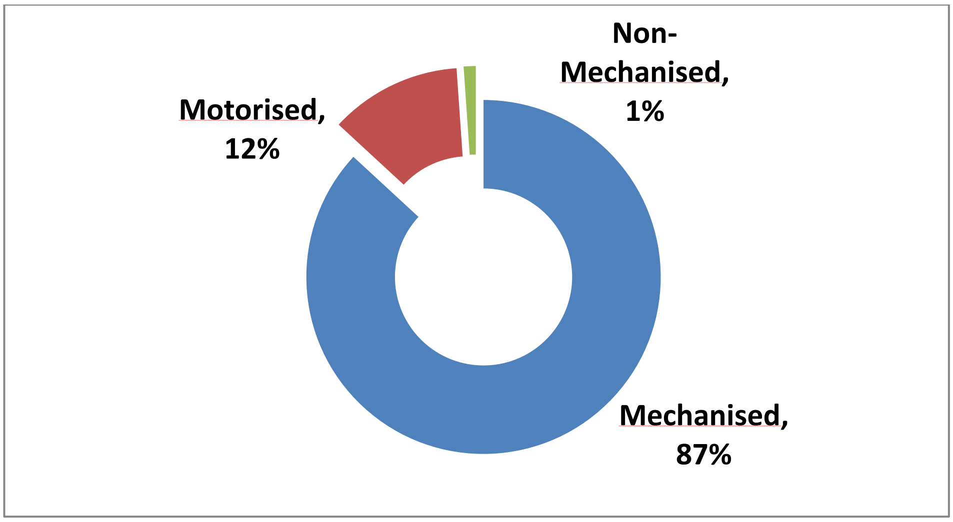

Fig. 2. Sector-wise landings of demersal finfishes for the period 2007 – 2017.

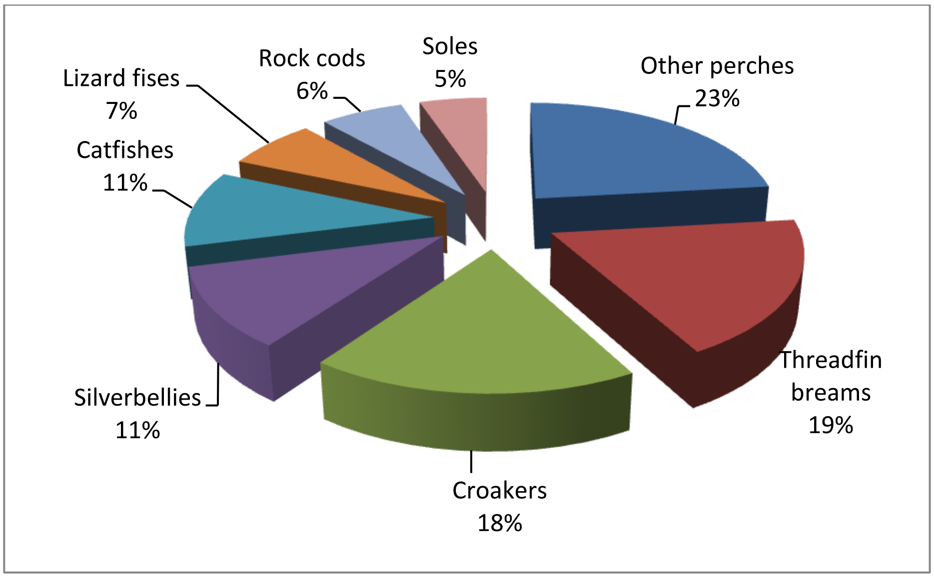

Fig. 3. Demersal finfish composition in the marine fish landings of India during 2017

The group wise composition of demersal finfish assemblages in Indian marine fish landings during 2016 indicate that the major contributors are the other perches including bulls eye (23%), followed by threadfin breams (19%), croakers (18%), silverbellies and catfishes contributed 11% each, lizardfishes (7%) rock cods (6%) and soles (5%). The exploitation status of the important groups of demersal finfishes along the coast of India are briefly given below.

ELASMOBRANCHS

In India, there are about 110 species of elasmobranchs, of which 66 species of sharks, 4 sawfishes, 8 guitarfishes and 32 species of rays are landed in the commercial catches. Among these, 34 species are commercially important. Some species of elasmobranchs are protected under the Wildlife Protection Act (10 species), which include, *Pristis microdon, Rhynchobatus djiddensis, Pristis zijsron, Carcharhinus hemiodon* (Pondicherry shark), *Glyphis glyphis, Rhincodon typus* (whale shark), *Urogymnus asperrimus* (Porcupine ray). Majority of the species of elasmobranchs in the Indian seas are viviparous, some are oviparous and few are ovo-viviparous with very low fecundity. All India landings of elasmobranchs during 2013-17 was 48,735 tonnes, forms 6% of demersal catch. Trawl nets accounting for 48.8%, gillnets 35.6% and hook & line units 6% of the total elasmobranch landings of the country.

Sharks: Average annual shark landings in India during 2013-17 was 21,998 tonnes, which formed 45% of the total elasmobranch landings of the country. The major families appeared in the landings were Carcharhinidae, Triakidae, Sphyrnidae, Echinorhinidae, Hemiscylliidae, Alopiidae, Lamnidae, Centrophoridae, Squalidae and Stegostomatidae. The dominant species in the landings were *Carcharhinus falciformis* (37.25%), *Alopias superciliosus (11.85%), Sphyrna lewini(11.53%), Alopias pelagicus* (8.53%). Most of the catch was contributed by multiday trawl nets (34%) followed by mechanised gillnet units (27%).

Fig. 4. Landings of sharks at Cochin Fisheries Harbour, Kerala coast

Rays: The landing of rays in India during 2016 was 26,211 tonnes, which formed 51% of the total elasmobranch landings of the country. The major families in the landings were Dasyatidae, Mobulidae, Myliobatidae, Gymnuridae and Rhinopteridae

Skates/guitar fishes: All India landings of guitarfishes were estimated at 3627 tonnes, which constituted 4% of the total elasmobranch landings of the country. The major families of guitarfishes landed along the coast are Rhinidae and Rhinobatidae.

There are significant changes in the share of sharks and rays to total elasmobranch landings recent years. All India production of elasmobranchs during 1999-2010 shows that sharks were dominant in the catch with 49.7% share and that of the rays was 44.5%. However, the landings during 2013-17 indicate that the rays have emerged as the dominant group with 48% followed by sharks with 45% share.

Sharks are crucial to marine ecosystems. They maintain a balance in populations of prey species. They are in a global decline. Overfishing & life history parameters have reduced many shark populations. Life history traits are making sharks, a vulnerable group of fishes. The shark's reproductive strategy is very different to most bony ocean fish that release millions of eggs in a lifetime. Long time to reach sexual maturity - dusky shark can take more than 20 years to reach sexual maturity and sharks have long gestation periods (one to two years). They have a small number of offspring (pups). Most shark species give birth to between 2 and 20 pups after a pregnancy of 8-12 months. They breed only every second or third year. Females of many shark species rest between breeding cycles for at least one year. Most of the shark species have a tendency to form groups based on their age, sex and/or maturity. India is the second largest shark fishing nations of the world after Indonesia. Conservation and management measures for shark species are initiated in India. Already 10 elasmobranch species are protected in India under Wildlife Protection Act. There is a blanket ban on the export of shark fins from India. Unlike many other countries, the sharks are landed 'fin on' in India and there is a great demand for shark meat in the local markets in many parts of the country.

PERCHES

This group was abundant in the rocky grounds off Kerala and Tamil Nadu and was exploited by drift nets, hooks and lines and traps. All India annual average landings of Perches during

2013-17 is 3.50 lakh tonnes and forms 36% of total demersal finfish landings. Among the different groups of perches landed along the Indian coast, threadfin breams were the dominant group with 47% of the total perch landings, followed by other perches mainly composed of bull's eyes belonging to the family priacanthidae with 34% share, rock cods/groupers 12%, pigface breams 4% and snappers contributed 3%.

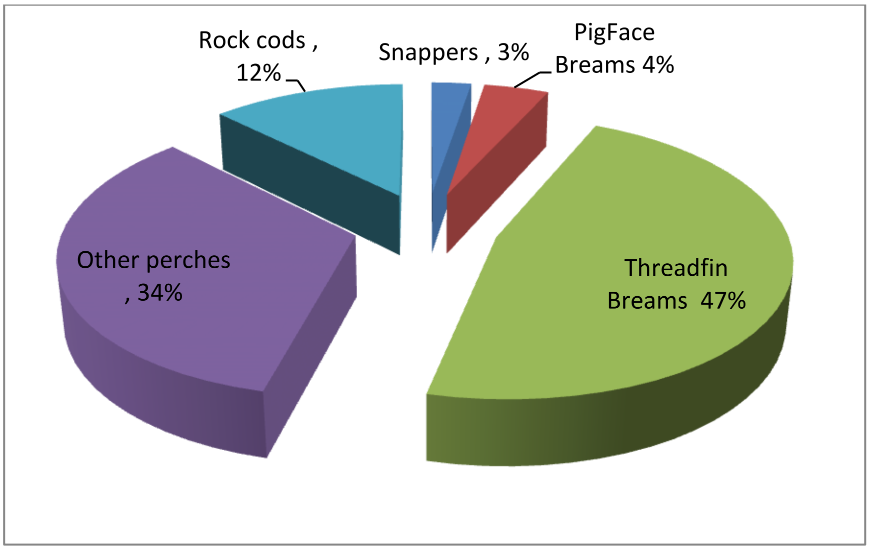

Fig. 5. Composition of different groups to the total perch landings in India

Threadfin breams

Six species of threadfin breams are known from the seas around India. *Nemipterus japonicus, N. randalli, N. bipunctatus, N. metopias, N. zysron, N. nematophorus, N. tolu.* Among these, *Nemipterus japonicus, N. randalli* are commercially important. Their abundance is influenced by upwelling and is known to move to inshore waters during monsoon period along the west coast. They are fractional spawners with protracted spawning periods. Spawning in *N. japonicus* takes place during October-April with a peak during October- December along Gujarat. In Kerala, *N. japonicus* and *N. randalli* spawn during monsoon and post monsoon periods with peaks during monsoon in the former and during post monsoon in the latter species. All India annual average landings of threadfin breams during 2013-17 was 1.62 lakh tonnes, forms 17% of the total demersal finfish catch in India.

Fig. 6. Landings of threadfin breams along southwest coast of India

Groupers

Rock cods or groupers are protogynous hermaphrodites, initially maturing as females then reverting to males as they grow in age and size. The major species observed in the landings are *Epinephelus chlorostigma, E. diacanthus, E. areolatus, E. tauvina, E. morrhua, E. bleekeri, E. longispinnis, Cephalopholis argus, Aetheloperca rogaa, Variola louti*. The annual landings of groupers during 2013-17 in India was 43,156 tonnes, which formed 4.5% of the demersal finfish landings of India. North-west coast comprising Gujarat and Maharashtra dominate in the catch with 68% of the total grouper landings of the country.

Fig. 7. Landings of Groupers and Snappers at Cochin Fisheries Harbour, Kerala

Snappers

The major species observed in the all India landings of snappers were *Pristipomoides typus, Lutjanus argentimaculatus, L. gibbus, L. rivulatus, L. bohar*, and *L. lutjanus*. The annual catch of snappers during 2013-17 in India was 8,893 tonnes. Southeast coast of India contributed the majority of landings of snappers in India with 63% followed by northwest coast of India.

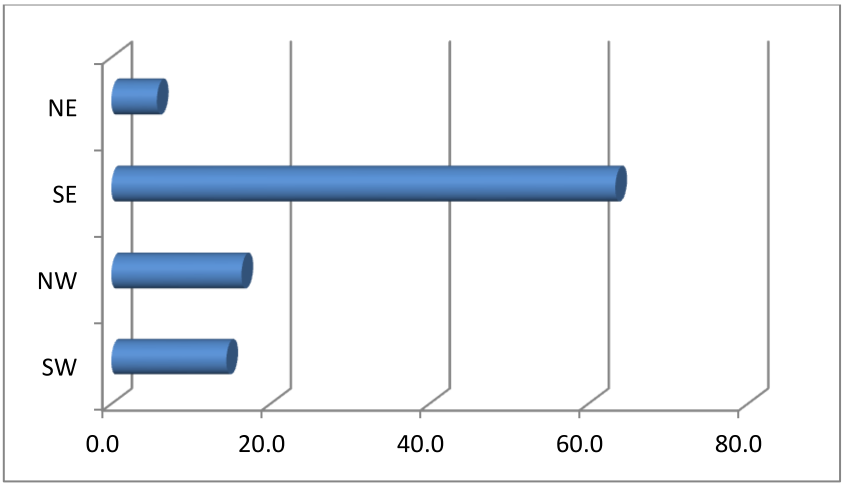

Fig. 8. Region wise distribution of snappers along the Indian coast

Bull's eyes

The annual landings of Bullseyes during 2016 in India was 1,30,740 tonnes, which formed 32% of the total perch landings of the country. They belong to a single family Priacanthidae. The major species observed in the landings are *Priacanthus hamrur*, *Oookeolus japonicus* and *Priacanthus Sagittarius*. From a mere 43,576 tonnes in 2015 its landings of bullseye has been escalated to a three- times-high of 1.3 lakh tonnes during 2016.

Fig. 9. Catch of Bulls Eye *Priacanthus* sp. and the Emperor bream/ pigface bream landings along the Kerala coast

Pigface breams

The major species observed in the landings of pigface breams/ emperor breams in India are *Lethrinus mahsena, L. lentjan, L. conchyliatus, L. nebulosus, L. ramak, L. elongatus* and *Lethrinus miniatus*. The landings of Pigface breams in India during 2017 was 14,492 t, which formed about 1.5% of the total demersal landings of the country. Southeast coast of India contributed the major share of landings of pigface breams in India.

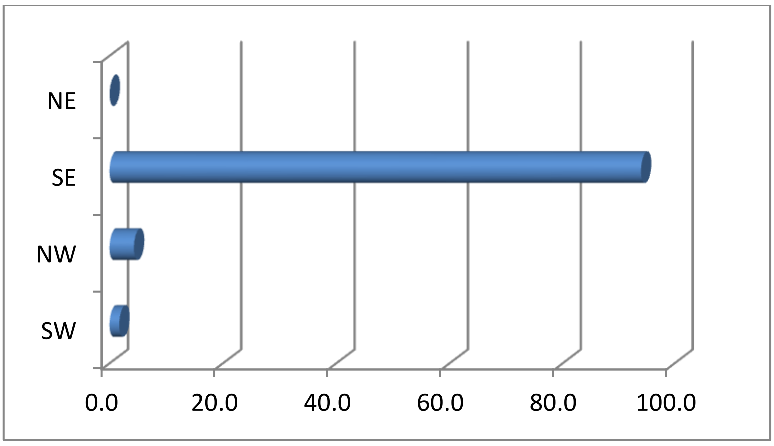

Fig. 10. Region wise distribution of pigface breams in India

Catfishes

Catfishes are important demersal resources which have wide distributional range in the Indo-Pacific region. They are distributed all along the Indian coastal waters upto the middle shelf with preferential concentration on muddy grounds of 30-70 m depths. Catfishes migrate both vertically (diurnal migration) and horizontally (seasonal) in small schools to large shoals in response to seasonal climatic / hydrographic variations. Marine catfishes belong to the family Ariidae, of which 11 species appear in the commercial fisheries.

West coast of India landed 70% of the total catfish catch and the east coast 30%, northwest coast landed 90% of the west coast catch. All species of cat fishes exhibit parental care - the male carrying the brood (25-120 eggs) in the oro-buccal cavity for 1 to 2 months' time until the juveniles (4-7 cm) are released. After spawning the brooding males segregate into shoals and move along the surface and prefer shallow water. The newly released juveniles of all species of tachysurids live in the shallow muddy grounds feeding on the bottom epi-and in-fauna – become easy target in fishing. The all India landings of catfishes is during 2016 was estimated at 80700 tonnes, which formed 8.4% of demersal finfish catch of India. Nearly 50% of the catch was from north west coast of India.

Lizardfishes

All India landings of lizardfishes is 68,329 tonnes, forms 7% of demersal catch 20 - 40 m depth up to 150-200 m depth. The species of lizardfishes landed along the west coast of

India are *Saurida tumbil, S. undosquamis, Trachinocephalus myops*, *Synodus englemani* and that of East coast are *S.undosquamis, S. longimanus* and *S. micropectoralis, S.tumbil, T. myops*, *S. englemani*. Spawning in *S. tumbil* occurs during September to March off Veraval and Bombay along North west coast; August to November off Cochin.

Fig. 11. Lizardfish landings along the west coast of India

Flatfishes

These were abundant in muddy and/or sandy bottom up to about 80 m depth belonging to genera such as *Cynoglossus, Psettodes, Pseudorhombus, Bothus, Paraplagusia,* etc. and exploited by trawl nets, gill nets and other artisanal gears. The Commercial exploitation of flatfishes along the Indian coast varies widely with *Cynoglossus macrostomus* dominating in the West Coast and *Cynoglossus macrolepidotus* along the East coast. The Fishery of *Psettodes erumei* showed a decline in recent years. The all India landings of flatfishes during 2013-17 was 44,354 tonnes, which formed 4.6% of demersal finfish catch of India. Bulk of the landings of soles are contributed by northwest coast followed by southwest coast.

Whitefish

This resource is also called butterfish and known to be depleted/overexploited by the mechanised trawl operations along the near-shore waters of west coast of India. Although distributed all along the coastline, it has been supporting notable fisheries along the southwest and southeast regions. All India landings of whitefish is 6,260 tonnes, forms 0.7% of demersal catch *Lactarius lactarius* is the only species available in this family. Whitefish production in India shows wide fluctuation. Shows steady fall except spurt in 1983 and 1985. In Karnataka it fluctuated between a lowest of 37 t in 1964 and highest of 2,930 t in 1988. East coast shows a steady decline from 4,738 t in 1960-69 to 8, 88 t in 1990-99. West coast showed an increase from 2,901 t in 1960-69 to 12,354 t in 1980-89 then steep decline to 6,109 in 1990-99.

Fig. 12. Flatfish and Whitefish landed along the Kerala coast

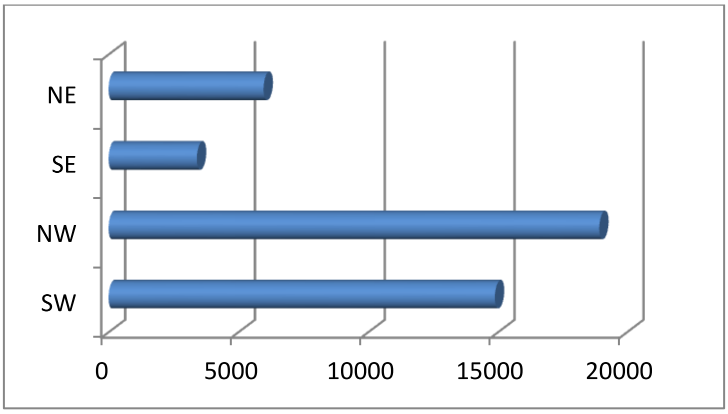

Fig. 13. Region wise distribution of soles along the Indian coast

Sciaenids

Sciaenids include high value demersal resources like croakers, which are landed mainly from Gujarat and Maharashtra. The important gears used are trawls and gill nets. These fishes are caught mainly during October - December and January - March. They mainly consist of the species like *Pseudosciaena diacanthus, Otolithes* spp. and *Johnieops* spp. *Protonibea diacanthus, Johniops macrorhynus, Otolithes cuvieri, J. dussumieri, J. glaucus,* and *O. ruber*. All India annual landings of Sciaenids during 2013-17 is 1, 61,177 tonnes, which formed 16.8% of demersal finfish catch of the country. Northwest region is the highest contributor followed by northeast region.

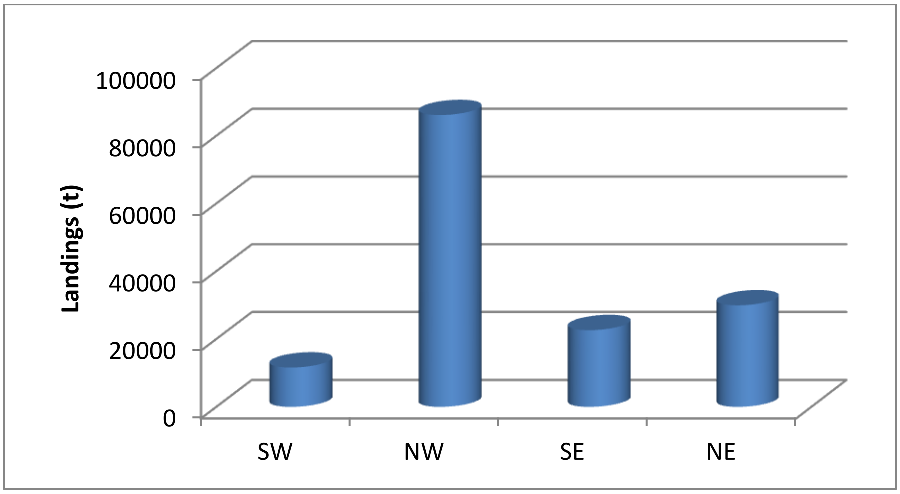

Fig. 14. Region wise distribution of croakers along the Indian coast

Pomfrets

Pomfrets belong to two families, the black pomfret *Parastromateus niger* is coming under the family Carangidae and the silver pomfret *Pampus argenteus* belongs to the family Stromateidae. They are landed abundantly in Gujarat and Maharashtra . The black pomfret landings in India during 2013-17 was 15,400 tonnes, and that of silver pomfret was 27,800 tonnes, which formed 3.3% of demersal finfish catch of the country

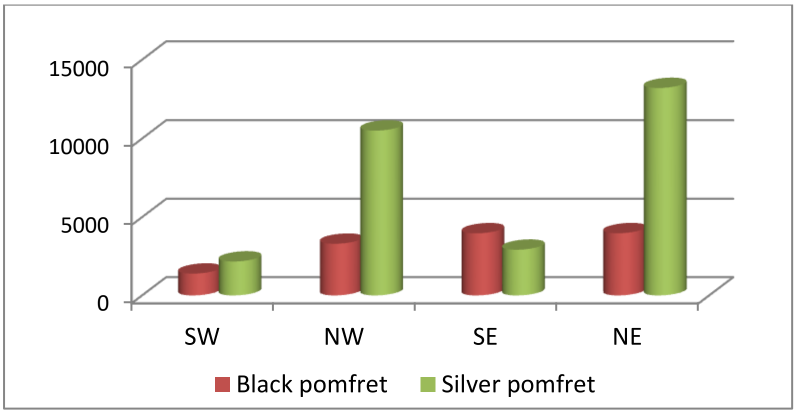

Fig. 15. Region wise distribution of pomfrets along the Indian coast

Silverbellies

Silverbellies belonging to the family Leiognathidae. Exploited by trawl nets and anisanal gears, this group formed about 11% of demersal finfish production. The major species landed along the coast of India are *Leiognathus splendens, L. equlus, Gazza minuta, L. bindus, L. dussumieri, L. jonesi, Secutor insidiator.* All India annual landings of silverbellies was

1,08,200 tonnes, which formed 11% of demersal finfish catch of India and most of the catch is contributed by southeast coast of India.

Goatfishes

This group has three important genera in India, *Upeneus, Parupeneus* and *Mulloidichthys*. These were exploited by trawls and traditional gears mostly in Tamil Nadu and Andhra Pradesh. Dominant species along the east coast of India include *Upneus taenipterus, U. bensasi, U. sulphureus, U. sundaicus* and *Parupenus indicus*. All India landings of goatfishes during 2016 was 30,276 tonnes, which formed 3.2% of demersal catch of the country.

Fig. 16. Goatfish landings along southeast coast of India

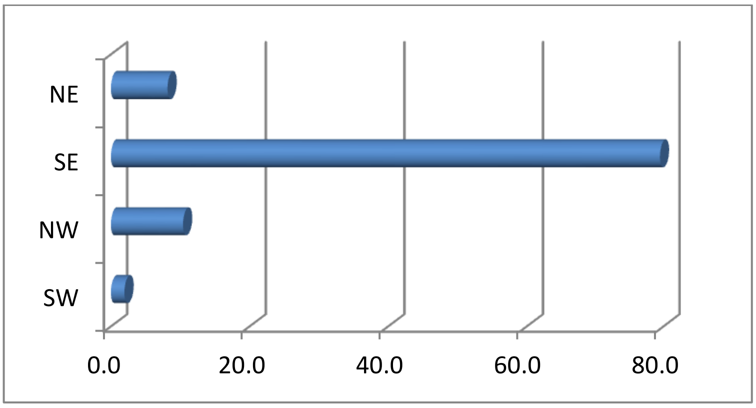

Fig. 17. Region wise distribution of goatfishes along the Indian coast

Eels

Eels are long-bodied, snake like fishes, having a crevice dwelling or sediment-burrowing mode of life, though some live in the pelagic realm of the open oceans. Traditionally marketable species of eels are caught from conventional fishing grounds of northwest and northeast coasts of India and are largely a by-catch. Pike congers belonging to the family

Muraenesocidae occur in tropical waters in the soft bottoms upto 100 m depth and in estuaries. Four species are recorded in Indian waters and they grow to a maximum length of 80 cm (*Congresox talabon*) (Cuvier, 1829), 250 cm (*C. talabonoidies*) (Bleeker, 1853), 180 cm (*Muraenesox bagio*) (Hamilton-Buchanan) and of 80 cm (*M. cinereus*) (Forsskal, 1775).

Fig. 18. Eels belonging to the family Muraenesocidae landed along the Kerala coast

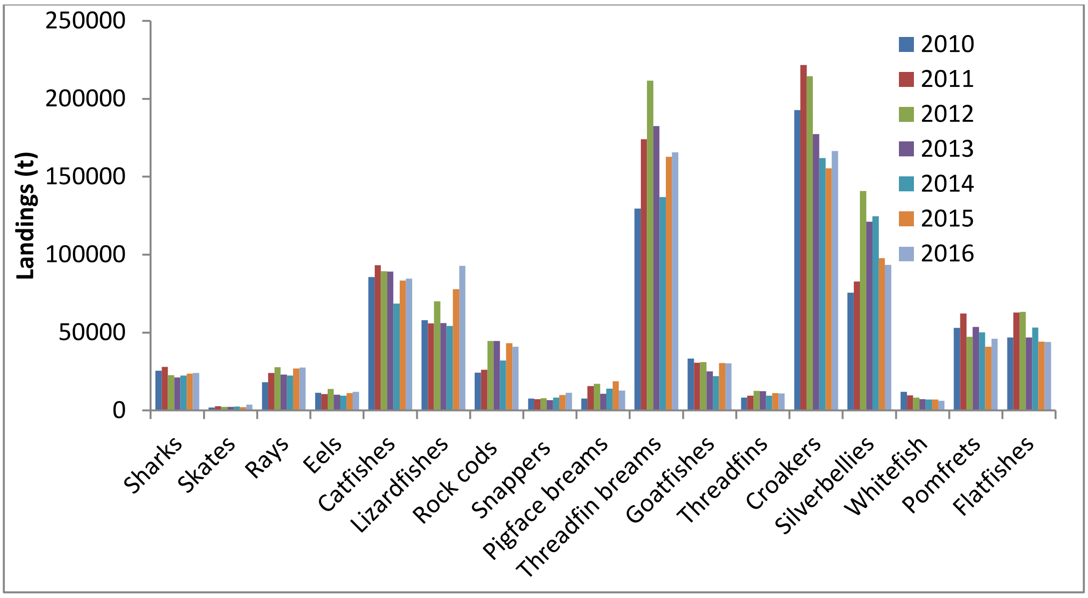

Fig. 19. Trends in the landings of major demersal finfish species during 2010-2016.

REGIONWISE DISTRIBUTION OF SPECIES

Finfishes exploited by trawls belong to 21 major fish groups, which are mostly demersal groups. Each maritime region of India is characterized by dominance of specific demersal finfish groups. Along the northeast (NE) coast , sciaenids, catfishes and pomfrets (74.0% to the demersal landings) are dominant. The southeast coast is characterised by the abundant landings of silverbellies and pigface breams. Along the southwest coast of India, threadfin breams and other perches are the major demersal resources and the northwest coast is characterised by the dominance of sciaenids, catfish, pomfrets and threadfin breams.

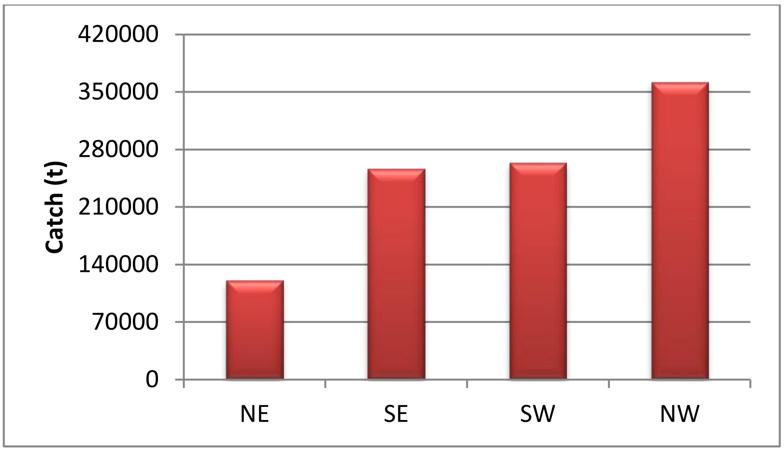

Fig. 20. Region-wise landings of demersal finfishes during 2017.

EXISTING MANAGEMENT PRACTICES

Seasonal closure of fishery: The regulations for "closed season were notified for the Eastern Arabian Sea from 1988 onwards. Maritime states along the west and east coasts of India are implementing closed season of 45 to 75 days for mechanised fishing vessels as a corollary to their Marine Fishing Regulation Acts. Earlier there was no uniformity of ban period, but after the intervention of the Ministry of Agriculture, Government of India, the ban has been made uniform all along the west coast (June15 – July 31) and east coast (April 15 – May 31) states and Union Territories.

Mesh size regulation and **Minimum Legal Size**: Minimum mesh size for different species were recommended for avoiding juvenile bycatch. Square mesh size of 40 mm showed that it provides better opportunity for the juveniles to escape and it is recommended for cod end of trawls. Minimum Legal Size (MLS) for 58 species of finfishes and shellfishes including demersal finfishes have recommended by the Central Marine Fisheries Research Institute which have been enacted by Gazette notification by Govt. of Kerala.

Table 1. Minimum Legal Size (MLS) recommendations for the selected demersal species in the fishery along the coast of Kerala.

No.	Species Name	Common Name	Recommended MLS (cm)
1	*Cynoglossus macrostomus*	Malabar sole	9 TL
2	*Saurida tumbil*	Lizardfish	17 TL
3	*Johnius sina*	Croaker	11 TL
4	*Nemipterus japonicus*	Threadfin bream (Yellow)	12 TL
5	*Lactarius lactarius*	White fish	10 TL
6	*Nemipterus randalli*	Threadfin bream (red)	10 TL
7	*Saurida undosquamis*	Lizardfish	10 TL
8	*Pampus argenteus*	Silver pomfret	13 TL
9	*Parastromateus niger*	Black pomfret	17 TL
10	*Priacanthus hamrur*	Bulls eye	14 TL
11	*Otolithes ruber*	Tiger toothed croaker	17 TL
12	*Epinephelus diacanthus*	Spiny cheek grouper	18 TL
13	*Gymnura poecilura*	Butterfly ray	29 DW

Restriction of fishing areas: In the context of persistent conflicts between artisanal and mechanized vessels in the inshore waters. Under this act, the trawl boats have been banned from fishing in inshore areas, which have been assigned exclusively to the artisanal craft. Community participation in the formulation of the management actions are yielding good results in some parts of the country.

Protected species and Marine Protected Areas (MPAs): Several species are protected under Wildlife Protection (1971) Act. Capture or trade on these species is prohibited under the act. Releasing sharks after finning is prohibited under a notification. Under this act, fishing for whale shark is prohibited. There are 31 MPAs along India's coastline that have been officially declared for conserving and protecting coastal and marine biodiversity (SCBD, 2006).

Chapter 03

Field Identification of Major Demersal Teleost Fish Species along the Indian Coast

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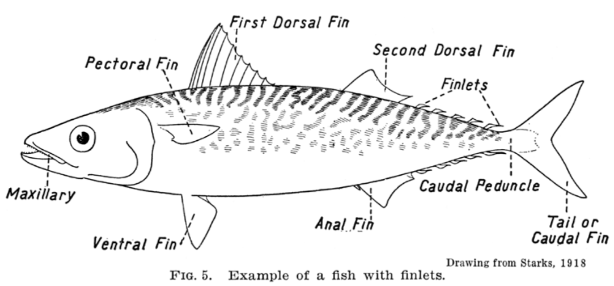
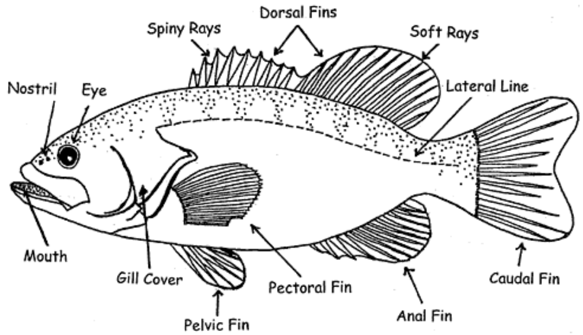
Based on their vertical distribution, fishes are broadly classified as pelagic or demersal. Species those are distributed from the seafloor to a 5 m depth above, are called demersal and those distributed from a depth of 5 m above the seafloor to the sea surface are called pelagic. The term *demersal* originates from the Latin word *demergere*, which means *to sink*. The demersal fish resources include the elasmobranchs, major perches, catfishes, threadfin breams, silverbellies, sciaenids, lizardfishes, pomfrets, bulls eye, flatfishes, goatfish and white fish. This chapter deals with identification of the major demersal teleost fish species.

Basic morphological differences between pelagic and demersal fish



Pelagic

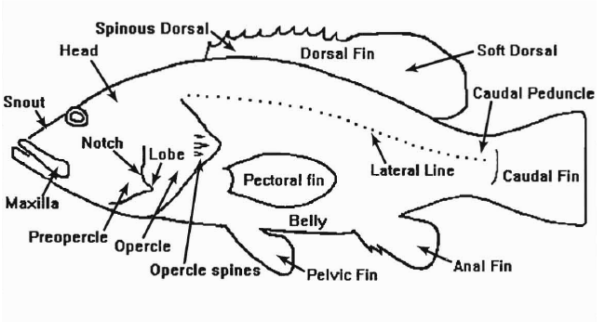


Demersal

MAJOR DEMERSAL FISH GROUPS

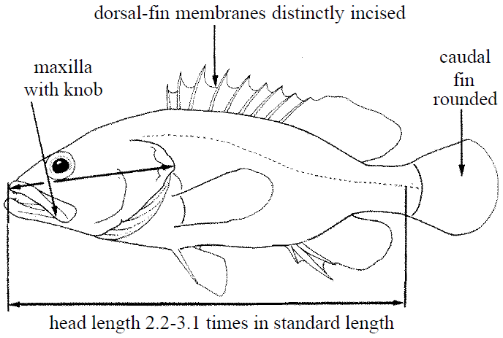
Family: Serranidae – Groupers

- 3 flat spines on the rear edge of opercle
- single dorsal fin
- body having patterns of spots, stripes, vertical or oblique bars, or maybe plain

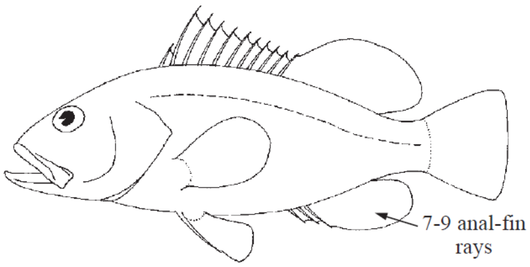


Key to the genera

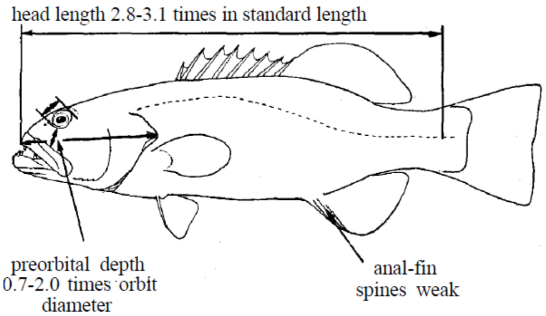
1. ***Cephalopholis***
   - ➢ dorsal fin membranes highly incised between the spines
   - ➢ IX dorsal fin spines
   - ➢ rounded or convex caudal fin



2. ***Epinephelus***
   - ➢ X or XI spines on dorsal fin and 13 to 19 soft rays
   - ➢ anal-fin rays 7 to 9

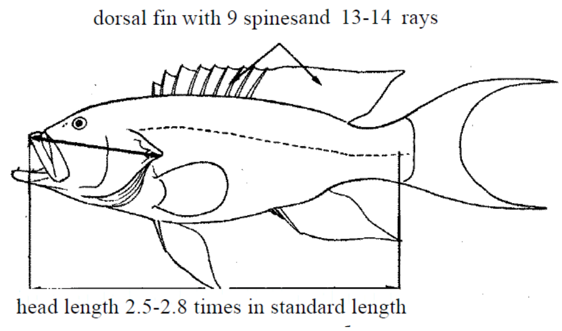


3. ***Plectropomus***
   - ➢ weak anal fin spines
   - ➢ preorbital depth 0.7 to 2 times orbit diameter
   - ➢ head length 2.8 to 3.1 times in standard length



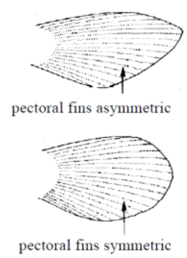
4. ***Variola***

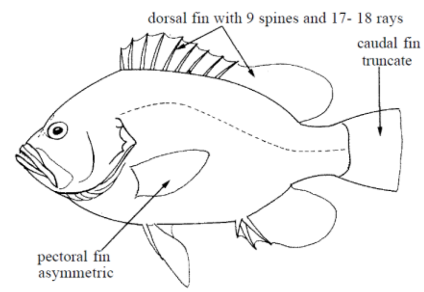
- lunate caudal fin (the lobes produced)
- head length 2.5 to 2.8 times in standard length
- IX spines and 13 or 14 rays on dorsal fin



5. ***Aethaloperca***

- markedly asymmetric pectoral fins
- IX spines and 17 or 18 rays on dorsal fin
- truncate shaped caudal fin





Key to the species (adopted and modified from FAO)

1. ***Cephalopholis***

a) *Cephalopholis sonnerati*

- colour red to brown with broadly distributed whitish blotches
- head, maxilla and lips with a noticeable purple network

b) *Cephalopholis sexmaculata*

- small blue ocelli is present on head, body and fins
- body with 4 or 5 quadrangular dark brown or black blotches along base of dorsal fin
- most specimens with dark-edged blue lines radiating from eyes

c) *Cephalopholis miniata*

- head, body and fins covered with small blue ocelli
- dark blotches absent dorsally on body
- absence of blue lines radiating from eyes

2. ***Epinephelus***

a) Epinephelus albomarginatus

- numerous small dark brown spots present on head, body, dorsal, and caudal fins
- no spots on ventral parts of head and body
- conspicuous white edge on the soft dorsal and anal fins

b) Epinephelus areolatus

- numerous close-set brownish yellow spots seen on the head, body and fins (the largest near size of pupil)
- distinct white margin on the posterior edge of caudal fin

c) *Epinephelus chlorostigma*

- smaller, more numerous, more closer dark brown spots seen on the head, body and fins (the largest near half size of pupil)
- posterior edge of caudal fin with a distinct white margin

d) Epinephelus bleekeri

- numerous reddish yellow spots on the head and body (except on ventral side)
- dorsal fin and upper third portion of caudal fin with spots like those on body and the lower two-thirds of caudal fin without spots/dusky

e) Epinephelus coioides

- head, median fins and body with numerous small brownish orange spots
- body with 5 faint, irregular, oblique, dark bars
- first dark bar below anterior dorsal-fin spines, last bar on caudal peduncle
- 2 dark spots on interopercle and another 1 or 2 at junction of interopercles
- midlateral-body scales ctenoid (rough)

f) Epinephelus malabaricus

- the dark spots of *E. malabaricus* are smaller, blackish brown (not brownish orange, as on *E. coioides*)
- has irregular white spots on the head and body (no white spots on *E. coioides*)
- 5 irregular, slanted, dark bars (interrupted by pale spots) often visible on body
- midlateral-body scales ctenoid (rough)

g) Epinephelus tauvina

- pale orange-red to dark brown, also with small faint white spots and blotches
- 5 faint subvertical dark bars on body
- often has a black blotch (larger than eye) on body at base of last 4 dorsal-fin spines and extending onto lower part of fin
- midlateral body - smooth (without scales) on fish 30-60 cm SL

h) *Epinephelus diacanthus*

- body pale greyish brown, usually with 5 dark vertical bars broader than interspaces, 4 below dorsal fin and fifth (faintest) on peduncle
- fins dusky grey and spots absent

i) *Epinephelus sexfasciatus*

- has 5 dark bars on the body
- greatly enlarged serrae at the angle of the preopercle
- having spots on the median fins

j) *Epinephelus epistictus*

- head, body, and fins brown with faint brownish black dots usually visible on dorsolateral part of body
- dark brown maxillary streak present
- juveniles with dark spots on head and on body dots are arranged in 3 longitudinal rows

k) *Epinephelus latifasciatus*

- presence of 2 black-edged white longitudinal bands
- the upper band from above eye to anterior dorsal-fin rays
- the lower band from below eye to lower caudal-fin rays

l) *Epinephelus fasciatus*

- fins reddish orange, pale yellowish green
- the outer triangular part of interspinous membranes of dorsal fin black

m) *Epinephelus flavocaeruleus*

- fins and jaws bright yellow in colour

n) *Epinephelus lanceolatus*

- the fins with numerous small black spots
- small black spots on the head and dorsal part of the body

o) *Epinephelus longispinis*

- head and body greyish with small, dark reddish brown spots that are round and widely spaced on head and front half of body, but obliquely elongated, closer together and darker posteriorly

3. *Plectropomus*

a) *Plectropomus areolatus*

- body with numerous dark-edged blue spots
- distance between spots subequal to spot diameters

b) *Plectropomus leopardus*

- orange-red or red, with numerous small (nostril sized and usually dark-edged) blue spots on head and body (except ventrally) and median fins
- often with a blue ring (dark brown in alcohol) on edge of orbit (sometimes broken into segments)
- an blurry dark band at rear margin of caudal fin, with a white line usually visible along middle of rear edge of the fin

4. *Variola*

a) *Variola albimarginata*

- rear margin of caudal fin with a black submarginal line and narrow white edge
- dorsal, anal, and pectoral fins without a distinct yellow posterior border
- pelvic fins usually not reaching anus

b) *Variola louti*

- caudal, dorsal, anal, and pectoral fins with a broad yellow rear margin
- pelvic fins reach beyond anus

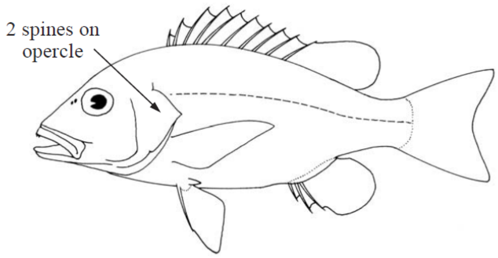
5. *Aethaloperca*

a) *Aethaloperca rogaa*

- inside of mouth, gill cavity and upper jaw membranes reddish orange
- body dark brown to black

Family: Lutjanidae – Snappers

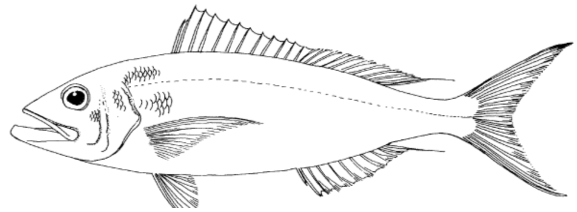
- scales on cheek and opercle but no scales between eye and mouth
- presence of 2 opercular spines
- well-developed canine teeth in jaws
- premaxillae usually moderately protrusible
- pelvic axillary process usually well developed



Lutjanidae

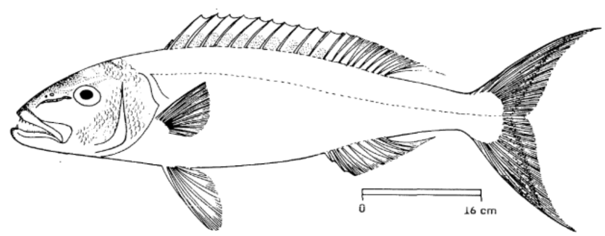
Key to the genera

1. ***Aphareus***



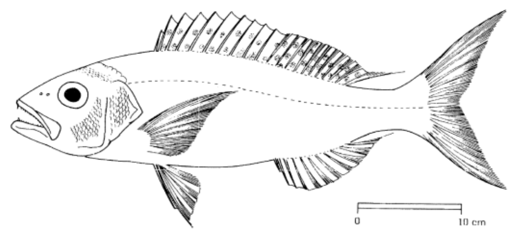
- premaxillae not protrusible
- no caniniform teeth
- caudal fin forked
- edges of preopercle and opercle outlined with black

2. ***Aprion virescens***



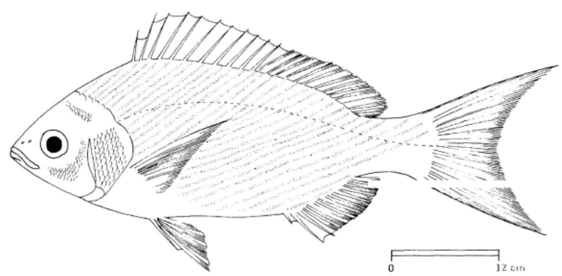
- a very distinct horizontal groove in front of eye
- last soft ray of both dorsal and anal fins longer than next to last soft ray
- caudal fin deeply forked, with pointed lobes

3. ***Pristipomoides***



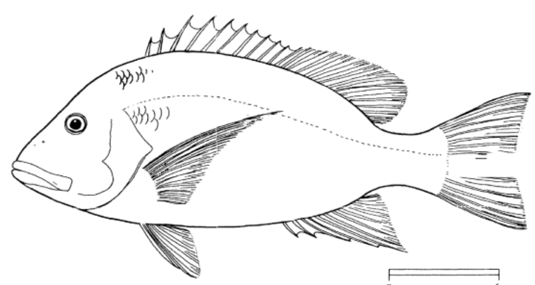
- teeth in jaws in bands with an outer row of distinct canines, no groove on snout
- last soft ray of dorsal and anal fins conspicuously longer than preceding rays

4. ***Pinjalo***



- upper and lower profiles of head equally rounded
- eye set toward middle of head
- mouth rather small
- no fang-like canines at anterior ends of jaws

5. ***Lutjanus***



- upper and lower profiles of head not equally rounded, upper profile evenly rounded to and lower profile flattened
- eye closer to upper profile of head than to lower, mouth larger
- some fang-like canines usually present at anterior ends of jaws

Key to the species (adopted and modified from FAO)

1. ***Aphareus***
    a. *Aphareus furcatus*
        - body relatively elongate, fusiform and compressed
        - gillrakers on lower branch of first gill arch ranges from 16 to 18, and 5 on upper branch
    b. *Aphareus rutilans*
        - body more slender
        - gillrakers on lower branch of first gill arch 30 to 34, and 16 to 18 on upper branch
        - presence of more deeply forked caudal fin

2. ***Pristipomoides***
    a. *Pristipomoides typus*
        - absence of golden stripes on snout and cheek
        - longitudinal vermiculations (differently shaped) on top of head
        - lateral line scales 48 to 52
    b. *Pristipomoides multidens*
        - presence of two golden stripes bordered with blue on snout and cheek
        - transverse vermiculations on top of head
        - lateral line scales 48 to 52
    c. *Pristipomoides filamentosus*
        - lateral line scales 60 to 65
        - small blue spots on top of head

3. ***Pinjalo***
    a. *Pinjalo pinjalo*
        - dorsal fin with XI spines and 14 or 15 soft rays
        - deeply emarginate caudal fin
    b. *Pinjalo lewisi*
        - dorsal fin with XII spines and 13 soft rays
        - caudal fin slightly emarginated with black edge

4. ***Lutjanus***
    a. *Lutjanus lutjanus*
        - preorbital ("suborbital") space (distance between upper jaw and eye) very narrow

- silvery white with a broad yellow stripe on middle of side to caudal-fin base, and fine yellowish lines, corresponding with longitudinal scale rows

b. *Lutjanus bengalensis*
   - body with a series of 4 or 5 longitudinal stripes (blue in life, often brownish in preservative) on side
   - dorsal-fin spines XI or XII
   - preopercular notch developed just above angle

c. *Lutjanus kasmira*
   - dorsal-fin spines X
   - four blue stripes on side, belly more or less abruptly whitish, frequently with thin grey lines
   - preopercular flange naked or with some embedded scales

d. *Lutjanus gibbus*
   - profile of head concave in adults
   - caudal fin distinctly forked with rounded lobes
   - preopercular notch deep and narrow, with a long interopercular knob fitting into it

e. *Lutjanus argentimaculatus*
   - red snapper with head profile straight or slightly convex
   - preopercle unnotched; interopercle with no distinct knob
   - scale rows above lateral line running parallel to dorsal body profile anteriorly, but slanting upward posteriorly
   - often a silvery patch in the centre of each scale

f. *Lutjanus bohar*
   - head profile slightly convex
   - prominent notch in front of eye containing the nostrils
   - shallow notch and an interopercular knob

Family: Lethrinidae- Pigface breams

- dorsal fin continuous, with X spines and 9 or 10 soft rays; anal fin with III spines and 8 to 10 soft rays
- cheek naked in Lethrinus and scaly in remaining genera
- preopercular edge typically smooth

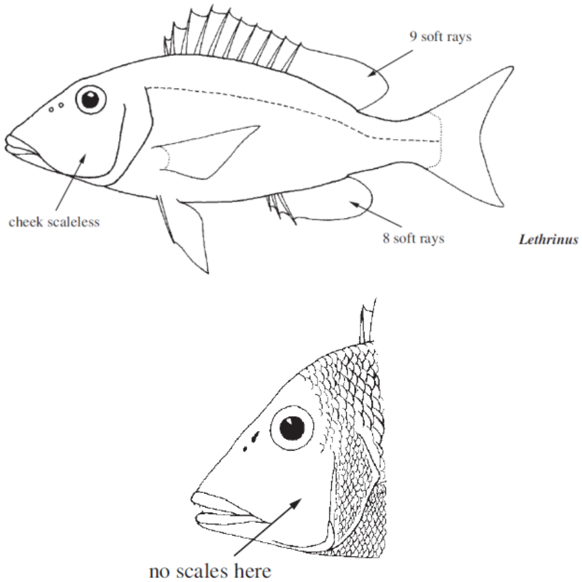
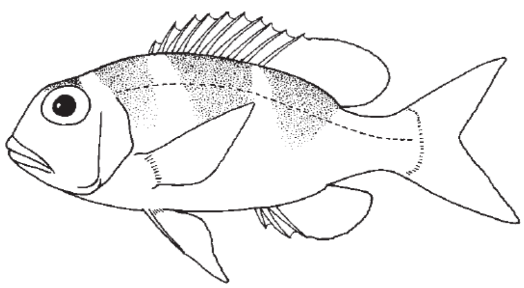


Fig. 1 ***Lethrinus***

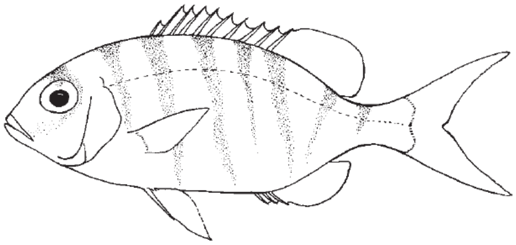
Key to the genera

1. ***Lethrinus***
   - cheek naked
   - 9 soft rays in dorsal fin
   - 8 soft rays in anal fin

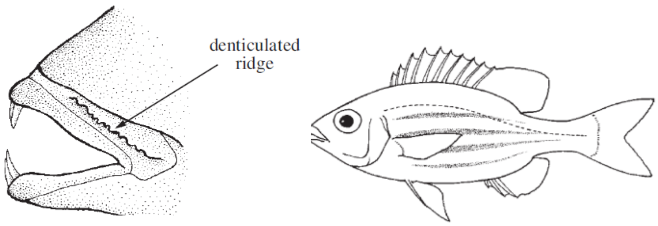
2. ***Monotaxis grandoculis***
   - cheek with 3 to 6 vertical rows of scales
   - 10 soft rays in dorsal fin
   - usually 9 or 10 soft rays in anal fin
   - inner surface of pectoral-fin base densely scaled; sides of jaws with round, flat molars



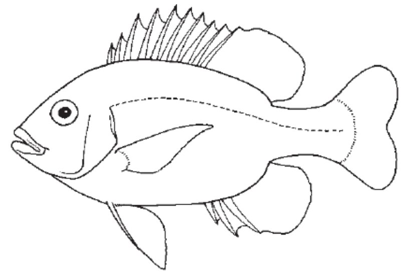
3. ***Gymnocranius***
   - inner surface of pectoral-fin base scaleless
   - sides of jaws with canines and villiform teeth
   - outer surface of maxilla smooth



4. ***Gnathodentex aurolineatus***
   - outer surface of maxilla with denticulated ridge
   - caudal-fin lobes pointed; anal fin with 8 or 9 soft rays; pectoral fins with 15 rays



5. *Wattsia mossambica*



- ➢ caudal-fin lobes rounded; anal fin with 10 soft rays; pectoral fins with 14 rays
- ➢ outer surface of maxilla with denticulated ridge

Key to the species (adopted and modified from FAO)

1. *Lethrinus*

a. Lethrinus conchyliatus

- ➢ body comparatively slender
- ➢ head length almost always distinctly greater than body depth
- ➢ prominent scaleless patch above base of pectoral fins (bright red in life)
- ➢ lips red

b. Lethrinus microdon

- ➢ snout long
- ➢ 3 dark streaks radiating advancing from eye on snout usually visible
- ➢ inner surface of pectoral-fin surface never red in life

c. Lethrinus rubrioperculatus

- ➢ wide naked (scaleless) area (red in colour) on upper posterior margin of opercle

d. Lethrinus nebulosus

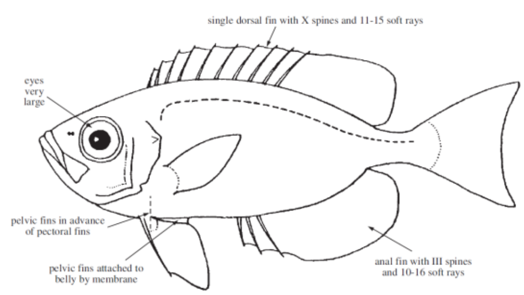
- ➢ blue spots and/or streaks radiating forward from eye

e. Lethrinus mahsena

- ➢ head is purplish gray, sometimes with a red blotch on the nape

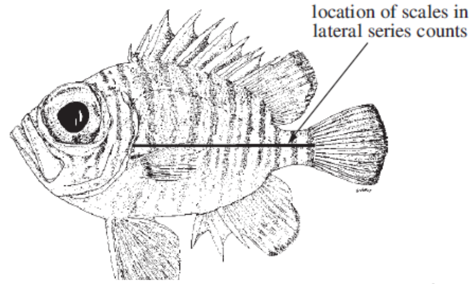
Family: Priacanthidae- Bigeyes

- extremely large eyes (about 1/2 head length) and upturned mouth
- pelvic fins in advance of pectoral fins
- pelvic fins attached to belly by membrane



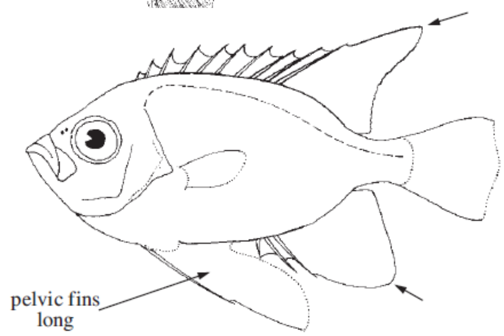
Key to the genera

1. ***Pristigenys***



- body profile very deep and broadly ovate, its depth 1.7 to 1.9 times in standard length
- anal-fin rays 10 or 11; dorsal-fin rays 11 or 12
- scales in lateral series 36 to 51

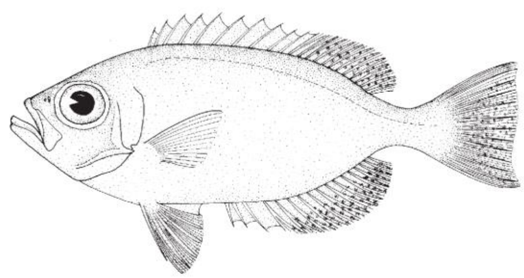
2. ***Cookeolus japonicas***



- pelvic fins very long except in large adults (30 cm standard length or larger) exceeding head length
- soft dorsal and anal fins long and broadly pointed except in very large specimens

3. ***Heteropriacanthus cruentatus***

- tip of lower jaw around on level with midline of body when mouth tightly closed
- well-developed spine at angle of preopercle
- caudal, soft dorsal, and anal fins with elliptical dark specks



4. ***Priacanthus***

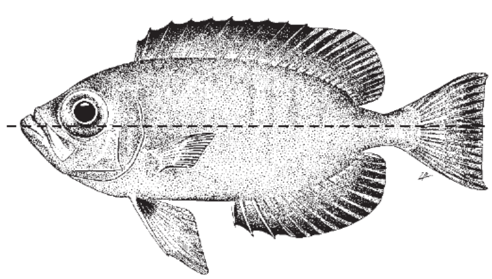
- posterior portion of preopercle having scales
- edge of lower jaw typically above level of midline of body
- fins bare or with larger dusky spots

Key to the species (adopted and modified from FAO)

1. ***Priacanthus***

a. Priacanthus hamrur

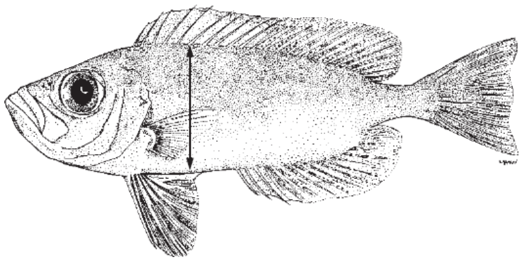
- caudal-fin margin concave, outer rays slightly to much longer than remainder of rays



- ➢ anal-fin rays usually 15 or 16
- ➢ total gill rakers on first gill arch 24 to 26
- ➢ body depth at sixth dorsal-fin spine about 2.6 to 2.8 times in standard length

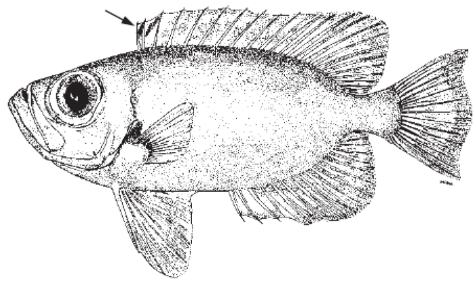
b. *Priacanthus prolixus*

- ➢ total gill rakers on first gill arch 29 to 31
- ➢ body depth at sixth dorsal-fin spine 3 or more times in standard length



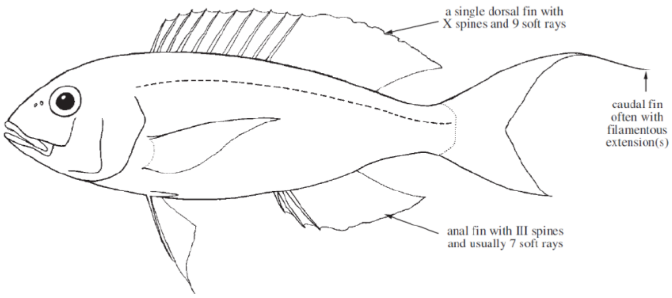
c. *Priacanthus sagittarius*

- ➢ first 2 spinous dorsal-fin membrane with black blotch
- ➢ length of second dorsal-fin spine about twice in length of tenth spine
- ➢ scales in lateral series 67 to 74
- ➢ total gill rakers on first gill arch 23 or fewer
- ➢ pectoral fins not bright yellow



Family: Nemipteridae- Threadfin breams

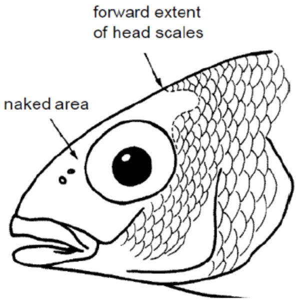
- a single continuous dorsal fin, with X spines and 9 soft rays
- anal fin with III spines and 7 (except *Nemipterus virgatus* with 8) soft rays
- caudal fin often with filamentous extension(s)



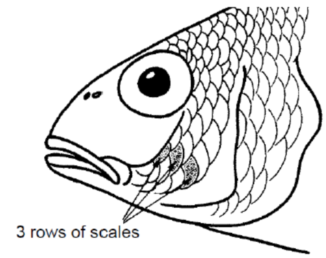
Key to the genera

1. *Scaevius*

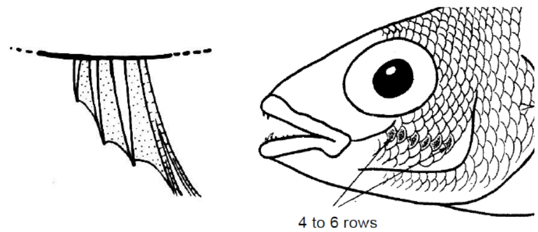
- ➢ scales present on top of head but not reaching to the level of eyes
- ➢ temporal parts of head scaleless



2. ***Nemipterus***
   - presence of 3 transverse rows of scales on preopercle

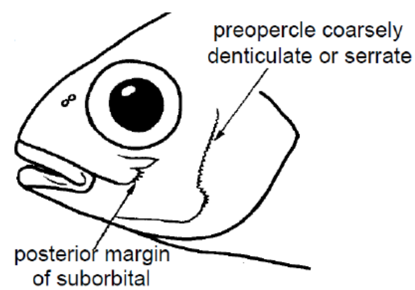


3. ***Pentapodus***
   - suborbital spine frail or absent
   - presence of 4-6 transverse scale rows on preopercle
   - second anal spine shorter in length and less stout than third



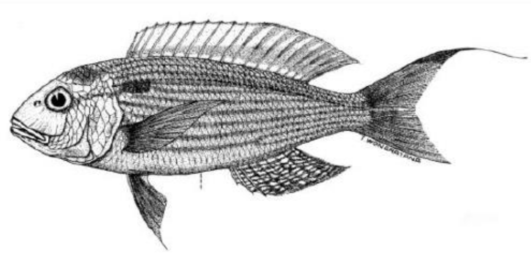
4. ***Parascolopsis***
   - absence of canine teeth in jaws
   - second anal spine generally longer and more robust than third spine

5. ***Scolopsis***
   - suborbital scaleless, with a large backwardly facing spine and a series of minor serrations on its posterior margin
   - posterior margin of preopercle serrated
   - absence of canine teeth



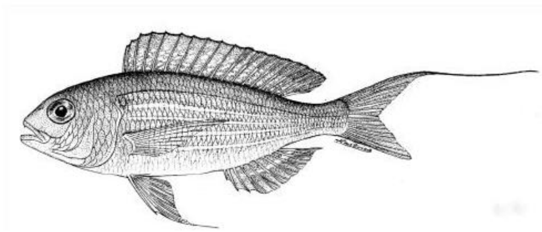
Key to the species (adopted and modified from FAO)

a. *Nemipterus japonicus*
   - pectoral fins reaching to or just past the level of origin of anal fin
   - upper part of caudal fin with moderately long filament, almost equal to head length



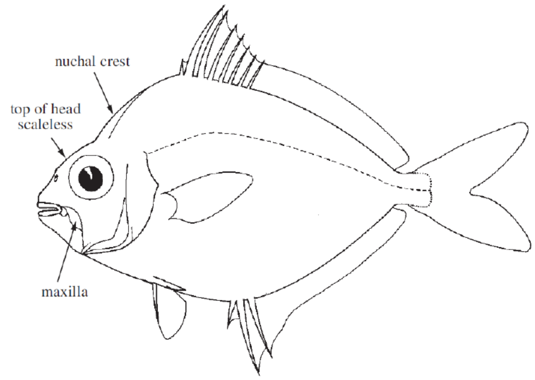
- ➢ pelvic fins moderately long, reaching to or just beyond anus
- ➢ caudal filament yellowish
- ➢ gill rakers count 14 to 17

b. Nemipterus randalli



- ➢ Pectoral and pelvic fins very long, reaching to or just past the origin of anal fin
- ➢ caudal fin forked and having the upper lobe into moderately long reddish filament
- ➢ gill rakers 12 to15

Family: Leiognathidae- Slipmouths



- body moderately to distinctly compressed laterally
- maxilla covered under the preorbital
- a well-built nuchal crest or spine
- mouth highly protrusible
- a single dorsal fin with VIII spines
- top of head scale less

Key to the genera

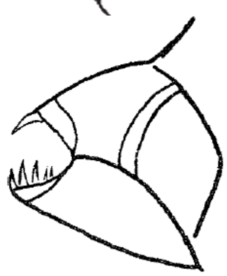
a. *Leiognathus*

- ➢ absence of caniniform teeth
- ➢ mouth straight, pointing forward or downward when protracted

b. *Secutor*

- ➢ oblique mouth
- ➢ pointing upward once protracted

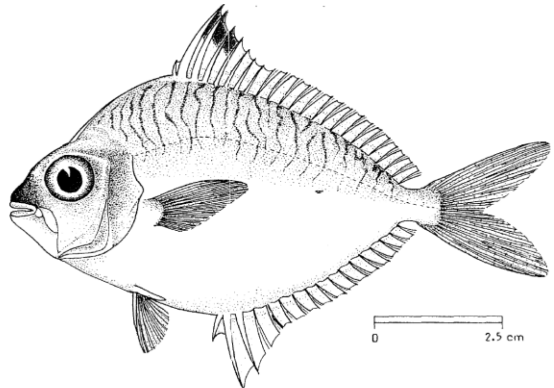
c. *Gazza*



- ➢ presence of caniniform teeth
- ➢ mouth pointing forward once protracted

Key to the species (adopted and modified from FAO)

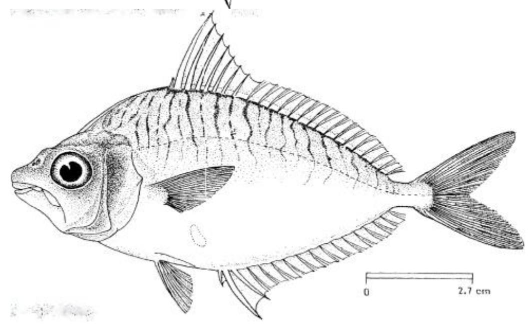
Eubleekeria splendens *(Leiognathus splendens)*



Splendid ponyfish

Short snout (shorter than eye diameter) besides blunt; mouth pointing slightly downward once protracted; head scaleless, but presence of prominent scales on breast; grey wavy vertical lines above lateral line in adults, spinous part of dorsal fin usually has a black spot.

Karalla dussumieri (*Leiognathus dussumieri*)

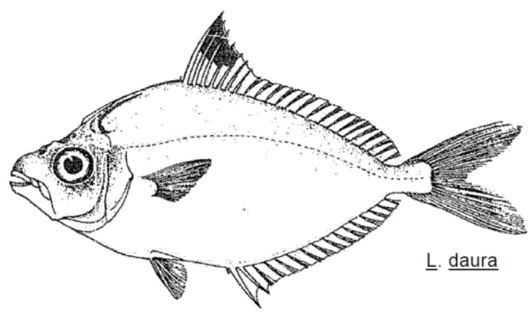


Dussumier's ponyfish

Pointed snout, slightly extended than eye diameter; mouth pointing downward once protracted. Head scaleless, but presence of conspicuous scales on breast. Body extra slender and certainly not a black blotch on dorsal fin.

Karalla daura (*Leiognathus daura*)

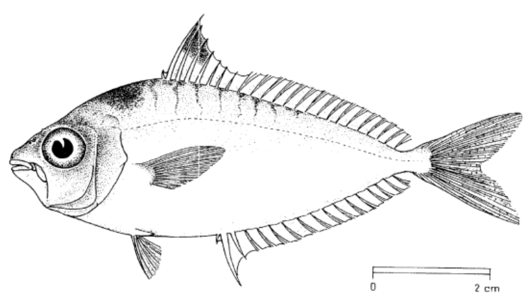
Goldstripe ponyfish



Body more often oval, dorsal and ventral profiles more or less consistently curved; a broad yellow band along lateral line; not any wavy vertical lines above lateral line; dark black blotch on spinous portion of dorsal fin.

Nuchequula blochii (*Leiognathus blochi*)

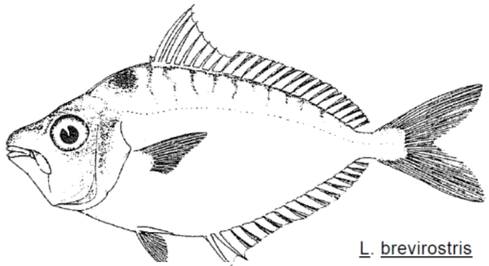
Two blotch ponyfish



Pointed snout; unequal vertical lines extending down to about lateral line; a brown blotch on nape; tip of snout, head and ventral half of body with fine black dots; underside of pectoral fin base have black dots. The dorsal fin membrane from about half its height to tips of second to fifth spines black.

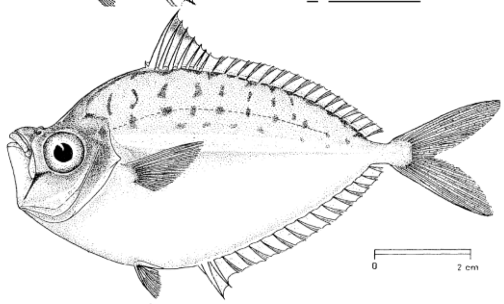
Leiognathus brevirostris (Shortnose ponyfish)

Nape with a dark blotch; grey dots on spinous dorsal fin membrane; a noticeable diffuse golden yellow patch on abdomen about middle between origin of ventrals and anal. Breast scaleless.



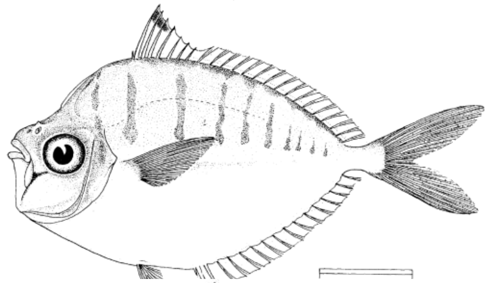
Secutor insidiator (Pugnose ponyfish)

Head intensely curved in above eye; pointed snout; mouth pointing upward once protracted. Lateral line reaching backward nearly to below end of dorsal fin. Cheek scaleless.



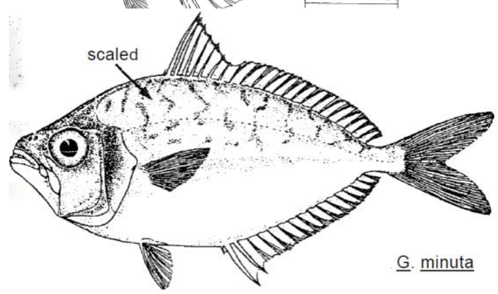
Secutor ruconius (Deep pugnose ponyfish)

Deeper body; lateral line extending to below about middle of soft portion of dorsal fin; presence of scales on cheek.



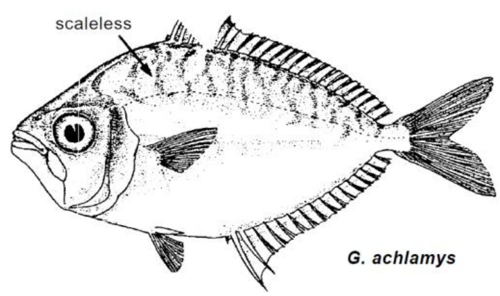
Gazza minuta (Toothpony)

Mouth pointing forward once protracted, presence of distinct caniniform teeth in both jaws. Head scaleless, nonetheless scales casing all of body except for breast ahead of a line from base of pectoral fin to origin of anal fin.



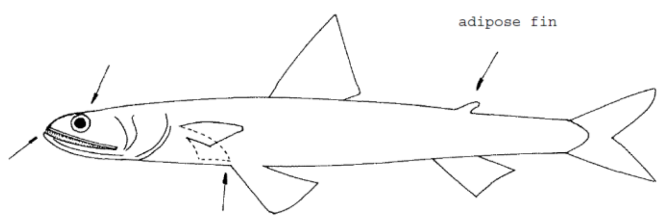
Gazza achlamys (Naked toothpony)

Deeper body; absence of scales anterior to a line from origin of soft dorsal to behind pectoral fin bases and then to origin of anal fin.



Family: Synodontidae- Lizardfishes

- body elongate, usually cylindrical and with adipose fin
- head usually lizard-like



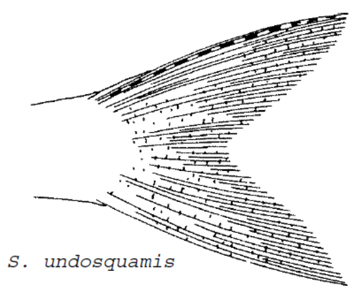
- terminal large mouth with rows of numerous small and pointed teeth visible even after mouth is closed
- teeth also on palate and tongue, those on palate in 1 or 2 bands

Key to the genera

1. ***Saurida***
   - 9 pelvic fin rays, inner barely longer than outer
   - palatine teeth in 2 pairs of bands

Key to the species (adopted and modified from FAO)

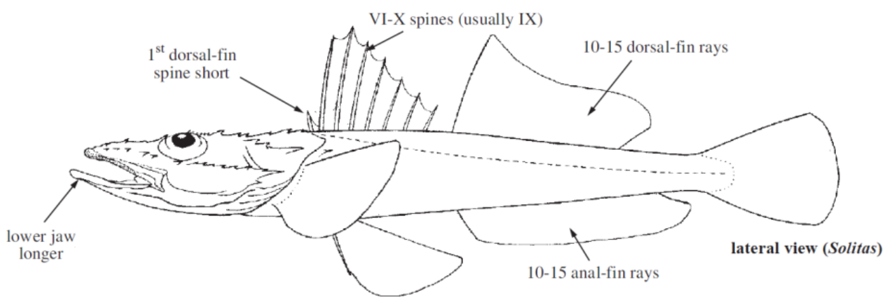
a. ***Saurida undosquamis***
   - body elongate, cylindrical, with lizard-like head and adipose fin
   - 2 rows of teeth on anterior part of outer palatine tooth bands
   - pectoral fins moderately long, reaching to level of pelvic fin base
   - pelvic fin rays almost equal in length
   - 4 to 7 dark dots on upper edge of caudal fin



b. ***Saurida tumbil***
   - 3 or more rows of teeth on anterior part of outer palatine tooth bands
   - pectoral fins just reaching to level of pelvic fin base
   - pelvic fin rays almost equal in length
   - no dark dots on upper edge of caudal fin

Family: Platycephalidae- Flat heads

- elongate fishes with head moderately to strongly depressed
- lower jaw longer than upper
- bony ridges of head typically have spines or serrations
- two dorsal fins, well



separated

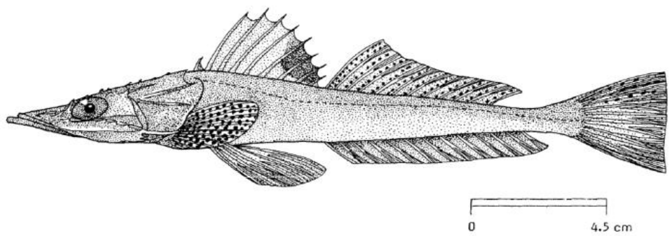
- spinous dorsal with 8 to 10 spines (usually 9), the first spine short and scarcely connected to the second

Key to the species (adopted and modified from FAO, Murty, V. Sriramachandra and Manikyam, Y. 2007)

1. ***Grammoplites***

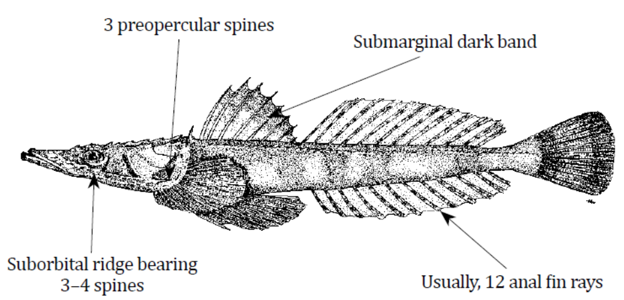
   - all lateral-line scales bearing a backward directed stout spine
   - all ridges on head bear spines
   - preopercle with three spines, the upper one is the longest
   - all pored scales in the lateral line with one spine each, the spine size increasing towards the posterior end of lateral line giving the appearance of a ridge that is more prominent on the posterior side
   - lateral line scales cycloid with one downwardly directed exterior opening

a. Grammoplites suppositus



- first dorsal fin with a large black blotch posteriorly
- upper pectoral rays, upper caudal rays and second dorsal rays with dark spots
- anal fin usually with 13 rays
- preopercular spines usually 3; the lower two small, the upper long, reaching beyond margin of opercular membrane

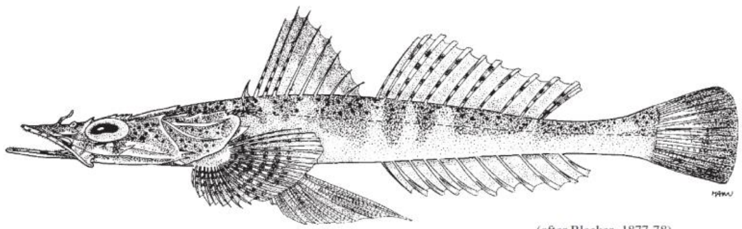
b. Grammoplites scaber



- upper preopercular spine not reaching margin of opercular membrane
- upper half of first dorsal black
- pectoral and caudal fins rounded
- usually 12 anal fin rays
- upper preopercular spine not reaching margin of opercular membrane

2. *Cociella punctata*

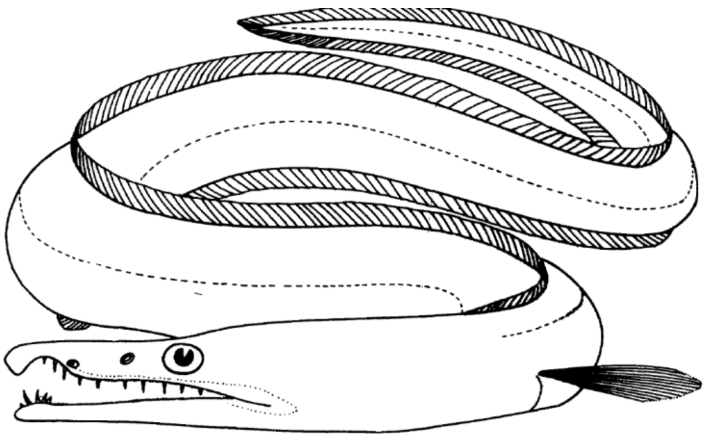
- ➢ suborbital ridge bearing 2 spines under eye, usually well developed
- ➢ upper preopercular spine shorter, reaching about half-way to opercular margin



(after Bleeker, 1877-78)

- ➢ iris lappet simple or slightly bilobed
- ➢ interopercular flap present
- ➢ numerous small dark spots on back reaching to below lateral line, more widely scattered posteriorly
- ➢ soft dorsal fin with dark spots on rays

Family: Muraenesocidae- Pike-congers



- eel-like fishes, cylindrical shaped body in front and compressed towards tail
- large mouth with upper jaw extending well behind eye
- **fangs on vomer** and at front of lower jaw tongue not free from base of mouth
- gill openings large, distinct and placed low on body
- **pectoral fins present**
- dorsal and anal fins long, continuous with caudal fin
- pelvic fins absent
- anus well behind pectoral fin and rather before center of body
- no scales

SIMILAR FAMILIES OCCURRING IN THE AREA

Muraenidae: lack pectoral fins.

Dysommidae: anus below the pectoral fin (well behind in the family Muraenesocidae).

All other eel families: lack large canine teeth on vomer.

Key to Genera

Muraenesox

- ✓ Distinct bulge at bases of canine teeth on middle part of vomer

Congresox

- ✓ Canine teeth on vomer conical, or if flattened, then not bulging at bases

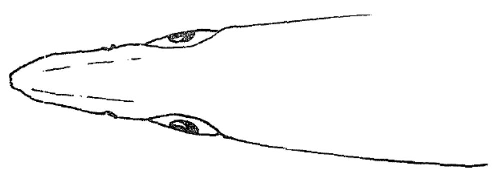
Key to the species (adopted and modified from FAO)

***Muraenesox bagio and Muraenesox cinereus* (common characters)**

- ✓ outer tooth row in lower jaw pointing straight upward
- ✓ body greyish
- ✓ middle canines on vomer with distinct basal lobes (blade-shaped, not needlelike)

a. Muraenesox bagio

- ➢ 35 to 38 pores in lateral line from head to above anus
- ➢ dorsal fin rays (47 to 59) before level of anus
- ➢ posterior nostril only a little closer to eye than to anterior nostril
- ➢ the interorbital width is about 10 or 11 times in head length
- ➢ head and body greyish



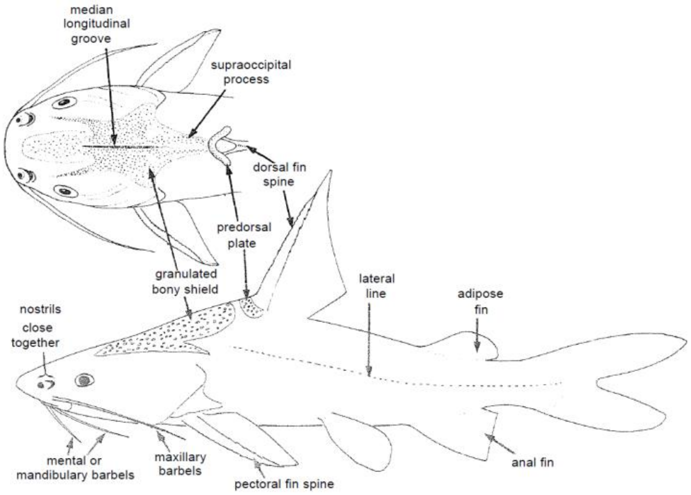
M. bagio

M. cinereus

b. Muraenesox cinereus

- ➢ 39 to 47 pores in lateral line from head to above anus
- ➢ more dorsal fin rays (66 to 78) before level of anus
- ➢ posterior nostril much nearer to eye than to anterior nostril
- ➢ a shorter, broader snout, so that the interorbital width is about 8 times in head length
- ➢ body dark to grey/black

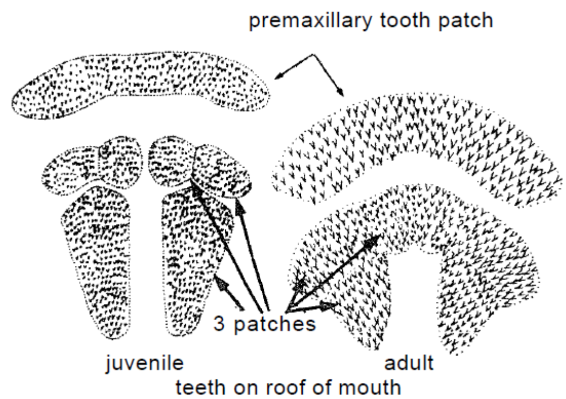
Family: Ariidae- Sea catfishes



- snout and head rounded to depressed, mouth terminal to inferior
- gill membranes attached with each other and close to isthmus
- fine and villiform teeth (in curved bands) is present in jaws, nostrils close together
- 1 to 3 pairs of barbels
- head covered with a bony shield
- first dorsal fin short having a long and rough spine

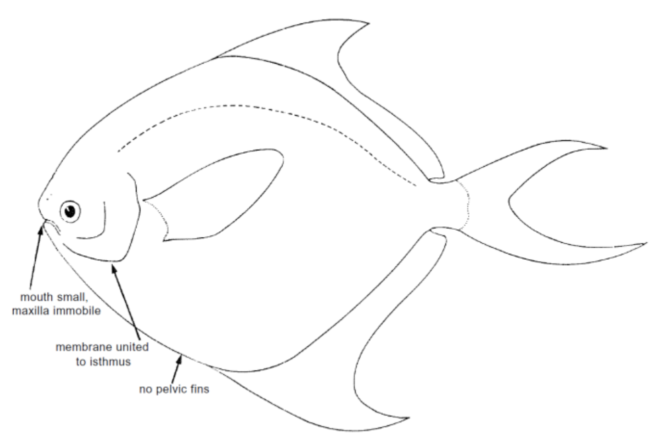
Key to the species (adopted and modified from FAO)

1. ***Netuma thalassina***
   - a prominent preorbital conical protuberance tapering as a wide V posteriorly
   - palate teeth (on roof of mouth) villiform, in 3 patches on each side, forming a triangle, posterior patch longest
   - patches usually fused (may be slightly separated in juveniles)



Arius thalassinus Fig.19

Family: Stromateidae- Butterfishes, silver pomfrets

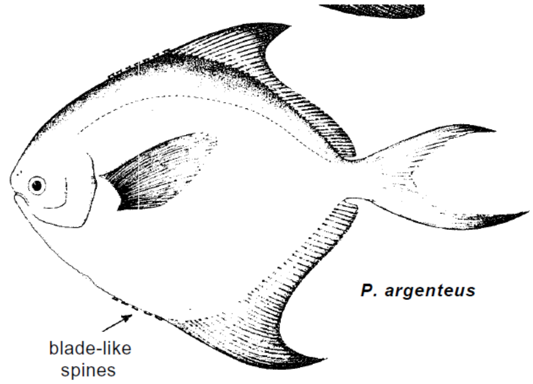


- body very deep and compressed with no keels or scutes
- immobile maxilla is covered with skin and unified to cheek
- gill membranes broadly united to the isthmus
- no pelvic fins
- caudal fin usually forked, in some species

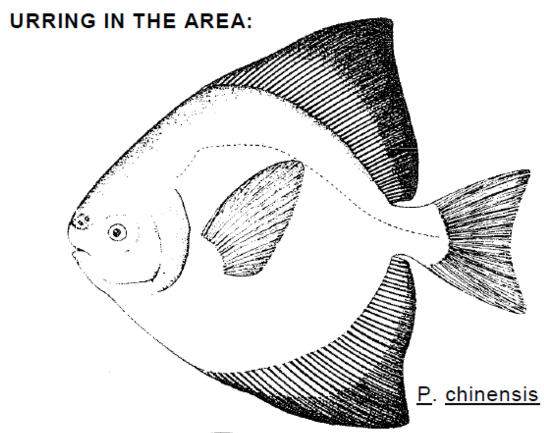
with very extended lobes

Key to the species (adopted and modified from FAO)

a. Pampus argenteus



- dorsal and anal fins preceded by 5 to 10 very low blade-like spines
- caudal fin stiff and forked
- the lower lobe longer than the upper anterior rays of median fins, especially the anal fin, and ventral lobe of caudal fin often greatly produced, decidedly falcate

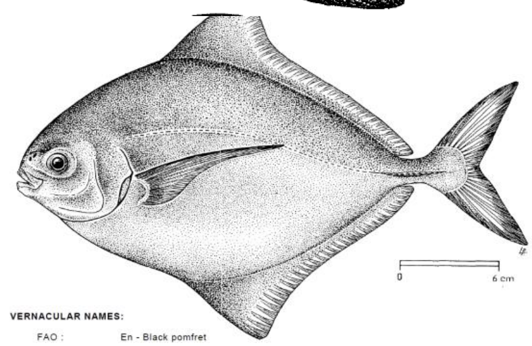


b. Pampus chinensis

- no spines preceding median fins
- fins never deeply falcate but the finrays gradually and uniformly diminishing in length posteriorly
- usually a smaller fish

Family: Carangidae- Jacks and scads

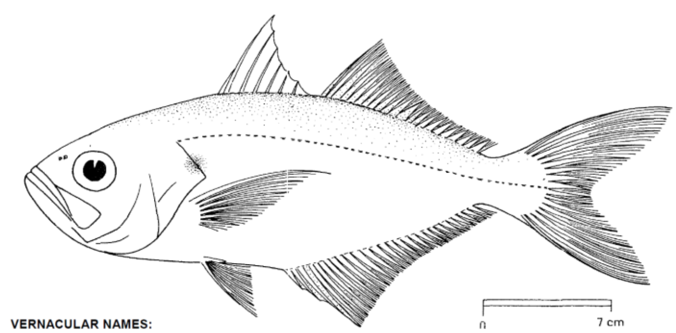
Parastromateus niger



- straight part of lateral line with 8 to 19 weak scutes, forming a slight keel on caudal peduncle
- pelvic fins absent in specimens larger than about 10 cm fork length

Family: Lactariidae- False trevallies

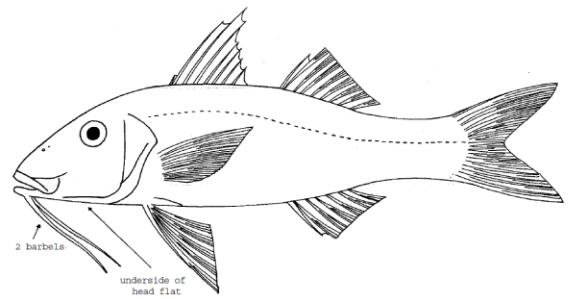
a. Lactarius lactarius



- mouth large and oblique, with a prominent lower jaw
- one pair of small, sharp canine teeth at front of each jaw

- ➢ dusky spot on upper part of gill cover

Family: Mullidae- Goatfishes



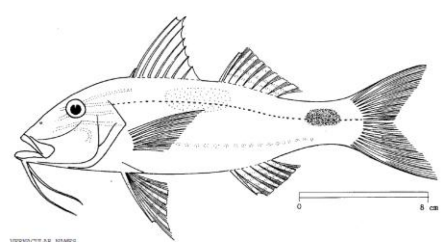
- two long unbranched barbels on chin
- 2 dorsal fins, the 1st with 7 to 8 spines, the 2nd with 1 spine and 8 soft rays
- anal fin having 1 spine and 6 rays
- caudal fin is deeply forked having 13 branched rays
- body usually bears coloured markings such as longitudinal bands or stripes in yellow, orange, red

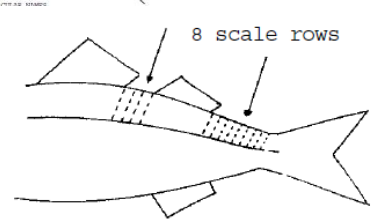
Key to Genera

1. ***Upeneus***
   - ➢ teeth on vomer and palatines (can be seen only after removing lower jaw)
   - ➢ stripes on both dorsal fins, but never on anal fin
   - ➢ no opercular spine
2. ***Parupeneus***
   - ➢ one row of large, blunt teeth in each jaw
   - ➢ 2 to 3 vertical rows of scales along the space between dorsal fins
   - ➢ 8 to 9 vertical rows of scales along upper part of caudal peduncle
   - ➢ stripes always present on 2nd dorsal and anal fins, but never on 1st dorsal fin

Key to the species (adopted and modified from FAO)

a. *Parupeneus indicus*

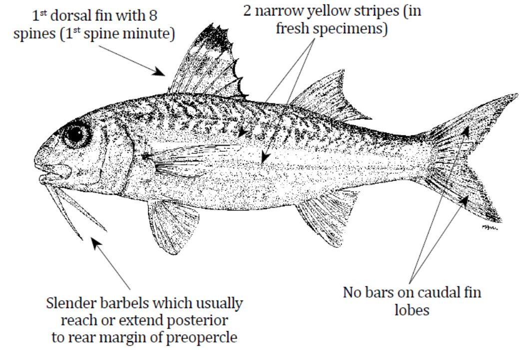




- ➢ head with 3 to 5 violet or blue lines from snout to operculum
- ➢ combination of a yellow blotch on sides and a dark blotch on midline of caudal peduncle
- ➢ 3 vertical rows of scales along the space between dorsal fins
- ➢ 8 vertical rows of scales along upper part of caudal peduncle

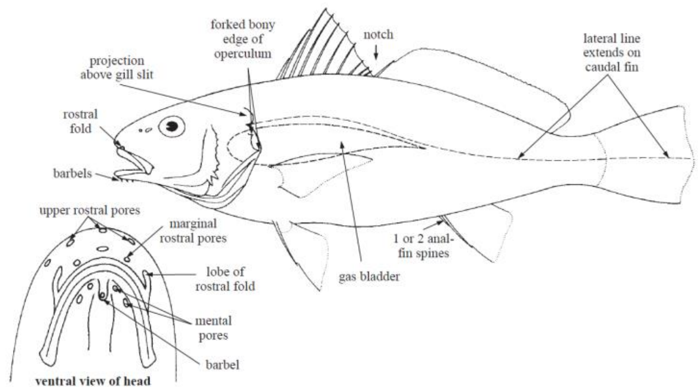
b. *Upeneus sulphureus*

- silvery white on side; tip of 1st dorsal fin black
- upper caudal fin lobe grey



Family: Sciaenidae- Croakers

- sensory pores present at tip of snout
- tip of lower jaw (chin) with 2 to 6 mental pores, some with barbels
- dorsal fin is long and continuous having a deep notch between spinous and soft portions
- anal fin with 2 spines
- caudal fin never forked, usually pointed in juveniles, becoming emarginate, truncate, rounded to rhomboidal, or S-shaped in adults
- a single continuous lateral line extending to hind margin of caudal fin

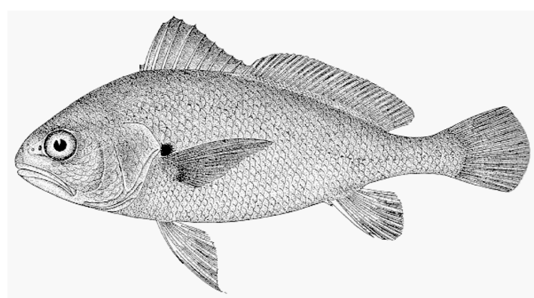


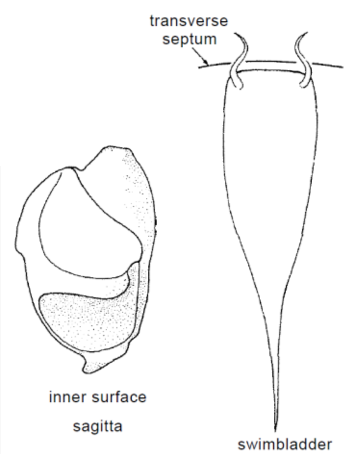
Identification note

Correct identification of genera of this family is possible only by the examination of swimbladder and the otoliths.

Kathala axillaris (Kathala croaker)

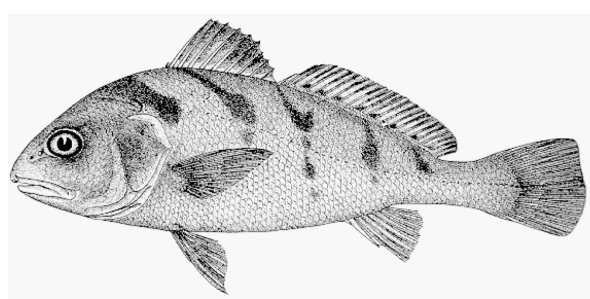
Carrot-shaped swimbladder; black blotch on pectoral fin axil; caudal fin rhomboid; gillraker count 20 to 23 and a dissimilar form of swimbladder.

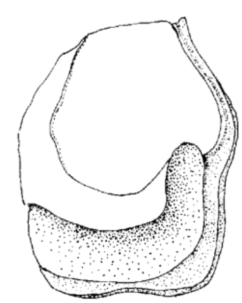




Nibea maculata (Blotched croaker)

Tadpole shaped impression on sagitta (large earstone); a typical colour pattern of 5 dark bars extending obliquely from the back to the lower part of flanks and a sixth dark blotch on top of caudal peduncle.

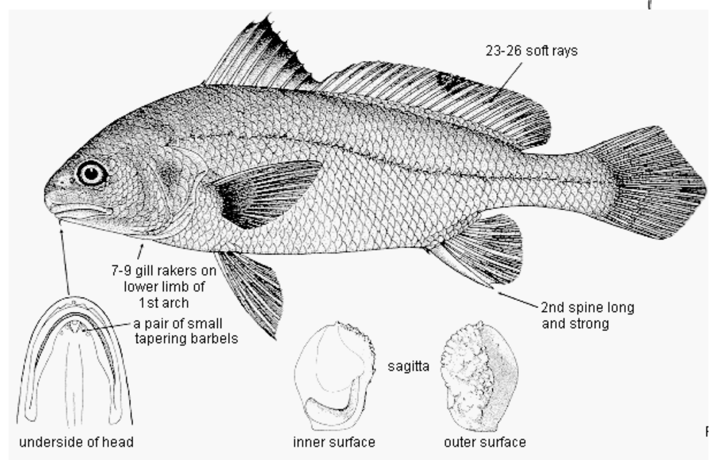




Nibea soldado (Soldier croaker)

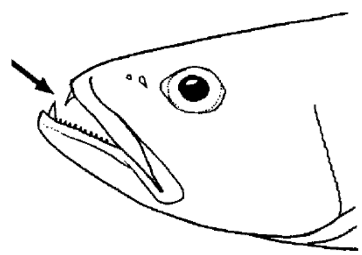
Carrot-shaped swim bladder, sharply constricted posteriorly to its tube-shaped end, with about 18 to 22 pairs of appendages; soft dorsal fin rays 28 to 31; no barbels on chin.

Nibea albida (Two-bearded croaker)



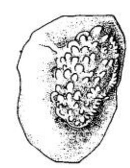
A pair of small tapering barbels on chin; 23 to 26 dorsal soft rays; spinous portion of dorsal fin black.

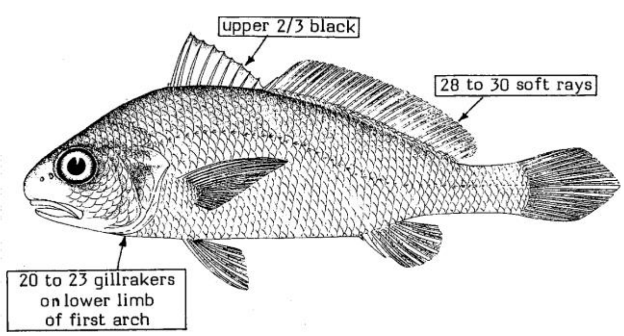
Otolithes cuvieri (Lesser tigertooth croaker)

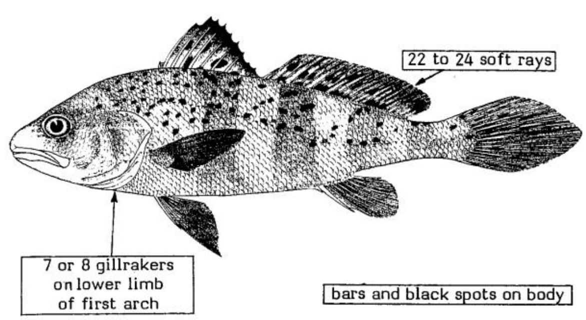


The body depth 3 1/4 to 4 ½ times in standard length. 1 or 2 pairs of robust canines in upper jaw and 1 pair at tip of lower jaw; gillrakers on lower limb of first arch 12 to 17; Carrot-shaped swimbladder, with about 28 pairs of arborescent appendages.

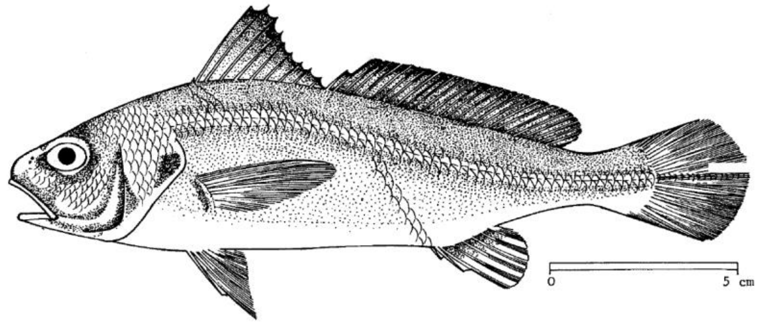
Johnius glaucus (Pale spotfin croaker)







Protonibea diacanthus (Spotted croaker)

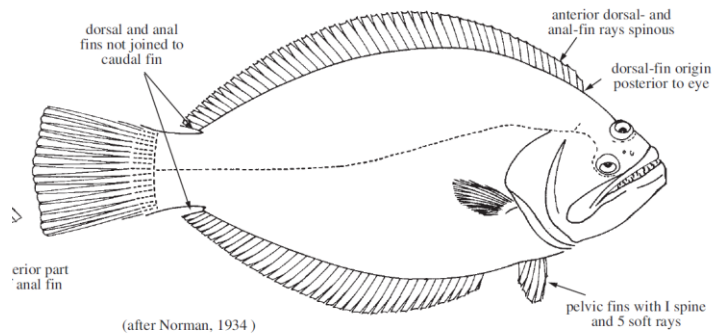


Johnius carutta (Karut croaker)

Rounded snout; Dorsal fin with 9 to 10 spines, trailed by a deep notch, second part of the fin with 1 spine and 25 to 28 soft rays; Teeth distinguished into large and small in upper jaw only.

Family: Psettodidae- Spiny turbots

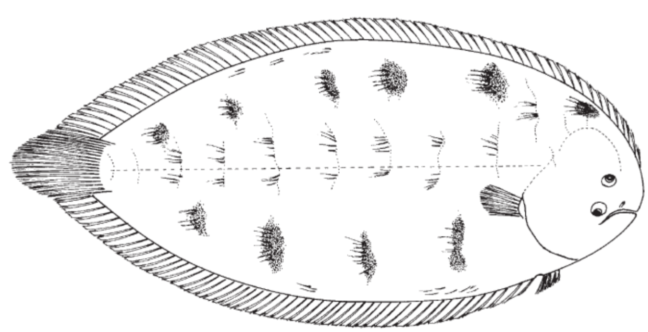
a. ***Psettodes erumei***



- body is oval-shaped and flat but fairly thick
- both eyes on right or left side of head; upper eye present on dorsal surface of head
- supramaxillary bone well developed
- mouth large, extending well beyond posterior margin of lower eye; lower jaw projecting
- teeth with large canines, several with barbed tips
- preopercular margin easily visible, not hidden by skin or scales
- dorsal-fin origin well posterior to upper eye
- anterior rays of dorsal and anal fins spinous
- pelvic fins having I spine and 5 soft rays

Family: Soleidae- Soles

a. ***Brachirus orientalis***



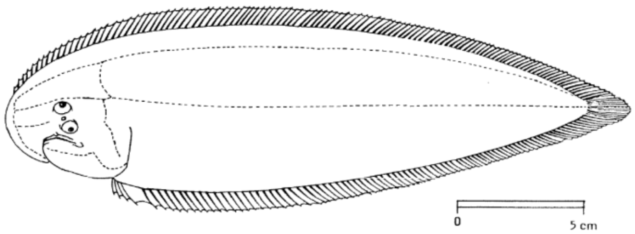
- body oval shaped, both curves equally arched
- scales intensely ctenoid on eyed side, weakly ctenoid on blind side with some cycloid scales also
- eyed side with 3 longitudinal series of black circular blotches parallel

to regions of filamentous scales

- blind side uniformly light yellow, without dusty blotches

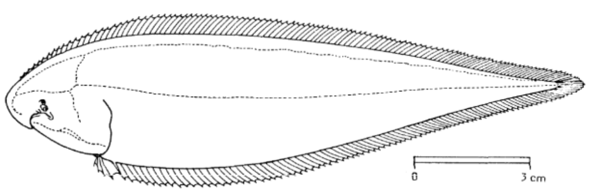
Family: Cynoglossidae- Tonguesoles

a. *Cynoglossus bilineatus*



- snout rounded
- body flat and elongate, with dorsal and anal fins joined to caudal fin
- eyes on left side of body, with a small scaly space between them
- two lateral lines on eyed side and 2 on blind side.
- scales ctenoid (rough to touch) on eyed side but cycloid (smooth) on blind side

b. *Cynoglossus macrostomus*



- snout short and obtusely pointed
- body flat and elongate, with dorsal and anal fins joined to caudal fin
- eyes on left side of body, with no space between them
- two lateral lines on eyed side but none on blind side
- scales ctenoid (rough to touch) on both sides of body

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Murty, V Sriramachandra and Manikyam, Y., 2007 Taxonomic revision of the flatheads (Platycephalidae : Pisces) of India. Records of the Zoological Survey of India Occasional Papers (259). Zoological Survey of India, Kolkata. ISBN 81-8171-134-3.

Chapter 04

Field Identification of the Major Elasmobranchs along the Indian Coast

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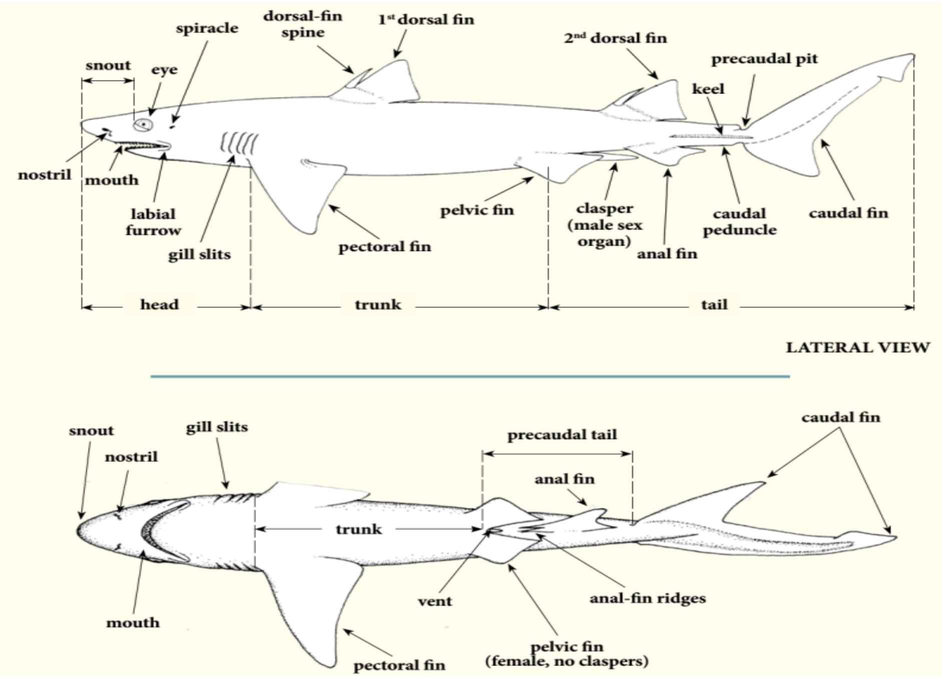
The elasmobranchs are an important group of demersal fishes which are represented by sharks, skates and rays. India is the world's second biggest shark fishing nation next to Indonesia. They belong to the Class Elasmobranchii under the Phylum Chordata. Sharks are caught with various gears like drift gillnets, longlines, hooks and line units and are landed throughout the year. They feed on bony fishes, other sharks, rays, crustaceans and squids.

Shark Morphology



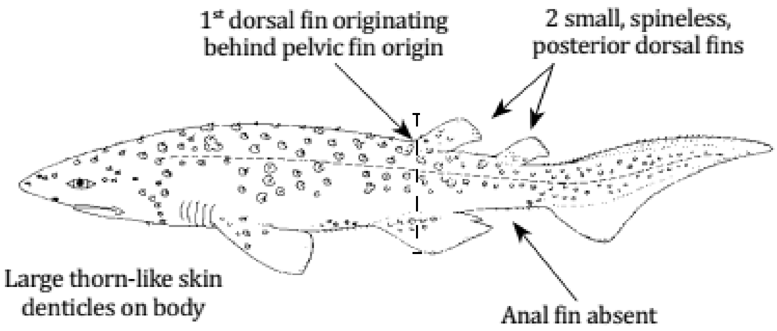
(Source: Ebert, D.A. and Mostarda, E. 2013)

KEY TO SHARK ORDERS AND FAMILIES

1. Order Echinorhiniformes

- gill slits five pairs
- 2 dorsal fins (without spines)
- no anal fin

a. **Family Echinorhinidae**: Bramble sharks



Echinorhinus brucus (Bonnaterre, 1788)

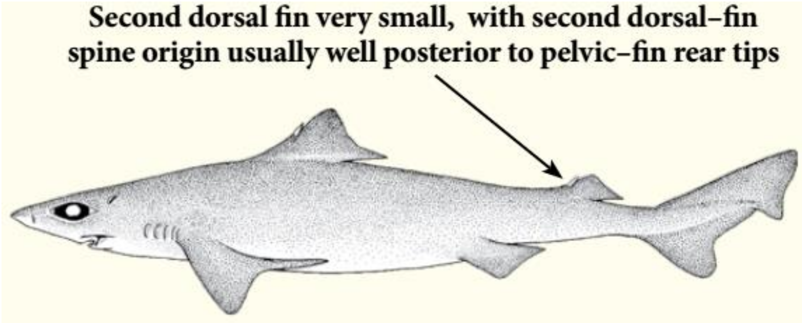
2. Order Squaliformes

- gill slits five pairs
- no anal fin
- 2 dorsal fins
- presence of dorsal fin spines

a. Family Centrophoridae : Gulper sharks

i. ***Centrophorus moluccensis*** Bleeker, 1860 **(Smallfin gulper shark)**

- two dorsal fins with large spines
- presence of blade like unicuspidate teeth with lowers much larger than uppers
- wide-spaced, cuspidate lateral denticles
- pectoral fins having rear tips narrowly angular and significantly elongated

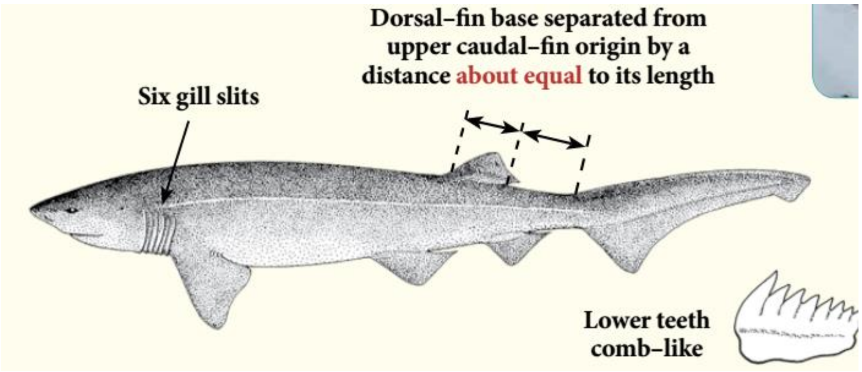


3. Order Hexanchiformes

- presence of 6 or 7 pairs of gill slits
- presence of anal fin
- 1 dorsal fin present

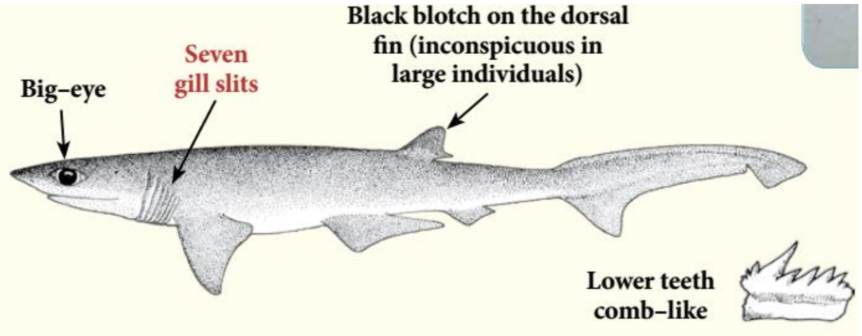
a. **Family Hexanchidae**: **Cow sharks**

i. ***Hexanchus griseus*** (Bonnaterre, 1788) **(Bluntnose sixgill shark)**



- ➢ presence of six pairs of gill slits
- ➢ bluntly rounded snout
- ➢ small eyes
- ➢ fluorescent green on fresh condition
- ➢ single small dorsal fin; its base separated from upper caudal fin origin by distance almost equal to its length.

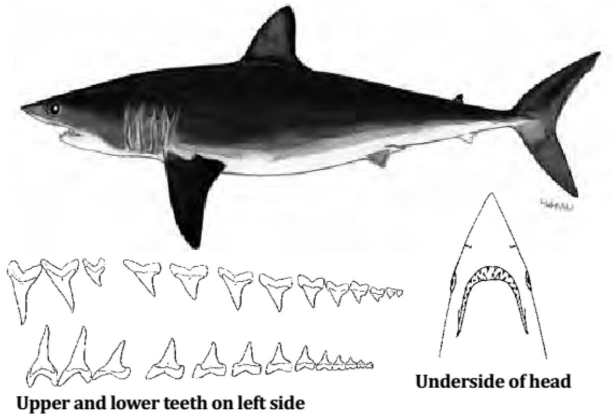
ii. ***Heptranchias perlo*** (Bonnaterre, 1788) **(Sharpnose seven gill shark)**



- ➢ presence of seven large pairs of gill slits
- ➢ snout sharply pointed
- ➢ large eyes
- ➢ fluorescent green colour on fresh condition
- ➢ single dorsal fin set back after pelvic fins
- ➢ faded dark blotch on dorsal fin, more noticeable in juveniles, may also have black blotch on upper caudal lobe.

4. Order Lamniformes

- presence of 5 pairs of gill slits
- anal fin present
- 2 dorsal fins
- mouth after front of eyes
- absence of nictitating eyelids



Size: To 400 cm, common 150 cm (TL)

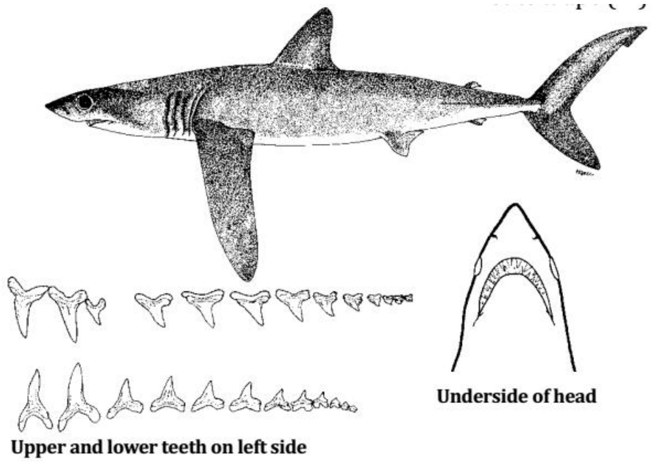
a. **Family Lamnidae**: **Mackerel sharks**

i. ***Isurus oxyrinchus*** Rafinesque, 1810

- ➢ acutely pointed snout
- ➢ pectoral fins shorter than head
- ➢ cusps of upper and lower anterior teeth arched having reversed tips

ii. ***Isurus paucus*** Guitart Manday, 1966

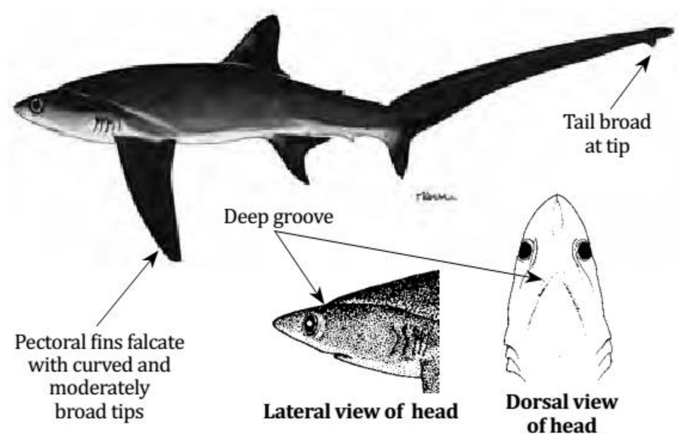
- narrowly to bluntly pointed snout
- pectoral fins about as long as head or longer
- cusps of upper and lower anterior teeth straight, having tips not reversed



b. Family Alopiidae: Thresher sharks

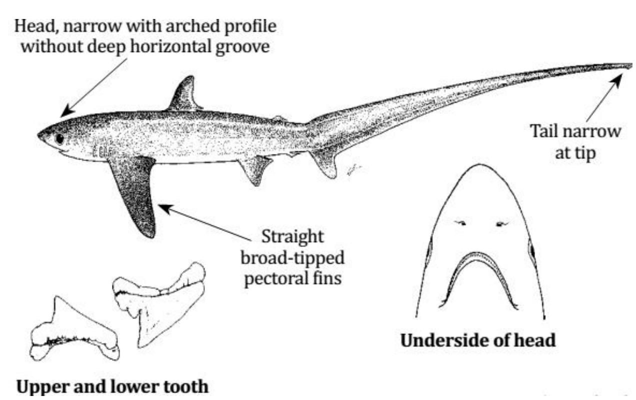
i. ***Alopias superciliosus*** Lowe, 1841

- short snout having exceptionally large eyes outspreading onto dorsal surface of head
- intense horizontal lateral grooves directly above gills on head
- skin just above pectoral and pelvic fins origin dark in color with no white patches

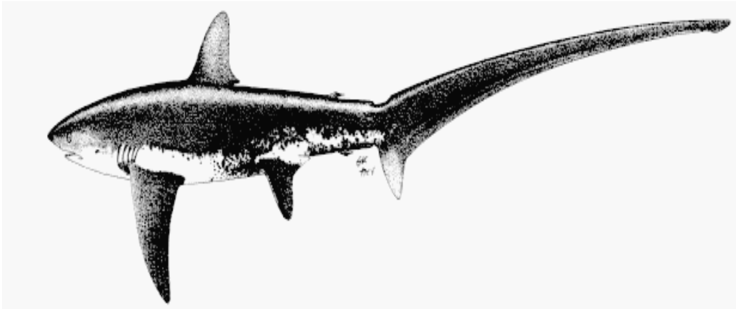


ii. ***Alopias pelagicus*** Nakamura, 1935

- short snout with moderately large eyes
- absence of labial furrows
- first dorsal origin closer to pectoral fin rear tip than pelvic fin base
- pectoral fins narrow, straight and long
- upper caudal lobe almost as long as rest of body
- skin just above pectoral and pelvic fins origin dark in color with no white patches.



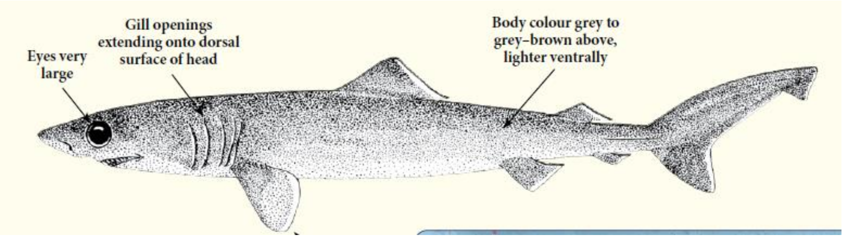
iii. ***Alopias vulpinus*** (Bonnaterre, 1788)



- snout short and pointed with small eyes
- arched mouth having labial furrows
- first dorsal fin almost midway between pectoral and pelvic fins having free rear tip over pelvic fins origin
- pectoral fins softly curved
- upper caudal lobe almost as long as rest of body
- presence of white spots occasionally on pectoral fin tips
- skin just above pectoral and pelvic fins origin dark in color having white patches

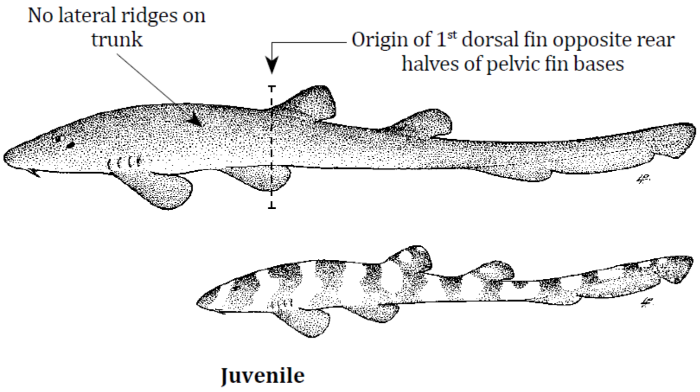
Family Pseudocarchariidae: Crocodile sharks

i. ***Pseudocarcharias kamoharai*** (Matsubara, 1936)



- small shark having big eyes
- nictitating eyelids absent
- gill slits long
- slender, spindle-shaped body
- long-cusped, prominent teeth with greatly protrusible jaws
- two small, dorsal fins without spines and an anal fin
- presence of fragile keels and precaudal pits

5. Order Orectolobiformes



- presence of five gill slits
- 2 dorsal fins and anal fin
- mouth well before eyes

a. Family Hemiscylliidae: Longtailed Carpetsharks

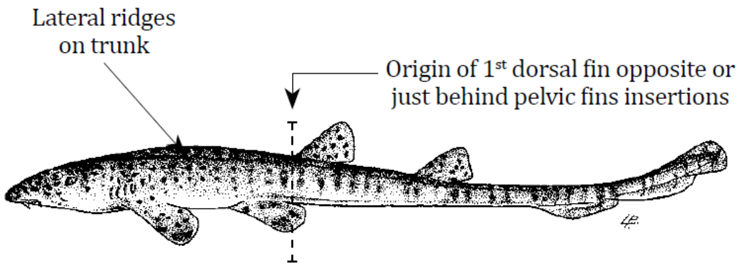
i. *Chiloscyllium griseum* Müller &Henle, 1838

(Grey Bamboo shark)

- rounded snout with small transverse mouth
- barbels present well before eyes
- body ridges absent
- juveniles with conspicuous dark saddle marks and transverse bands

ii. ***Chiloscyllium indicum*** (Gmelin, 1789)

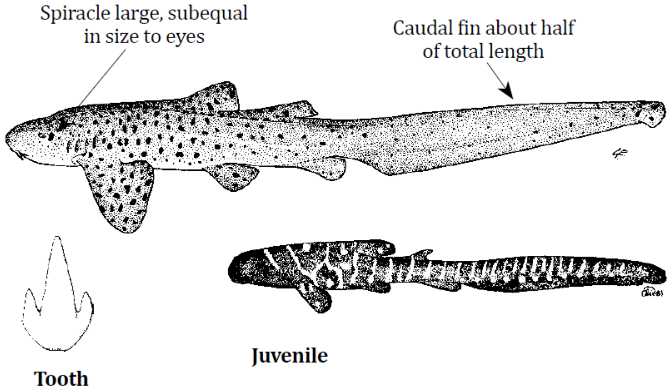
- very slender body and tail
- presence of lateral ridges on trunk
- several dark brown or blackish spots, dashes and bars on light brown background present in juveniles and adults



b. Family Stegostomatidae : Zebra sharks

i. ***Stegostoma fasciatum*** (Hermann, 1783)

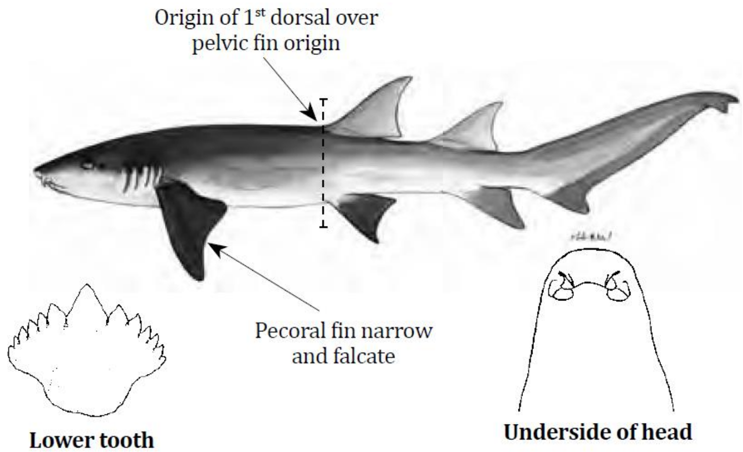
- moderately firm body with conspicuous ridges on dorsal surface and sides
- small transverse mouth before eyes
- small barbles present
- caudal fin lower lobe hardly developed
- lateral keels absent
- caudal fin about half of total length



c. Family Ginglymostomatidae- Nurse sharks

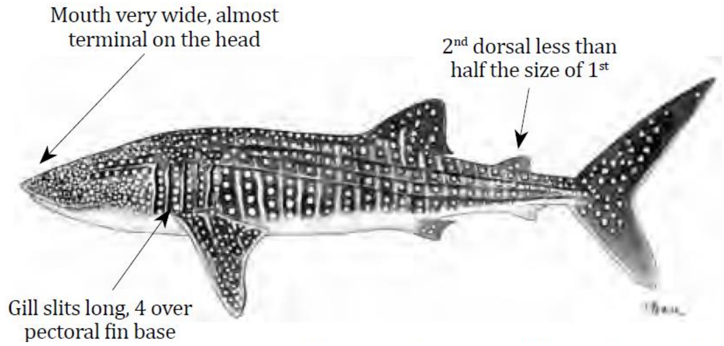
i. ***Nebrius ferrugineus*** (Lesson, 1831)

- presence of long barbels
- mouth before laterally positioned eyes
- minute spiracles present
- 1st dorsal fin larger than 2nd dorsal and anal fins
- pectoral, dorsal and anal fins apically angular
- absence of circumnarial grooves and body lateral ridges.



d. Family Rhincodontidae: Whale shark

i. ***Rhincodon typus*** Smith, 1828



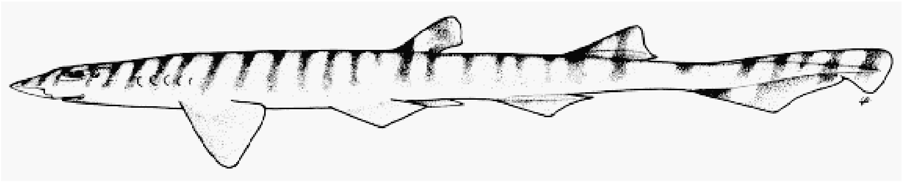
- very wide and compressed head
- minute teeth present
- caudal peduncle depressed with a strong keel on both side
- upper precaudal pit exist
- presence of white or yellow spots and transverse stripes

6. Order Carcharhiniformes

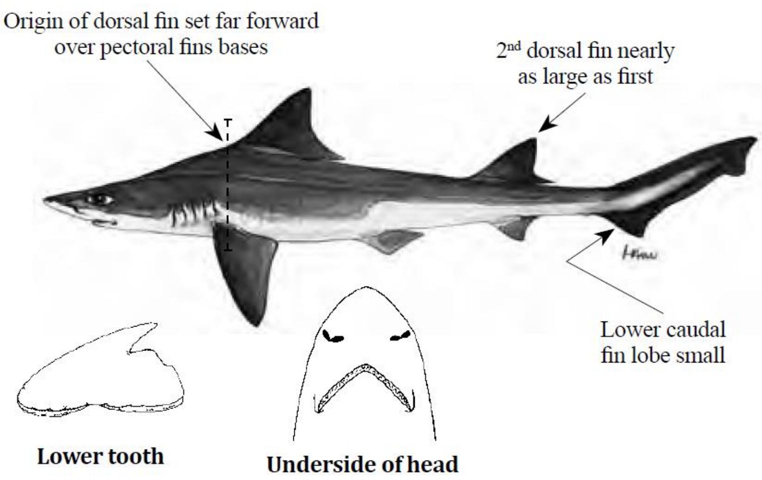
- presence of 5 pairs of gill slits
- anal fin present
- 2 dorsal fins
- mouth behind front of eyes
- nictitating eyelids exist

a. Family Scyliorhinidae: Catsharks

i. ***Halaelurus quagga* (Alcock, 1899) (Quagga Catshark)**



- pointed snout
- eyes raised above head
- mouth moderately large having small labial furrows
- about twenty narrow, dark vertical bars on body making saddles near dorsal fins
- gills on upper surface of head above level of mouth
- first dorsal fin origin over pelvic fin insertions



b. Family Triakidae: Houndsharks

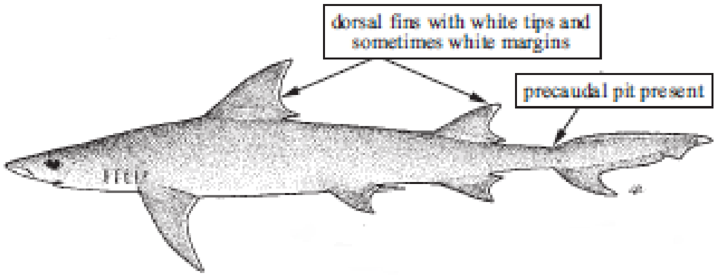
i. ***Iago omanensis* (Norman, 1939) (Bigeye Houndshark)**

- short snout and slender body
- big eyes on lateral side
- large gill slits and small blade-like teeth present

c. Family Hemigaleidae: Weasel sharks

i. *Hemigaleus microstoma* Bleeker, 1852 (Sickelfin Weasel Shark)

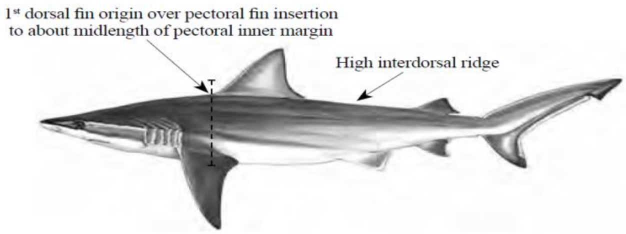
- long and rounded snout
- mouth curved and short, teeth covered once closed
- short gill slits
- dorsal fins, pelvic fins and lower caudal lobe deeply curved
- side of body often with white spots



d. Family Carcharhinidae: Requiem sharks

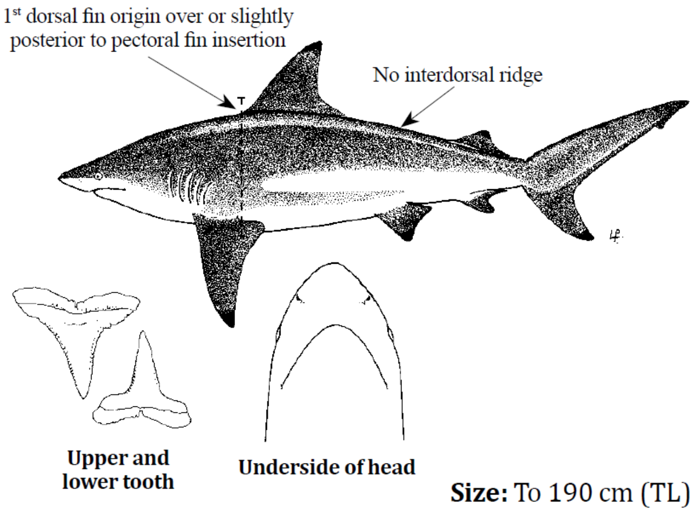
i. *Carcharhinus altimus* (Springer, 1950) (Bignose shark)

- bluntly pointed to rounded snout
- nasal flaps long
- nearly straight pectoral fins
- high interdorsal ridge

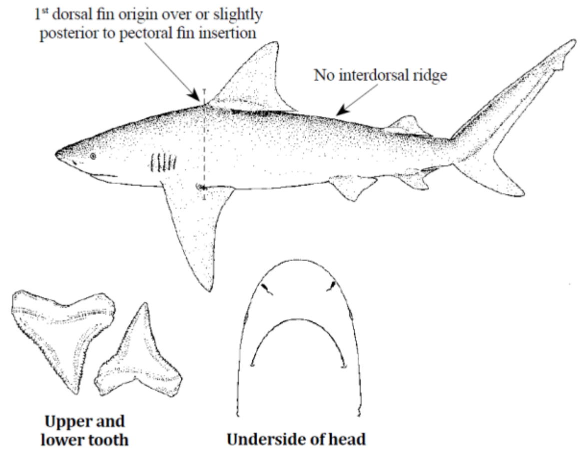


ii. *Carcharhinus amblyrhynchoides* (Whitley, 1934) (Graceful shark)

- short snout
- absence of interdorsal ridge
- moderately large falcate pectoral fins

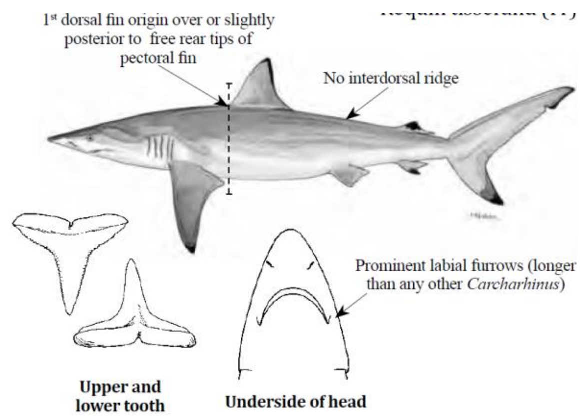


iii. ***Carcharhinus amboinensis* (Müller &Henle, 1839)**
(Pigeye shark)



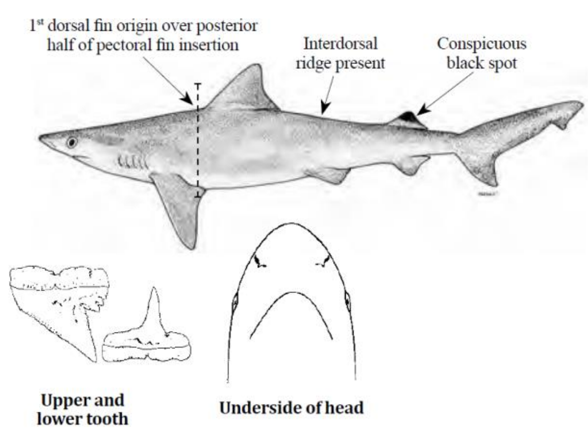
- very short and bluntly rounded snout
- small eyes
- large triangular 1stdorsal fin (above 3 times 2nd dorsal height)
- large angular pectoral fins
- absence of interdorsal ridge

iv. ***Carcharhinus brevipinna* (Müller &Henle, 1839)**
(Spinner shark)



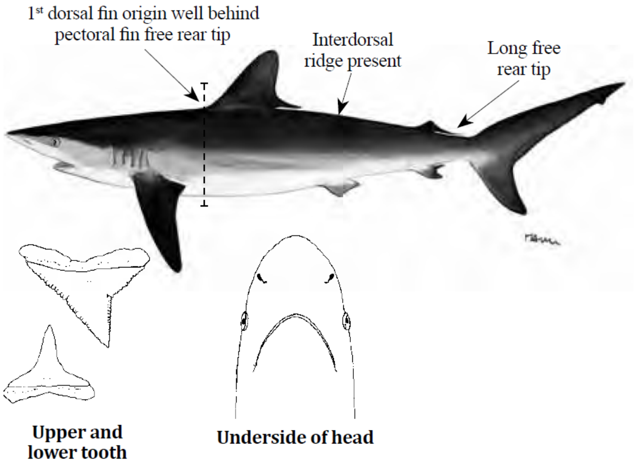
- pointed and long snout
- pectoral fins small and falcate
- prominent labial furrows
- 2nd dorsal, anal, bases of pectorals and lower caudal fin lobe black or dark grey-tipped in adults, but unmarked in small individuals below 1 m in length

v. ***Carcharhinus dussumieri* (Müller &Henle, 1839)**
(Whitecheek shark)



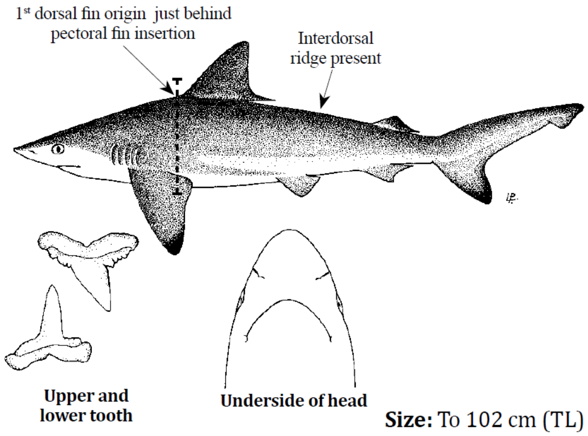
- moderately long and rounded snout
- eyes large and horizontally-oval
- pectoral fins small and semifalcate
- black spot present on 2nd dorsal fin only
- interdorsal ridge present

vi. ***Carcharhinus falciformis*** **(Müller &Henle, 1839)**
(Silky shark)



- narrowly rounded snout
- long free rear tip on 2nd dorsal fin
- pectoral fins long and narrow

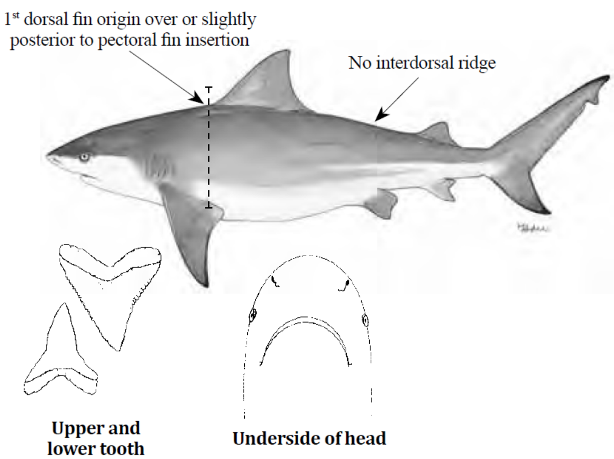
vii. ***Carcharhinus hemiodon (Müller &Henle, 1839)***
(Pondicherry shark)



Size: To 102 cm (TL)

- long and pointed snout
- pectoral fins small
- upper teeth weakly serrated with strong cusplets
- lower teeth without serrations
- conspicuous black tips present on pectorals, 2nd dorsal, dorsal and ventral caudal lobes

viii. ***Carcharhinus leucas*** **(Müller &Henle, 1839)**
(Bull shark)

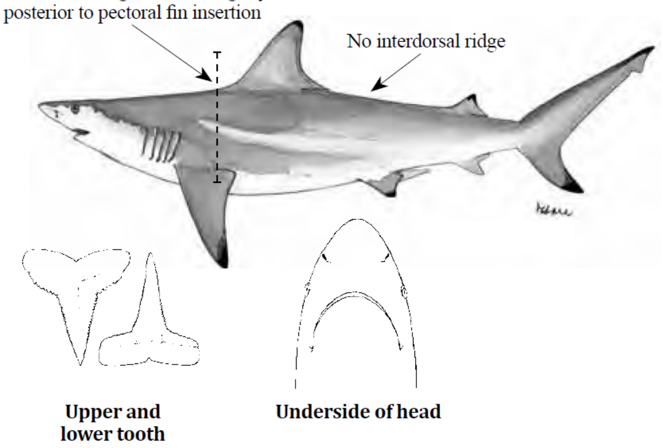


Size: To 360 cm (TL)

- short snout, curved/ rounded with small eyes
- 1st dorsal fin triangular shaped
- upper jaw with serrated teeth while cusped teeth with arched roots in lower jaw
- a white band present on side

ix. ***Carcharhinus limbatus* (Müller &Henle, 1839)**
(Blacktip shark)

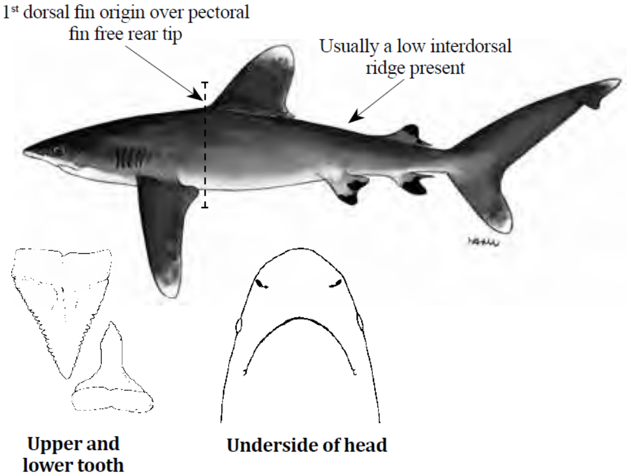
- long and pointed snout
- short rear tips in both 1st and 2nd dorsal fins
- narrow-cusped serrated teeth in both jaws



Size: To 297 cm

x. ***Carcharhinus longimanus* (Poey, 1861)**
(Oceanic whitetip shark)

- short snout
- 1st dorsal fin conspicuously large with a rounded apex
- pectoral fins paddle-shaped
- spotted white fin tips on 1st dorsal, pectoral, pelvic, upper and lower caudal fin lobes
- black saddle-marks present on caudal peduncle

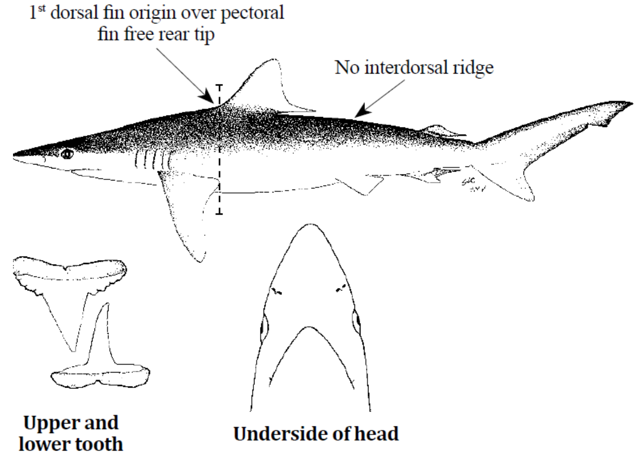


Size: To 350 cm (TL)

xi. ***Carcharhinus macloti* (Müller &Henle, 1839)**
(Hardnose shark)

- pointed snout with a hypercalcified rostrum which can be felt by pinching its snout
- upper teeth oblique-cusped and smooth-edged

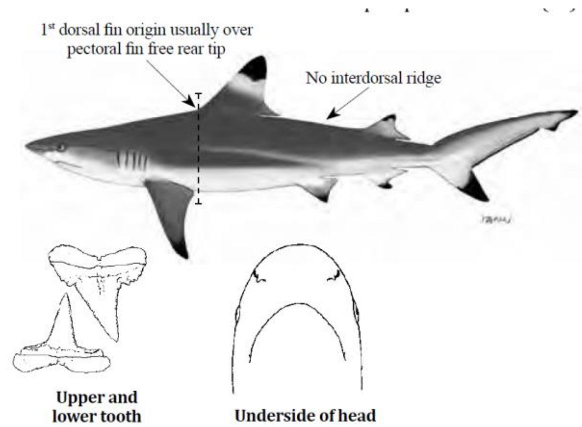
.



Size: To 100 cm (TL)

xii. ***Carcharhinus melanopterus*(Quoy&Gaimard, 1824)**
(Blacktip reef shark)

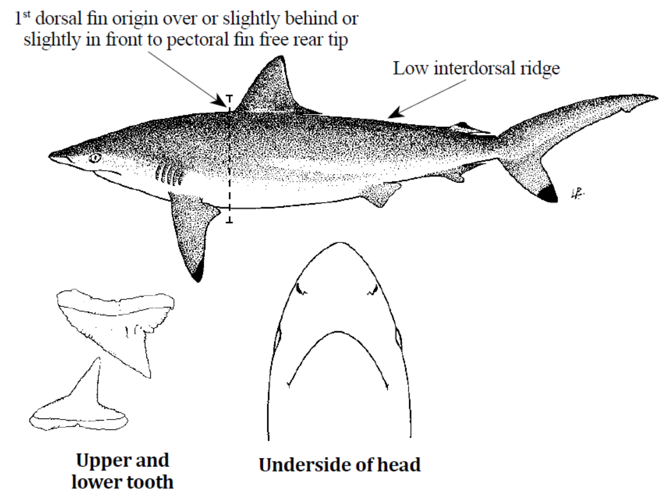
- striking black apical mark on the ventral caudal lobe, other fins, usually with less prominent black fin tips
- noticeable white band on side



Size: To 200 cm (TL)

xiii. ***Carcharhinus sorrah* (Müller &Henle, 1839)**
(Spot-tail shark)

- long and pointed snout
- prominent black tip on the pectorals, 2nd dorsal, and ventral caudal lobe
- 1st dorsal fin with black border
- a conspicuous white band on side

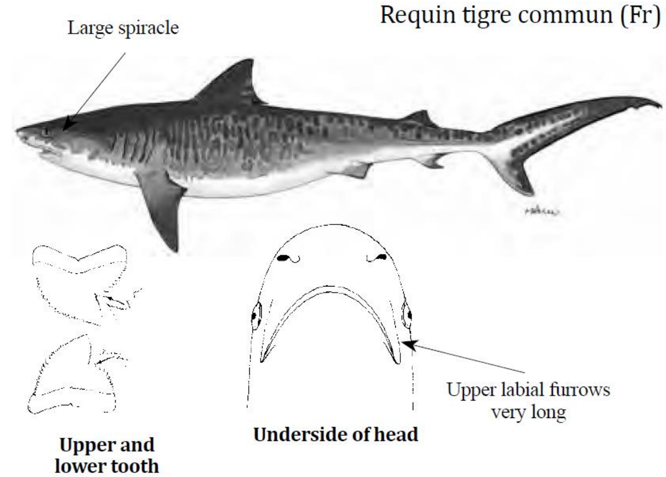


Size: To 160 cm (TL)

xiv. ***Galeocerdo cuvier* (Péron&Lesueur, 1822)**
(Tiger shark)

- blunt and short snout
- long upper labial furrows extending to the front of eye
- spiracles are present
- a rounded keel present on both sides of the caudal peduncle curved teeth with cocks comb-shape and heavy serrations as well as distal cusplets

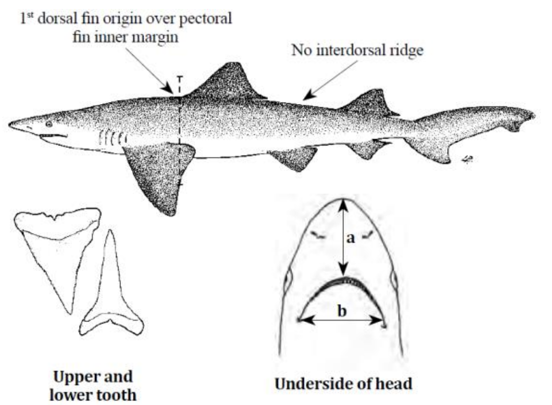
Requin tigre commun (Fr)



Size: To 550 cm, common 400 cm (TL)

xv. ***Lamiopsis temminckii* (Müller &Henle, 1839) (Broadfin shark)**

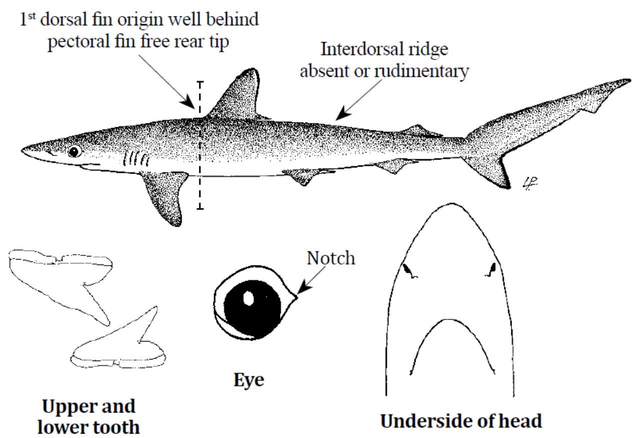
- snout length almost comparable to that of mouth width
- 2nd dorsal fin large as 1st
- longitudinal upper precaudal pit
- broad and triangular pectoral fin



Size: To 168 cm (TL)

xvi. ***Loxodon macrorhinus* Müller &Henle, 1839 (Sliteye shark)**

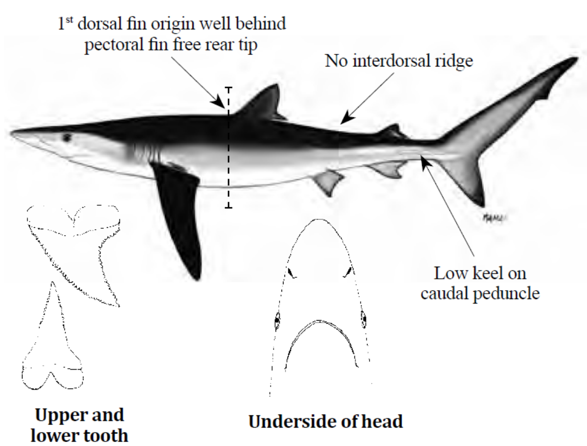
- long snout
- labial furrows short
- 2nd dorsal fin originates behind origin of anal fin
- very long preanal ridges on anal fin
- a slender dark margin on 1st dorsal fin



Size: To 98 cm (TL)

xvii. ***Prionace glauca* (Linnaeus, 1758) (Blue shark)**

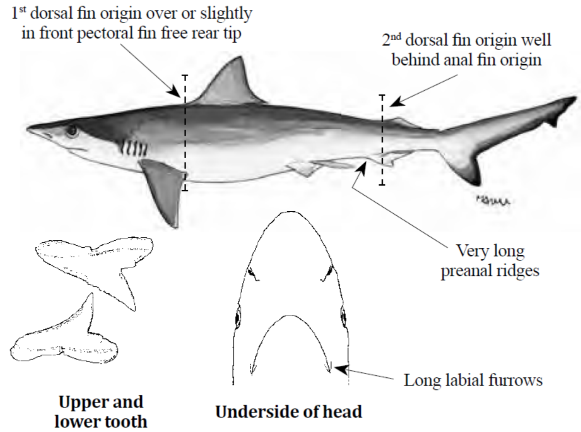
- long and pointed pectoral fins
- dark blue colour on back, bright blue shade on either sides, white tint underneath, fading to purple blackish hue following death
- tips of pectoral and anal fins dusky



Size: To 385 cm (TL)

xviii. *Rhizoprionodon acutus* (Rüppell, 1837) (Milk shark)

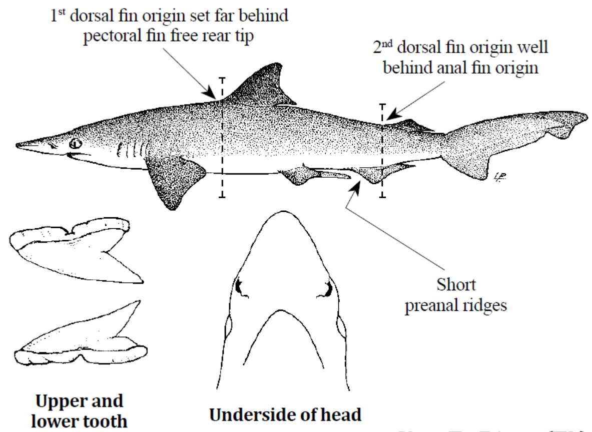
- elongated upper and lower labial furrows
- 2nd dorsal fin smaller as compared to anal fin
- inter dorsal ridge not present or rudimentary
- greyish brown on top, white underneath
- dorsal and anal fins somewhat darker than backside



Size: To 180 cm, common 70 cm (TL)

xix. *Scoliodon laticaudus* Müller &Henle, 1838 (Spadenose shark)

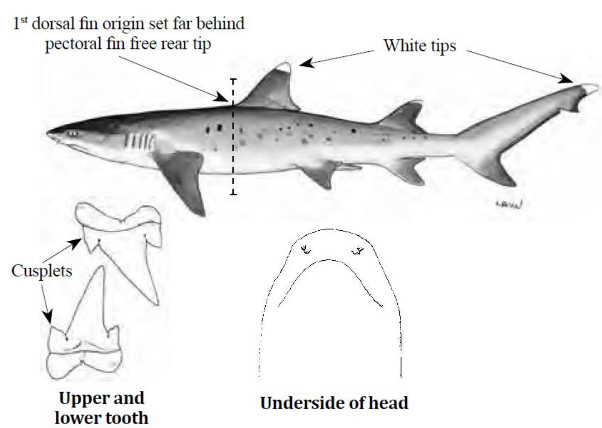
- elongated flattened/ compressed, spade-like snout
- pectoral fins wide triangular shaped interdorsal ridge not present
- greyish-brown colour on top, light hue underneath
- light borders present on all fins



Size: To 74 cm (TL)

xx. *Triaenodon obesus* (Rüppell, 1837) (Whitetip reef shark)

- short and broadly rounded snout
- posterior notches on horizontally oval eyes
- down slanted mouth and prominent tubular anterior nasal flaps
- no interdorsal ridge
- 1st dorsal and caudal lobes with conspicuous white tips
- 2nd dorsal and caudal lobes sometimes white-tipped

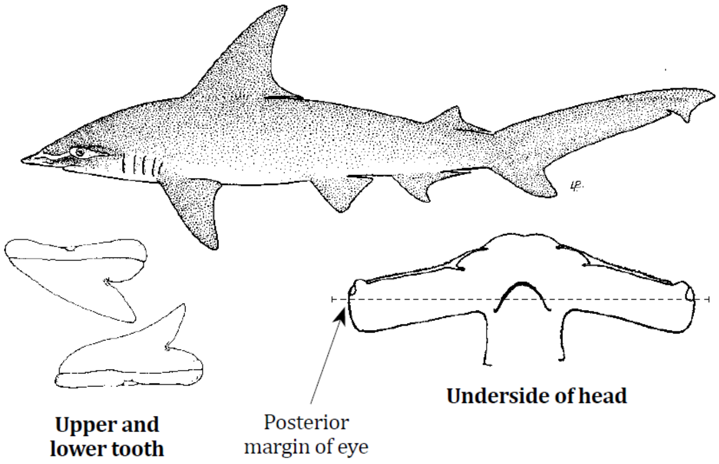


Size: To 215 cm, common 160 cm (TL)

e. **Family Sphyrnidae: Hammerhead sharks**

i. ***Eusphyra blochii* (Cuvier, 1816) (Winghead shark)**

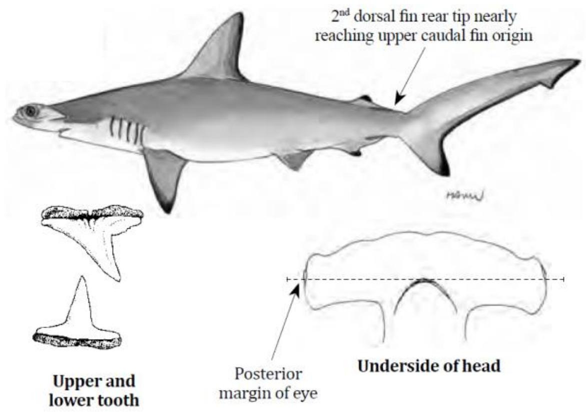
- head broad and wing-shaped with narrow blades almost or quite half the shark's length
- posterior margin of eyes below level of front of mouth
- upper precaudal pit longitudinal



Size: To 180 cm (TL)

ii. ***Sphyrna lewini* (Griffith & Smith, 1834) (Scalloped hammerhead)**

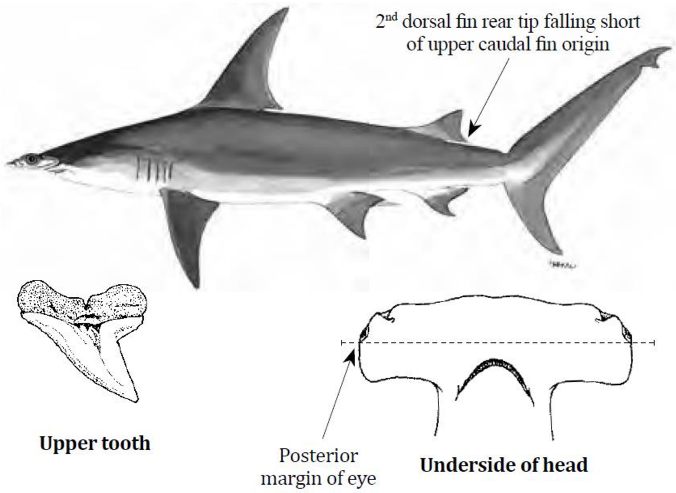
- anterior margin of head having a middle notch and two smaller lateral indentations
- moderately falcate 1st dorsal fin



Size: To 420 cm, common 370 cm (TL)

iii. ***Sphyrna mokarran* (Rüppell, 1837) (Great hammerhead)**

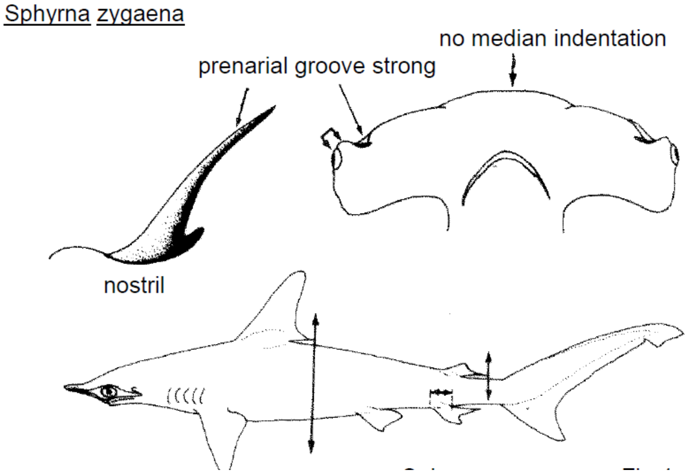
- anterior margin of head almost straight having a notch at the middle
- posterior margin of eyes well anterior to front of mouth
- very high and strongly falcate 1st dorsal fin
- long and arched pectoral fins



Size: To 600 cm (TL)

iv. *Sphyrna zygaena* (Linnaeus, 1758) (Smooth Hammerhead)

- curved and broad head
- central notch absent
- no median indentation
- first dorsal fin free rear tip prior to pelvic fin origin
- short and broad pectoral fins, having dusky edges underneath



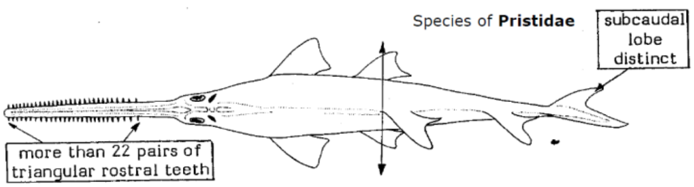
7. Order Pristioforiformes

- body shark–like
- a saw–like elongated snout bearing a row of strong lateral teeth on each side is present

a. Family Pristiophoridae :Sawsharks

i. *Anoxypristis cuspidata* (Latham, 1794)

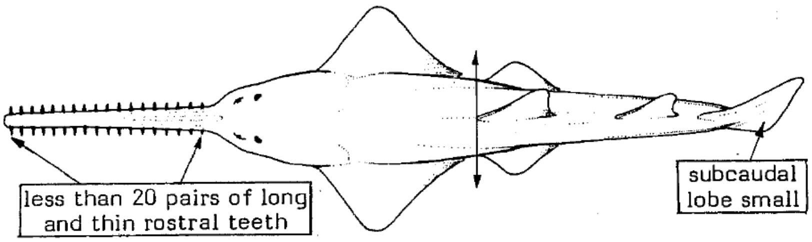
- no rostral teeth on basal quarter of saw
- caudal fin lunate with distinctive subterminal projection on upper lobe
- lower lobe well developed



Anoxypristis cuspidata (Latham, 1794)

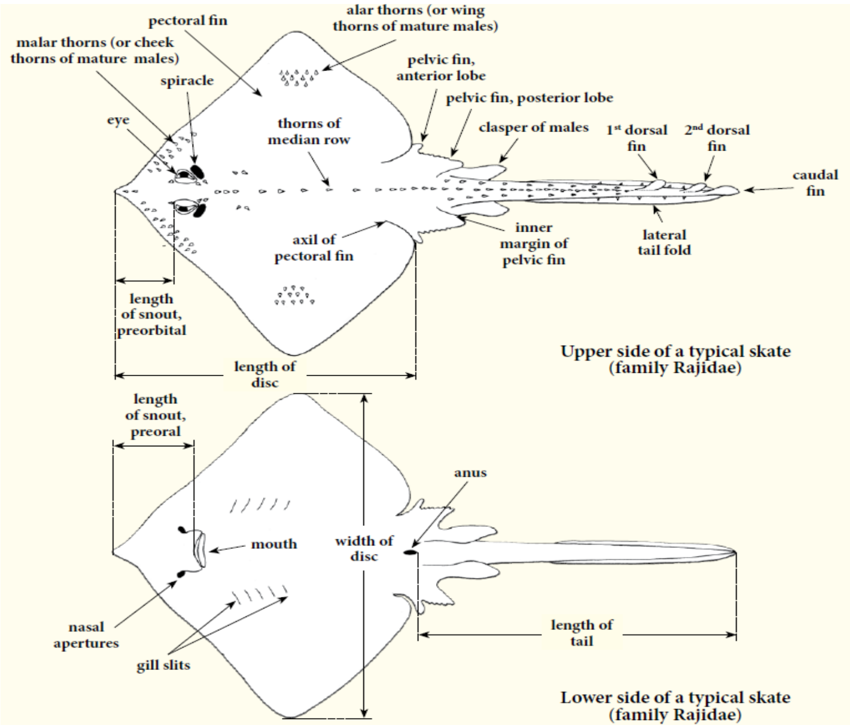
ii. *Pristis pristis* (Linnaeus, 1758) (Common sawfish, earlier *Pristis microdon*)

- rostral teeth present on basal quarter of saw
- pectoral fin bases broad
- caudal fin without a subterminal notch but with a short ventral lobe



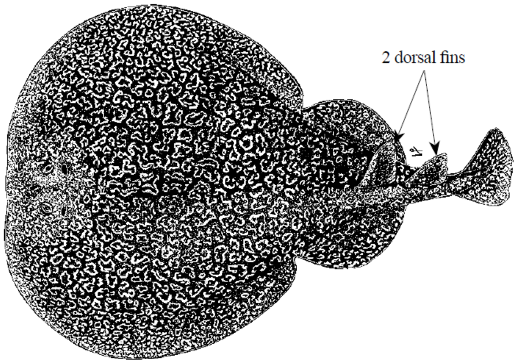
Pristis pristis Linnaeus, 1758

MORPHOLOGY- SKATES AND RAYS



(Source: Ebert, D.A. and Mostarda, E. 2013)

Family Torpedinidae: Torpedos

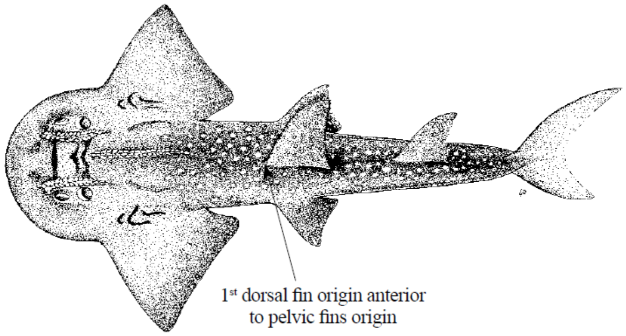


i. ***Torpedo sinuspersici* Olfers, 1831**

- spiracles having margin with small tentacles
- height of tail fin is lesser than distance from upper tail fin origin to 1st dorsal fin

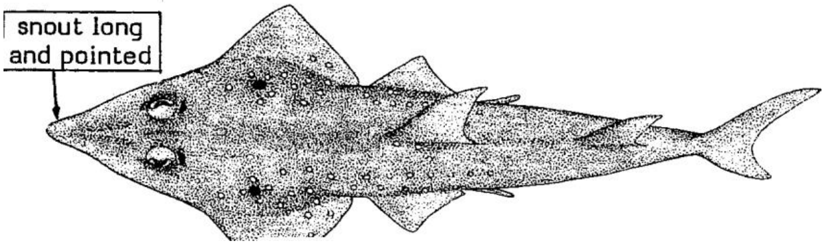
a. Family Rhinidae: Bowmouth guitarfish

i. ***Rhina ancylostoma* Bloch & Schneider, 1801**



- rounded snout
- thick ridges with expanded denticles on back, over eyes and spiracles
- nearly symmetrical lunate caudal fin

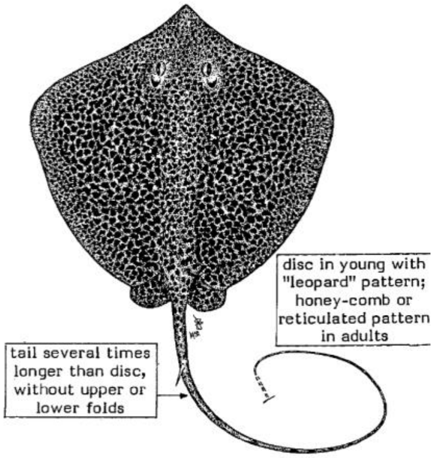
ii. *Rhynchobatus djeddensis*



- snout long and pointed
- lower caudal lobe short
- white spots on dorsal surface

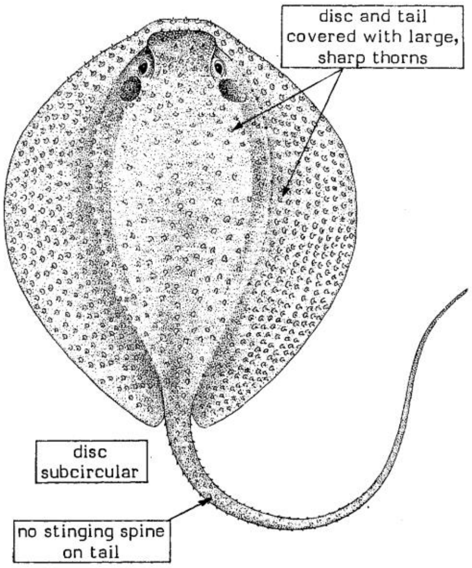
b. Family Dasyatidae

i. *Himantura uarnak* (Gmelin, 1789) (Reticulate whipray)



- disc with a rhomboidal shape having narrowly rounded apices (mostly rounded in juveniles)
- mostly triangular snout having pointed tip
- longer and slender tail, whip-like beyond sting
- cutaneous folds on tail absent
- a broad median denticle band from interorbit, outspreading along center of disc and onto upper tail

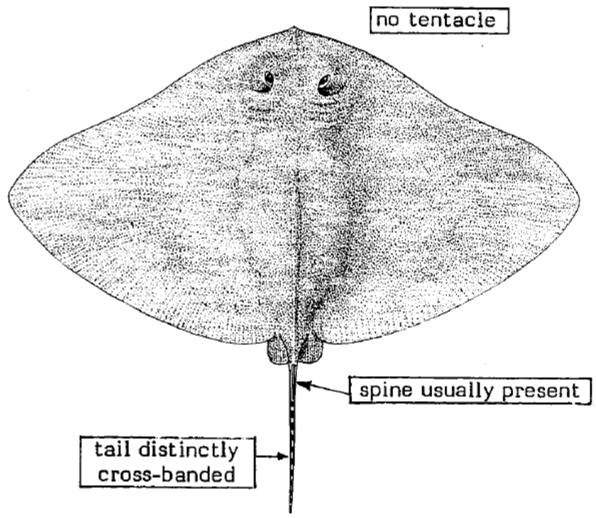
ii. *Urogymnus asperrimus* (Bloch & Schneider, 1801) (Porcupine ray)



- heavily armored stingray without a venomous spine on tail
- young ones with large, flat denticles on upper surface
- larger juveniles and adults having sharp conical thorns and minor sharp denticles
- disc light grey and blackish tail tip
-

d) Family Gymnuridae : Butterfly rays

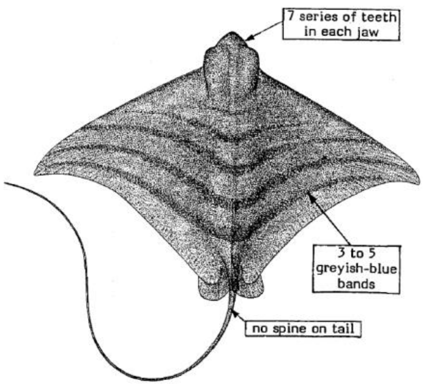
i. *Gymnura poecilura* (Shaw, 1804)



- disc lozenge shaped with at least twice as broad as long
- no dordal fin
- tentacle absent on posterior margin of spiracle
- small venomous spine is present on tail base
- cross-banded black and white pattern in tail

e. Family Myliobatidae Eagle rays

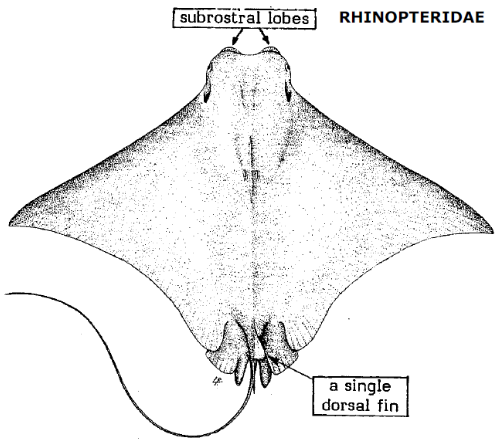
i. *Aetomylaeus nichofii* (Bloch & Schneider, 1801)



- disc much wider than long
- head with a prominent rostral lobe
- teeth present in 7 rows in both jaws
- stinging spine absent
- disc with 3 to 5 greyish pale blue cross bands

f. Family Rhinopteridae: Cownose rays

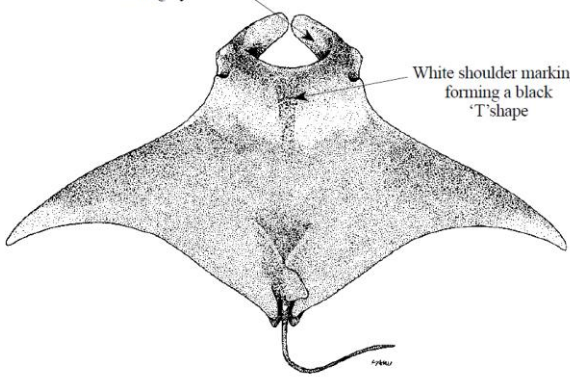
i. *Rhinoptera javanica* Müller & Henle, 1841



- snout strongly notched medially to form two lobes
- relatively narrow head
- fleshy posterior edge of rostral flap not (or just) reaching mouth
- length of tail is about 2.6–3.4 in disc length
- posterior margin of dorsal fin strongly concave sting (when present) behind dorsal fin free rear tip
- conspicuous markings absent

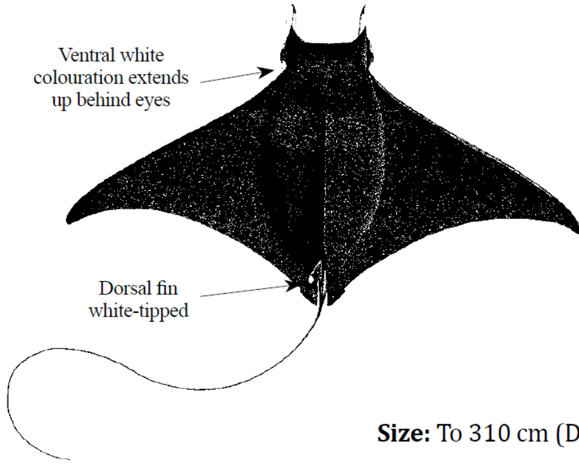
g. Family MOBULIDAE: Manta rays – Devil rays

i. *Mobula birostris* (Walbaum, 1792) Earlier *Manta birostris*



- giant ray with a very broad head having anterior flaps
- terminal mouth which is in front of head
- whip-like slender tail
- stinging spine mostly encased in a calcified mass on tail base
- presence of noticeable white shoulder patches
- gill slits posterior commonly with black flaring
- cephalic fins and inside of mouth black in colour

ii. *Mobula mobular* (Bonnaterre, 1788) (Earlier *Mobula japonica*)

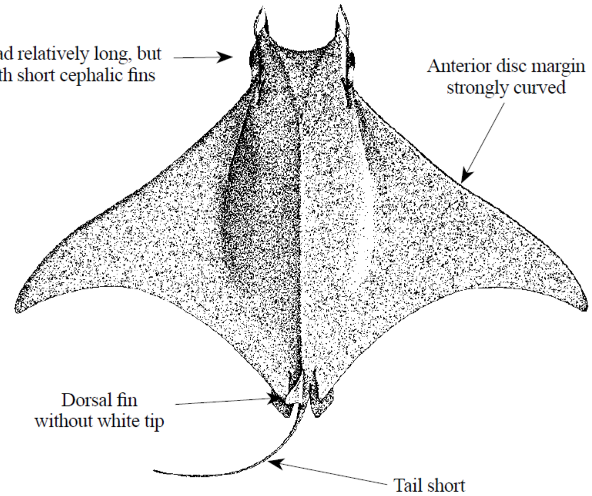


- ray with a short head and cephalic fins
- spiracles are slitlike and present above disc edge
- wing tips sharply pointed
- tail very long mostly equal or longer than disc width
- a short and serrated stinging spine is present on tail
- white tipped dorsal fin
- white colouration extends up behind eyes in ventral side

Size: To 310 cm (DW)

iii. *Mobula tarapacana* (Philippi, 1892)

- large devil ray having a long head and short cephalic fins
- strongly curved anterior disc margins
- short tail without a stinging spine
- dark area outspreading from cephalic fins posteriorly along the gill areas



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Chapter
05

Inshore Shrimps

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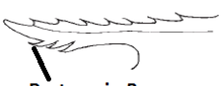
Family penaeidae includes majority of the commercial marine shrimps. There are also few species of commercial importance belonging to the families Solenoceridae, Sergestidae and Carideae. They are commercially exploited mostly by single and multiday trawlers.

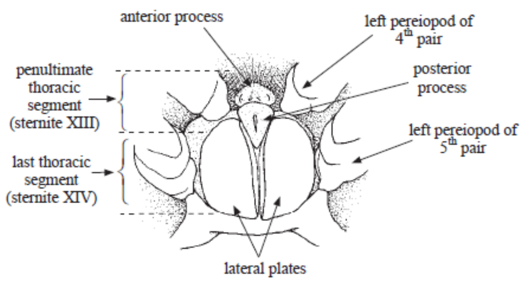
Major commercial coastal species are *Penaeus indicus, Penaeus monodon, Metapenaeus dobsoni, Penaeus semisulcatus, Metapenaeus monocoeros, Metapenaeus affinis, Penaeus canaliculatus, Penaeus japonicus, Penaeus pencillatus, Penaeus merguiensis and Parapenaeopsis stylifera.* Besides species belonging to genera *Metapenaeopsis, Trachysalambria* and *Solenocera* also form minor fishery in some maritime states. The juveniles except *P. stylifera* are caught from estuaries/backwaters using stakenets, bagnets etc. along with other fishes. They complete their life cycle in two phases- in the sea and in the estuaries/backwaters. They move to the sea from the estuaries to spawn. *P. stylifera* are stenohaline and complete their life cycle in the sea.

General characters of the commercially important genera:

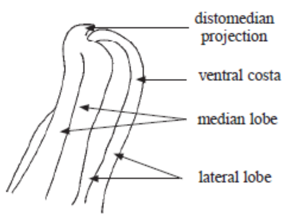
Penaeus- Rostrum serrated on dorsal and ventral margins. Hepatic carina prominent. Thelycum closed. Abdomen smooth. Petasma with ventral costa long, reaching distal margin of lateral lobe.



Rostrum in *Penaeus*



Thelycum



Petasma

Parapenaeopsis: Rostrum serrated only on dorsal margin. Telson without fixed subapical spines but with lateral movable spines. Exopod present on all pereiopods. Third pereiopod without epipod. Body slender integument thin.

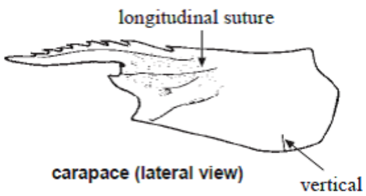
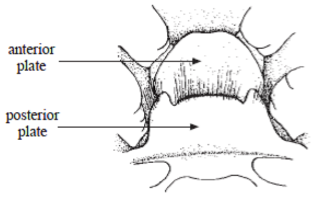
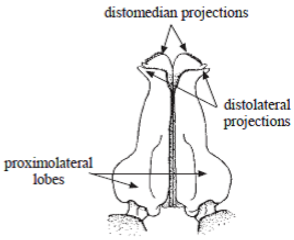


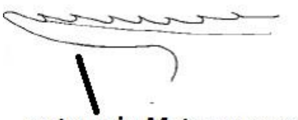
Fig. *Parapenaeopsis*



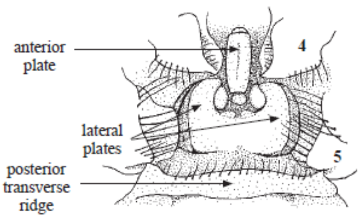


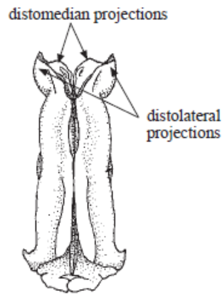
Thelycum **Petasma**

Metapenaeus: Rostrum serrated only on the dorsal margin. Telson generally without fixed subapical spine, but usually with movable lateral spines; antennular peduncle lacking parapenaeid spine. Pleurobrach present on somite XIII; exopods on maxillipeds and anterior four pairs of pereiopods; fifth pereiopod without exopod.



rostrum in *Metapenaeus*





Thelycum **Petasma**

Metapenaeopsis: Rostrum serrated only on the dorsal margin**.** Telson with two or more pairs of conspicuous spines anterior to subapical spines. Third maxilliped and second pereiopod with basial spine; petasma asymmetrical.

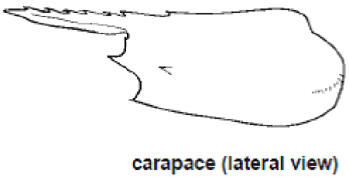
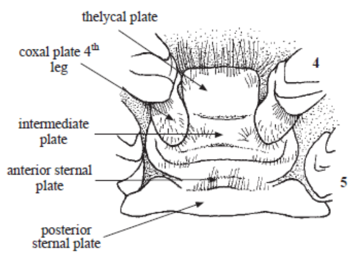
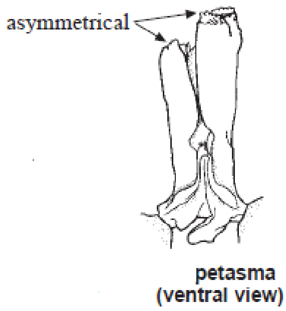


Fig. *Metapenaeopsis*





Thelycum **Petasma**

The maturity stages in these shrimps can be discerned externally through the chitinous exoskeleton and the stages are divided into five – immature (IM), early mature (EM), late mature (LM), mature (M) and spent (SP). To determine the gonado somatic index (GSI) the ovary is dissected out, weighed and GSI is calculated using the formula

GSI = Gonad weight/Weight of whole animal X 100

Size at maturity for *P. indicus* was estimated as 120 mm total length (TL), *M. dobsoni* 64 mm TL, *P. stylifera* 71 mm TL, *M. monoceros* 114 mm TL.

Penaeid shrimps have high fecundity and fecundity varies based on species, weight of ovary and size of females. In *M. monoceros* fecundity range from 49,000 to 3, 90,000. *P. stylifera* produce 35,000 to 2,39,00 eggs (88 to 115 mm total length). Fecundity in *M. dobsoni* range from 35,000 to 1,59,000.

Estimates of size or age at maturity and fecundity are crucial parameters in calculating spawning stock biomass (SSB) and spawning potential ratio (SPR) in fishery stock assessments.

For gut content analysis, the stomach is dissected out preserved in 2% formalin. It is pressed between two fingers to determine its condition – full, half, one fourth, traces or empty. From full or half filled stomach, the contents are placed in a petri dish and identified up to the lowest possible taxon, using a microscope. Penaeid shrimps are carnivorous and the different food items found in their stomach are usually crustacean remains, fish scales, semi digested matter, zooplankton.

For more information read:

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Chapter 06

Taxonomy, Biology and Distribution of Deep Sea Shrimps and Lobsters

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Shellfish systematics is the most unique one in Fisheries Science in view of its importance and implications in diversity. The systematic zoology is the science that discovers names, determines relationships, classifies and studies the evolution of living organisms. It is an important branch in biology and is considered to be one of the major subdivisions of biology having a broader base than genetics, biochemistry and physiology. The shellfish includes two highly diversified phyla i.e. phylum ***Arthropoda*** and phylum ***Mollusca***. These two groups are named as shellfishes because of the presence of ***exoskeleton made of chitin in arthropods*** and ***shells made of calcium in molluscs***. These two major phyla are ***invertebrates***. They show enormous diversity in their morphology, in the habitats they occupy and in their biology. Phylum Arthropoda includes economically important groups such as lobsters, shrimps, and crabs. Taxonomical study reveals numerous interesting phenomena in shellfish phylogeny and the study is most indispensable for the correct identification of candidate species for conservation and management of our fishery resources and aquaculture practices. On the whole taxonomic study on shellfishes furnishes the urgently needed information about species and it cultivates a way of thinking and approaching of all biological problems, which are much needed for the balance and well being of shellfish biology as a whole.

Shrimp resources are available both from inshore and from offshore waters. As the fish resource from inshore waters remained static during the last two decades, fishing pattern underwent several changes in the previous decade, leading to the exploitation of deep sea resources either with deployment of large sized vessels or modified medium/small sized vessels. Deepwater shrimps appear to have a world-wide distribution in tropical waters. They have been caught in surveys using baited traps in depths between 200 m and 800 m off continents and at 200- 500 m depth in the Indian Ocean.

Deepwater shrimps appear to have a world-wide distribution in tropical waters. They have been caught in surveys using baited traps in depths between 200 m and 800 m off continents and at 200- 500 m depth in the Indian Ocean. The deep sea prawns landed at various harbours of Kerala is an assemblage of wide array of species representing various families, the prominent being *Pandalidae, Aristeidae, Solenoceridae and Penaeidae while family Oplophoridae* contributes to only a minor portion of the deep sea trawl catches in Kerala. The deep water penaeid shrimp is an important commercial crustacean resource along the Indian coast. In recent times, the deep sea shrimps emerged as the valuable resources as high health food items both in domestic and international markets due to the presence of various essential nutrients, particularly long chain omega -3 polyunsaturated fatty acids (ω3-PUFAs)viz., eicosapentaenoic acid (EPA,20:5ω3) and docosahexaenoic acid (DHA,22:6ω3) along with essential amino acids although the structure and organization of their community are not well known as that of coastal penaeid shrimps. The pioneering works of Alcock (1901, 1906) are one of the systematic of inshore penaeid shrimps of Indian origin. Identification of these deep sea shrimps to species level by conventional taxonomy is a herculean task because of their complex morphological characters.

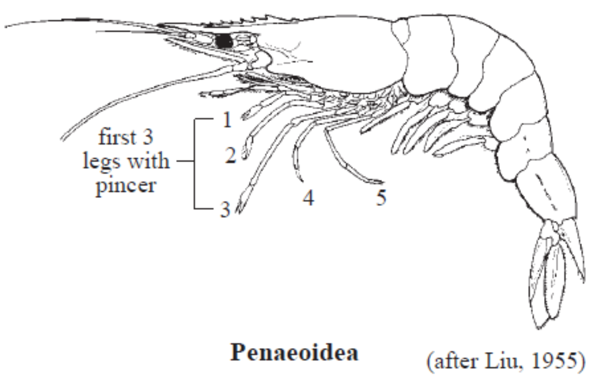
Difference between penaeid and non penaeid shrimps

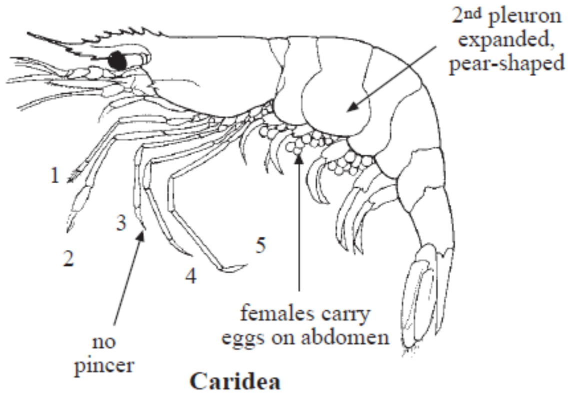
Penaeid shrimp

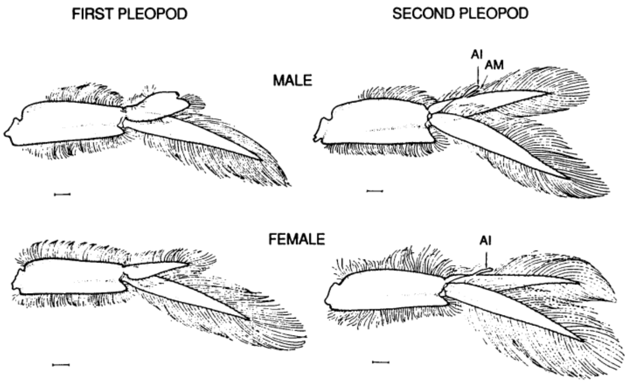
- Abdomen with posterior part of pleura covering anterior part of succeeding pleura.
- Thelycum and petasma present, eggs are released directly into water and not attached to the female

Caridean shrimp

- 2nd abdominal pleuron greatly expanded, pear shaped and overlapping posterior part of 1st pleuron and anterior part of 3rd pleuron.
- No specific copulatory organs, females carry eggs on the abdomen until hatching







Penaeid shrimps

Aristeus alcocki **Ramadan 1938,** Common name: Red ring

Family Aristeidae

Diagnostic characters: Large size red abdominal rings. Rostrum in female long and slender upper margin curved downwards till distal end of 2nd segment of antennular peduncle. Rostrum in males much shorter and seldom surpassing tip of antennular peduncle, armed with three teeth above orbit; **and no teeth on ventral side, lacks hepatic spine, upper antennular flagellum very short, Eyestalk with a tubercle.** Petasma simple, membranous, right and left halves united with each other

along the whole length of dorsomedian with a papilla-like projection directed posteromedially. Thelycum represented by a shield shaped plate directed anteroventrally bordered by an oblique ridge on either side.

Colour: Pink with reddish bands on the posterior border of all abdominal segments.

Fishery & Biology: The catches were mainly composed of females and their size ranged from 78 mm to 188 mm in total length. The size distribution showed unimodal pattern with majority in size groups 146-165 mm. The males, which were very poorly represented in the catches, were relatively smaller in size and their total length varied from 67 mm to 110 mm.

Distribution: Indian Ocean; Arabian Sea and Bay of Bengal, at depth of 350-450 m off Quillon and Alleppey.

Solenocera hextii **Wood-Mason & Alcock, 1891,** Deep sea mud shrimp

Family: Solenoceridae

Diagnostic characters: Flattened rostrum with 7 teeth on dorsal side and no teeth on ventral side of the rostrum. Post rostral carina sharp but not laminose. Antennular flagella with red and white bands. The spines on the cervical groove situated ventral to the posterior most rostral tooth which is well developed. The characteristic 'L' shaped groove on either side of the branchiostegal region is also clearly defined.

Colour: Pink to red

Distribution: Found all along the east and west coast of India at depths between 250 to 547m.

Metapenaeopsis andamanensis **(Wood-Mason, 1891),** Rice velvet shrimp

Family: *Penaeidae*

Diagnostic characters: Rostrum more or less horizontal and straight with 6 to 7 teeth on dorsal side and no teeth on the ventral side.

Lower antennular flagellum longer than the upper, much longer than the entire antennular peduncle but 0.7 times the carapace length. 3rd pereopod surpass the rostrum by the length of the entire chela. Asymmetrical petasma. 3rd maxilliped and 1st pereopod with a basal spine, distal fixed pair of spines on telson.

Colour: Pale pink to red

Fishery & Biology: The total length of males varied from 67 mm to 115 mm and that of females from 68 mm to 130 mm.

Distribution: A penaeid prawn commonly encountered in the trawl catches at all depths ranges up to 400 m and was obtained from all areas.

Caridean shrimps

Heterocarpus woodmasoni Alcock, 1901, Indian Nylon Shrimp

Family : *Pandalidae*

Diagnostic characters: Carapace with 2 longitudinal crests on each side, extending over full length of carapace – post antennal crest and branchiostegal crest. A conspicuous elevated, sharp tooth at middle of dorsal crest of 3rd abdominal segment, telson bears 5 pairs of dorsolateral spinules besides those at the tip.

Fishery & biology: Size in the catches ranged from 72 to 135 mm in total length but dominated by 111-120 mm size groups in both the sexes. The fertilized eggs on the pleopods and the head-roe are light orange and this colour stands out in contrast with the pink colour of the prawn. The berry becomes greyish in advanced stages of development.

Distribution: Andamans, Southwest coast of India, off Cochin and Alleppey at depths of 250-400 m

Heterocarpus gibbosus Bate, 1888

Humpback nylon shrimp

Diagnostic characters: The teeth on the dorsal crest and the rostrum together vary from 8 to 10. Teeth on the rostrum proper varying from 2 to 4 and 13-15 on ventral side. The dactyli of the 3 posterior legs short, median carination of the 3rd abdominal tergum is quite prominent. Carapace with 2 longitudinal crests on each side, extending over full length of carapace- post-ocular crest and branchiostegal crest. Post antennal crest very short.

Fishery & biology: The size of the individual prawn varied from 67 to 140 mm in total length and the catches were represented by all groups of the females. Males are mostly in 90-100 mm size groups. The colour of the berry is light **orange** and turns dirty grey as embryo develops.

Distribution: Southeast and Southwest coast off Cochin, off Alleppey at depths of 250-400 m. immature specimens were found in greater numbers in shallow waters while the bigger prawns seemed to prefer deeper grounds beyond 350 m.

Plesionika quasigrandis **(Chace, 1985)**

Diagnostic characters: Rostrum upturned at the tip. Rostrum is armed with 46 teeth on the dorsal side and 31 teeth on the ventral side. very long slender legs, Telson is double the length of the 5th abdominal somite. Lower antennular flagellum longer than the upper and about 5.4 times the carapace length. 3rd maxilliped extends beyond the antennal scale by the length of its dactylus. Second pereopod exceeds the tip of antennal scale by its chela and 1/8 length of carpus. Minute tubercle on the dorsal surface of the carapace at about 1/6th of its length from the hinder edge which corresponds in position to the small blunt median spine which is present in all the specimens.

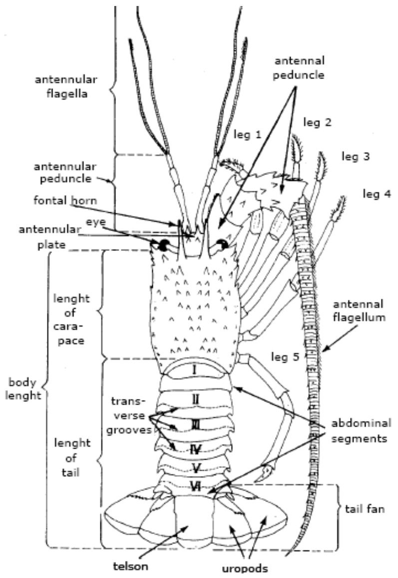
Colour: Body pale red in colour

Fishery & biology: The size of this prawn in the catches ranged from 63 to 125 mm but the size groups 95-110 mm in both sexes predominated. Berry is greenish-blue in colour with ovoid shape of fertilized eggs.

Distribution: In Indian waters this species is known to occur in south-east and south-west coast of India abundantly noticed from Quilon and Mangalore regions from the depth of 250-400 m.

Lobsters

Lobsters are among the most prized of fisheries resources and of significant commercial interest in many countries. Because of their high value and esteemed culinary worth, much attention has been paid to lobsters in biological, fisheries, and systematic literature. They have a great demand in the domestic market as a delicacy and is a foreign exchange earner for the country.



The suborder Macrura Reptantia consists of three infraorders: Astacidea (Marine lobsters and freshwater crayfishes), Palinuridea (Spiny lobsters and slipper lobsters) and Thalassinidea (mud lobsters). The infraorder Astacidea contains three super families of which only one (the Nephropoidea) is considered here. The remaining two super families (Astacoidea and parastacoidea) contain the freshwater crayfishes. The superfamily Nephropoidea (40 species) consists almost entirely of commercial or potentially commercial species.

The infraorder Palinuridea also contains three super families (Eryonoidea, Glypheoidea and Palinuroidea) all of which are marine. The Eryonoidea are deepwater species of insignificant commercial interest. The Glypheoidea includes an almost exclusively fossil group. About 120 species are included in the superfamily Palinuroidea.

The third infraorder, the Thalassinidea, contains a single superfamily, the Thalassinoidea which contains around 100 species. Only few representatives of this superfamily are known to be used as food and bait.

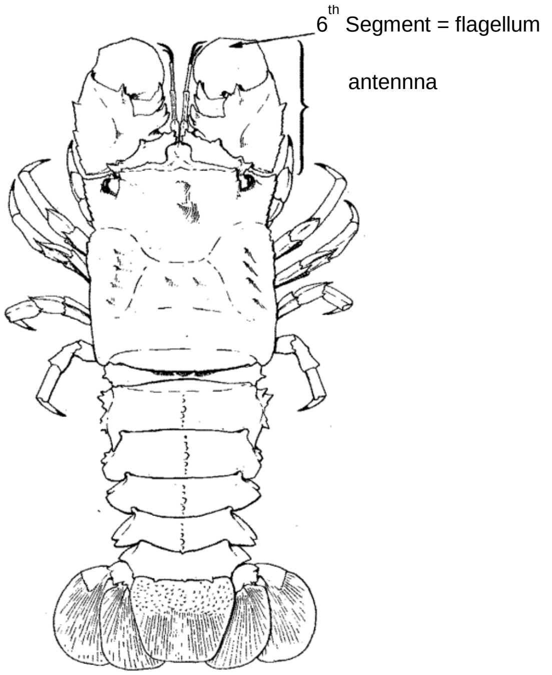
SUPERFAMILY **PALINUROIDEA** Latreille, 1802

Three families make up this superfamily, namely the Palinuridae (spiny lobsters), Synaxidae (furry lobsters) and Scyllaridae (slipper lobsters).

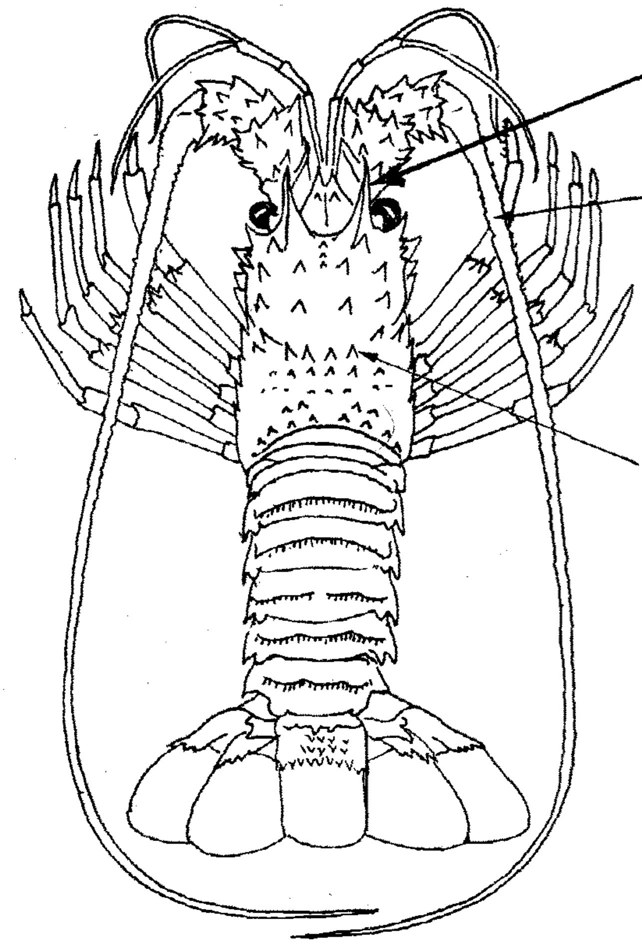
Key to families

1a. Antennal flagellum reduced to a single, flat, plate which forms the sixth and final segment of the antenna. The shovel-like appearance of the antennae is responsible for the names shovel-nose lobster and bulldozer lobster also used for the animals of this group

.... Scyllaridae



1b. Antennal flagellum long and consisting of numerous small articles, whip-like or spear-like



Panulirus homarus homarus **(Linnaeus, 1758)**

Diagnosis: Abdominal segments 2-5 with transverse grooves interrupted in the middle; minute squammae on the upper margin of the groove; antennular plate with four spines; exopod of third maxilliped absent; second maxilliped with no flagellum; olive green in specimens with minute squamae.

Distribution: The ***P. homarus homarus*** subspecies has a broad geographic range extending from East Africa to Japan including Indonesia, Australia, New Caledonia and the Marquesas Archipelago (Holthius, 1991). Northwest, southwest, southeast coast of India, A& N Islands and Lakshadweep Islands. Forms fishery along southwest and southeast coast; promising species for aquaculture

Habitat and ecology: The species is commonly found in very shallow water (1-15m), although can be found to depths of 90m. It inhabits rocky reefs for shelter (Holthius, 1991).

Biology: Maximum total length 31cm, carapace length 12cm. Average total length 20 to 25cm Major fisheries are on the southeast and southwest coast of India. The commercial fishery at Muttom, Kanyakumari district was found to be largely supported by 1st and 2nd year animals. At a given carapace length females are heavier than males. Females attain functional maturity at a carapace length (CL) of 55mm. Males attain maturity at 63mm CL on the basis of allometric growth of III walking leg. Peak breeding season is from November to December.

Panulirus ornatus (Fabricius, 1798)

Diagnosis: Abdominal somites smooth and naked; colour of abdomen brownish or greenish-grey with utmost minute indistinct speckles. The usually large eyespot in the anterior half near the base of the pleura is accompanied by an oblique pale streak placed somewhat median of the eyespot. Legs not streaked, but with very sharply defined irregular dark spots.

Distribution: Tropical Indo-Pacific; It ranges from Natal in South Africa, along the coast of East Africa and the Red sea to southern Japan, the Solomon island, Papu New Guinea, Australia, New Caledonia and Fiji (Holthius, 1991). Forms fishery along the southeast coast of India.

Habitat and ecology: In shallow, sometimes slightly turbid coastal waters; from 1 to 8m depth, with a few records from depths as great as 50m; on sandy and muddy substrates and sometimes on rocky bottom often near the mouth of rivers, but also on coral reefs. The species has been reported as solitary or as a living in pairs, but has also been found in larger concentrations.

Biology: This is the largest of the *Panulirus* species and can attain a total body length of about 50cm, but usually is much smaller (25-30cm). Mainly form fishery along the southeast coast of India. *P.ornatus* is caught both by trawlers and gillnets. *P.ornatus* forms major component of the trawler catch. *P.ornatus* appears throughout the year, but highest catch is in May at Tuticorin. The size of lobsters in the fishery ranges from 113 to 233mm TL in males and 128-452mm TL in females with 41% falling in the size range of 181-190mm TL, which are juveniles. At Tuticorin the inshore fishery for juveniles *P.ornatus* is detrimental to the stock. Occasionally found along the west coast of Kanyakumari district and form a small fishery at Tikkoti, Calicut. Occurrence of adult and egg bearing population at 40-60m depth indicated that the species breed probably at relatively deeper areas. This is a fast growing spiny lobster among the tropical species. Females mature at 90mm CL. The Fecundity in specimens caught along the Chennai coast (104.4mm to 145.1mm CL) ranges from 5,18,181 to 19,79,522 eggs.

Panulirus versicolor (Latreille, 1804)

Diagnosis: Antennular plate with 4 strong spines arranged in a quadrangle. Carapace whitish with well-defined, sharply delimited area of bluish black; antennal peduncles pink; antennal flagella white; abdominal somites 2 to 5 with white transverse bands; legs with streaks of white lines.

Distribution: This species known throughout Indian ocean (east coast of Africa and the Red sea) east to Japan, Micronesia, Melanesia, Polynesia, and northern Australia (Holthius, 1991). Along the Indian coast the species has been reported from southeast, southwest, A&N Islands and Lakshadweep.

Habitat and ecology: This species is found in areas of coral reef, most often on the seaward edge of the reef plateau, where it utilizes the reef and rocks for shelter. It is found in shallow waters to a maximum depth of 15m (Holthius, 1991). Furthermore, they are nocturnal and they only aggregate in very small numbers.

Biology: Fishery of lower magnitude reported along the Chennai, Mandapam, Trivandrum coasts. In A& N Islands, *P.versicolor* formed 26% of total landings (0.12t) in 1999-2000 *(Kumar et al., 2010)*. The fecundity of *P.versicolor* (66.0 to 95mm CL) from Chennai coast was estimated to range from 1, 70, 212 to 7, 33, 752

Puerulus sewelli **Ramadan, 1938**

Diagnosis: Median keel of carapace with 5 post-cervical and 2 or 3 intestinal teeth**.** Fifth pereopod of male not chelate

Distribution: Western Indian Ocean; Somalia, Gulf of Eden, off Pakistan, southwest (Quilon Bank, Mangalore) and southeast (off mandapam and Tuticorin, Gulf of Mannar) of India and A&N Islands.

Habitat and ecology: Known from depth between 180 and 300m on a substrate of coarse sand hard mud and shells (Holthius, 1991).

Biology: Maximum total body length 20cm, maximum carapace length about 8cm. Average total length about 15 cm. The species was commercially exploited along the southwest and southeast coast of India. A catch rate of 200-300kg/hr was reported from vessels opening off Mandapam. January to April is the peak period of abundance. During 1998-2000, 524t were landed at Sakthikulangara, Kollam, and Kerala. The sizes of *P.sewelli* ranged from 76-80mm to 176-180 TL in Males and from 81-85mm to 176-180mm in females. 26% of females were found in mature/berried stage. Due to coincidence of peak breeding and the fishery, the breeding population has been heavily exploited. The species has been overexploited and the current landing is around 2 tonnes/annum from Quilon Bank.

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Chapter 07

Marine Molluscan Fishery Resources in India - An Overview

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Molluscs are soft-bodied invertebrates belonging to the phylum Mollusca, which includes Gastropoda, Bivalvia and Cephalopoda. The remaining groups such as Monoplacophora (cap-shaped neopilinids), Polyplacophora (chitons), Scaphopoda (tuskshells), Solenogastres (crawling worm-molluscs), and Caudofoveata (shell-less burrowing worm-molluscs) are known to a much lesser extent. Brief description about the major groups of molluscs is given in Table 1.

Molluscs have been exploited for food, pearls, and shells. The estimate number of species of molluscs vary from different parts of the world, however, estimates number of existing species are about more than 1,00000 (Haszprunar and Wanninger, 2012). About 5070 species have been reported from India belonging to 290 families and 784 genera. Nearly 3,370 species of molluscs are recorded from marine habitat (Venkataraman and Wafar, 2005). Among these, gastropods are the most diverse, followed by bivalves, cephalopods, polyplacophores and scaphopods. At present over 1.5 lakh tonnes of cephalopods, over 1 lakh tonnes of bivalves and nearly 20,000 t of gastropods are exploited from Indian waters. The large number of marine gastropods (19 species) followed by bivalves (4 species) and cephalopod (1 species) has been placed in the endangered list which is a major cause of concern (Table 2). The collection, possession and trading of these scheduled molluscs (Table 2) or their products (live or dead) are prosecuted and will attract a punishment of severe imprisonment up to 7 years along with heavy fine under section 50, 51 of wildlife (Protection) Act 1972.

Table 1. Major groups of molluscs (Source: Haszprunar and Wanninger, 2012)

Gastropoda	Comprises more than 1,00000 species that inhabit all marine, freshwater and terrestrial habitats and size range from 0.5 mm to 100 cm in body length. All types of feeding habits (filter-feeders, herbivores, predators, ecto- and endoparasites, and detritovores) and all mode of reproduction are found in this group.
Bivalvia	Includes more than 20,000 extant species (1mm to over 150 cm) that live in all kinds of marine and freshwater habitats. They are not only filter feeder, but also include detritivorous and carnivorous bivalves. Some of them also use symbiotic zooxanthellae for nourishment. Most are epibenthic or burrow in soft bottoms, some burrow in limestone, wood (e.g. shipworms). Fertilization is mostly external. Trochophore, veliger and glochidia type larvae are known in this group.
Cephalopoda	Comprises only about 1,000 extant species that inhabit exclusively marine and range from 3 cm up to 7m in body length. Some members (Nautiloidea and Ammonitoidea) have external shells, while all other (Coleoidea) have internal, reduced / lost shells. All bear 8 - 10 arms (about 80 arms in Nautilus) for capturing prey. Fertilization is external.
Scaphopoda	Includes about 800 marine species of 2mm to 20 cm body length. They burrow in sand or mud and feed chiefly on foraminiferans. Fertilization is external and they have lecithotrophic (trochophore-like) larvae.
Monoplacophora	Comprises less than 30 extant species with a size range from 1-40 mm long. They inhabit from about 200 m down to 7000 m depth. Dorsal surface is protected by a single cup-shaped shell and the mode of feeding is more or less similar to those of chitons.
Polyplacophora	Includes about 1000 extant marine species with range from 3mm to 30 cm body length. Dorsal side is protected by eight serial plates. They are mostly either herbivorous or detritovorous. They have strong rasping tongue for food uptake. Fertilization is external and they have lecithotrophic (trochophore-like) larvae.
Solenogastres	Includes small marine group (280 species) of 1mm to 30 cm body length covered with cuticle with spicules or scales. They live interstitially and feed on cnidarians. The mode of reproduction is through copulation and they have lecithotrophic (modified trochophore or pericalymma - type) larvae.
Caudofoveata	Comprises small marine group (180 species) of 2mm to 15 cm body length covered with cuticle with spicules or scales. They burrow in sand or mud and lose their foot sole entirely. They have lecithotrophic (modified trochophore type) larvae.

Table 2. Scheduled marine molluscs from India

Endangered list of molluscs	
Class: Gastropoda	
1	*Cassis cornuta* (Linnaeus, 1758)
2	*Charonia tritonis* (Linnaeus, 1758)
3	*Conus milneedwardsi* Jousseaume,1894
4	*Cypraecassis rufa* (Linnaeus, 1758)
5	*Tudicla spirillus* (Linnaeus, 1767)
6	*Staphylaea limacina* (Lamarck, 1810) (= *Cypraea limacina*)
7	*Leporicypraea mappa* (Linnaeus, 1758) (= *Cypraea mappa*)
8	*Talparia talpa* (Linnaeus, 1758) (= *Cypraea talpa*)
9	*Pleuroploca trapezium* (Linnaeus, 1758) (= *Fasciolaria trapezium*)
10	*Harpulina arausiaca* (Lightfoot, 1786)
11	*Dolomena plicata sibbaldi* (G.B. Sowerby II, 1842) (= *Strombus plicatus sibbaldi*)
12	*Ophioglossolambis digitata* (Perry, 1811) (= *Lambis crocea*)
13	*Lambis millepeda* (Linnaeus, 1758)
14	*Lambis scorpius* (Linnaeus, 1758)
15	*Lambis truncata* ([Lightfoot],1786)
16	*Harpago chiragra* (Linnaeus, 1758) (= *Lambis chiragra*)
17	*Harpago arthriticus* (Roding 1798) (= *Lambis chiragra arthritica*)
18	*Rochia nilotica* (Linnaeus,1767) (= *Trochus niloticus*)
19	*Turbo marmoratus* Linnaeus, 1758
Class: Bivalvia	
1	*Hippopus hippopus* (Linnaeus, 1758)
2	*Tridacna maxima* (Roding, 1798)
3	*Tridacna squamosa* Lamarck, 1819
4	*Placuna placenta* (Linnaeus, 1758)
Class:Cephalopoda	
1	*Nautilus pompilius* Linnaeus, 1758

Commercially exploited molluscs of India

Cephalopods

Squids, cuttlefishes and octopuses are the three groups of cephalopods exploited from Indian seas (Table 3). The main species occurring in commercial catches are *Uroteuthis*

(Photololigo) duvaucelii (= *Loligo duvauceli*), *Sepia pharaonis*, *S. aculeata* and *Amphioctopus neglectus* (= *Octopus membranaceous*).

Table 3. Commercially exploited cephalopods from Indian Seas (Source: Mohamed and Venkatesan, 2017)

Species	Common Name	Distribution
Squids		
Uroteuthis (P.) duvaucelii	Indian squid	All along Indian coast
Loliolus (N) uyii	Little squid	Chennai & Visakhapatnam
U (P) edulis	Swordtip squid	SW coast
U (P) singhalensis	Long barrel squid	SW & SE coast
Loliolus (L) hardwickei	Little Indian squid	All along Indian coast
Sepioteuthis lessoniana	Palk Bay squid	Palk Bay & Gulf of Mannar
Sthenoteuthis oualaniensis	Purple-back Flying squid	Oceanic Indian EEZ
Thysanoteuthis rhombus	Diamond squid	Oceanic Indian EEZ
Cuttlefishes		
Sepia pharaonis	Pharaoh cuttlefish	All along Indian coast
S. aculeata	Needle cuttlefish	All along Indian coast
S. elliptica	Golden cuttlefish	Veraval & Kochi
S. prashadi	Hooded cuttlefish	SW & SE coast
S. brevimana	Shortclub cuttlefish	Chennai & Visakhapatnam
Sepiella inermis	Spineless cuttlefish	All along Indian coast
Octopuses		
Amphioctopus neglectus	Webfoot octopus	SW & SE coast and islands
A. marginatus	Veined octopus	SW & SE coast and islands
A. aegina	Marbled Octopus	SW & SE coast and islands
O. lobensis	Lobed octopus	SW & SE coast and islands
O. vulgaris	Common octopus	SW & SE coast and islands
Cistopus indicus	Old woman octopus	SW & SE coast and islands

Bivalves

Clams, oysters, mussels, and windowpane oysters are the various groups of bivalves exploited along the Indian coast for food and shells (Table 4).

Table 4. Commercial important bivalves of India

Resource	Common name
Clams and cockles	
Villorita cyprinoides	Black clam
Paphia malabarica, Paphia sp	Short neck clam, textile clam
Meretrix casta, Meretrix meretrix	Yellow clam
Mercia opima	Baby clam
Mesodesma glabaratum	
Sunetta scripta	Marine clam
Donax sp	Surf clam
Geloina bengalensis	Big black clam
Tegillarca granosa (= Anadara granosa)	Cockle
Placuna placenta	Window pane oyster
Tridacna sp, Hippopus hippopus	Giant clam
Mussel	
Perna viridis	Green mussel
Perna indica	Brown mussel
Pearl oyster	
Pinctada fucata	Indian pearl oyster
Pinctada margaritifera	Blacklip pearl oyster
Edible oyster	
Crassostrea madrasensis	Indian backwater oyster
Saccostrea cucullata	Rock oyster

Molluscan Fisheries in India

Cephalopods are the most important group of molluscs with estimated all India production of about 2, 61,663 tonnes in 2017 which was 11.6 % more compared to the previous year. They are landed either as by-catch or as a targeted fishery. Targeted fishery is mostly carried out in mechanized trawlers operating up to 200 m depth, and beyond in some areas.

Bivalve fishery is the next in importance and fishing is practiced in limited extent mostly at a subsistence level in various estuaries and coastal seas. Clams and cockles contribute 73.8%, followed by oysters (12.5%), mussels (7.5%) and windowpane oysters (6.2%) (Mohamed and Venkatesan, 2017). The annual average clam production is about 57,000 t, oysters about 18,800 t, and marine mussels about 14,900 t (Mohamed and Venkatesan, 2017). At present, there was no fishery for marine pearl oysters, but it was the major fisheries before 1962 in the Gulf of

Mannar area. Scallops occur in certain area in stray numbers and do not contribute in fishery, whereas the windowpane oyster formed considerable fishery till a few year back (Mohamed and Venkatesan, 2017).

Gastropods in India are exploited for both as food and as curios. Among gastropods, the sacred chank is most important with annual production of over 1,000 t till a few years back (Mohamed and Venkatesan, 2017). The fishing of top shell *viz.,* *Rochia nilotica* and *Turbo marmoratus* has been banned as they have been declared as endangered. One species of Abalone *viz.,* *Haliotis varia* occur in stray numbers and are not fished. Mining for subsoil shell deposits was carried out from time immemorial especially in the Ashtamudi and Pulicat Lakes for industrial purposes.

Mollusc biology

Molluscs are extremely large group and diverse in all phases of life. They occur in all marine habitats of the world including deep-sea hydrothermal vents, freshwater environments up to 40° C, land (gastropod alone) and permanent ice (Haszprunar and Wanninger, 2012). They range in size from 0.4 mm (omalogyrid gastropods) to more than 15 m (*Architeuthis* squids) (Haszprunar and Wanninger, 2012). Their longevity can range from a few months to up to more than 150 years (Deep sea giant bivalves) (Haszprunar and Wanninger, 2012). They mostly crawl or glide through cilia or muscle waves with mucous (Haszprunar and Wanninger, 2012). Some animals can permanently cement to the substrate, such as giant clam and edible oyster while some can attach to the substrate through byssus thread such as mussels. Modes of feeding are also diverse including filter feeders, omnivores, predators, grazers, detritovores, ecto- and endoparasites, and various kinds of symbioses with bacteria, plankton (Zooxanthellae), and algae.

The body of theoretical molluscs comprises five fundamental parts – the foot, the head, the visceral mass, the mantle and the shell. The alimentary tract or system of theoretical molluscs consists of ingestion, digestion, absorbtion and assimilation of food. The system starts with mouth which leads to the buccal cavity having pair of jaws in each side. Pharynx, located at the anterior of the buccal cavity, is occupied by the *odontophore* which supports the tongue like structure called *radula*. Ducts from one or two pairs of salivary glands are present at the anterior of pharynx which in some species (*Conus* sp) are modified into organs to secret venom used to paralyze or kill the prey. The tract goes on with the esophagus and then enlarges in a stomach where the food has been partially digested as threads of particles linked together by mucus. Food is mostly digested in the ducts of two large digestive glands by tiny cilia (whip like structure). These digestive glands occupy almost all the space within the visceral mass. Digestion of molluscs takes place both extracellularly and intracellularly. Extracellular digestion occurs especially in the stomach while, intracellular digestion takes place especially in the hepatopancreas. These organs (stomach /hepatopancreas) do the dual functions – secretion of digestive enzymes and absorption of food particles. The structure of posterior portion of the stomach is conical in many molluscs and a translucent rod shape in bivalves. This structure is known as *crystalline style* which secrets enzymes to digest certain carbohydrates. After the stomach comes the intestine which opens at the anus into the pallial cavity.

Circulatory system in molluscs is open except cephalopods. Heart, made up of two dorsal auricles/atria and a single ventricle, gets only oxygenated blood from gills and send it to different regions of the body through posterior aorta. Blood/hemolymph transport through blood vessels directly to the openings or spaces between the organs. Respiratory pigments in molluscs are of two main types *viz.,* red hemoglobin and blue, copper containing hemocyanin.

Excretory system removes the waste materials that are formed from the breakdown of assimilated food chiefly nitrogenous waste such as ammonia and urea. This function is carried out by one or more kidneys which are diverse in the various groups of molluscs. In primitive group, these organs are linked to the pericardial cavity and at least one of the excretory passages is modified to form a gonoduct for transfer of gametes. Excretory system opens into the pallial chamber. Pallial chamber is also an important structure which mediates between the animal and its external environment.

Respiratory system in molluscs is generally formed by the pair of gills in the pallial chamber. However, most of the gastropods have single gill. Gills are the site of gas exchange and look like a feather, with a central axis. Gills are of different forms in different group of the molluscs depending on their environment and feeding habits. Land snails do not possess gills instead they have primitive form of lung.

Molluscs show various mode of reproduction. Most of them are either gonochoristic or hermaphroditic. Percentage of gonochoristic and hermaphroditic species are more or less equal (Haszprunar and Wanninger, 2012). Few of them occasionally show parthenogenesis. Majority of the molluscs, especially gastropods and cephalopods transfer sperm by means of copulatory organs, whereas, many species, especially gastropods, scaphopods and chitons shed their gametes liberally into the water. Their egg sizes range from about 80 μm (many bivalves and gastropods) to 2 cm (*Nautilus* spp) (Haszprunar and Wanninger, 2012).

Larvae of them are either intracapsular or direct development into miniature form or planktotrophic or lecithotrophic. Larvae may look different from adult form. Typical molluscan larvae are veligers which are usually more or less modified form of Trochophore larvae. Example of special type of larvae is glochidium of freshwater unionoids which is well known as parasite on fish gills.

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Chapter

08

Molluscan Biology and Taxonomy

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The molluscs belong to the large and diverse phylum Mollusca, which includes a variety of soft-bodied invertebrates well-known as decorative shells or as seafood. They range in size from less than 1 mm to more than 15 m (for example the giant squid) and their population density may exceed 40,000/m^2 in some areas. Three classes of the phylum Mollusca namely, Gastropoda (snails, limpets, whelks and slugs), Bivalvia (oysters, mussels, clams, scallops, and cockles) and Cephalopoda (squids, cuttlefishes, and octopuses) are of fisheries interest. About 3270 species have been reported from India belonging to 220 families and 591 genera. Among these the bivalves are the most diverse (1100 species) followed by cephalopods (210 species), gastropods (190 species), polyplacophores (41 species) and scaphopods (20 species).

Commercially exploited molluscs of India

Cephalopods

Three groups of cephalopods viz., Squids (order Teuthoidea), Cuttlefishes (order Sepiiodea) and Octopuses (order Octopodidea), are exploited from Indian seas (Table 1). The main species occurring in commercial catches are *Uroteuthis (Photololigo) duvaucelii* (= *Loligo duvauceli*), *Sepia pharaonis, S. aculeata* and *Amphioctopus neglectus (= Octopus membranaceous)*

Cephalopod Taxonomy

Cephalopods are found to occur in all the oceans of the world from the tropics to the polar seas and at all depths ranging from the surface to below 5000 m. Chambered nautilus, cuttlefishes, squids and octopus are the four major groups of cephalopods, which belong to the highly evolved class of phylum Mollusca. Cephalopods are the third largest molluscan class after bivalves and gastropods and consist of more than 800 species (Lindgren et al., 2004). Of these less than a hundred species are of commercial importance. About 210 species cephalopods have been reported from India. There are about 80 species of cephalopods of commercial and scientific interest distributed in the Indian Seas.

Table 1. Commercially exploited cephalopods from Indian Seas

Species	Common Name	Distribution
Squids		
Uroteuthis (P.) duvaucelii	Indian squid	All along Indian coast
Loliolus (N) uyii	Little squid	Chennai & Visakhapatnam
U (P) edulis	Swordtip squid	SW coast
U (P) singhalensis	Long barrel squid	SW & SE coast
Loliolus (L) hardwickei	Little Indian squid	All along Indian coast
Sepioteuthis lessoniana	Palk Bay squid	Palk Bay & Gulf of Mannar
Sthenoteuthis oualaniensis	Purple-back Flying squid	Oceanic Indian EEZ
Thysanoteuthis rhombus	Diamond squid	Oceanic Indian EEZ
Cuttlefishes		
Sepia pharaonis	Pharaoh cuttlefish	All along Indian coast
S. aculeata	Needle cuttlefish	All along Indian coast
S. elliptica	Golden cuttlefish	Veraval & Kochi
S. prashadi	Hooded cuttlefish	SW & SE coast
S. brevimana	Shortclub cuttlefish	Chennai & Visakhapatnam
Sepiella inermis	Spineless cuttlefish	All along Indian coast
Octopuses		
Amphioctopus neglectus	Webfoot octopus	SW & SE coast and islands
A. marginatus	Veined octopus	SW & SE coast and islands
A. aegina	Marbled Octopus	SW & SE coast and islands
O. lobensis	Lobed octopus	SW & SE coast and islands
O. vulgaris	Common octopus	SW & SE coast and islands
Cistopus indicus	Old woman octopus	SW & SE coast and islands

Subclass Nautiloidea

Shell complete external, smooth, coiled and chambered, more than 10 (63 - 94) circumoral appendages without suckers, a funnel bilobed, two pairs of gills, and the absence of an ink sac.

Family Nautilidae

The ''chambered or pearly nautiluses '' comprises single family and genus and six species. They have approximately 100 suckers-less tentacles, simple eye without lenses, and thick rigid hood used to protect the animal when retracted within the shell.

Subclass Coleoidea

This subclass includes all living cephalopods – squids, cuttlefish and octopuses, other than chambered nautiluses. Key diagnostic characters are shell internal, calcareous, chitinous or cartilaginous, 8-10 circumoral appendages with suckers, only one pair of gills (dibranchiate) and funnel tube-like.

Order Teuthoidea

This order contains the squids, characterized by internal shell (gladius or pen) chitinous feather or rod shaped, eight arms; two contractile but not retractile, pocket absent, tentacles lost secondarily in some, fin on the mantle and stalked suckers with or without chitinous hooks, with horny rings and constricted necks; fin lobes fused posteriorly. Eyes either covered or open and without supplementary eyelid.

Suborder Myopsida

Myopsid squids are characterized by eyes entirely covered by a transparent corneal membrane. Eye cavity communicates with the exterior through a tiny hole. Arms and tentacles have suckers only, no hooks. Mantle locking apparatus is simple (linear) and the gladius is pen-like.

Suborder Oegopsida

Oegopsid squids (Oceanic squid or Open-eyed squids) are characterized by eyes not covered with a corneal membrane and open to the surrounding medium, arms and tentacles bear suckers and / or hooks. Mantle locking apparatus ranges from simple too complex to fused.

Family Loliginidae

***Sepioteuthis lessoniana* (Ferussac in Lesson, 1831)**

Body elongate, cylindrical in outline; fins marginal, wide and muscular, very long almost running along entire length of mantle; elliptical in shape.

***Uroteuthis (Photololigo) duvaucelii* (Orbigny, 1835)**

Body elongate, mid-rib of gladius clearly visible through mantle skin; fin length in adults up to 60 per cent of mantle length; tentacular clubs large median manal sucker ring with 14 – 17 teeth; Arm sucker rings with broad, large, square teeth (5 to 9) on the distal margin; in males, more than half the length (up to 75 %) of the left ventral arm hectocotylized, papillae not fused.

***U. (P.) sibogae* (Adam, 1954)**

Mantle long, narrow and slender, no ridge but chromatophore concentration ventrally along midline; fins narrow and less than 60 per cent of mantle length; less than half of left ventral arm hectocotylized distally in males; gladius narrow, sharply accumulate posteriorly.

***U. (P.) singhalensis* (Ortmann, 1891)**

Mantle is long, slender, cylindrical, and it tapers posteriorly into as sharply-pointed tip. Mantle bout 4-7 times as long as wide. Mantle with a ridge along midline in males; the tentacles are short and slender. Clubs are rather short. Left ventral arm IV is hectocotylized distally in mature males for 40 - 45% of its length. The chitinous sucker rings are smooth or wavy proximally, while the distal margin bears 6-11 (most commonly 9) plate-like, truncate, squared teeth.

***U. (P.) edulis* (Hoyle, 1885)**

Mantle more or less stout, elongate and slender. Fins large, rhombic with the anterior margin slightly convex, the posterior margin gently concave and the lateral angles rounded. Fins become slightly longer than wide in adult specimens (up to 70% of mantle length), Gladius long, somewhat narrow, Arms somewhat long (25- 45% of mantle). More than half of left ventral arm hectocotylized distally in males.

U. (P.) chinensis **(Gray, 1849)**

Fin length in adults greater than 60% of mantle length. Hectocotylized portion of the left arm IV from 33% to 50% of total arm length. Arm sucker rings with 10-15 stout, pointed, conical teeth distally, the proximal margin smooth; occasionally with rudimentary teeth only. Although the record of this species along the Indian east coast is available in the literature, this species is not recorded in the cephalopod samples of Institute.

Loliolus (Loliolus) hardwickei **(Gray, 1849)**

Small squids. Mantle length of adults less than 60 mm; fins heart shaped; vane of gladius conspicuously broad at midlength.

Loliolus (Nipponololigo) uyii **(Wakiya and Ishikawa, 1921)**

Body short and stout; mid rib of gladius clearly visible through dorsal mantle skin as a median dark line; fins 55-65 per cent of mantle length; Tentacular clubs have median manal suckers with smooth rings; in males left ventral arm hectocotylized almost the entire arm; papillae on ventral margin fused with membrane.

L. (N.) sumatrensis **(D'Orbigny, 1835)**

Body short, sub-cylindrical, gradually decrease in width posteriorly to blunt point, head small with large eyes; fins 60-65% of mantle length; fin rhomboidal in shape; arm sucker ring with 6-9 broad, squared teeth; in male left ventral arm hectocotylized up to 87%.

Onychoteuthidae

Onchoteuthis banksii **(Leach, 1817)**

Oceanic squids with muscular body; head with nuchal folds on the dorsal side at posterior end; rachis of gladius visible as a longitudinal ridge middorsally along the entire length of mantle; tentacular clubs with two rows of hooks, marginal suckers lacking.

Thysanoteuthidae

Thysanoteuthis rhombus **Troschel, 1857**

Funnel locking cartilage shaped consisting of a narrow longitudinal groove and a short transverse groove branching from it medially. Fins broad and rhombus-shaped occupying nearly entire length of mantle.

Ommastrephidae

***Sthenoteuthis oualaniensis* (Lesson, 1830)**

Funnel and mantle cartilages of the locking apparatus fused together. An oval photophoric patch present middorsally near anterior margin of mantle; muscle of mantle ventrally without embedded light organs; two intestinal photophores present.

Order Sepioidea

This order includes the cuttlefishes, characterized by an oval body shape, compressed dorsoventrally and framed along both sides of the body by narrow fins that do not attach at the posterior end. The arms bear 2 to 4 rows of suckers. The tentacles are totally retractile into pockets. The internal shell, cuttlebone (calcareous) lies dorsally in the body below the skin. The shell is oval in shape, thick, containing several gas and water filled chambers for buoyancy control.

Family Sepiidae

Small to medium- sized animals characterized by an oval body; flattened dorsoventrally, calcareous internal shell, head free from dorsal mantle, Fins marginal and narrow, light organ absent.

Family Sepiolidae

Small animals characterized by saccular body, wide, round bottomed; fins circular; internal shell lacking; dorsal mantle and head united by a nuchal commissure; saddle- shaped light organ present on ink sac.

Genus Sepia

Body without a glandular pore at posterior extremity; cuttlebone mostly with a spine (rostrum) at posterior end.

***Sepiella inermis* (Van Hasselt, 1835) (in Ferussac and d' Orbigny, 1834 – 1848**)

Body with a distinct glandular pore at posterior extremely on ventral side; with brownish fluid oozing out; cuttlebone devoid of spine.

***Sepia pharaonis* (Ehrenberg, 1831)**

Body robust, fins broad commencing from edge of anterior mantle margin; tentacular clubs moderately long and well expanded; 5 or 6 suckers in middle row of manus greatly enlarged; cuttlebone broad, thick and with a midventral flattening anteriorly in striated area; inner cone forms a conspicuous yellow flat ledge; a sharp thick spine present; when alive, body brownish, tiger-stripe pattern prominent.

***Sepia aculeata* (Van Hasselt, 1835) (in Ferussac and d' Orbigny, 1834 – 1848)**

Tentacular clubs very long, with 10-14 rows of minute sub-equal suckers. Cuttlebone broad and thick with a median longitudinal edge with a faint groove running medially on striated area; inner cone forms a ledge-like callosity.

***Sepia prashadi* (Winckworth, 1936)**

Body not robust, fin narrow commencing a few mm behind edge of anterior mantle margin; tentacular clubs short, expanded; not more than 3 suckers in middle row of manus greatly enlarged; cuttlebone narrow, midventral groove narrow and distinct, striae anteriorly broadly truncate with lateral corners slightly produced forward; dorsal surface pinkish in colour, a sharp thin spine present; When alive, dusty brownish, transverse stripes less distinct.

***Sepia elliptica* (Hoyle, 1885)**

Tentacular clubs moderately long, with 10 rows of small suckers of uniform size. Cuttlebone thin, elliptical in shape, dorsal surface smooth; two conspicuous lateral ridges more prominent anteriorly resulting in three longitudinal furrows in striated area; spine thick, sharp, long and well curved.

***Sepia trygonina* (Rochebrune, 1884)**

No fleshy projections on head; fins extend upto end of mantle; tentacles with short clubs, suckers in eight rows, about five in third row enlarged. Cuttlebone lanceolite with acuminate anterior tip with edges of outer cone winged giving an arrow head appearance; spine small.

Sepia brevimana **(Steenstrup, 1875)**

Tentacular club short with 6-8 small subequal suckers. Cuttlebone flat and distinctly acuminate anteriorly, dorsal surface rugose, a shallow median groove in the striated area, the striae with a median shallow groove broadening anteriorly; inner cone and its limbs pinkish in colour; spine small, sharp and slightly curved.

Onychoteuthidae

Onchoteuthis banksii **(Leach, 1817)**

Oceanic squids with muscular body; head with nuchal folds on the dorsal side at posterior end; rachis of gladius visible as a longitudinal ridge middorsally along the entire length of mantle; tentacular clubs with two rows of hooks, marginal suckers lacking.

Thysanoteuthidae

Thysanoteuthis rhombus **(Troschel, 1857)**

Funnel locking cartilage shaped consisting of a narrow longitudinal groove and a short transverse groove branching from it medially. Fins broad and rhombus-shaped occupying nearly entire length of mantle.

Ommastrephidae

Sthenoteuthis oualaniensis **(Lesson, 1830)**

Funnel and mantle cartilages of the locking apparatus fused together. An oval photophoric patch present middorsally near anterior margin of mantle; muscle of mantle ventrally without embedded light organs; two intestinal photophores present.

Order Octopoda

This order includes all octopuses, described by eight arms with 1 or 2 rows of suckers. Most species have web sectors between the arms.

Sub-order Cirrata

Finned or Cirrate octopods are deep sea octopuses characterized by round to tongue- like fins on the mantle and single rows of suckers interspersed by cirri. Mantle aperture is very narrow. Only the left oviduct is developed

Sub-order Incirrata

Incirrate octopuses are characterize by fins lacking, and have 1 or 2 rows of suckers and no cirri.

Family Argonautidae

This family of pelagic octopuses is known as paper nautiluses or Argonauts, the females of which secrete an external shell. This calcareous external shell is brittle and white in colour with fine corrugations. The male is much smaller than the female. Male lacks the external shell and possesses a large modified third left arm which is detached during mating.

Family Octopodidae

This family includes tiny to very large benthic octopuses characterized by eight arms with 1 or 2 rows of sessile suckers and modified third right arm in males, without an external shell; internal shell either vestigial or lacking; no great disparity between males and females in size.

Amphioctopus aegina **(Gray, 1849)**

Eyes prominent; a single large cirrus posterior to each eye. Ligula small, 5 to 8 per cent of arm; with shallow groove; penis and diverticulum together form U-shaped loop; spermatophores long and unarmed.

Amphioctopus neglectus **(Nateewathana and Norman, 1999)**

Medium-sized species characterized by elongate and ovoid body, U-shaped iridescent transverse bar on the head between the eyes, Dark ocellus including blue ring present at base of 2nd and 3rd arm pair, Head relatively wider in males than in female, 1 or 2 papillae present over each eye. Ligula long and slender.

Cistopus indicus **(Rapp, 1835 in Ferussac and d' Orbigny, 1834 – 1848)**

Hectocotylized arm only slightly modified, ligula small about 3 per cent of arm. Small water pores leading to embedded pouches between bases of arms.

Haplochlaena maculosa **(Hoyle, 1883)**

Body globular smaller in size; skin smooth without reticulate pattern; white fresh dusty brown in colour with prominent bluish rings on mantle, head, web and arms.

Systematic position of potentially important cephalopods of India

Class	CEPHALOPODA	
Sub class	NAUTILOIDEA	
Family	Nautilidae	*Nautilus pompilius*
Subclass	COLEOIDEA	
Order	TEUTHOIDEA	
Suborder	Myopsida	
Family	Loliginidae	
Genus	*Uroteuthis*	*Uroteuthis (Photololigo) duvaucelii*
		U (P) sibogæ
		U (P) singhalensis
		U (P) edulis
		U (P) chinensis
Genus	*Sepioteuthis*	*Sepioteuthis lessoniana*
Genus	*Loliolus*	*Loliolus (Loliolus) hardwickei*
		Loliolus (Nipponololigo) uyii
		L (N) sumatrensis

Suborder	Oegopsida	
Family	Onychoteuthidae	
Genus	*Onchoteuthis*	*Onchoteuthis banksii*
Family	Ommastrephidae	
Subfamily	Ommastrephinae	
Genus	*Sthenoteuthis*	*Sthenoteuthis oualaniensis*
Family	Thysanoteuthidae	
Genus	*Thysanoteuthis*	*Thysanoteuthis rhombus*
Order	SEPIODIDAE	
Family	Sepiidae	
Genus	*Sepia*	*Sepia pharaonis*
		Sepia aculeata
		Sepia prashadi
		Sepia elliptica
		Sepia trygonina
		Sepia brevimana
		Sepia arabica
		Sepia kobiensis
		Sepia prabahari
		Sepia ramani
		Sepia omani
Genus	*Sepiella*	*Sepiella inermis*
Family	Sepiolidae	
Genus	*Euprymna*	*Euprymna stenodactyla*

Order	OCTOPODA	
Suborder	Incirrata	
Family	Octopodidae	
Genus	*Amphioctopus*	*Amphioctopus aegina*
		Amphioctopus neglectus
		Amphioctopus marginatus
		Amphioctopus rex
Genus	*Cistopus*	*Cistopus indicus*
		Cistopus taiwanicus
Genus	*Haplochlaena*	*Haplochlaena maculosa*
Genus	*Callistoctopus*	*Callistoctopus luteus*
Genus	*Octopus*	*Octopus vulgaris*
Genus	*Pteroctopus*	*Pteroctopus keralensis*
Family	Argonautidae	
Genus	*Argonauta*	*Argonauta hians*
		Argonauta argo

Bivalves

Various groups of bivalves such as clams, oysters, mussels, and windowpane oysters are exploited along the Indian coast for food and shells (Table 2).

Table2. Commercial important bivalves of India

Resource	Common name
Clams and cockles	
Villorita cyprinoides	Black clam
Paphia malabarica, Paphia sp	Short neck clam, textile clam
Meretrix casta, Meretrix meretrix	Yellow clam
Mercia opima	Baby clam
Mesodesma glabaratum	
Sunetta scripta	Marine clam
Donax sp	Surf clam
Geloina bengalensis	Big black clam
Tegillarca granosa (= Anadara granosa)	Cockle
Placuna placenta	Window pane oyster
Tridacna sp, Hippopus hippopus	Giant clam
Mussel	
Perna viridis	Green mussel
Perna indica	Brown mussel
Pearl oyster	
Pinctada fucata	Indian pearl oyster
Pinctada margaritifera	Blacklip pearl oyster
Edible oyster	
Crassostrea madrasensis	Indian backwater oyster
Saccostrea cucullata	Rock oyster

Biology of Molluscs

Molluscs are extremely large group and diverse in all phases of life. They occur in all marine habitats of the world including deep-sea hydrothermal vents, freshwater environments upto 40° C, land (gastropod alone) and permanent ice (Haszprunar and Wanninger, 2012). They range in size from 0.4 mm (omalogyrid gastropods) to more than 15 m (Architeuthis squids) (Haszprunar and Wanninger, 2012). Their longevity can range from a few months to up to more than 150 years (Deep sea giant bivalves) (Haszprunar and Wanninger, 2012). They mostly crawl or glide through cilia or muscle waves with mucous (Haszprunar and Wanninger, 2012). Some animals can permanently cement to the substrate, such as giant clam and edible oyster while some can attach to the substrate through byssus thread such as mussels. Modes of feeding are also diverse including filter feeders, omnivores, predators, grazers, detritovores, ecto- and endoparasites, and various kinds of symbioses with bacteria, plankton (Zooxanthellae), and algae.

The body of theoretical molluscs comprises five fundamental parts – the foot, the head, the visceral mass, the mantle and the shell. The alimentary tract or system of theoretical mollusks consists of ingestion, digestion, absorbtion and assimilation of food. The system starts with mouth which leads to the buccal cavity having pair of jaws in each side. Pharynx, located at the anterior of the buccal cavity, is occupied by the odontophore which supports the tongue like structure called radula. Ducts from one or two pairs of salivary glands are present at the anterior of pharynx which in some species (*Conus* sp) are modified into organs to secret venom used to paralyze or kill the prey. The tract goes on with the esophagus and then enlarges in a stomach where the food has been partially digested as threads of particles linked together by mucus. Food is mostly digested in the ducts of two large digestive glands by tiny cilia (whiplike structure). These digestive glands occupy almost all the space within the visceral mass. Digestion of molluscs takes place both extracellularly and intracellularly. Extracellular digestion occurs especially in the stomach while, intracellular digestion takes place especially in the hepatopancreas. These organs (stomach / hepatopancreas) do the dual functions – secretion of digestive enzymes and absorption of food particles. The structure of posterior portion of the stomach is conical in many molluscs and a translucent rod shape in bivalves. This structure is known as crystalline style which secrets enzymes to digest certain carbohydrates. After the stomach comes the intestine which opens at the anus into the pallial cavity.

Circulatory system in molluscs is open except cephalopods. Heart, made up of two dorsal auricles/atria and a single ventricle, gets only oxygenated blood from gills and send it to different regions of the body through posterior aorta. Blood/hemolymph transport through blood vessels directly to the openings or spaces between the organs. Respiratory pigments in molluscs are of two main types' viz., red hemoglobin and blue, copper containing hemocyanin. Excretory system removes the waste materials that are formed from the breakdown of assimilated food chiefly nitrogenous waste such as ammonia and urea. This function is carried out by one or more kidneys which are diverse in the various groups of molluscs. In primitive group, these organs are linked to the pericardial cavity and at least one of the excretory passages is modified to form a gonoduct for transfer of gametes. Excretory system opens into the pallial chamber. Pallial chamber is also an important structure which mediates between the animal and its external environment.

Respiratory system in molluscs is generally formed by the pair of gills in the pallial chamber. However, most of the gastropods have single gill. Gills are the site of gas exchange and look like a feather, with a central axis. Gills are of different forms in different group of the molluscs depending on their environment and feeding habits. Land snails do not possess gills instead they have primitive form of lung.

Molluscs show various mode of reproduction. Most of them are either gonochoristic or hermaphroditic. Percentage of gonochoristic and hermaphroditic species are more or less equal (Haszprunar and Wanninger, 2012). Few of them occasionally show parthenogenesis. Majority of the molluscs, especially gastropods and cephalopods transfer sperm by means of copulatory organs, whereas, many species, especially gastropods, scaphopods and chitons shed their gametes liberally into the water. Their egg sizes range from about 80 µm (many bivalves and gastropods) to 2 cm (Nautilus spp) (Haszprunar and Wanninger, 2012).

Larvae of them are either intracapsular or direct development into miniature form or planktotrophic or lecithotrophic. Larvae may look different from adult form. Typical molluscan larvae are veligers which are usually more or less modified form of Trochophore larvae. Example of special type of larvae is glochidium of freshwater unionoids which is well known as parasite on fish gills.

Biology of commercially important cephalopods

All cephalopods are active predators that feed on live prey, mainly fishes and crustaceans. Fish always occurs in the diet of squid U.(P.) duvaucelii of all sizes (Mohamed and Joseph, 2005). The fondness of crustacean diet diminishes with increase in size and there is indication of cannibalism above 80 mm DML (Oommen, 1977). Cephalopods are one of the major preys for a variety of marine fishes including tunas, billfishes, cetaceans, and whales (Silas, 1985). Many researchers have observed the high proportion of empty stomachs in samples and fatigue in feeding during spawning (Oommen, 1977).

The characteristic of length weight relationship of Indian cephalopods has been reported to be hypoallometric with the ‘b’ value is lower than 3 (Meiyappan et al., 1993). This relationship is also significantly different for males and females (Mohamed, 1996).

Cephalopods along the Indian coast are reported to spawn almost throughout the year. The earlier work on the reproductive biology of the Palk Bay squid *Sepioteuthis lessoniana* has been carried out by Rao (1954). Later on, the maturity of three species of squids and six species of cuttlefishes has been reported by Silas et al. (1985ab). Maturity stages for biological studies of squids and cuttlefishes have been standardized (Silas, 1985) and described as four-point (Immature, Maturing, Mature, and Spent) maturity scale. This maturity scale has been used by all workers on Indian cephalopods.

Mature and partially spawned individuals of *U. (P) duvaucelii* are found throughout the year along both the coasts, but along the west coast, peak spawning has been observed during post monsoon i.e. Sep-Nov. (Silas et al., 1985a; Mohamed, 1993). This species forms large congregation during this season and becomes vulnerable to the purse seine fleet operating along Karnataka coast (Mohamed, 1993) and also to cast netters along coastal water of Alleppey (Meiyappan and Srinath, 1989). This squids congregate for spawning in near shore waters after which the female migrate to the shallow subtidal regions with hard substratum for laying the fertilized eggs (Mohamed, 1993). Fertilized eggs from the subtidal regions of Karwar seas have been collected for rearing (Asokan and Kakati, 1991). Based on sex ratio (M 80:F20) of such squid schools, it would be easy to conclude that female was semelparous. However the evidence such as relatively low GSI levels and the occurrence of mature females over a wide range of size classes, suggests that this species is multiple spawner and not a semelparous species (Mohamed, 1993). Biology of the commercially important cephalopods (Source: Silas et al, 1985ab; Abdussamad et al., 2004; Abdussamad & Somayajulu, 2004; John Chembian, 2013.

Biology of commercially important bivalves

The biology of commercially important species of bivalves from India is given in Table3. Physical factors such as temperature and salinity are the important factors for influencing the reproductive cycles and spawning in bivalves (Sastry, 1979). In addition to temperature, food supply and latitudinal distribution effects the reproductive cycle of bivalves (Newell et al., 1982).

The number of spawning events and duration of spawning period can also differ greatly with respect to species, geographic area and environmental conditions (Gosling, 2003). In general, an environment play an important role to influence the growth, reproduction and recruitment of bivalves and same species shows different growth rates and spawning periods in different areas (Kripa and Appukuttan, 2003). They found that the combination of different hydrographic parameters like salinity, availability of settlement substrate and current pattern are responsible for controlling the spat fall, population growth, zonation and species dominance. Although, most of bivalves are gonochoristic, in certain bivalves like oysters hermaphroditism has been observed.

Table 3. The biological details of the commercially important bivalves (Source: Kripa and Appukuttan, 2003)

Species	L_m	Spawning period	L_{max}	Length (mm) in I yr	II yr	III yr	Distribution
V.cyprinoides	20 - 25	May-June & Nov	52	30	41	-	West coast
P. malabarica	20	Sep-Feb	55	43.1	-	-	West coast
P. viridis	15.5-28	Dec-Jan Jul-Nov		91.5 96	117 117	129 129	East coast West coast
C. madrasensis	12-14(M) 24-26(F)	Nov-Feb Jul-Sep Feb-Apr	128	86 70-80	112 90-110	 120-130	East coast West coast
M. casta	11-17.	Throughout the year	55	42.6			East &West coast
M. meretrix	21-26	May-June Feb - Sep	91	47	61.5		East coast
M. opima	11-20.	Dec May-Aug	53.8	30 22	43.5 31	 43	East coast West coast
T. granosa	20-24	Throughout the year	73.4	41.1	55.3	66.3	East coast

Gastropod taxonomy

Gastropoda is the largest molluscan class with about 35,000 extant species. The gastropods are torted asymmetrical molluscs and usually possess a coiled shell. The soft body normally consists of head, foot, visceral mass and the mantle. Among the marine gastropods, the members belonging to the subclass Prosobranchia, are of major fishery importance (Poutiers, 1998). The shell in this subclass is typically coiled with an opening at the ventral end known as aperture. The aperture is covered by operculum which closes the opening of the shell. The head normally protrudes anteriorly from the shell and bears mouth, eyes and tentacles. The foot is muscular, ventrally located with a flattened base and is used for creeping or burrowing. The visceral mass fills dorsally the spire of the shell and contains most of the organs. The mantle forms mantle cavity which lines and secretes the shell. Asymmetry of the internal anatomy of the gastropods is due to twisting through 180^0 called the `torsion' which takes place during the first few hours of larval development.

Classification

Gastropods classification based on different morphological and anatomical features of their bodies and shells has come across several problems. During the 19th century, researchers were proposed several different classifications of the Gastropoda based on the place of the mantle cavity or on the array of various organs and shape of the shells. By and large, all these classification methods used only a restricted number of distinctive characters. At the start of the 20th century, the German researcher, Johannes Thiele (1929 - 1935), put together earlier classifications and proposed Thiele's system of classifications which was used by zoologists for most of the century. He divided the gastropods into three subclasses: Prosobranchia, Opisthobranchia, and Pulmonata. Besides, the Prosobranchia were divided into three orders: Archaeogastropoda, Mesogastropoda, and Neogastropoda.

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Chapter

09

Sampling Design for the Estimation of Marine Fish Landings in India

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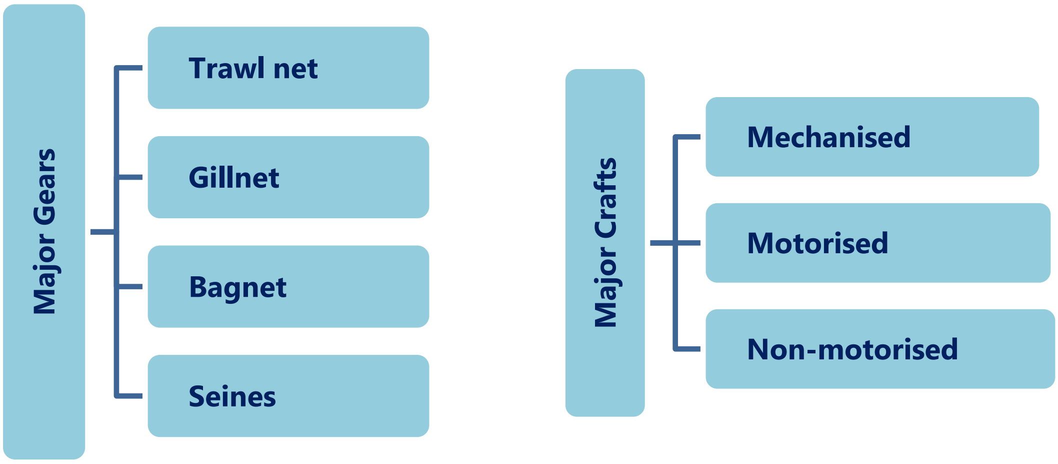
The marine fisheries sector in India provide livelihood to nearly 4.0 million people and contributes to the food and nutritional security of the nation. With a coastline of over 8,000 km, an Exclusive Economic Zone (EEZ) of over 2 million sq km, is blessed with enormous diversity of species. Monitoring of the harvest of the diverse marine fishery resources of the country is being carried out regularly by CMFRI since its inception through a scientific data collection and estimation system from all along the Indian coast for deriving management measures to keep the harvest of the resources at sustainable levels.

Indian Marine Fisheries	
Length of coastline (km)	**8129**
Exclusive Economic Zone (Million square km)	**2.02**
Continental Shelf (million sq km)	**0.53**

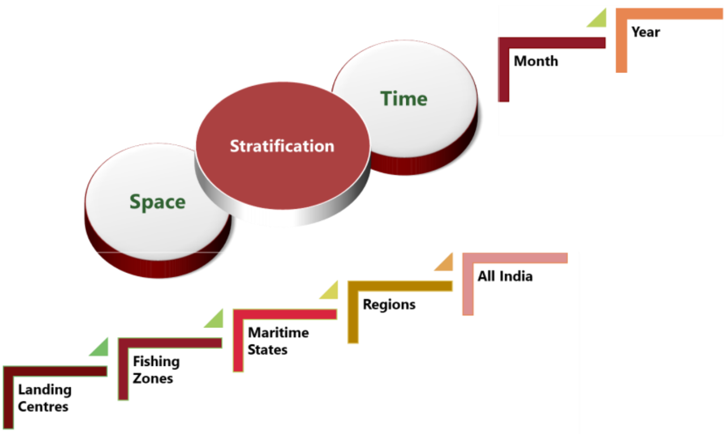
Marine fish landings in India are estimated from the sampling of commercial landings. Statistics on marine fish production are available from 1950 onwards when the Institute started nationwide sample survey for estimating the marine fish landings in the country. Keeping in pace with the changing marine fisheries scenario, the sampling procedure has been modified over the periods.

The marine fisheries of India is characterized by open access, multispecies and multigear fishery. The resources are exploited using a variety of gears in using mechanised motorised and non-motorised crafts. Fish landings takes place at numerous locations all along the coastline in all seasons during day and night. Sampling and estimation are performed for geographical area referred as fishing zone. There are 75 fishing zones covering 9 maritime states and two coastal Union territories. All the landing centres are covered under the



sample design and data collection is by qualified and trained field staff stationed at different locations across all maritime states. The overall operation is coordinated by the Fishery Resources Assessment Division of CMFRI.

The sampling design adopted by the CMFRI to estimate resource-wise/region-wise landings is based on stratified multi-stage random sampling technique. In this, the stratification is over space and time. Over space, each maritime state is divided into suitable, non-overlapping fishing zones. These fishing zones consist of different fish landing centres and the quantity of fish landed in each of the places varies. The landing centres in a zone are again grouped into different strata on the basis of fishing intensity, type of fishing craft and fishing method employed, number of fishing crafts operated and other geographical considerations. The number of landing centres may vary from zone to zone. There are some major fisheries harbours/centres which are classified as single centre zones for which there is an exclusive and extensive coverage.



The stratification over time is a calendar month. For observation, a month is divided into 3 groups, each of 10 days. From the first five days of a month, a day is selected at random, and the next 5 consecutive days are automatically selected. From this three clusters of two consecutive days are formed. One zone and a calendar month is a space-time stratum and primary stage sampling units are landing centre days.

If in a zone, there are 10 landing centres, there will be 10 x 30 = 300 landing centre days in that zone for that month (of 30 days). For example, for a given zone, in a given month, from the five days if the date (day) selected at random is 4, then these clusters are formed, namely, (4, 5); (6, 7) and (8, 9) in the first ten day group. In the remaining ten day groups, the clusters are systematically selected with an interval of 10 days. For example, in the above case, the cluster of observation days in the remaining groups are (14, 15), (16, 17), (18, 19) (24, 25), (26, 27) and (28, 29). Normally, in a month there will be 9 clusters of two days each. From among the total number of landing centers in the given zone, 9 centres are selected with replacement and allotted to the 9 cluster days. Thus in a month 9 landing centre days are observed in a zone. 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. For the intervening period of these two days, the information on landings from 1800 hrs of the first day of observation to 0600 hrs of the 2nd day of observation of a landing centre-day,-night landings- are collected by enquiry. 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 24 hour period (landing centre day).

Time strata	Days in a month									
1	1	2	3	4	5	6	7	8	9	10
2	11	12	13	14	15	16	17	18	19	20
3	21	22	23	24	25	26	27	28	29	30

Period 1: 1200 to 1800hrs on 1st day

Period 2 : 0600 to 1200 hrs on 2nd day

Period 3 : 1800hrs on 1st day to 0600hrs on 2nd day

Selection of fishing crafts and recording of landings

The second stage units are fishing crafts landed on a selected landing centre. When the total number of boats landed is 15 or less, the landings from all the boats are enumerated for species-wise catch and other particulars. It may not be practicable to record the species-wise catches of all boats landed during an observation period, if the number of boats/craft landed is large. A sampling of the boats/craft becomes essential. When the total number of boats exceeds 15, the following procedure is followed to sample the number of boats.

The data collection official should reach the landing centre before the commencement of the observation time and have to make local enquiry on the number of units gone for fishing and the number of units expected to land during his observation period. This information is required for determining the number of units to be selected for observation. Depending on the fraction of selection, choose a number from the random number table. Check all the other numbers systematically at intervals appropriate to the fraction. As soon as the fishing unit for corresponding to the checked number lands, the field staff should examine and record all information. From the boats, the catches are normally removed in baskets of standard volume. The weight of fish contained in these baskets being known, the weight of different species of fish in each boat under observation is obtained. Names of species of all commercially important fishes and shell fishes should be recorded along with the quantity landed.

Number of boats landed	Fraction to be observed
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

The species wise landings for each craft-gear combinations are estimated from the observed boats during each period of observation. The monthly estimates for each zone are obtained by pooling these information for different landing centre days in different strata. Estimates of district-wise, state-wise, region-wise and all India landings are also computed from these estimates. The estimates of sampling errors at each level are also worked out. The different schedules used for data collection along with detailed procedure on estimation of landings and their standard error are given in Srinath *et al.* (2005) (available online at http://eprints.cmfri.org.in/4053/).

Execution of the survey

The data collection is usually carried out by the staff of CMFRI and immediately after recruitment each person undergoes training on identification of species and data collection methodology. Work programme schedules for data collection indicating the landing centre to be visited, date and period of observation are send every month from HQ to field staff. The programme is carefully designed at the headquarters by the staff of Fishery Resources Assessment Division. From 2017 onwards data collection is carried out using electronic tablets and centralized processing and retrieval of marine fish landings data at headquarters through the database server. Each survey staff is provided with an electronic tablet and is provided with login id/username. They can login and download the work program for the month. Using the web application software for online data entry, they can directly record the information from landings centers and can transmit the information to the server. The estimation of landings will be carried out at headquarters.

Chapter 10

Collection of Data for Fishery Biology Studies and Fish Stock Assessment

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Basic objective of fisheries research is to provide ample information on the status of fish stocks. This information is collected through various sampling procedures and the data are used to provide advice on the sustainable management of fish stocks, upon which the entire fishing industry depends. There are two main sources of data collected and used in fisheries research. These can be divided into fishery independent and fishery dependent data. The first usually involves monitoring the changes in distribution over time in the relative or absolute abundance of fish populations using vessel based surveys in a way that is not subject to the biases inherent in commercial fishery data. The collection and accurate interpretation of both fishery dependent and fishery independent data are of fundamental importance to our understanding of the fished species. Both are needed to gain an understanding of the magnitude of localized changes in fish communities, landings and productivity of the resource. Fishery dependent information involves collection of catch and effort data (CPUE) as well as biological sampling from commercial fisheries. CPUE data are usually collected from logbooks or using direct observation at the site of landings. The underlying assumption is that changes in CPUE accurately reflect changes in the abundance of the fish stocks.

Biological characteristics of the fish catch such as length/age, reproductive and feeding biology are important basic inputs in stock assessment studies. These data can be collected either from commercial fisheries or from resource surveys. It is known that sampling from commercial fishery is subject to many limitations and biases. On the other hand it is the only possibility, for the moment, to be "in touch" with the exploited fish populations. Most of the quantities involved in fish population work can not be obtained or measured throughout the whole population; e.g. it is virtually impossible to measure all the fish caught. Therefore, a part, or a sample, of the population is collected. A good sampling can not be set up until something is known about the variability of the data and how the precision and reliability of the results are affected by the sampling deficiencies and other sources of uncertainty.

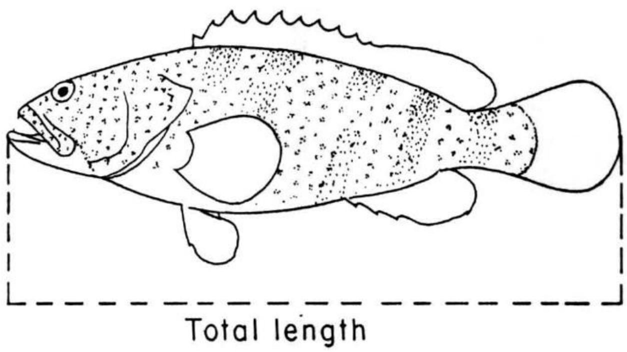
The critical assumption is that a reasonable estimate can be obtained of the true value of the sampled population. The fundamental feature of any sampling system is to collect the data in a random way. Random sampling can be defined as a sampling from some population where each entry has an equal chance of being drawn. In practical terms this means that any fish from the stock under investigation should have the same probability of being sampled. Indeed, this condition is hardly fulfilled. However, the aim to achieve it should always be present in any sampling action. Length measurements of a large representative sample can be taken from the landing centre itself. For biological studies, wherein more tedious effort is required, a small representative sample have to be collected at random and transported to the laboratory in ice boxes.

LABORATORY ANALYSIS

Fish samples previously collected at the landing centre, and stored in the ice box in separate plastic bags, should be analyzed preferably as soon as possible i.e. the same day. This is almost compulsory for the fishes, which spoil easily, to facilitate the collection of data such as sexual maturity stages. The data pertaining to biological characteristics are collected from individual fishes and recorded separately in the data sheets.

Length measurements

Individual Total Length (TL) measurements - from the tip of the snout to the tips of the largest caudal fin rays - are made with the fish placed on its right side, snout to the left, on the measuring board, against the headboard the snout of the fish with its mouth closed is gently pressed. Holding the fish in position with the left hand, its body and tail are straightened along the midline with a single stroke movement using the right hand, and the reading is taken from the measuring ruler. The method of taking length measurement varies from species to species. Usually the maximum length from the tip of the snout to the longest ray of the caudal fin, either upper or lower, as the case maybe, is considered as the total length of the species. However, in certain cases, for example threadfin bream in which the upper lobe is extended into a filament which is likely to be broken, the lower lobe is taken for measurement of the total length.



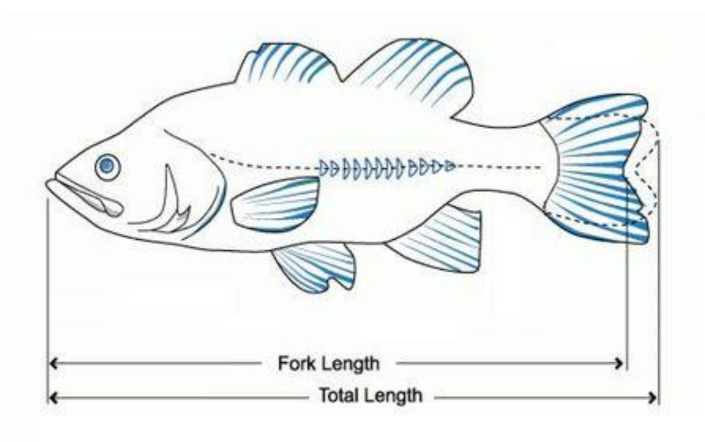


Fig. 1. Length measurements of demersal teleost fishes

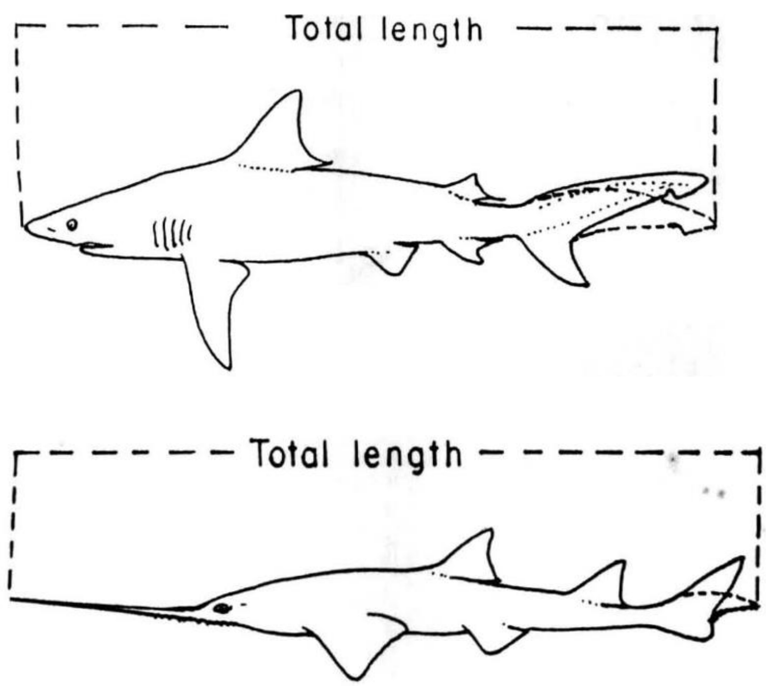


Fig. 2. Length measurements of demersal elasmobrach fishes

In rays and other dorso-ventrally flattened fishes, disc width (Fig. 3) rather than total length is generally used.

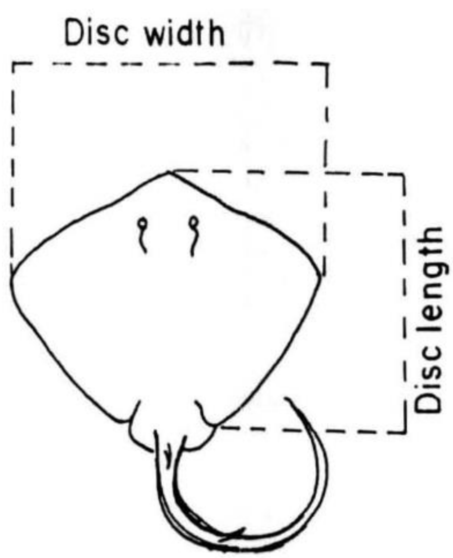


Fig. 3. Length measurements of dorso ventrally flattened fish-Rays

For all length measurements it is essential to have a convenient measuring device. A standard type of measuring board consisting of a flat wooden or plastic platform with a scale centrally fitted on it with a headpiece at the zero end of the scale is useful in field and in laboratory. To measure a fish its mouth is closed, placed in its right side, snout to the left on the measuring board. The snout is pressed down gently at the zero end of the measuring board and the body and tail straightened along the midline before reading is taken from the board.

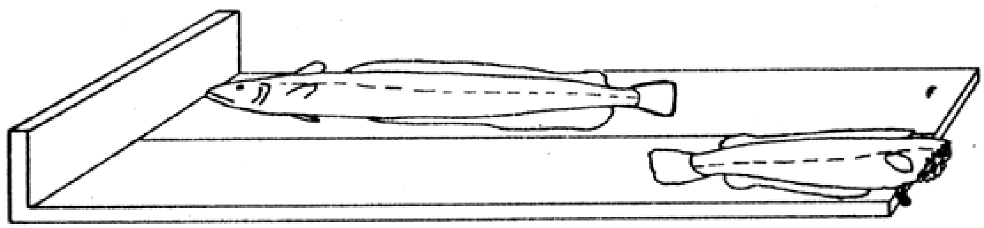


Fig. 4. A graduated measuring board, which is generally used to measure the total length of the fish

Alternatively the length measurements can be taken using high precision scales such as digital Vernier calipers with high sensitivity. Length of large fishes also can be measured using the advanced methods such as laser encoders. With a typical measurement accuracy upto ± 0.05% and equipped with a quadrature output, the Laser-Encoder is a perfectly suited gauge to replace length measurements using other methods. A laser distance meter works by use measuring the time it takes a pulse of laser light to be reflected off a target and returned to the sender. This is known as the "time of flight" principle, and the method is known either as "time of flight" or "pulse" measurement. The distance between the meter and target is given by D=ct/2, where c equals the speed of light and t equals the amount of time for the round trip between meter and target. Given the high speed at which the pulse travels and its focus, this rough calculation is very accurate over distances of feet or miles but loses accuracy over much closer or farther distances. The laser measuring device can be fitted on a measuring board with a movable reflector piece will help to measure large fish specimens such as tuna, seerfishes and sharks.

Fig. 5. High precision digital Vernier calipers for fish length measurement

After recording lengths from a large set of measurements, a length frequency distribution table may be prepared. The length should be grouped into corresponding length groups and the number falling in each interval is called the frequency of the class interval. The length data should not be combined into large or narrow groupings. A range of about 20 groupings is fairly sufficient for most purposes. The length groupings can usually be 50 mm for species which grow larger than 500 mm, 10 mm for species which grow larger than 200 mm, and 5 mm for species which do not reach 200 mm. The midpoint of the length group is important for the calculation of mean, standard deviation etc.

Fig. 6. Laser measuring device which can be fitted on measuring board for fish length measurement

Weight measurements

For weight measurement of individual fishes, total wet body weight is to be recorded to the nearest 0.1 g on a top-loading balance. Weights of various parts of the fish may be required for biological studies; stomachs for the determination of food eaten, gonads for the estimation of egg numbers and livers for liver-condition assessment.

Fig. 7. Electronic weighing balance for fish weight measurement

The individual weight of each specimen is then recorded in the data sheet against their respective lengths. The length and weight data thus collected will be utilized to fit the length weight relationship, which usually expressed by the equation

$$W = aL^b$$

Where W is the weight of the fish, L is the length and 'a' and 'b' are constants

Sex determination

Sex of the individual fish is determined by gross appearance of gonadal structures. Maturity stages of each gonad are recorded on the basis of morphological appearance (macroscopic observations) such as colour, texture and degree of vascularisation in both the sexes. However, in the case of females, microscopic observations also may be used. Representative gonads were randomly taken from each stage of gonadal development to measure diameter of oocytes. At least 50 oocyte samples from anterior, middle and posterior of the ovary were measured by using a stereo microscope. Intra-ovarian oocyte diameter is measured using an ocular micrometer. Oocytes are grouped in to three to five OMD intervals. Oocyte diameter from the ovaries of same maturity stages are pooled and plotted to study ova development.

After ascertaining the sexes, the sex ratio is calculated for different months and size groups of fish and is tested for equality for using Chi-square test. Sex ratio is mostly represented by Male: Female (M: F) ratio.

The whole gonad is weighed to the nearest 0.01 g on a digital analytical balance. The weight of the gonad relative to body weight, the gonado-somatic index (GSI), was calculated using the formula:

$$GSI = \frac{\text{Weight of ovary}}{\text{Weight of fish} - \text{Weight of ovary}} \times 100$$

Histological procedure

Part of the gonad identified may be stored for detailed histological analysis. For this, samples of the central portion of the gonads of 0.5 cm thickness are washed, and preserved in 10% neutral buffered formalin (NBF), which is then dehydrated in an increasing ethanol series, n-butilic alcohol, embedded in paraffin and sectioned for 7-10 µm in thickness using a rotary microtome. The sections were stretched in a water bath (40 °C) of distilled water. Three replicate section samples were gathered with the object glass properly labelled and dried for 24 hours at 37 °C followed by one hour at 60 °C over a stove. Sections were stained with a solution of Ehrlich haematoxylin and eosin for a general assessment of the histological components of the gonads.

Sex determination of elasmobranchs

The sex of elasmobranchs can always be determined from external characters because male fish have a pair of mixopterygia (intermittent organs, claspers) which are visible from an early stage of development on the inside edge of the pelvic fins (Fig. 6). The females do not have mixopterygia.

Analysis of Sexual maturity

In most of the demersal teleost fishes, identification of six or seven maturity stages is carried out. They are; Stage 1- Immature, Stage 2- Maturing 1 or spent recovering, Stage 3- Maturing 2, Stage 4- Mature, Stage 5- Ripe/Running and Stage 6- Spent.

Table 1. Description of different maturity stages of demersal teleost fishes

Stage of Maturity	Male	Female	
	Nature and extent of testis in body cavity	**Nature and extent of ovary in body cavity**	**Appearance of ova under microscope**
I Immature	Small, transparent, pale, occupying a very small portion to 1/3 of body cavity	Small, transparent, pale, occupying a very small portion to 1/3 of body cavity, ova not visible to naked eye.	Irregular, small, yolkless/yolk deposit just started, transparent with clearly visible/partially visible nucleus
II Maturing 1/Spent recovering	Whitish, translucent, occupying about 1/2 of body cavity	Pale yellow, granular ova visible to naked eye, occupying about 1/2 of body cavity	Medium sized, assume round shape, opaque, with fair amount of yolk
III Maturing 2	Creamy white, occupy about 3/4 of body cavity	Pale yellowish, blood vessels visible on dorsal side, ova clearly visible, occupying about 3/4 of body cavity	Medium sized, opaque, fully yolked
IV Mature	Creamy white, soft, occupying about full length of body cavity	Pinkish yellow, blood vessels prominent, large ova prominently visible, occupying about full length of body cavity	Large sized, mature, transparent at periphery
V Ripe/Running	Bright creamish, soft and swollen occupying full body cavity	Reddish with fully packed ova visible to naked eye, occupying full length of body cavity	Large sized ova fully packed in the ovary
VI Spent	Flabby, little reddish, occupying about 1/2 of body cavity.	Flaccid, reddish, occupying about 1/2 of body cavity	Medium sized ova present with disintegrating ripe ova

The identification of sexual maturity stages is particularly easy in fresh specimens; however table/hand magnifying lenses have to be used to make the analysis less tiring and time demanding. Initially, when uncertainty arises because of the small size of the specimens and their gonads, then there is only one thing to do to determine the sex: examine the gonads using dissecting microscope.

Steps for the dissection of demersal fishes for biological data collection

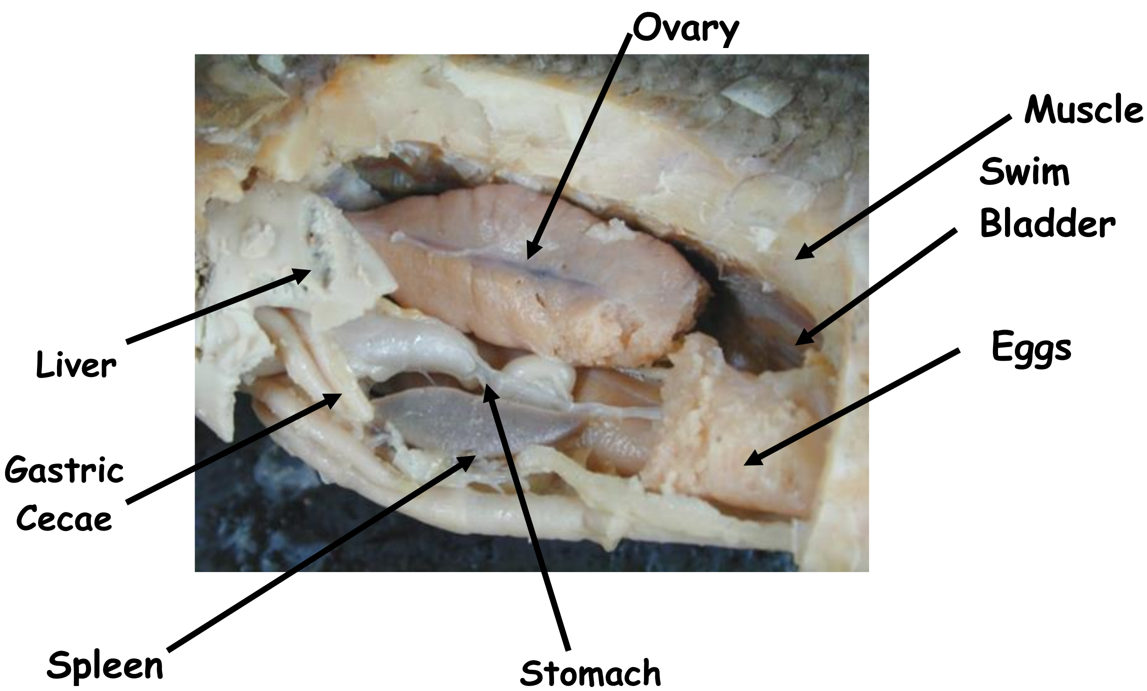


Fig. 8. Close up picture of the body cavity of a demersal teleost fish, showing ripe gonad and other internal organs.

- Remove operculum with scissors
  - Observe gill anatomy
    - Rakers - white, comb-like arches
    - Filaments - Red fingerlike projections
- With a scalpel, remove a section of the lateral line

- Begin the main incision
    - Open the abdomen (below the gill) carefully with a scalpel
    - Cut with a scissors: remove a oval-shaped piece of skin (only skin) running from underneath the gills, to the anus, up to the lateral line, along the lateral line, to the gill, down to where you started the incision. Remove flap of skin (see diagram on next slide)
- Only cut through scales, muscles, and skin
- Take special care not to cut too deep!

Fishes belonging to the maturity stage 4 onwards are considered as mature fish and used for determining the size at first maturity. For this, the fishes belonging to different length groups are to be selected at random for the determination of maturity stages. The length at which 50% of fish are mature is considered as size at first maturity.

The logistic equation used for this is: $P = 100 / (1 + \exp(-r (L-Lm)))$

Where P = percent mature fish in length class L, r = the width of the maturity curve and Lm = length at 50% maturity.

Maturity stages of elasmobranchs

The maturity of males can be easily and best defined from the state of development of the mixopterygia. These of immature fish are small and flaccid and do not reach the posterior edge of the pelvic fin (Fig. 6a). In maturing fish, the mixopterygia are larger; they extend to the posterior edge of the pelvic fins and the internal structure is visible but soft and not ossified (Fig. 6b); in mature fish the mixopterygia extend well beyond the posterior edge of the pelvic fin, the internal structure is visible and is hard and ossified (Fig. 6c).

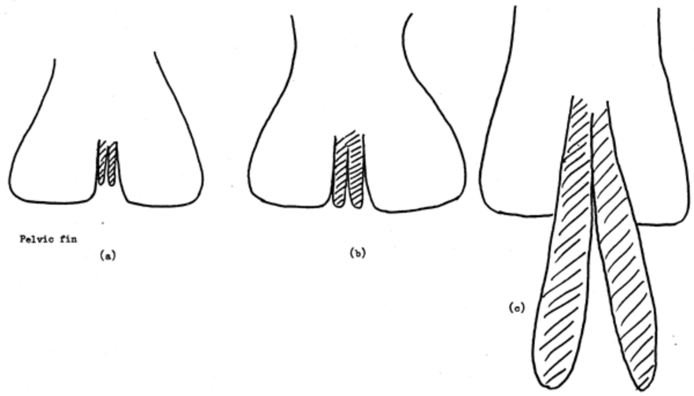


Fig. 9. Maturity stages of male elasmobranchs; mixopterygia are cross hatched. (a) immature, (b) maturing and (c) mature

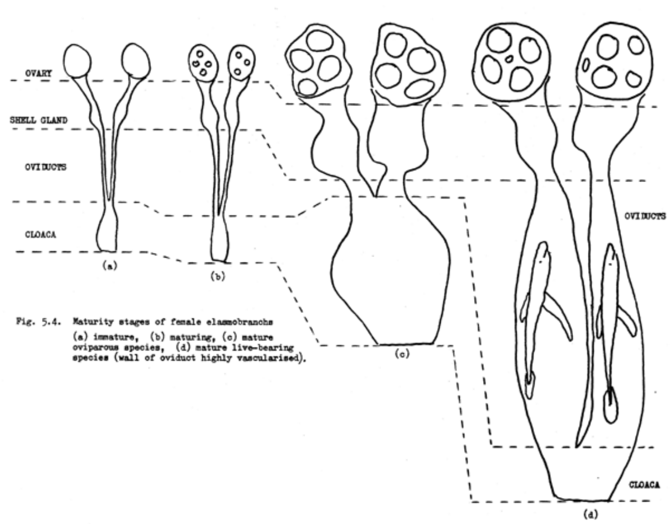


Fig. 10. Maturity stages of female elasmobranchs (a) immature, (b) maturing, (c) mature oviparous species, (d) mature live-bearing species (wall of oviduct highly vascularised).

Maturity of females must be determined by internal examination. The reproductive system of females consists of ovaries (usually two but in some species one only is present), shell glands and oviducts (Fig. 7). In immature fish the ovary is barely discernible and it contains no eggs; the shell gland is also very small and the oviducts are thick-walled and white (Fig. 7a). In maturing fish, white eggs are visible in the ovary but the remainder of the reproductive system is similar to that of immature fish (Fig. 7b). In mature fish, the ovaries contain yellow eggs, except immediately after ovulation in viviparous species and at the end of the spawning season in oviparous species; the shell gland is enlarged and the oviducts distended and, in viviparous species, thin-walled, flaccid and often highly vascularized (Fig. 7d). In viviparous species maturity is also associated with changes in the size of the cloaca (Fig. 7c).

Sampling the Otolith fish ageing

Age of fishes is estimated using a small bone found in the head of fish called the otolith. Counting the rings on these otoliths gives an estimate of the age of the fish (similar to the rings of a tree). Otoliths, commonly known as "earstones," are hard, calcium carbonate structures located directly behind the brain of bony fishes. Otoliths are popular because compared to other structure they generally provide the most accurate ages, mainly due to their continued growth throughout the life of the fish. Otoliths provide an abundance of information ranging from temperature history, detection of anadromy, determination of migration pathways, stock identification, use as a natural tag, and most importantly age validation.

Different species have otoliths of different shapes and sizes; and cartilaginous fishes, such as sharks, skates, and rays, have none. This figure shows the growth rings of a sagittal otolith section viewed under reflected light. The dark translucent zone represents a period of fast growth. The white opaque zone represents a period of slower growth. Biologists estimate fish age by counting these opaque zones, called annuli, just as one would count rings on a tree to determine its age.There are three types of otoliths, all of which aid fish in balance and hearing:

1. Sagitta: The largest of the 3 pairs of otoliths, sagitta is involved in the detection of sound and the process of hearing, or converting sound waves into electrical signals
2. Asteriscus: This type of otolith is involved in the detection of sound and the process of hearing.
3. Lapillus: This type of otolith is involved in the detection of gravitational force and sound (Popper and Lu 2000)

Otoliths, as well as other boney structures form yearly rings (similar to that of a tree) known as annuli. Each annulus is composed of opaque and translucent zones, which correspond to periods of fast and slow growth (figure 1). The most common method of age validation is marginal increment analysis. The marginal increment is the measurement from the last annulus to the margin (or edge of the otolith). Each graph above represents the average monthly marginal increment values for one year for ages one through four. The marginal increment cycles down only once during each year, which means that one annulus was deposited once per year.

Fig. 11. Removal of otolith from teleost fishes

Otolith removal procedure

1. Cut the operculum to fold forward and open it wide towards the anterior end of the fish.
2. Cut away the gill arches at their insertion.
3. Use a chisel to scrape away tissue from the otolith capsule, the capsule will feel like a large knob or protrusion.
4. Open the capsule with a chisel, the large sagittal otoliths can be easily removed with forceps.

5. Rub off any attached membranes from the otolith, rinse with fresh water and pat dry.
6. Place otolith in the paper envelope.

Each label should be filled with the appropriate fishery information. Use a soft lead pencil on the label. Alcohol and water will dissolve ink and sample information will be lost. Wash otoliths off with water, using the supplied spray bottle and dry each otoliths before placing them in sample centrifuge tube.

The otoliths will not degrade easily. Avoid putting them in fixatives like formalin which can become acidic over time and lead to dissolution of the otoliths. In the fisheries labs they are usually stored in small paper packets which can then be labeled and stored very easily. If there is any chance you might want to do any microchemistry on the otoliths later on, you have to be more careful to avoid contamination from metal forceps etc.

Collection of data for fecundity estimation

Knowledge of the fecundity of a species is an important factor in fish stock management. It is used to calculate the reproductive potential of a stock and the survival from egg to describe a fish which is spawning for the first time. For fecundity estimation, female gonads belonging to the stage 5 are used. After ascertaining the sex and maturity stages, portions are cut from the mid-region of the ovary, weigh to the nearest 0.01 g, and place in Gilson’s fluid for fecundity estimates. Gilson's fluid is prepared by mixing 100 ml 60% alcohol, 15 ml 80% nitric acid, 18 ml glacial acetic acid, 20 g mercuric chloride in 800 ml of water. The material for fecundity estimates can be stored in Gilson’s fluid for 3 months.

The plastic bottles containing the material are vigorously shaken from time to time to aid in the release of oocytes from the ovarian walls. Before counting, the contents of each bottle are to be poured into a petridish and those oocytes not liberated from the ovarian tissue removed by teasing. The oocytes were repeatedly washed in tap water. The clean and separated oocytes were transferred to another 1 litre beaker containing a known volume of 1 molar sugar solution. A plastic ruler can be used to stir vigorously the egg suspension to ensure an even distribution of oocytes in the suspension column. After 10 strokes of the ruler a sub-sample was taken by a pipette. One aliquot will usually give sufficient numbers of large and small oocytes to yield satisfactory counts and diameter distributions. The oocytes are pipetted into a counting chamber, and their diameter should be measured along a horizontal axis using a calibrated eye-piece ocular micrometer under a standard dissecting microscope at a magnification of 40X. The accuracy of the sub-sampling method was tested by taking 10 replicates and calculating the coefficient of variation which was found to be 5.8%. The fecundity (*F*) for each female fish was calculated as follows:

$$F = \frac{V}{V_1} n \times \frac{W}{W_1}$$

where, n = number of oocytes in the sub-sample; V = volume of the egg suspension; V1 = volume of sub-sample; W = weight of whole ovary; W1 = weight of portions of ovary fixed.

The relationships between total length of fish (TL) and fecundity (F), total weight of fish (TW) and fecundity (F) and ovary weight (OW) and fecundity (F) were estimated by linear regression analysis based on the equation,

$$\text{Log } F = \text{Log } a + b \text{ Log } X$$

Table 2. Record sheet for collecting biological data on demersal finfishes

Species:			Landing Centre:				Date:		
Sl. No.	**Length (mm)**	**Weight (g)**	**Sex (M/F)**	**Maturity (1-6)**	**Gonad wt (g)**	**Stomach condition**	**Stomach wt (g)**	**Stomach Contents**	**Remarks**

Table 3. Sample data sheet for tabulation of biological data after analysis.

CENTRAL MARINE FISHERIES RESEARCH INSITUTE

Project Code: **P-3a**

Period: January -December2010 **Centre: Cochin Fisheries Harbour** **Resource: *S. undosquamis***

Month	Length Range (mm)	Modes (mm)	Mean Size (mm)	Sample size(nos.)	Sample weight(kg)	Sex ratio M:F	Immature%	Mature(%)	Gravid/ Spent (%)	Sample size(nos.)
Jan	201-300	235,245,285,	240	36	4.074	1:1.6	0	0	0	0
Feb	191-290	215,235,	230	39	4	1:2.1	0	0	0	0
Mar	161-300	215,255	227	76	6.235	1:2.5	43	11	46	28
April	181-330	195,215,225	232	47	5.355	1:12.6	80	10	10	39
May	131-340	215,225	224	69	6.415	1:3.3	94	0	6	53
June	171-320	245,255	234	61	5.241	1:0.8	75	18	7	28
August	201-290		248	79	6.577	1:1.6	100	0	0	24
Sept.	211-300	265	251	36	5.087	1:1	11	50	39	18
Oct.	171-330	235,255,275	236	61	6.232	1:1.2	10	72	18	33
Nov.	141-300	165,235,245	221	82	7.029	1:1.7	14	45	24	29
Dec.	171-310	235,275	242	82	9.47	1:1	6	77	18	17
Annual	131-340			668	65.45	1:2.7				269

Table 4. Tabulation form for collecting data on fecundity of fishes

Sl. No.	Length (cm)	Total weight (g)	Ovary wt (g)	Fecundity (Nos.)

Collection of data on stomach contents

The simplest measurement for gut contents is occurrence frequency, as it demands only the stomach food observation. The other best known methods are the Relative Importance Index, and the Feeding Index. For all of them, the principle involved is that food items should be counted or, at least, weighed or measured by their volume. When the fish is cut open for the examination of the gonad maturity condition, the stomach contents also examined. The stomach condition is determined by the degree of distension of the stomach and classified as Gorged, Full, ¾ full, ½ full, ¼ full, trace and empty. The above classification gives the intensity of feeding and the empty, trace and ¼ full stomachs are considered as poorly fed and others as actively fed. The gut is then dissected and the contents are removed into a Petri dish for qualitative and quantitative analysis. In many cases, the food matter in the gut, especially the crustacean matter will be found to be in an advanced state of digestion and in such cases only the generic level identification of the food components will be possible.

The total weight of the stomach as well as the individual food components are taken to the nearest mg in an electronic digital balance. The quantitative analysis by volumetric method, the gut contents are sorted out and the total volume of each food item is measured using a measuring cylinder graduated to 0.1 ml.

Other morphometric measurements of demersal finfishes

Historically, the morphology of fishes has been the primary source of information for taxonomic and evolutionary studies. There are numerous characters available for morphological study. These characters are most commonly divided in to two categories: morphometric and meristic.

Morphometric characters refer to measurable structures such as fin length, head length, eye diameter, or ratios between such measurements. **Meristic** characters include almost any countable structure, including fin rays, scales, gill rakers, and so on.

Chapter 11

Fish Stock Assessment Models- Evolution and Possibilities

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Quantitative fish stock assessment has been a topic full of challenges and opportunities. It has held spellbound researchers, both biologists and statisticians alike ever since the first seeds were sown in the form of growth curves and biomass prediction, some seven decades back. The challenges were multi-faceted although the candidate resources remained almost stable on most of the angles from which they were assessed at. The life pattern or cycle of any given resource was well recorded with the distinct phases of arrival, survival, maturity and reproduction. In most of these models which were fancied at various points of time main focus was always on growth, mortality and reproduction. The epoch of an average fish was always kept in mind before any such paradigm was carved out. The life period was clearly interspersed with bionomical occurrences like larval stage, recruitment, predation, migration etc. The dynamics was what mostly targeted in the modeling initiatives and the jarring note in the smooth dynamics was the fishing related mortality, which is man-made. The populations were imagined to be a biomass pool with the eternal cycle of churning occurring incessantly. The period of study under most of the models is assumed to be based on blocks of a year or parts thereof and most of the defining parameters of these flux was measured per annum. When the annual biomass addition matches the natural depletion, the state and rate of various dynamic functions were most amenable for computational rigour. This stage referred to as “equilibrium” has spawned a whole set of models like the Schafer production models, which are a class of exponential growth functions. Interestingly be it mass dynamics or average fish growth or for that matter depletion/ mortality the basic relationship assumed between the change in biomass and the age or time was exponential. Thus a whole lot of models both working on the growth trajectory of average fish as well as the one used in macro-analytical situations, were exponential in nature. From the analytical point of view most of these models revolved around fitting the model by using observed time series of field data by way of estimating the parameters and trying to forecast the future scenario. Thus from a statisticians point of view, these were fitting of regression models to sample data with one or many responses to one or many causes, either non-linearly or pseudo linearly. The disturbance caused to the biomass dynamics by way of fishing efforts was also incorporated in the biomass dynamic models and an optimization function was carved out based on a pair of equations, one of Schaefer kind and the other linking the catch and effort. That optimization function is minimized or maximized as the cases may be and the parameters are estimated.

Such modeling-based efforts yield a comprehensive relationship function under given assumptions relating the various causal factors like effort, environment, oceanic factors with the biomass, yield or availability status of a given resource or set of resources. Once this relationship is modelled satisfactorily scenarios can be built to aid the fishery manager to foretell the direction towards which the fishery is leading or to explain the present status of the fishery. These tools will be the core to any management plan at any level, local at a state/ province level to national and large marine ecosystem level. Thus depending upon the canvas to which the planning is applicable suitable modelling tools are adopted from time to time by researchers and fishery resource planners.

Tropical fish stock assessment

The stock dynamics and the modeling thereof are situation or state invariant in its core. This means that a model which relates present biomass of a stock with that of the previous year's biomass is bound to be similarly structured, whether applied for tropical fisheries or Mediterranean fisheries or temperate fisheries. The real difference between the models qualified to be applied in tropical fisheries and those which are not, happens to be those which take into account the complex nature of the tropical waters and the intertwined nature of phenology and dynamics of the resources which were coexisting in such waters more often than not. Also interfering in this picture is the nature of gears that get used in such regions and their inherent and forced non-selectivity. So, the models when being discussed for tropical conditions must be the ones which give room for such multiplicity of species competing for common food resources and which get caught by more than one type of generic gears. Rest of the issues which hog the single species model, which were aplenty initially, are still valid with possible inclusion of the factors arising out of such scenarios. A most important collateral challenge that arises while dealing with such situations is the standardization of effort as applicable to each resource, which would lead to more dependable catch rates, which are often used as indices of stock wealth or biomass. Hence, we would see in subsequent sections those models and tools which incorporate these kinds of uniqueness tagged with tropical waters.

Classical fish stock assessment approach

The classical approach to fish stock assessment had been founded on the stages in the life cycle of a fish and some mathematical relationships that are most suited for describing a cause and effect relationship suited to these stages. Mostly the causes used to be those morphometric features that were visible and easily measurable and the effects used to be those which were of use as index to describe a particular stage of the animal’s life. For example to describe the spawning ground, the cause used to be the total number of spawners and the effect used to be the recruits for surviving spawners. Similarly for the estimation of number of survivors at a particular stage of lifetime of cohorts, the starting population at the beginning of the year used to be the cause and the effect used to be the number of survivors at the end of the given age of the cohorts, thereby leading to the mortality. Thus similar relationships were defined for growth as well as biomass and these were all dependent on some established templates like exponential models that describe growth as well as depletion or decay, which were evolved in other branches of science. The best example is the classic Von Bertalanffy (1934) and that in fact spawned a plethora of modeling approaches, which were seminal in the context of fish stock assessment. By large the approaches to stock assessment can be broadly categorized into two viz. Analytical Methods and Holistic Methods. The Analytical Methods delve deep into the various life stages of the resource under focus and takes cue from applicable templates of models at each stage and combines all of them to arrive at the status of stock. This is more broad-based and biologically sound leading to more precise estimation of stock health, but is heavy in data demand. These need time series of length frequency categorized count of animal at various time stamps and the type of gears and the effort expended on such gears with details of the mesh size etc. On the other hand holistic methods are simple optimization based models, wherein for a given stock/ sub-stock time series of catch rates and efforts/ catch are sufficient to arrive at the status of exploitation based upon the concept of surplus production, which again is templated on growth functions. Another set of methods falling in this category are the experimental cruise based data sets, like swept area method, which scales up the biomass based on the catch obtained during fixed duration trawling with fixed mouth width at randomly selected locations.

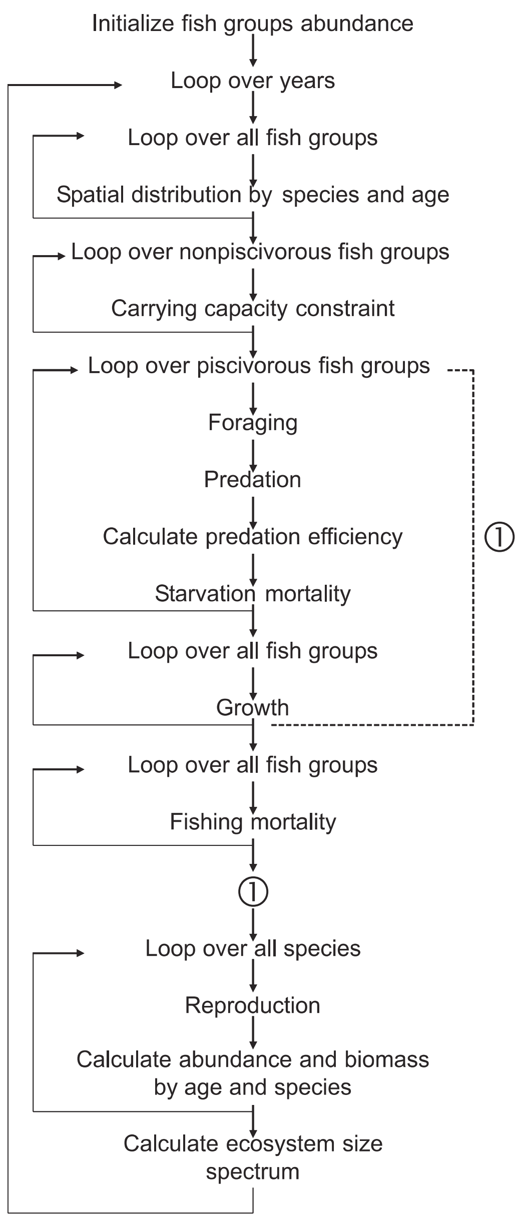
If the trail of evolution of these types of classical methods of fish stock assessment is studied in detail, one common phenomenon can be traced. All along the templates had been exponential growth or decay or depletion curves. But due to the difficulties faced in computationally estimating them, the all were attempted to be dealt with as linear relationship by means of appropriate transformations. The classic von Bertalanffy equation was converted into a linear type of relationship by logarithmic transformation, whose slope and intercept denoted the parametric estimates of relevance. Even in length frequency data, to convert them into age frequency, the method adopted was to treat each sample as a mixture of normally distributed values of animals of different age groups and to separate each one out of the mixture log transformation was again utilized whereby the parabolic normal functions got into linear forms and from them the probable distinct linear groups were culled out and their mean and standard deviations were computed. As the samples were taken on equal or known intervals the progress of the means of such culled out groups was traced and based on the rate of increment of mean growth for each cohort, the growth parameters were then estimated. Thus classic tools in fish stock assessment used a proper admixture of templates of non-linear models and suitable linearization antidotes for each of them. This itself gave the first possibility of improvement as computational facilities were improved- to estimate nonlinear relationship in its raw form. A lot of optimization and estimation tools like ADMB, Genetic Algorithm etc. were applied for this purpose. Also developed were Bayesian estimation tools which presumed known distributional vagaries for the parameters in a particular range, thus providing more realistic estimates of parameters of growth, mortality and recruitment thereby leading to improved estimates of biological reference points (BRP) like maximum sustainable yield (MSY). All these methods were flawed on one key thing, that they targeted a single stock, which meant one species at a given location, without much information on the interaction of that focused species with its environment as well as its peer species and these analysis and inference were always carried out for "average fish" and with stringent assumptions like instantaneous and "knife edge" shifting of ages. These were dealt a more realistic smoothening in the later concepts on stock assessment methods.

Individual based models (IBM)

IBMs are models which are made up of a combination of relationships which contribute towards defining the current condition of the niche in which the resource under focus thrives comprehensively bundled with its feed, prey, predators, fishing intervention, physiological attributes. These types of models are mostly collection of modules which are best suited in predicting the crucial factors that proceed to impact the biomass of the species under focus. These types of hybrid prediction and simulation approaches are quite pliable for inclusion of many extraneous factors that can have cascading impact on the fish stock. With the advent of high power computational facilities such hybridization has been exploited to the hilt by researchers.

A typical IBM could be one including much broader habitat based components like availability of lower trophic level (LTL) biomass and the higher level foragers and their predators. The availability of food and the growth stage combination clearly heralding the status of larval mortality and the resultant niche based competitions between resources could also be included through IBM thereby scaling up to simulate regional ecosystems. One such comprehensive model is "Object oriented Simulator of Marine ecosystem Exploitation (OSMOSE)" (Shin and Cury, 2001, 2004). Herein the criterion for the selection of prey by a predator was considered to be firmly based on body sizes with opportunism applied at individual level with a localization principle based on the vicinity coming into picture. A cohort or super individual was made as pivot and the bio-ecological dynamics applied on that and replicated to the tune existing in the area and focus. Four model classes, which represent particular ecological entities, are used: the class "system", the class "species", the class "age class", and the class "fish group" (Shin and Cury 2001). From each class, which is characterized by attributes and functions (e.g., growth, predation), a number of objects are created that are part of the simulated system. The architecture of OSMOSE is hierarchical, because a fish group belongs to an age class, which in turn belongs to a species. This structure enables the investigation of some key variables at different levels of aggregation, in particular the size spectrum of fish assemblages.

The process of implementation of OSMOSE can best explained using the flow-chart given below:



As can be seen from the above figure, the dynamics associated with growth, mortality, reproduction (spawning) etc. could be modelled using the conceptualisation described in the previous case. But the new broad based habitat and trophism based components need some elaboration. The parameterization of the components is presented in the following table;

Stage/ Component	**Model Definition**
Foraging	This is to be planned in such a way that the movement probabilities to the nearest spatial cell is highest and the availability of suitable prey/ LTL leading to feeding / starvation otherwise; It is a function of biomass and vicinity
Predation	This is functioned based on the spatio-temporal co-occurrence of prey- predator and the size of both; The prey- predator size ratio was subjected to a literature (FishBase) based threshold and the subsequent dynamics planned thereafter.
Starvation mortality	This is depicted as a function of density dependent issue dependent on intra specific competition and is built upon predation efficiency as defined by Beverton and Holt (1957)

With these cardinal principles in place OSMOSE is rolled out to simulate regions under study but with two very important safeguards, first being the localised calibration and the second the sensitivity analysis. These are computationally intensive procedures leading to thousands of trial runs with various combinations of input parameters including crucial ones like larval mortality and plankton availability, whose sensitivity have been historically be recorded as delicate and hence crucial. Once validated with a decent strip of time step these calibrated tweaked models can be put to great use in estimating, simulating and forecasting marine fishery resources.

This approach is more generally followed in the size spectrum models, where again the sub modular relationships are modeled simultaneously while arriving at the biomass at any given time step based on the feeder causes.

Stock Synthesis

Yet another approach that has gained popularity in view of the fast paced developments in the field of modeling is the maximalist approach, wherein all kinds of data, which were not collected for a homogeneous goal, including the details on a routine log sheet of a fishing fleet and those like capture recapture type of highly research oriented ones could very well be utilized to arrive at parametric estimates which would have been obtained by all kinds of data pertinent spatially and temporally to the stock under study. Such an approach dwells heavily onto statistical approaches which deal with data deprived conditions like Bayesian inference etc. The latest version of stock synthesis model (SS3) revolves around fortran code based old efforts rehashed and strengthened with the power of optimization tools like Automatic Differentian Model Builder (ADMB), where in partial derivatives of a suitable objective function would be used to zero in on the most efficient parametric estimates. The following are the key components of the species dynamics which are targeted in this method.

a) Stock structure

This hovers around the concept of stock, which starts with a spatial delineation followed by the year of birth (cohorts) and finally leading to the seasonally delineated morphs. This conglomeration of biological entities is further categorized into fast growing or tardy groups called as platoons with sexual discrimination enshrined. Upon these basic units, platoons, the size/ age selective fishing vulnerability conditions are applied, which in turn leads to age specific mortality, which again is a factor of classification within platoons/ morphs. When a multi-site scenario is modeled under this arrangement it is presumed that each of these platoons is distributed across and has an opportunity to mingle with as per norms. Such arrangements ultimately end up mostly as one platoon per morph differentiated sex-wise. Even the phenomenon of hermaphroditism gets implanted in this model by means of a fraction of females to males at each time step.

b) Spawner- Recruitment

The second major feature of SS3 is the definition options available to link reproductive potential with expected total number of newborns. The Beverton- Holt type or Ricker type of relationships are available as options and the output of this function is the expected mean number of age 0 animals of a kind. This module takes into account the seasonality vis a vis date of birth animals and that age grouping is retained till the next season occurs or recruitment takes place.

c) Life history/ biology

SS3 follows a unique procedure to compute biomass from population. Departing from the oft used procedure of empirical body weight at age method, SS3 arrives at the weight directly from length and superimposing the gear selectivity aspect over it. It allocates differential weights to those retained and those discarded, thereby giving a larger emphasis on length-at-age, which is less prone to sampling errors. The body growth aspect is attempted in the usual fashion mostly by using VBGF. This has options for year wise and cohort wise specification of growth rates, which would be incorporated dynamically. This feature accounts for the improbable density dependent growth in marine ambience, too. These growth characteristics are tagged only with the morph/ platoon and are spatially invariant. SS3 also follows the reparametrized VBGF wherein the growth parameters get redefined as per reference ages.

d) Selectivity

This methodology gives ample space for age-, size- and gender-selectivity for each fishing fleet being modeled for. A distinction is made between catch and survey here, by which fleets' are distinguished by there primary output, which is fed as input in population dynamics viz. catch, whilst a survey has a sense and role of observation only. This tool has a wide range of selection ogives to choose from, which can aptly describe any gear- resource scenario. This also paves way for a more practical modification of selection ogives as the fishery gets older and older. An option of using non-parametric smoothed selection curves is also available.

e) Fishing mortality

SS3 framework revolves around the concept of absolute catch being known well enough to allow the model to compute fishing intensity required as a sort of reverse calculation. Thus this setup permits the forecast both in terms of numbers as well as weight. A seasonal, fleet-specific fishing intensity is directly derived to match the observed catch, which is almost on simulation lines. This tool gives three options for computing fishing mortality viz. effort needed to match midpoint of a season, continuous instantaneous rates of mortality and a hybrid one. Due to the existence of multiple fleets and differential rates of exploitation SS3 gives a sense of "fishing intensity" in one of the three output forms, viz. exploitation fraction, equilibrium reproductive output per recruit and annual numbers weighted F over a range of ages.

f) Expected values for data

A powerful feature of SS3 is its ability to calculate expected values for a wide variety of data types. In each time step this tool tracks numbers at age as well as mean and distribution of time at age for each morph. Upon this matrix formed by these two dimensions age/ size or gender selectivity is applied to arrive at the most probable numbers and distribution of animals selected by a given fleet. This matrix formulation enables the tool to computed expected catch figures too. This is accomplished by a simulation process involving recruitment, growth and selectivity along with mortality. The catch weights thus arrived at are then assorted into weight bins thereby leading to an expected value of catch.

g) Fishery management targets and forecasts

SS3 computes fishing intensity levels that would satisfy several common fishery management templates. This is done by a mechanism of computation of stock per recruit and yields per recruit that would occur at trial level of fishing intensity, uses the unfished stock per recruit rate to calculate the absolute level of recruitment, spawning biomass and yield that would occur if fishing intensity were maintained at that rate. It then proceeds to iteratively compute fishing intensities that would yield known stock per recruit as compared to virgin stock per recruit or target equilibrium spawning biomass or MSY, which are all user specified. This bolsters the armory of fishery managers with multi-dimensional assessment and targets, which are bound to be more robust than single index based management. This dovetails many a harvest policy induced models and hence SS3 is the most preferred analytical tool in countries which utilize catch quotas. The software through which this methodology is rolled out has many features that integrate with quite a few established tool boxes and generic software as well as ensuring significant scalability. As SS3 has kept its constant tryst with evolution steadfastly quite frequent version upgrades signaling quantum leap on evolution are expected and hence this could very well be an option of multi gear tropical fishery managers.

Depletions based stock assessment

As it had been recorded initially, dynamic depletion concepts were very much in vogue in fish stock assessment protocols for long. Hence there is little surprise in the vista of stock dynamic models which are broadly based on various combinations of stock population or biomass depletion owing to fishing mortality generated by various kinds and numbers of fleets. These kind of models involve estimation of population parameters which fall in two groups viz. stock abundance (initial biomass, periodic spikes of abundance and natural mortality) and secondly fishing operation (hyper stability/ hyper depletion, saturability, catchability). The bouquet of optional models is derived from number of fleets, various perturbations of distribution, and the status of migratory flux of the stock. The options also have a sense of probabilistic touch in the form of various likelihood options. Starting with knowing the pulses using simple exploratory plots to maximization of likelihood functions these set of tools have a palette in various shades of stock and effort combinations. The best model chosen from these analytical routines are used for inferential and management purposes. The computational process initiates with a plotting and observation of fitness based short listing of options followed by the generation of a wrapper function, which is put to test by way of optimization under exponential depletion models incorporating situations like immigration, emigration, stock in transit through fishing grounds. All these model formulations involve the nominal catch by the fleet/ gear, a parameter of saturability, perturbation index (which clearly defines the rate and state of depletion crucial to the selection of best suited model) and natural mortality. Here again as in the case of SS3 the instants are time steps. This procedure has provisions for short duration- high frequent time steps as well as longer annual time steps. The two- fleet scenario operates additively exhibiting complementary information about stock abundance. The models based on which the catch are modeled are usually the ones of rare events or negative binomial counts with random normal term added as noise and a multiplicative exponential term to deal with underlying various forms of Gaussian curves. The main index observed in these type of models based on generalized depletion is the rate of depletion at each time step and their dynamics. The depletion index is the difference of the ratio of fish population under fishing assumption to the fish population under no fishing assumption from unity. Thus quite obviously more computational maneuvers may have to be done to arrive at forecast populations based on the time spaced depletion index rates.

One common thread running across all these approaches to quantitative fish stock assessment is the availability of computational options as ready made package, with just inputs to be supplied. This makes the lives of the researchers/ managers easy, as it serves the twin purpose of directly dishing out the decision provoking pointers like biological reference points, while flagging the appropriate kind, type and granularity of data to be collected from the field.

Conclusion

With the common theme of linking common causes like effort with practically tangible effects like catch/ biomass the fish stock assessment models though falling under a few generic approaches, ultimately revolve around the fulcrum of how much is known and how much of what is known is dependable and precise. So as it can be noticed the later developments in these models always revolved around in built simulation of Bayesian type iterations rather than the single valued classical frequentist solutions, thereby making the solutions more broad based and less sensitive to violations of assumptions.

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Chapter 12

Fish Stock Assessment Method: Virtual Population Analysis

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The basic purpose of fish stock assessment is to provide advice on the optimum exploitation of aquatic living resources such as fish and shrimp. In fisheries, optimum exploitation is called Maximum Sustainable yield (MSY). Fishing effort level which gives the Maximum Sustainable yield is indicated by Maximum Sustainable effort. The understanding of concept about stock is very essential in fisheries before applying the fish stock assessment method. Stock can be defined as sub-set of one species having the same growth and mortality parameters, and inhabiting a particular geographical area. Growth parameters are numerical values in an equation by which we can predict the body size of a fish when it reaches a certain age and mortality parameters reflect the rate at which the animals die *i.e.* the number of deaths per time unit.

Models

Fish stock assessment use tools for linking between input and output called "models". Basically, two type of model are applied in fish stock assessment *i. e.* holistic models and analytical models. Holistic models use fewer population parameters than the analytical models. Holistic models consider a fish stock as a homogeneous biomass and also do not take into account the length or age-structure of the stock e. g. Swept area method, Surplus production model. Whereas, analytical models are based on a more detailed description of the stock and more demanding in terms of quality and quantity of the input data. Analytical models give more reliable predictions in comparison to holistic models. Also analytical models are age-structured models. The basic concept in age-structured models is that of a "cohort". A "cohort" of fish is a group of fish all of the same age belonging to the same stock. Basic ideas of the analytical models are, if *there are "too few old fish" the stock is overfished and the fishing pressure on the stock should be reduced* and *if there are "very many old fish" the stock is underfished and more fish should be caught in order to maximize the yield*.

Virtual population analysis

Virtual population analysis (VPA) is a modelling technique commonly used in fisheries science for reconstructing the historical population structure of fish stock using information on the deaths of individuals due to fishing and natural mortality in each time step. VPA calculates the number of fish alive in each cohort for each past year by observing the commercial fisheries and helps fishery scientists to predict the future catches from the stock. It is also called cohort analysis because each cohort is analysed separately. The idea behind the method is to analyse that what can be seen, the catch, in order to calculate the population that must have been in the water to produce this catch. The total landing from a cohort in its lifetime is the first estimate of the numbers of recruits from that cohort.

The basic equation for VPA is

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

VPA is based on three equations;

1. C (y, t, t+1) = N (y, t) * $[\frac{F(y,\ t,\ t+1)}{M+F(y,\ t,\ t+1)}$*{1-exp(-z)}]
2. C (y, t, t+1) = N (y+1, t+1)∗ $\frac{F(y,t,t+1)}{M+F(y,t,t+1)}$ [exp {F*(y, t, t+1)+M}-1]
3. N (y, t) = N (y+1, t+1) ∗exp [F (y, t, t+1)+M]

   Where, C (y, t, t+1) = number caught between age't' and age 't+1' in 'y' year

   N (y, t) = No. of survivors in the sea with 't' age in starting of 'y' year

   N (y+1, t+1) = No. of survivors in the sea with 't+1' age in starting of 'y+1' year

   F = Fishing mortality coefficient and M= Natural mortality coefficient

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

Pope's cohort analysis is the version of VPA developed by Pope (1972). It is based on an approximation. 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 on 1 July becomes:

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

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

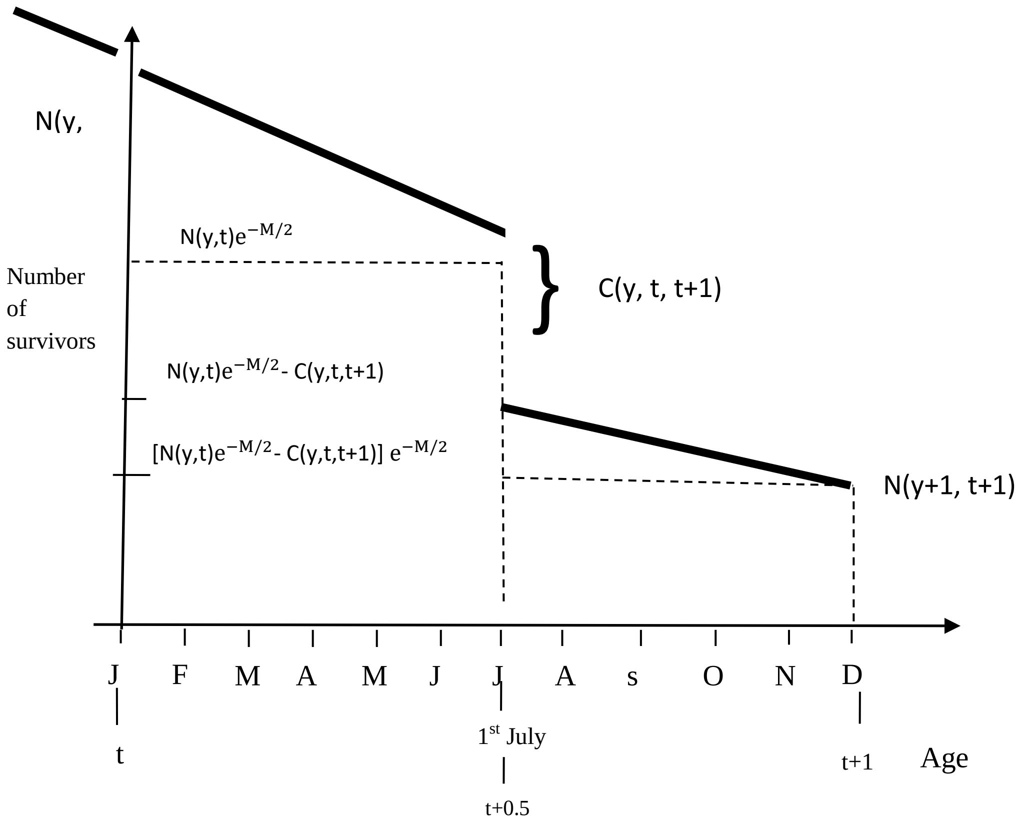
N (y, t) * exp (-M/2) – C (y, t, t + 1)

This number of survivors then suffers further only natural mortality in the second 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)



Diagrammatic representation of age-based cohort analysis

Jones' Length-based cohort analysis

It *is length based cohort analysis* and based on the assumption of all length (or age) classes caught during one year reflects a single cohort during its entire life span. Example for length-based cohort analysis is length composition of total catch of hake (*Merluccius merluccius*):

Length group (cm) L1-L2	Number caught ('000) C(L1, L2)	Length group (cm) L1-L2	Number caught ('000) C(L1, L2)
6-12	1823	48-54	653
12-18	14463	54-60	322
18-24	25227	60-66	228
24-30	8134	66-72	181
30-36	3889	72-78	96
26-42	2959	78-84	16
42-48	1871	84-∞	46

Here length group is converted into age intervals by the inverse Von Bertalanffy equation:

t (L1) = $t_0 - \frac{1}{K} * \ln[1 - \frac{L1}{L\infty}]$, therefore, Δt = t (L2)- t (L1) = $-\frac{1}{K} * \ln[\frac{L\infty - L1}{L\infty - L2}]$

To convert the cohort analysis equation into a length-based version, only the term

exp [(M* Δ t)/2] has to be changed. This is done by substituting Δt with following equation:

exp [(M* Δ t)/2] = exp $[\frac{M}{2} * \frac{1}{K} * \ln(\frac{L\infty - L1}{L\infty - L2})]$ = exp $[\ln\left(\frac{L\infty - L1}{L\infty - L2}\right)^{\frac{M}{2K}}]$ = $(\frac{L\infty - L1}{L\infty - L2})^{\frac{M}{2K}}$

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

N (L1) = N [t (L1)] = Number of fish that attain length L1

= Number of fish that attain age t (L1)

(also called the number of survivors)

N (L2) = N (t (L1 + Δ t) = Number of fish that attain length L2

= Number of fish that attain age t (L2)

[= t (L1) + Δ t]

C (L1, L2) = C (t, t + Δ t) = Number of fish caught of lengths between L1 and L2

= the number of fish caught of ages between t (L1) and t (L2)

H (L1, L2) = $\left(\frac{L\infty - L1}{L\infty - L2}\right)^{\frac{M}{2K}}$

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

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

C (L1, L2) = N (L1) * $\frac{F}{Z}[\,1 - \exp(-z * \Delta t)]$

Limitation

1. Natural mortality of cohort at age't' (M) is constant.
2. It deals with the population dynamics of single species, whereas natural fish populations almost always interact among themselves and with others.

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Chapter
13

Marine Biodiversity and Conservation in India

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The term "Earth" is a misnomer for this planet which is covered by oceans for 70% of its area. Life on Earth began from the oceans and they hold of the biological diversity of the planet. In 1992 the United Nations held the Earth Summit in Rio de Janiero, Brazil to discuss the state of the environment and the living beings which populate the Earth, which was attended by 172 nation states. A parallel summit of 2400 NGOs was also held. From the deliberation of the Summit arose three legally binding documents: "Convention on Biological Diversity, UN Framework Convention on Climate Change" and "UN Convention to Combat Desertification" which was subsequently signed by most of the attending states and the guiding principles of which laid the foundation for future legislation in the signatory countries. The term biological diversity was coined by Dasmann in 1968. The definition of biodiversity was given by United Nations, 1992 at the Earth Summit is as follows: **"**The variability among living organisms from all sources, including, *inter alia*, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems." It includes genetic diversity, species diversity and ecosystem diversity.

Why is it important to conserve biodiversity?

In Nature we find food chains which comprise of hierarchical representations of prey and predator relationships from primary producers to tertiary consumers. However in real terms in an ecosystem the food chains are interlinked to each other. Had ecosystems comprised of linear food chains, many life forms would had been in danger of perishing is any of the links in the food chain were broken. When food chains are interlinked to form a food web, many life forms have an alternate option of food when one source becomes scarce or one link in the food chain is broken. Hence the more complex a food web, the more likely that the ecosystem remains stable, which translates into the more number of interdependent species in an ecosystem, the more stable it becomes.

In the history of the earth, it is gathered from fossil records that there have been six incidents of mass extinction of species namely during the Ordovician, Devonian, Permian, Triassic, Cretaceous and Quaternary eras. The earlier five were caused by geological and cosmological events whereas the last, which s prevalent during our times is mainly caused by the activities of a single species i.e. the Homo sapiens. Man has been causing such sweeping and irreversible changes to the environment through habitat destruction, pollution etc. that it is no longer sustainable for the maintenance of biological diversity on the scale which the Earth has known previously. To arrest this trend steps such as the Earth Summit and its follow up have been found necessary.

India is a land of tremendous biological diversity and is considered one of the "biodiversity hotspots" of the world. In terms of marine biodiversity, India has a coastline of 7517 km and an Exclusive economic Zone (EEZ) of 2.02 million square km. Together with a tropical climate, this vast marine realm offers myriad niches for the sustained growth of marine organisms and hence harbours substantial biodiversity. Of the 2, 63,581 marine species found worldwide, Indian marine biodiversity is comprised of 17,795 species which is about 6.8% of the total diversity. Our assessment of Indian biodiversity is incomplete as we have incomplete or little on groups such as Protista, Euglenophyta, Chrysophyceae, Dinomastigota, Radiolaria, Cubozoa, Isopoda, Orthonectida, Ciliata, Nematomorpha, Priapulida, Chelicerata, Pogonophora, Cephalochordata and marine fungi.

Table 1: Marine Ecosystems in India

ECOSYTEM TYPE	AREA (SQ.KM.)	ECOSYTEM TYPE	AREA (SQ.KM.)
Estuaries	1540	Sandy beaches	4210
Lagoons	1564	Rocky coasts	177
Creeks	192	Salt marshes	1698
Backwaters	171	Salt pans	655
Mud flats	23621	Aquaculture ponds	769
Coral reefs	2330	Sea grass beds etc.	1391
Mangroves	3401		

Source: NBSAP, 2004

The most recalled marine ecosystem is the sandy beach, popularised due to tourism. It comprises of stretches of sand deposited along the coast. The organisms found to inhabit this ecosystem type are adept at burrowing and gathering food from the intertidal regions. Common forms are brachyuran crabs such as the ghost crab (*Ocypode* sp.) and the mole crab (*Hippa* sp.). Also common are burrowing worms such as the lugworm *Arenicola* sp. The marine ecosystem covering the maximum area in India are mudflats along the coasts which are teeming with life such as diatoms and algae, nereid worms, crabs and molluscs. These are rich staging grounds for resident and migratory birds such as flamingos, plovers, godwits, terns and gulls, to name a few. Mangroves comprise a marine ecosystem which has gone severe degradation in the past decades. The largest stand of mangroves, the Sunderban delta, lies partially in India. 69 species of mangroves are available in India, with *Rhizhophora, Avicennia, Sonneratia* and *Brugeierra* being the most commonly found genera. The Sunderban is home to endangered species such as the Royal Bengal tiger, saltwater crocodiles (*Crocodylus porosus*) and the Gangetic Susu or Gangetic dolphin (*Platanista gangetica*). Rocky coasts are comparatively few in India. The organisms found here are adapted which withstand desiccation and wave action and are usually with tensile adaptations. Limpets, mussels (*Perna* sp.), barnacles (*Amphitrite* sp.) are the most common forms.

The coral reefs of India are distributed in limited areas mainly along its island territories and in two major areas on the east and west coast. In comparison to other areas of similar latitude the coral cover along the Indian mainland is less owing to large quantities of freshwater and silt brought by its rivers to the coastal regions which are not conducive for coral growth.

Table 2: Details of coral reefs in India:

Location	**Type of reef**	**Extent**	**Status**	**No. of species of corals**
Gulf of Kachch, Gujarat	Fringing reefs	352.5 km^2	Mostly in degraded state due to high sediment load. Live corals found on reef edge and crest.	49
Malwan, Maharashtra	Fringing reefs	29 km^2	Fairly healthy but prone to degradation	ˆ 11
Lakshadweep islands	Atoll	933.7 km^2 (510.7 km^2 lagoon, 147.7 km2 shelf region)	Near pristine in uninhabited Islands. Showing signs of degradation in inhabited islands	>130
Gulf of Mannar and Palk Bay, Tamil Nadu	Fringing (Palk Bay) and atoll reefs	75.93 km^2 (21 islands in GOM, 10.8 km^2 lagoon, 10.2 km^2 continental shelf region)	Degraded in places. Overgrown with seagrasses and algae in several areas.	96
Andaman and Nicobar islands	Fringing, atoll and barrier reefs	1021.46 km^2 (530 islands, barrier reef of 329 km)	Pristine in uninhabited islands, fringing reefs in inhabited islands show signs of degradation.	>400

Apart from these major areas there are patch and fringing reefs along the coast and islands scattered in the seas. Two such areas with patch reefs namely, Netrani Island (approx 1 km^2), Uttar Kannada district, Karnataka and Ennayam reef (approx 0.5 km^2), Kanyakumari district, Tamil Nadu

Threats to Marine Biodiversity:

The major threats to marine biodiversity can be summerised under the following:

1) *Unsustainable fishing*:

Overharvesting of marine living resources has led to the decline, depletion or collapses of fisheries the world over in several instances. It is estimated that 34% of the world fisheries are being exploited unsustainably. Overharvesting or fishing above the maximum sustainable yield could be a result of several factors such as excess fleet capacity, deployment of small meshed gear or excess units of gear, use of baits such as LED lights or fish aggregating devices, capture of spawning or migrating shoals, overproduction/overconsumption in years of abundance etc.

Overfishing is of two kinds: growth overfishing which results from the removal of excess numbers of juvenile fish from the stock which results in reduced numbers reaching maturity and the ability to spawn further generations and recruitment overfishing, when excess numbers of mature spawners are removed from the stock resulting in lower production of eggs for recruitment to the next fishery.

Some examples of collapsed fisheries due to overfishing are the Peruvian anchovy fishery and the Atlantic cod fishery. There is an estimated 74% decline in the stocks of tuna, mackerel and bonito and 50% of decline in populations of seabirds, mammals and reptiles globally in the period 1970-2010. On the southwest coast of India, stocks of barracuda, ribbonfish, tuna, anchovy, Indian mackerel, wolf herring, silver bellies, half beaks and sharks are currently seen to be in the declining phase, false trevally and silver pomfret in a depleted state and catfish fishery in a collapsed state. The populations of sand lobsters, gorgonids and sea cucumbers have been severely depleted due to overfishing. There is 55% overcapacity in the trawler fleet which contributes to 67% of marine landings.10-40% of the total catch ends up as discards or fishery byecatch in trawler fishery. The loss to biodiversity is total where this catch is not taken as fishmeal. A large number of marine mammals and sea turtles also perish in fishery bye catch.

2) *Climate change*:

The number of tropical storms and cyclones are on the rise die to changes in global oceanic and atmospheric circulation changes accompanying rise in sea surface temperatures. This has a catastrophic effect on the world's population a huge majority of which lives along the coastline and in coastal metropolises. Foods and inundations caused during such inclemental weather phenomena have become a matter of routine in the past decade. Earlier it was hypothesized that the cloud cover would increase due to sea surface warming due to increased phytoplankton and consequently higher cloud seeding nuclei produced (CLAW hypothesis). However in actuality the phytoplankton numbers have been found to reduce due to increased SST causing fewer cloud seeding nuclei in the atmosphere and increased amount of radiation reaching the earth due to decrease in cloud cover (Anti CLAW hypothesis). Decreased productivity of the oceans is a looming threat with further increase in global temperatures. Coastal and inshore water anoxia is predicted to show an increased trend with rising temperatures, creating more dead zones in the sea.

3) *Ocean acidification*:

As a consequence of the increased amount of carbon dioxide in the atmosphere the pH of the oceans has been reducing due to its dissolution. In fact, the oceans pH has reduced by 28.8% since the preindustrial era levels and is expected to further lower by upto 69% by 2050. Acidification of the ocean would result in decalcification and dissolution of carbonates, decline in primary production, reduced survival of larvae, depressed metabolic rates and depressed immune systems of sea creatures. Coral bleaching, already enhanced by rise in sea surface temperature, would further intensify.

4) *Habitat destruction*:

Direct loss of habitat due to anthropogenic activities leads to critical loss of biodiversity and is most prominent in vulnerable ecosystems such as mangrove forests, coral reefs and estuaries.

Diversion of mangrove forests for residential and industrial development has led to ill planned urbanisation where water logging and inundation during inclement weather phenomena is common. Coral mining is widespread in areas with coral reefs though extraction of corals for construction etc. is banned by law. Conversion of coastal wetlands for aquaculture when not carefully planned upsets the ecology and hydrology of the region resulting in poorly constructed farms with disease outbreaks.

5) *Marine debris and pollution*:

Waste disposal by humans into the sea and coastal regions is a major cause of the loss of biodiversity. Huge areas of coastal seas and adjoining water bodies are choked with plastics and the water eutrophied due to sewage and agricultural and industrial run offs. Plastic pollution along the coastline is ubiquitous and increasing. Increased shipping traffic is resulting in higher incidences of oil spills and wastes from ships entering the ocean. Even light pollution from human installations has a detrimental effect on marine biodiversity. In areas where there is sea turtle nesting, the hatchlings emerging at night inadvertently crawl towards the landward light source at night and perish. With increased human populations the pressure on coastal seas in terms of increased pollution levels is steadily increasing and is often not tackled with the urgency and scale it deserves.

Table 3: Pollutants Annually Entering the Coastal Seas

TYPE OF POLLUTANT	QUANTITY
Untreated Domestic sewage	1.41×10^{9} cu.m.
Industrial effluent	50×10^{6} cu.m.
River transported sewage	75×10^{9} cu.m.
Solid wastes and garbage	34×10^{6} tonnes
Fertilizers	5×10^{6} tonnes
Pesticides	65000 tonnes
Detergents	130000 tonnes
Petroleum hydrocarbons	3500 tonnes

Source: NIO, 2008

6) *Invasive alien species*:

Many species of marine organisms are transported to our coastal regions through shipping of introduced for aquaculture and have since established themselves in our water bodies, often causing deleterious effects on the local ecology. Such marine invasives are a threat to local biodiversity. For example, the water hyacinth which was introduced as an ornamental plant by the British has overrun the backwaters of Kerala, causing choking of the waterways and eutrophication during certain seasons due to its prolific growth.

7) *Marine warfare*:

Only a few direct and more apparent consequences such as the oil pollution caused during the Gulf War are evident to the public as consequences of marine warfare. 6 million barrels of crude oil were released into the Arabian Sea and a slick 168 km x 68 km, 5 inches thick was formed. However in peacetime, underwater detonations and the use of sonars cause damage to marine life which is largely undocumented. Disturbances caused by sonars of ships and especially submarines are considered to be a plausible cause behind the mass stranding of whales and dolphins.

8) *Tourism*:

While regulated tourism is a major economic driver, the unsustainable use and neglect of the environment for this purpose results on axing the proverbial tree which bears the fruit. Diversion of natural habitat for tourism purpose and the accompanying pollution resulting from tourism cause irrevocable damage, especially in sensitive and fragile ecoregions such as coral reef islands and mainland beaches. The footfall of a large number of people on urban beaches is detrimental to the intertidal biota. Curiose and trophy hunting especially due to ignorance of existing legislation is a major cause of destruction to marine biota by tourists.

Conservation measures:

Taking into consideration all the threats to marine biodiversity and the urgency and importance of according it protection a number of national and international legal instruments have been put in place:

National:

1. The Biological Diversity Bill, 2002
2. Coastal Regulation Zone Notification, 1991
3. The Indian Wildlife (Protection), Act, 1972
4. The Environmental (Protection) Act, 1986
5. The Indian Fisheries Act, 1897
6. (State wise) Marine Fishery Regulation Acts
7. CMFRI initiatives: Monsoon trawling ban, Minimum Legal Size

International:

1. Convention on Biological Diversity, 1992
2. Convention on International Trade In Species of Wild Fauna and Flora (CITES), 1963
3. Convention of Migratory Species of Wild Animals, 1983
4. Ramsar Convention on Wetlands, 1971
5. MARPOL, 1973/78

Some Marine Conservation Initiatives

National:

1. Marine Protected Areas
2. National Biodiversity Strategy And Action Plan
3. Coastal Zone Management Plans
4. National And State Biodiversity Boards
5. COMAPS: 88 Stations Pollution-Ministry of Earth Sciences
6. Peoples initiatives such as the Versova beach cleanup.

International:

1. Census Of Marine Life
2. Oceanographic Biogeographic Information System

3. Global Ocean Observing System
4. International Coral Reef Initiative : Global Coral Reef Monitoring Network

***<u>Marine Protected Areas in India</u>*:**

6.79% of the total coastline under MPAs. Most of these in Andaman & Nicobar Islands. 24 MPAs in mainland India covering an area of 8214 sq.km (4.92% of PAs). Some of the major MPAs are Gulf of Kachch Marine National Park, Gujarat, Gulf of Mannar Marine National Park, Tamil Nadu, Sunderbans National Park, West Bengal, Bhitarkanika Wildlife Sanctuary, Orissa and Coringa Wildlife Sanctuary, Andhra Pradesh.

In order to conserve marine biodiversity it is necessary to enlighten, motivate and persuade the general public. Where there is exploitation due to compulsion, there is the possibility of providing alternate livelihoods or practicing judicious use. Educating future generations through school curriculums and field activities will go a long way in influencing the minds on future generations towards conservation.

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Chapter 14

Climate Change Impacts on Indian Marine Fisheries and adaptation strategies

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The increase in greenhouse gases (GHGs) in the atmosphere has resulted in warming of climate systems or global warming. Global warming is a long-term rise in the average temperature of the earth's climate system, an aspect of climate change shown by temperature measurements and by multiple effects of the warming. The term commonly refers to the mainly human-caused observed warming since pre-industrial times and its projected continuation, though there were also much earlier periods of global warming. In the modern context the terms are commonly used interchangeably, but *global warming* more specifically relates to worldwide surface temperature increases; while *climate change* is any regional or global statistically identifiable persistent change in the state of climate which lasts for decades or longer, including warming or cooling. Many of the observed warming changes since the 1950s are unprecedented in the instrumental temperature record and in historical and paleoclimate proxy records of climate change over thousands to millions of years.

Global mean surface-temperature change from 1880 to 2017, relative to the 1951–1980 mean. The 1951–1980 mean is 14.19 °C (57.54 °F). The black line is the global annual mean, and the red line is the five-year local regression line. The blue uncertainty bars show a 95% confidence interval. In the latest IPCC report (IPCC, 2014), climate model projections indicated that the global surface temperature during the 21st century is likely to rise a further 0.3 to 1.7°C (0.5 to 3.1°F) for their lowest emissions scenario and 2.6 to 4.8°C (4.7 to 8.6°F) for the highest emissions scenario.

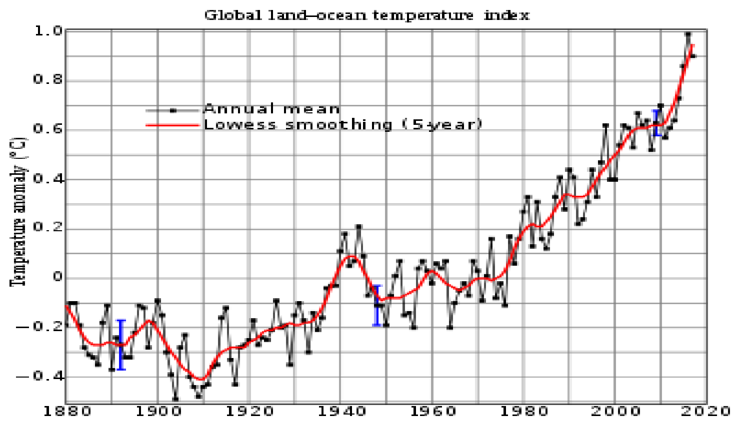

Fig. 1. Global mean surface-temperature change from 1880 to 2017, relative to the 1951–1980 mean.

Global mean surface-temperature change from 1880 to 2017, relative to the 1951–1980 mean. The 1951–1980 mean is 14.19 °C (57.54 °F). The black line is the global annual mean, and the red line is the five-year local regression line. The blue uncertainty bars show a 95% confidence interval. In the latest IPCC report (IPCC, 2014), climate model projections indicated that the global surface temperature during the 21st century is likely to rise a further 0.3 to 1.7°C (0.5 to 3.1°F) for their lowest emissions scenario and 2.6 to 4.8°C (4.7 to 8.6°F) for the highest emissions scenario.

The major cause of present global warming has been attributed to anthropogenic contribution to Greenhouse effect expansion through trapping the radiating heat from atmosphere. Water vapour, carbon dioxide, Methane, Nitrous oxide and Chloroflurocarbons (CFCs) are major gases that contribute to greenhouse effect. Release of these gases to atmosphere happens through natural process such as hydrological cycles, volcanic eruptions and decomposition process or through human activities such as burning of fossil fuels, agricultural practices and industrial process.

Intergovernmental Panel on Climate Change (IPCC) through its Fifth Assessment Report emphasis that probability more than 95 % of earth's warming is through human activities during past five decades. However there are a group of scientists who claims that the climate change could be a result of natural solar process change. But the climate models that include solar irradiance could not reproduce the observed temperature trend over the past century or more without including a rise in greenhouse gases.

History of climate change

The history of climate change science began in the early 19th century when ice ages and other natural changes in paleoclimate were first suspected and the natural greenhouse effect first identified. In the late 19th century, scientists first argued that human emissions of greenhouse gases could change the climate. In the 1960s, the warming effect of carbon dioxide gas became increasingly convincing. By the 1990s, greenhouse gases were acknowledged to be deeply involved in most climate changes and human caused emissions were bringing discernible global warming. Since the 1990s, scientific research on climate change has included multiple disciplines and has expanded. Research during this period has been summarized in the Assessment Reports by the Intergovernmental Panel on Climate Change.

Evidences for climate change

IPCC states that scientific evidence for warming of climate system is unequivocal. The heat trapping nature of carbon dioxide and other gases were demonstrated in the mid of 19th century. Antropogenic activities since the mid-20th century have been attributed as cause for global warming and were observed to increase thereafter. Indications for climate change have been derived from data collected through earth-orbiting satellites. Ice cores samples from Greenland, Antartica and tropical mountain glaciers indicate earth's climate response to greenhouse gas concentrations. Paleoclimatic evidences found in tree rings, ocean sediments, coral reefs and layers of sedimentary rocks indicates that current warming is occuring around 10 times faster than average rate of ice age recovery warming (NRC, 2006). NASA is an expert in climate and Earth science. While its role is not to set climate policy or prescribe particular responses or solutions to climate change, its purview does include providing the robust scientific data needed to understand climate change and evaluating the impact of efforts to combat it.

NASA then makes this information available to the global community – the public, policy- and decision-makers and scientific and planning agencies around the world. The compelling evidences for rapid climate change as per NASA are as listed below.

- Global temperature rise since late 19th century
- Ocean warming since 1926

- Sea level rise (8 inches in last century)
- Declining Artic sea ice (extend and thickness over last several decades)
- Shrinking ice sheets (loss around 281 billion tons of ice per year at Greenland and loss around 119 billion tons at Antartica between 1993 and 2016)
- Glacial retreats (Alps, Himalayas, Andes, Rockies, Alaska and Africa)
- Decrease in snow cover (Northern hemisphere in past five decades)
- Extreme events (Increase in high temperature events, decrease in low temperature events since 1950 and increase in intense rainfall events)

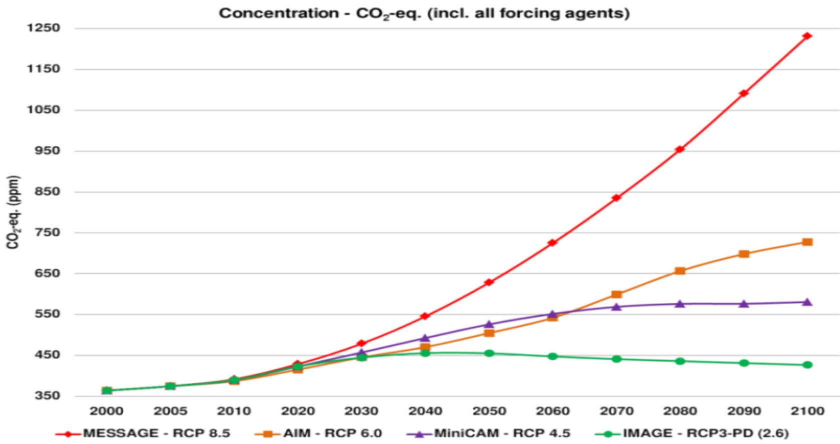

Fig. 2. Future CO_2 projections, including all forcing agents' atmospheric CO2-equivalent concentrations (in parts-per-million-by-volume (ppmv)) according to four RCPs (Representative Concentration Pathways)

The Intergovernmental Panel on Climate Change (IPCC)

IPCC was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. 195 countries are now Members of the IPCC. IPCC reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. IPCC also prepares and publishes Special Reports, Methodology Reports, Technical papers and Supporting Material. The Nobel Peace Prize 2007 was awarded jointly to Intergovernmental Panel on Climate Change (IPCC) and Albert Arnold (Al) Gore Jr. "for their efforts to build up and disseminate greater knowledge about man-made climate change and to lay the foundations for the measures that are needed to counteract such change".

Environmental effects of global warming

The environmental effects of global warming are broad and far reaching, including: Arctic sea ice decline, sea level rise, retreat of glaciers: Global warming has led to decades of shrinking and thinning in a warm climate that has put the Arctic sea ice in a precarious position, it is now vulnerable to atmospheric anomalies. Recent projections suggest that Arctic summers could be ice-free (defined as ice extent less than 1 million square km) as early as 2025–2030. The sea level rise since 1993 has been estimated to have been on average 2.6 mm and 2.9 mm per year ± 0.4 mm. Additionally, sea level rise has accelerated from 1995 to 2015. Over the 21st century, the IPCC projects for a high emissions scenario, that global mean sea level could rise by 52–98 cm.

The major environmental consequences of global warming will lead to extreme weather, extreme events and tropical cyclones, ecosystem changes and changes in ocean properties and abrupt climate changes. On the timescale of centuries to millennia, the magnitude of global warming will be determined primarily by anthropogenic CO_2 emissions. This is due to carbon dioxide's very long lifetime in the atmosphere. Climate change could result in global, large-scale changes in natural and social systems. Examples include ocean acidification caused by increased atmospheric concentrations of carbon dioxide, and the long-term melting of ice sheets, which contributes to sea level rise.

Impact of climate change on fisheries

India is one of major fish producing countries in the world contributing over 3% of both marine and freshwater fishes to the world production with third position in capture fisheries. Fisheries and aquaculture play very important role in terms of food supply, food security and employment opportunities in India. The marine fisheries of the country are highly diverse but predominantly comprising small-scale and artisanal fishers. It is estimated that 63% of the marine catch in India originates from the western coast, with the remaining being made up by the eastern coast. The marine fisheries wealth is estimated at an annual harvestable potential of 4.412 million metric tonnes. India’s freshwater resources consist of 1, 95,210 km of rivers and canals, along with 2.9 million hectares of minor and major reservoirs, 2.4 million hectares of ponds and lakes and 0.8 million hectares of flood plains and derelict water bodies. Inland fisheries contribute 13% to the total fish production of the country (FAO. 2016). Fishing is an industry of great cultural and economic significance in India, and historically, one of the fastest growing industrial sectors as well. Production of fish has increased eleven fold since independence, with total production growing from 0.75 million tonnes to 9.6 million tonnes. Indian seafood exports reached an all-time high to the tune of 10, 51,243 metric tonnes and 5.52 billion USD in 2014-15. Marine product exports, crossed all previous records in quantity, rupee value and US$ terms.

Climate change will intensify by 2050 and though climate outcomes cannot be precisely predicted, the probability towards greater impacts of climate challenge is becoming clearer. Climate change is one of the most important global environmental challenges with implications on food production including fisheries and aquaculture sector, natural ecosystems, freshwater supply, health, etc. Climatic scenarios generated by computer models shows that India could experience warmer and wetter conditions as a result of climate change including an increase in the frequency and intensity of heavy rains and extreme weather events (EWEs). The effects of climate change in aquatic ecosystems can be direct, through rise in sea surface temperature (SST), and associated changes in the phenology of the organisms, or indirect *i.e*., through ocean acidification, through shifts in hydrodynamics and rise in sea level.

Sea Surface Temperature (SST) is likely the single most important factor in among the environmental variables affecting the growth and development of aquatic organisms. The rate of change in SST over Indian Seas revealed that west coast has more impact than in the east coast of India. Northern Indian Ocean has been identified as one of the 17 climate change hotspots among world oceans. These areas will warm faster than 90% of the world oceans. Long-term climate change is likely to impact the marine environment and its capacity to sustain fish stocks and exacerbate stress on marine fish stocks.

The ongoing reduction in the pH of the Earth’s oceans presents a significant challenge to the survival of marine fish. Seawater, by absorbing carbon dioxide and forming carbonic acid, is slowly dropping in pH from its natural, slightly basic state towards pH neutral conditions. Studies indicated an increasing trend in the annual number of instances when pH of surface waters off Kochi was less than 6. armer water temperatures can result in coral bleaching that resulting in the expulsion of the symbiotic zooxanthellae from the tissues of coral. Between 1979 and 1990, sixty major episodes of coral bleaching were recorded, and in 2016 the longest coral bleaching event on record was observed. Several studies relate bleaching events with global warming and climate change during the last few decades (Lix *et al*., 2016),

Sea level rise at long time scales is mainly due to thermal expansion and exchange of water between the other reservoirs (glaciers, ice caps, etc.) including through anthropogenic change in land hydrology and the atmosphere. Sea-level rise estimates for the Indian coast are between 1.06–1.75 mm per year, with a regional average of 1.29 mm per year, when corrected for GIA using model data (Unnikrishnan and Shankar, 2007). Changes in average precipitation, potential increase in seasonal and annual variability and extremes are likely to be the most significant drivers of climate change in aquatic systems. Variations in annual rainfall intensity, dry season rainfall and the resulting growing season length are likely to create impact on shrimp/ fish farming and could lead to conflict with other agricultural, industrial and domestic users in water scarce areas.

Impact on fish stock

Climate change will result in changes in distributions, recruitment and abundance of fish stocks. Changes in timing of life history events are expected with climate change. Species with short-life span and rapid turnover of generations such as plankton and small pelagic fishes are most likely to experience such changes. Changes in abundance will alter the species composition and result in changes in the structure and functions of the ecosystems. Many tropical fish stocks are already exposed to high extremes of temperature tolerance and shifts in spawning periods of fishes have already been observed in a number of commercially important fish stocks, such as threadfin bream (Zacharia *et al*., 2016).Changes in distribution patterns of two key species in Indian fisheries have already been established – migration patterns of the Indian oil sardine and Indian mackerel have changed greatly over the past 50 years (Vivekanandan *et al*., 2009). Changes in sea surface temperature due to global warming could result in changes in the seasonal distribution of certain species, and ultimately disruption in their harvest, which is usually based on indigenous knowledge (Zacharia *et al*., 2016).

Impact on aquaculture

Rapidly depleting fish stocks necessitate aquaculture as an invaluable component of the world's agricultural output, especially if sustainable consumption is to be attained. As the farmed fish species are poikilothermic, any increase or decrease of the temperature of the associated habitats of these stock animals would significantly influence metabolism and growth, and hence, output and income. Increased water temperature would increase the production of mariculture. However, these benefits will likely be superseded by adverse effects of growth at higher temperatures. At higher temperatures significant defects in growth were observed, particularly in the musculoskeletal system and internal abnormalities including bile duct hyperplasia and acute tubular necrosis. Rising temperatures will also ultimately limit the spectrum of species that can be successfully cultured.

Climate change adaptations and mitigations options for coastal fisheries and aquaculture in India

Climate change adaptation is another policy response. The adaptation may be planned, either in reaction to or anticipation of global warming, or spontaneous, i.e., without government intervention. Planned adaptation is already occurring on a limited basis. The barriers, limits, and costs of future adaptation are not fully understood. Mitigation of climate change refers to actions taken to reduce greenhouse gas emissions, or enhance the capacity of carbon sinks to absorb greenhouse gases from the atmosphere. There is a large potential for future reductions in emissions by a combination of activities, including energy conservation and increased energy efficiency; the use of low-carbon energy technologies, such as renewable energy, nuclear energy, and carbon capture and storage. Resilience options and management plans are envisaged to cope up with the implications of climate change on fresh, cold-water, brackish, inland and marine systems, as well as the resilience of infrastructure that allow stakeholders to utilize these systems. The adaptation plans targeted a multifaceted action plan, which would compose several key elements – targeted scientific, a robust coastal ecosystem, community and industry cooperation and climate sensitive technologies with reduced carbon footprints. The following are the key adaptation strategies envisionised to reduce the impact of climate change along the Indian coast.

Resilience of fish habitat

Habitat mapping and modeling: Regional or zone wise mapping and spatial representation of Indian aquatic habitat and its linkage with eco-system services is identified as a prospective adaptation option. Habitat mapping could be extended specifically for commercial as well as vulnerable species for better conservation, management and sustainable utilization of aquatic resources.. Habitat mapping coupled with regional models and continuous monitoring of habitat change provides better adaptation and management of fisheries habitat.

Mangrove mapping, conservation and restoration: India accounts for nearly 3 % of world's mangrove vegetation and carbon sequestration potential of mangroves and their sediments makes more significant in the context of climate change. Mangrove ecosystem provides a significant habitat for several aquatic species and act as breeding ground and nursery of valuable biota. Mangroves ecosystem mapping, conservation and restoration is identified as an adaptation option to enhance coastal resilience. Ecosystem productivity could be increased by improving the habitat resulting in beneficial implications on coastal fisheries.

Resilience of fish stocks

Stock modeling: To enhance the resiliency of stocks and their ability to recover from population collapses stock modeling could be done. Several research institutions are capable of carrying this out.

Vulnerability assessment along Indian coastal zones and conservation: Scientific criteria developed by CMFRI for long term vulnerability assessment of Indian marine fishes could be used to assess the species level adaptability to climate change. Species identified as highly vulnerable could be prioritized for conservation and management strategies. Conservation and fishing protocols based on species stock vulnerability could also be developed so as to enhance the sustainability.

Monitoring, Control and Surveillance (MCS): India has effective Monitoring, Control and Surveillance (MCS) mechanism in the EEZ for sustainable usage of oceanic resources. Highly vulnerable stocks identified after scientific analysis could also be brought under MCS for better conservation and adaptation for an optimum period.

Fish stock availability

Potential fishing zone could be identified for reducing scouting time and increasing fishing profitability. Activities at fishing zones could be monitored for sustainable exploitation of fisheries resources. Fish catch forecast models could be developed for Indian coast, so as to enable the fishermen folks and stakeholders to cope up with the stock shift. New technologies and fishing methods developed could be implemented in the context of climate change and stock availability. Fishermen folks, self-help groups and other stakeholders could be trained and empowered to augment marine fish production. Regulation of fishing (fleet size, mesh size, spatiotemporal closure) could be ensured for sustainable fisheries stock utilization.

Sustainable fish harvesting

Implementation of Minimum Legal Size: Catch is of serious concern in the harvesting sector which could be directly attributed to climate change and stock distribution. However, this increases the fishing pressure on vulnerable populations. Hence to bring about sustainability, minimum legal size could be implemented to reduce growth overfishing there by to reduce excess pressure on the stocks.

Green fishing protocols for carbon foot print reduction: Alternative energy usage in fishing operations could be considered. However owing to the direct contribution of fisheries sector directly to food and nutritional security to millions of populations, implementation of shift in operational techniques to reduce the C footprint need to be done only after caution.

Adaptation on coastal aquaculture

Identification of climate resilient species suitable for mariculture: After experiments on impacts of climatic parameters, stress tolerant species (Silver pompano, Cobia, etc) were identified along with development of technologies for its culture. As climate change had affected wild species distribution and catch, focus on mariculture is an adaptive option and accordingly identification of stress tolerant species is significant. Zone wise commercially valuable stress tolerant species could be identified and cultured for better adaptation.

Adaptations to integrated farming technologies: Integrated Multi Trophic Aquaculture with farming fish with seaweed and mussel was demonstrated as a successful adaptation measure. Integrated cultivation doubled the weight of seaweed yield and also enhances the fishermen income through co-farming yields as well. Paddy-fish integrated farming was successfully implemented as an adaptive measure across several states of the nation. Successful demonstration of integrated farming of paddy (pokkali) with finfishes (mullet and pearlspot) in Kerala resulted in profitability.

Regional wetland restoration and implementing scientific fish farming: Wetland restoration along with incorporation of scientific fish farming at village level was identified as a prospective climate resilient strategy. In India 5,55,557 small wetlands were detected and mapped as point features (Panigrahy Sushma et. al, 2012) Developing wetlands of size below 2 ha for fish farming could enhance the regional resilience along with village level food and nutritional security and the surplus production could be channelized to global supply chain.

Seaweed farming along Indian coasts: Seaweed farming is identified as a prospective climate resilient strategy. Large scale seaweed cultivation along Indian coastal waters aimed at carbon sequestration, reducing ocean acidification, coastal pollution abatement, co-farming of mussels, oysters and fishes, marine product development, coastal livelihood supplementation and fish feed formulation could enhance the adaptability level of coastal aquaculture.

Development of climate resilient products: Development of climate resilient products from mariculture residues is another adaptive measure. Biochar with C sequestration ability could be further utilized for aquaculture treatment applications. Biofuel production from micro and macro algae is also a significant climate resilient strategy upon which India is focusing.

Adaptation on fishing communities

Climate change preparedness of vulnerable coastal populations: The major Climate Preparedness activities (CPAs) recommended are as Increase awareness, preparedness and adaptation among fishers on climate change related threats to the livelihood through suitable scientific interactions and trainings, Strengthen supplementary avocations available across the different fishing villages to negate the risks and uncertainties of climate change, Scientifically develop location specific elevation levels for new settlement areas for coastal erosion adaptation, Train on disaster management and evacuation plans.

Strengthen basic amenities in coastal villages: As extreme climate events negatively impacts on basic needs of coastal population, alternative facilities need to be developed for easy access to food, potable water, sanitation, shelters, etc. Local infrastructure (roads, health supports, etc) could be developed for reducing climate change vulnerability. Since fishermen are forced to move out to deeper areas, protection aids must be made available even for traditional /artisanal fishers. Strengthen seawalls and bioshields (coastal forestry). Regulate unplanned coastal activities which would affect tidal amplitudes in village canals/ riparian areas.

Increase disaster preparedness: India had established early warning system and also has a very good natural disaster management system to deal with extreme climatic events Successful disaster management plans of the nation could be implemented at each coastal village to cope with even moderate climate change events. Installations of automatic weather stations and similar facilities along with awareness at village level shall enable better weather forecasting and climate change adaptations.

Development and familiarization of E-commerce technologies for fishermen communities: Though E Commerce solutions for fish products are available, gap still exists to develop multivendor platform for directly engaging various self-help groups of fishermen communities as multiple vendors. We are ambitiously working out on the concept to develop such a system for fishermen community livelihood improvement and empowerment. Such systems could be in line with the national goal of farmer income increment. The system could fetch better income as well as better marketing for the engaged fishermen communities.

Interventions towards climate resilience through NICRA Project of ICAR-CMFRI

ICAR sponsored national level network project to bring out best climate resilient agriculture practices and strategies in each related sectors and ICAR-CMFRI has been entrusted with marine fisheries sector. The climate change research task was undertaken across the total operating centres. The project could bring several major outputs and outcomes. The project enabled the formulation of scientific criteria to assess the vulnerability of marine species of the nation, which is first of its kind and pave ways for future research in this direction. Several climate resilient products development research could also be accelerated through the project. Biofuel and biochar production from aquatic vegetation such as Seaweeds and Water Hyacinth has been attained, which paves way towards exploration of new horizons of climate resilience in marine fisheries sector. Beneficial effects of biochar in fish and paddy growth could also be established through the project.

Conclusion

Climatic resilience of the marine sector could be attained and the adaptation and mitigation options explored are feasible for time bound implementation. However, more research support could bring these strategies to village level. Climate smart coastal villages could directly contribute towards food and nutritional security of millions and the research interventions in this direction could bring significant improvements. Technology development and empowerment of fishing communities could bring significant changes in the livelihoods as well as national contributions of fisheries sector. E-commerce solution being developed through the project, provides opportunities for the involvement of SHGs of fishermen communities, which could result in the attainment of national goal of farmer income improvement/ doubling. Integrated farming methods are more economically feasible and policies need to be accordingly framed to undertake aquaculture, agriculture and farm tourism as a comprehensive package rather than depending on single sector.

Chapter 15

Technological advancement in Mariculture in India for production enhancement and sustainability

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Mariculture is the farming and husbandry of marine plants and animals in the marine environment. Mariculture produces many high value finfishes and shellfishes (crustaceans, and molluscs - oysters, mussels and clams). As the production from the capture fisheries reached its sustainable limits, mariculture is the next viable alternative for increasing seafood production of the country. Indian coastline offers immense potential for the expansion of mariculture activities. CMFRI through its research programmes over the years has developed technologies for seed production and farming of bivalves, marine pearl oysters, marine food fishes and ornamental fishes, marine crustaceans and seaweeds.

Existing major mariculture species and farming technologies

Mussel farming

Various methods for mussel farming like raft method (in bays, inshore waters), rack method (in brackish water, estuaries) or long line method (open sea) were developed for mussels. Commonly adopted species for mussel farming are *Perna indica and P. viridis*. Commercially important edible oyster species are *Crassostrea madrasensis*, *C. cucullata* and *C. gryphoides*.

Recently CMFRI has perfected spat production and nursery rearing system for green mussel at its Vizhinjam Centre. An average small scale unit can produce 10 million spats/annum. Nursery production of green mussel spat can significantly reduce wild collection of seeds.

Edible oyster farming

CMFRI has developed methods for edible oyster (*Crassostrea madrasensis)* culture and has produced a complete package of technology, which is presently being widely adopted by small scale farmers in shallow estuaries, bays and backwaters all along the coast. Technology for production of oyster spat was also perfected by CMFRI.

Marine pearl culture

Technology for the production of spherical pearls from *Pinctada fucata and Pinctada margaritifera* was developed by CMFRI. Raft culture and rack culture in nearshore areas are the two methods commonly adopted techniques for rearing pearl oysters. Shell bead nucleus (3-8 mm) implantation along with graft tissue is done in the gonads of the oyster through surgical incision for production of pearls. Implanted oysters were stocked in suitable cages for rearing in the farm. Harvesting of Pearls was carried out after 3-12 months and harvested pearls were graded based on their quality as 'A', 'B' and 'C" grades for marketing.

Mabe pearls

Technology for production of image pearls/designer pearls is very simple and can be easily carried out by farmers, unlike the technology for free round pearl production. A Mabe pearl is a dome-shaped or image pearl produced by placing a hemisphere or miniature image against the side of the oyster shell interior. The result is an exquisite pearly nacre-coated miniature image which can be made into pendants, eardrops, rings etc.

Clam Culture

Package of clam culture practices has been developed for the blood clam *Anadara granosa* and *Paphia malabarica,* where production of 40 tonnes/ha/6 months and 15-25 tonnes/ha/4-5 months have been achieved in field trials. Induced spawning and larval rearing to setting of spat has been perfected for clams like *P. malabarica, Meretrix meretrix and Marcia opima.*

Lobster farming and fattening

Increasing demand for live lobsters in the export market led the farmers and entrepreneurs to collect juvenile lobsters from the wild and grow to marketable size in ponds, cages and tanks by feeding trash fishes and other discards.

Crab farming / fattening

Seed production of the blue swimming crab, *Portunus pelagicus,* has also been developed. Protocols for fattening and grow out have been successfully developed.

Seaweed Culture

Since 1972 the CMFRI is engaged in the cultivation of important seaweeds such as *Gracilaria edulis*, *Gelidiella acerosa, Sargassum wightii, Acanthophora spicifera* and *Ulva lactuca*. Mariculture of seaweeds in India mostly deals with cultivation of *Gracilaria edulis*. Very recently the cultivation of *Kappaphycus sp*, gained popularity among farmers. There are two methods for cultivation of seaweeds - Vegetative propagation using fragments and also by different kinds of spores.

Marine ornamental fish catch and trade

Based on the Global Marine Aquarium Database (GMAD) the annual global trade is between 20 - 24 million numbers for marine ornamental fish, 11-12 million numbers for corals and 9-10 million for other ornamental invertebrates. A total of 848 numbers of reef associated fishes are reported in Indian waters. Out of which about 350 species are reported to be of ornamental value. Some important ornamental fish families are Family Pomacentridae (Clown fishes and damsel fishes), Family Labridae (Wrasses), Family Scaridae (Parrot fishes), Family Chaetodontidae (butterfly fishes and banner fishes) and Family Acanthuridae (Surgeonfishes).

Marine ornamental fishes are caught in India either as a by-catch in gears such as traps or bottom-set gillnets or caught unscientifically in coral reef areas. Indiscriminate collection practices followed at coral reef habitats inflict damage to the ecosystem.

Hatchery Production of marine ornamental fishes

CMFRI developed package of technologies on bloodstock development, captive breeding and larval rearing of several species of marine ornamental fishes. The methodologies developed can be scaled up for commercial level production and a hatchery produced marine ornamental fish trade could be developed in the country. It is high time that the fisheries developmental agencies should come forward with attractive schemes to popularize the technology.

Hatchery technology for following species marine ornamental fishes was developed at CMFRI and these technologies are being transferred to fishermen/women SHG's at various maritime states of the country.

- Clown fishes: *Amphiprion sebae, A. ocellaris, A. percula, Premnas biaculeatus, A. sandaracinos, A. frenatus, A. clarkii.*
- Damsels: *Dascyllus trimaculatus, D. aruanus, Pomacentrus caeruleus, P. pavo, Neopomacentrus nemurus, N. filamentous, Chrysiptera unimaculata, C. cyanea, Chormis viridis, D. carneus*
- Dottybacks: *Pseudochromis dilectus*
- Marcia'santhias: *Pseudanthias marcia*
- Marine invertebrates: *Rhynchocinetes durbanensis* (Camel shrimp)

Cage aquaculture

Production of farmed aquatic organisms in caged enclosures has been a relatively recent aquaculture innovation. Cage culture utilizes existing water resources, but encloses the fish in a cage or basket which allows water to pass freely between the fish and pond. Cage and pen culture are viewed as the aquaculture system of the millennium. Cage culture has made possible the large scale production of commercial finfish and will probably the most efficient and economical way of rearing fish. Depletion of ocean and coastal fishery resources has led to the development of marine cage culture.

Site selection

Choice of site in any fish farming operation is of paramount importance since it greatly influences economic viability by determining capital outlay and affecting running costs, production and mortality.

Important criteria to be considered in site selection are Lakes, bays, lagoons, straits and inland seas are ideal sites for cage-culture which are protected from strong winds and rough weather.

Water current 5-10 cm/s

Depth> 2 m

Dissolved oxygen levels>5ppm

Salinity 34 ppt

Temperature 25-30° C.

Cage design and construction

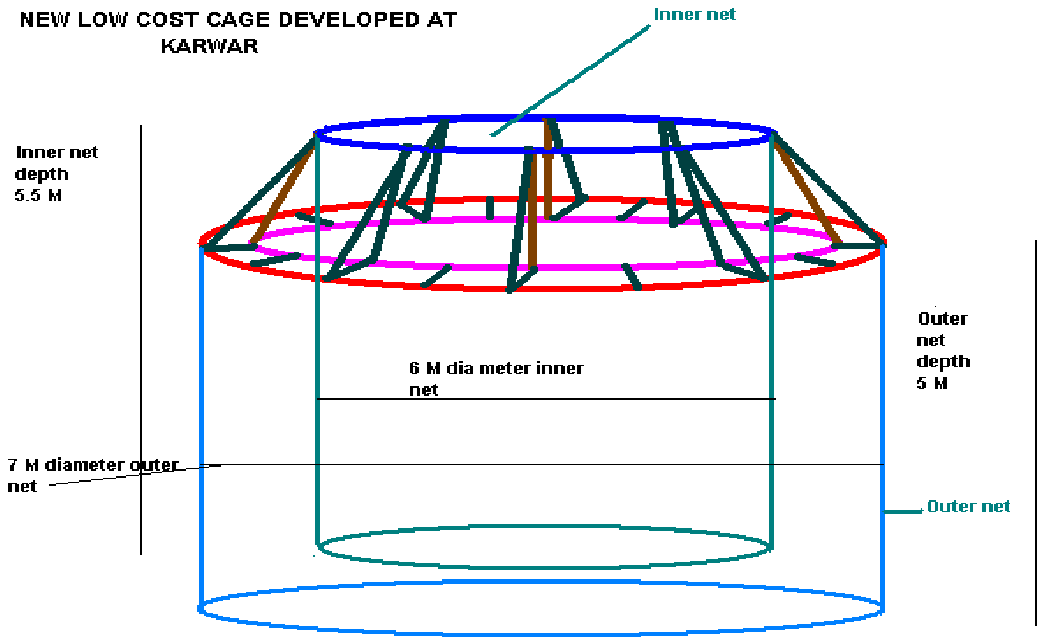
A good and practical design of a cage will meet the requirements of the species farmed and the staff who will operate the system. The structure must be strong to withstand the forces of winds, waves and water currents while holding the stock securely. They must be durable and resistant to corrosion since they are exposed to highly corrosive effects of seawater. The net bags must be strong enough to hold the stock securely and must be weather resistant. The floatation system must support the combined weights of the walkways and framing, the people working on the raft, net full of fish during harvest and fouling organisms of the net. The structure must be securely anchored to avoid being carried away by strong currents.

Shape: Shapes of the cages are likely influenced by the swimming behaviour of the fishes. Circular shape cage bag offers the most economical cost of netting materials of the same area and deep than the other shapes such as squares, rectangular, octagon etc. Rectangular cages have a greatest water exchange to volume ratio when the broader side is exposed to current.

Size: With the increase in bag size the cost per unit volume of the cage will reduce. This is one reason for using large rearing units in intensive marine fish culture. The common sizes used for floating net cages are 6 m and 10 m diameter and 4x4 m and 4x5 m and 5x5 m floating cages with a net deep of 3.5-5.0 m including freeboard. Larger size floating cages will require equipment and manpower for its management.

Materials: The main criteria for selecting the materials for the construction of cages are light weight, strong, weather and corrosion resistant, fouling resistant, drag free, smooth textured, easy to construct and repair, cheap and locally available. Netting materials must not be harmful or stressful to the cultured species.

Mooring systems: Most of the mooring systems consist of lines and anchors that secure cages in a particular location. Mooring lines must withstand forces acting on the floating cage system and transmit this to anchors. The total length of mooring lines must be at least 3 times the maximum depth of the water. Depending on the set up of floating cages, mooring system can be single or multiple point. Anchors must be strong enough to resist the forces acting and to secure the floating cages system in place. Components of a cage include cage bag, floats, frame, service system, mooring system and anchor system.



Cage nets

Net bags fabricated with synthetic nylon or polythene netting reinforced with polythene ropes are used for farming. Recently new stronger materials from different manufactures are available in the market. Netting material is twisted, braided or even knotless.

Types of net bags are used in cage culture

Outer net or predator net for protection from competitors and predators in open waters: Braided HDPE net 3 mm/80 mm mesh (square) of required size with 14 mm PP vertical rope lining

Inner net for holding the fish: For fish Nylon / Sapphire/ HDPE net with 15 -40 mm mesh, for periodic change are used.

Bird net: Birds should be particularly prevented from cages because they prey on fish and are in many cases are carriers of disease agents and parasites. Bird nets are made with 1.25 mm/80 mm twisted HDPE, provided with rings to connect to the inner cage net, prevent birds from picking caged fish.

Service system

Service system helps the farmers for feeding, cleaning, monitoring, grading etc during cage farming. Max height of handrail should be about 100 cm.

Mooring system

Two functions of mooring line are to withstand and transmit forces. This must be powerful enough to resist the worst possible combination of forces. There are two types of mooring system exist single point & multi point mooring systems in open sea cages. Fixed mooring system is more commonly used in backwaters/ rivers etc. Different types of anchor systems are using in cage culture practices. Some common types of anchors are dead weight anchors, block of concrete stones, gabion bags filled with stones, scrap metal etc.

Selection of species for farming

The species selected should have a ready market for local consumption or for export. The farmer should decide whether he would culture high volume, low priced species or low volume, high priced species.

Attributes for an ideal candidate species for cage culture

- Hardy species that tolerates crowding and wide physiological tolerances.
- High fecundity of female fish with plenty of material for hatchery production of seed.
- Hatchery production of seed to be relatively simple.

- Those feed well on pellet diets, and juveniles easy to wean to pellets.
- Those which grow rapidly, reaching a harvestable size (350 g – 3 kg) in six to eight months.

Potential species for India

- Marine: Cobia, Sea bass, Groupers, Snappers, Mullets, Lobsters etc.
- Inland: Carps, Pangasius, Tilapia etc.

The stocking densities for cage culture generally range from 15 to 40 no/m^3, although densities can be as high as 60 no/m^3. Cannibalistic fish should be graded into several size groups and stocked in separate cages. The stocking should be done in the early hours (06 00–08 00 hours) or late in the evening (20 00–22 00 hours) when the temperature is lower.

Two to three months thereafter, when the fish have attained a weight between 150–200 g, the stocking density can be reduced to 10–20 fish per cubic meter. Higher stocking densities require more frequent monitoring of water quality and more feeds.

Table 1. Farming details of food fishes in cages

Sl. No.	Species	Length (cm)	weight (g)	Stocking density (nos/ m^3)	Culture period (months)	Weight (Kg)
1	Sea bass	12	10	35	8-10	1-1.5
2	Cobia	15	15	12	6-8	3
3	Snapper	5	4	30	10-12	1.5
4	Mullet	8	5	35	8-10	1

Feed and feed management in cages

Main components of fish feeds are Protein, Carbohydrate, Fat, Minerals, and Vitamins etc. Deficiency of a nutritious feed leads to growth retardation and subsequent disease outbreak. Marine fish require high protein (35-40 %) for their optimal growth. Overfeeding leads to wastage and pollution. Feeding rate, frequency of feeding and time of feeding are important factors to be considered in cage farming. Feeding rate and frequencies are related to age and size of fish. Larval fish and fry need to be fed on high protein diet more frequently. As fishes grow bigger, feeding rate and frequencies can be reduced. Feeding is labour intensive, so frequency has to be adjusted to become economically viable. Growth and feed conversion increases with increase in feeding frequency. Feeding of fish also influenced by the time of the day, season, water temperature, dissolved oxygen level and other water quality parameters

Mapping of suitable cage culture sites

The primary requirement for development of sea cage farming is the selection of suitable sites with required depth, current and water quality parameters. Suitable locations all along the East and West Coast of India for sea cage farming of high value marine finfishes were mapped in GIS platform. Satellite data were also used in identification of satiable sites for cage farming. The available physico-chemical and oceanographic parameter data obtained from Landsat 8 and MODIS satellite data were pooled and used on GIS based platform. The maps were layered, and were combined to generate a final output showing the "most suitable, suitable, moderately suitable and unsuitable", locations for open sea mariculture development along the Gujarat coast. Such maps were developing almost all coastal districts for the easy execution of sea cage farming.

Integrated Multi-Trophic Aquaculture (IMTA)

On a global basis the current mariculture practices are dominated by intensive monocultures which have led to sustainability problems, environmental degradation and consequent disease outbreaks. Integrated Multi Trophic Aquaculture (IMTA) is the practice which combines in appropriate proportions, the cultivation of fed aquaculture species (e.g. finfish/shrimp) with organic extractive aquaculture species (e.g. shellfish/herbivorous fish) and inorganic extractive aquaculture species (e.g. seaweed) to create balanced systems for environmental stability (bio-mitigation), economic stability (product diversification and risk reduction) and social acceptability (better management practices). The IMTA can also increase the production capacity of a particular site. It is well understood that the increasing use of coastal waters worldwide, coupled with rapid growth and expansion in mariculture, demand for more sustainable farming practices and hence integrated mariculture has much relevance and scope.

The CMFRI has successfully conducted the demonstration of IMTA under participatory mode with fishermen groups by integrating seaweed with cage farming of cobia. A total of 16 bamboo rafts (12× 12 feet) with 75 Kg of seaweed per raft can be integrated with one cobia (*Rachycentron canadum*) cage of 6 meter diameter. It has been proved that in one crop of 45 days the seaweed rafts integrated with cobia cage will give an average yield of 260 Kg per raft while the same was 150 Kg per raft for the rafts which were not integrated. The technology is being adopted by 100 farmers of Palk Bay, Ramanathapuram, Tamil Nadu. In addition to the revenue generated from cobia farming, an additional income of Rs.32 lakhs could be realized due to additional seaweed yield (11 tons) from IMTA. The IMTA adopted by 100 farmers would generate additional 1200 mandays per crop of 45 days.

Recirculating Aquaculture system

Recirculation aquaculture is essentially a technology for farming fish or other aquatic organisms by re-using the water in the production. The technology is based on the use of mechanical and biological filters, and the method can in principle be used for any species grown in aquaculture such as fish, shrimps, clams, etc. Recirculation technology is however primarily used in fish farming,

In a recirculation system it is necessary to treat the water continuously to remove the waste products excreted by the fish, and to add oxygen to keep the fish alive and well. A recirculation system is in fact quite simple. From the outlet of the fish tanks the water flows to a mechanical filter and further on to a biological filter before it is aerated and stripped of carbon dioxide and returned to the fish tanks. This is the basic principle of recirculation. Several other facilities can be added, such as oxygenation with pure oxygen, ultraviolet light or ozone disinfection, automatic pH regulation, heat exchanging, denitrification, etc. depending on the exact requirements.

Breeding technology of fin fishes standardized in CMFRI

It has long been recognized that a good source of juveniles is the most important prerequisite for fish farming. Non availability of the seed for stocking in quantity and quality at the right time, will affect the production plans. Most of the world’s fish aquaculture still depend on the fry almost comes exclusively from wild. Seed supply from the wild is often unpredictable and seasonal. Hatchery production of seeds of economically important finfish ensures a steady supply of quality seeds for aquaculture operations.

The successful hatchery production of marine finfishes depends on various factors like proper maintenance of broodstock, efficient live feed production systems, larval rearing protocols including water quality management, feed management and nursery rearing systems. CMFRI has developed hatchery production technologies for marine food fishes like Cobia (*Rachycentron canadum*), Silver Pompano (*Trachinotus blochii),* Indian Pompano *(Trachinotus mookalee),* Orange spotted grouper (*Epinephelus coioides)* and Pink ear emperor *(Lethrinus lentjan)*.

Efforts are being taken by various government agencies for improving the availability of marine fish seed for farming by supporting the hatcheries to take up the production of marine finfish seed production. The increased availability of seed for farming in the coming will contribute to increased production through the mariculture in the country.

Conclusion

Even though the capture fisheries will continue to be the mainstay of the Indian marine fisheries, it is evident that further increase in fishing pressure will not yield the required quantity of seafood to meet the increasing per capita requirement in the future years. In India till date mariculture activities are confined only to coastal brackish water aquaculture, chiefly shrimp farming. Other coastal aquaculture activities like green mussel farming which is confined to Malabar Coast in Kerala and seaweed farming along Ramanathapuram and Tuticorin coasts of Tamil Nadu producing about 5000 tonnes annually.

India is still in infancy in mariculture production in comparison with the global scenario. When we compare the situation in the Asia-Pacific region also, we can find that a lot of advances have been made in the development and expansion of mariculture. Since, mariculture is the only sunrise sector for increasing seafood production in the coming years, the research and development in this sector is of paramount importance to develop mariculture as a substantial contributor of seafood production in the country.

Chapter 16

Applications of Molecular Markers in Fisheries and Aquaculture

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Organisms are characterized by unique biological attributes which enhance their fitness and survival to a particular environment. The driving force for enhanced survival and fitness is the genetic variation inherent in an individual as well as in a population. The information regarding genetic diversity and variation has wide application in research on evolution, conservation and management of natural populations. The advent of DNA cloning and sequencing methods have contributed immensely to the development of molecular taxonomy and population genetics over the last 2 decades. These modern methods have revolutionized the field of molecular taxonomy and population genetics with improved analytical power and precision.

Molecular markers can be characterized as Type I and Type II markers; Type I markers are associated with genes of known function and type II markers are associated with genes of unknown function. Allozyme markers are type I markers as the proteins they encode are associated with some functions. Microsatellites and other neutral markers are type II markers unless they are associated with genes of some known function.

Allozyme

Allozyme electrophoresis is a method which can identify genetic variation at the level of enzymes that are directly encoded by DNA. Protein variants called allozymes originates from allelic variants and they will differ slightly in electric charge. Allozymes are codominant markers having been expressed in a heterozygous individual in a Mendelian way. Thus allozyme analysis provides us with data on single locus genetic variation which can answer many questions about fish and fish populations. To detect allozyme variation, the first step is to extract allozymes from tissues using specific protocols. Then the variation is detected through electrophoresis in an acrylamide or cellulose acetate gel. Individuals that are homozygous show a single band whereas heterozygous individuals show two bands. Allozymes are one of the most studied form of molecular variation due to their simplicity, low cost and the requirement of little specialized equipment. Any kind of soluble protein is suitable for allozyme analysis. A large number of loci can be screened at a time. The limitations of this technique include requirement of a large amount of tissue and consequently this method could not be applied when the organisms are small (for e.g.; larval forms). The tissue sampling method is invasive and so the fish needs to be sacrificed and the tissue needs to be stored cryogenically. A point mutation in a nucleotide sequence may not result in a change in amino acid at all and thus could not be detected by protein electrophoresis. In addition to that, a change in DNA that results in a change in amino acid will not result in the overall charge of the protein and therefore is not detected. In spite of their limitations, the use of allozyme analysis has been widespread in fisheries mainly in fish systematics, population structure, conservation genetics, mixed stock fishery analysis and forensic analysis.

Mitochondrial DNA markers

Mitochondrial DNA is non- nuclear DNA in the cell having located in within organelles in the cytoplasm called mitochondria. Mitochondrial DNA is maternally inherited with a haploid genome. The entire genome undergoes transcription as one single unit. They are not subjected to recombination and thus they are homologous markers. They are selectively neutral occurring in multiple copies in each cell. Mitochondrial DNA is physically separate from the rest of cell's DNA and so it is relatively easy to isolate from any tissue or blood sample. Due to the maternal inheritance of mitochondrial DNA, the effective population size is smaller than nuclear DNA and so mitochondrial DNA variation is more sensitive to population bottlenecks and hybridizations. The differences in the nucleotide sequence of DNA molecule in the mitochondria can be determined directly or indirectly by several methods. Many population genetic studies have employed RFLP (Restriction Fragment Length Polymorphism) analysis of mitochondrial DNA for understanding population genetic variation either by digesting the whole purified mtDNA with restriction endonucleases or by DNA sequencing of small segments of mtDNA molecule obtained by PCR amplification. These techniques with increased resolution and maximum information have made mtDNA analysis very popular.

The newly emerged sequencing technologies have enabled direct sequencing of mitochondrial genes and several sets of universal primers have been developed from conserved sequence regions. Slow evolving gene regions are being used for inter species comparisons and fast evolving gene regions for population comparisons. The only non-coding region of mtDNA is D-loop region and this region is fast evolving and mostly used for population comparisons. The cytochrome b and ND-1 and ND-5/6 gene regions are also being used widely. Mitochondrial Cytochrome C Oxidase I gene has been identified as the universal barcode for species level identification due to its conserved nature across a wide range of taxa. DNA barcodes are segments of approximately 600 base pairs of the mitochondrial COI gene which is a fast, efficient and inexpensive technique helpful in cataloguing the biodiversity. During the last two decades, mitochondrial DNA genes have found widespread application fish taxonomy, biology and population genetics.

Arbitrary Nuclear DNA markers

Arbitrary markers are used when we target a segment of DNA of unknown function. The widely used methods of amplifying unknown regions are RAPD (Random Amplified Polymorphic DNA) and AFLP (Amplified Fragment Length Polymorphism) DNA. RAPD uses an arbitrary primer which can amplify anonymous loci. It is fast, cheap and shows very high amount of polymorphism and this marker does not require knowledge of the genetic makeup of the organism. The major drawback with RAPD markers is the lack of reproducibility and repeatability and the large number of products generated. RAPD is a dominant marker and so homozygous and heterozygous states cannot be differentiated and these patterns are sensitive to slight changes in amplification conditions. Amplified Fragment Length Polymorphism (AFLP) markers combine the benefits of both RFLP and RAPD. The total genomic DNA is digested using two restriction enzymes. Double–stranded nucleotide adapters are ligated to the ends of DNA fragments to serve as primer binding sites for PCR amplification. Primers complementary to the adapter and restriction site sequence, with additional nucleotides at the 3′-end, are used as selective agents to amplify a subset of ligated fragments. The presence of absence of DNA fragments are detected on polyacrylamide gels and thus polymorphisms are studied.

Specific Nuclear DNA markers

Variable Number of Tandem Repeat is a segment of DNA that is repeated tens or even hundreds to thousands of times in nuclear genome of eukaryotes. They repeat in tandem; vary in number in different loci and differently in individuals. There are two main classes of repetitive and highly polymorphic DNA; minisatellite DNA referring to genetic loci with repeats of length 9-65 bp and microsatellite DNA with repeats of 2-8 bp (1-6) long. Microsatellites are much more numerous in the genome of vertebrates than mini satellites. They are widely used in population genetics of fishes and aquatic invertebrates. Minisatellites can be classified into multilocus and single-locus minisatellites. Multilocus minisatellites are composed of tandem repeats of 9-65 base pair and have a total length ranging from 0.1 to 7kb. Minisatellite loci are used mainly in parentage analysis. They are less useful for population genetic analysis unless we use large sample sizes. The complexity of mutation processes undergone by minisatellite loci is also a limitation. Due to the difficulties in the interpretation of multilocus fingerprints, the research work were concentrated on single locus minisatellite probes and this procedure required reasonable quantities of high-quality DNA. These single locus minisatellite probes have been very useful and successful in detecting genetic variations within and between populations. It has also been used in fisheries for forensics, parentage, genetic identity, estimating mating success and confirming gynogenesis.

Microsatellites

A microsatellite is a simple DNA sequence which is repeated several times across various points in the DNA of an organism. These repeats are highly variable and these loci can be used as markers. Microsatellite occur once in every 10 kbp while minisatellite loci occur once in every

1500 kbp in fishes and due this, microsatellites are more useful in genome mapping and population genetics studies. They are highly variable, non-coding and selectively neutral and the basic assumption while using microsatellite loci is that the predicted amount of sequence divergence between units of interest is directly related to length of time since separation. Microsatellites are codominant markers which are inherited in a Mendelian fashion and they are highly evolving with 10^{-3}-10^{-4} mutation/generation. The high levels of polymorphism shown by microsatellites have made them one of the most popular genetic markers. Cross amplification with primers developed in closely related species is also possible which minimizes the cost associated with detecting microsatellite sequences in a different species. The analysis of microsatellite loci involves DNA extraction, amplification of the microsatellite loci using specific primers in a PCR machine and examination of the bands using poly acrylamide gel electrophoresis. The recent introduction of automated genotyping machines has made the analysis of size polymorphisms of microsatellite loci with automated genotyping using labeled primers. The use of large number of samples and loci is now possible due to automated genotyping which has increased precision and speed with microsatellite analysis. The constraints of using microsatellite markers are the presence of null alleles and presence of stutter bands. Null alleles are found when mutations occur at primer binding sites of microsatellite locus. The presence of null alleles reduce accuracy especially in parentage or relatedness analysis and assignment tests and the best option is to discard loci showing null alleles. Stutter bands occur when a ladder of bands differing between 1-2 bp is seen and these occur due to slipped strands impairing during PCR or incomplete denaturation of amplification products. Tri-nucleotide and tetra nucleotide repeats usually do not show significant amounts of stuttering. Microsatellite markers are used in fisheries and aquaculture for phylogenetics and phylogeography, population genetic structure, biodiversity conservation, stocking impacts and hybridization. It is also being increasingly used for forensic identification of individuals, genome mapping and determination of kinship and behavioral patterns.

Single Nucleotide Polymorphisms

Single nucleotide polymorphisms arise due to single nucleotide substitutions (transitions/transversions) or single nucleotide insertions/deletions. These point mutations give rise to different alleles with alternative bases at a particular nucleotide position. SNP,s are the most abundant polymorphisms in the genome (coding and non-coding) of any organism. These single nucleotide variants can be detected using PCR, microchip arrays or fluorescence technology. They are considered as next generation markers in fisheries and can be employed for population genetics studies, genomics studies and for detection of diseases.

DNA microarrays or DNA chips

DNA microarray consists of small glass microscope slides, silicon chip or nylon membranes with many immobilized DNA fragments arranged in a standard pattern. A DNA microarray can be utilized as a medium for matching a reporter probe of known sequence against the DNA isolated from the target sample which is of unknown origin. Species-specific DNA sequences could be incorporated to a DNA microarray and this could be used for identification purposes. DNA extracted from a target sample should be labeled with a specific fluorescent molecule and hybridized to the microarray DNA. When the hybridization is positive a fluorescent signal is detected with appropriate fluorescence scanning/imaging equipment.

Expressed Sequence Tags (ESTs)

ESTs are single-pass sequences which were generated from random sequencing of cDNA clones. ESTs can be used to identify genes and analyze their expression by means of expression analysis. Fast and reliable analysis can be made for the genes expressed in particular tissue types under specific physiological conditions or developmental stages. Differentially expressed genes could be identified using cDNA microarrays in a systematic way. ESTs are most valuable for linkage mapping.

Applications of molecular markers in fisheries

Inter specific and intra specific variations

Molecular genetic markers can be used as a supplementary marker system which will increase resolution in taxonomic research. The molecular evolution among taxa is highly variable and the extent of divergence in DNA or genes can be taken as the basis for differentiation among species. The morphological and ecological characters may diverge at a faster rate compared to genetic differentiation at neutral loci and so sometimes we may observe poor correlation between morphological traits and gene divergence. Thus molecular markers have to be interpreted critically among different sets of traits. Molecular markers are most useful when some species which occur in mixed catches is to be identified and where morphological identification is very difficult. Processed fish products (filleted, smoked or salted) and early life stages of fishes like planktonic eggs and larval forms cannot be identified using morphological characters and molecular markers can be employed in such instances. Endangered and threatened whales, sharks and dolphins which are dead and stranded can also be identified using these methods as in most cases morphological identification is not possible. Within a species, genetic differences are more than between populations and so identification is possible even when sample size is small (3-5). Molecular markers have also been used in sub-species identification. Some of the high evolving loci will show more divergence within species and so these loci can be used for finding out intra-specific variations.

Phylogenetic and Phylogeograhical studies

Phylogenetic studies assess the historical processes which affect relationships and phylogeographic studies assess the geographical distributions. Phylogenetic and phylogeographic studies started with the introduction of mtDNA markers in population genetic analyses. The evolutionary history of groups of fishes could be reconstructed which will give vital information regarding historical demography. Information regarding conservation units and ecological patterns could also be derived using phylogenetic studies. Mitochondrial DNA analysis has been used widely as a powerful tool for intraspecific phylogenetic patterns inference in many animal species. The high levels of mutation rate, smaller levels of effective population size and predominantly maternal inheritance of mtDNA will provide greater power to identify population structure. The lack of recombination and low efficiency of repair mechanisms induces high rate of evolution in mtDNA which makes this molecule highly useful in phylogenetic analyses. MtDNA has been used to resolve relationships among species that had diverged as much as 8-10 million years.

Structure of populations: between and within populations

Identification of stock structure is a very important issue in fisheries management and conservation programmes. Stocks are groups within species which are reproductively isolated with different physiological and behavioural patterns. Morphological and meristic features have genetic and environmentally influenced components and so morphological and meristic data should be used in conjunction with genetic data. Thus when a combination of these methods is used, we get information regarding actual genetic differences and important environmental effects on phenotype. Microsatellite DNA is the most favored DNA marker for stock structure studies due to their high rate of evolution. The non-coding region of mtDNA (D-loop) has also been used for stock structure studies due to their high rate of evolution. Mixed fisheries are comprised of subunits of different populations, different life stages or individuals from different stocks. Data from microsatellite markers, allozymes or mitochondrial DNA markers is useful for identifying the origin of stock components from mixed stock fisheries.

Genetic tagging/marking

There are instances when we need to mark individual fish for various purposes like tracking movement or migration, estimating population size or evaluating contributions of individual stock to mixed fishery. Physical tags are not heritable and so cannot be employed for generations. Genetic marking by finding a rare allele in an individual or populations and following them over generations will provide information regarding the contribution of hatchery programme on harvest, proportion of stocked individuals on growth of targeted population and identifying migrants from source populations.

Forensic investigation

In samples where morphological identification is not possible like dead or stranded fishes, preserved or canned fish flesh and fish fillets, molecular markers could be employed for identification and certification. Forensics uses scientific methods to draw inferences about past events and it is being increasingly used in certification of fishery products and detection of illegal trading in fish and fisheries products. Deliberate or accidental release into natural waters also could be monitored using molecular tools.

Studying the trophic relationships

The most essential component of any ecological study is determining trophic relationships within an ecosystem and data on diet composition is very vital. Identifying the diet components of species level is very difficult as most the morphological features might get lost due to partial or complete digestion. In many cases solid remains do not exist inside the gut and this makes identification difficult. Molecular methods could be used for diet analysis studies as it is possible to extract DNA from partially digested samples.

Analysis of ancient DNA

Retrieval of DNA sequence information from preserved samples in museums, fossil remains, archaeological finds and other unusual sources of DNA is now possible with several methods. These types of studies have improved our understanding regarding the evolutionary relationships among different taxa.

Applications in aquaculture

Molecular markers have wide range of applications in aquaculture mainly; in genetic identification and discrimination of hatchery stocks, finding out inbreeding events, assignment of progeny to parents using genetic tags, finding out quantitative trait loci, marker assisted selection for selective breeding trials and assessment of the effect of polyploidy induction and gynogenesis. Genetic variability can also be assessed between and within stocks using molecular markers. They are also useful in determining the contribution of possible parents in mass spawning events. Genome mapping and identification of quantitative trait loci (QTL), (the locations of commercially important quantitative traits) is also possible. QTLs are important in breeding programmes and they are detected by analyzing phenotypes with linked marker maps and identification of markers related to QTLs can provide information on relatedness between strains and families and this knowledge is useful in marker-assisted programmes to improve production related traits. Disease diagnosis is another major area where the benefits of molecular markers can be successfully harnessed. PCR assays for different pathogens have become inexpensive, safe and user friendly in many diagnostic laboratories. Several PCR based disease diagnosis methods have been developed for pathogens like white spot syndrome virus

(WSSV), channel catfish virus (CCV), infectious hematopoietic necrosis virus (IHNV), infectious pancreatic necrosis virus (IPNV), viral hemorrhagic septicemia virus (VHSV), viral nervous necrosis virus (VNNV) and several other diseases. Genes that are resistant to pathogens like Major Histo Compatibility genes (MHC) can be identified and used for selection programmes to produce disease resistant strains of fin or shell fishes.

Conclusion

Molecular markers find wide range of application fisheries and aquaculture and their application has revolutionized the field of fish genetics. The choice of a marker type should be made cautiously in each case so as to maximize the quality of output. No single molecular marker is superior to any other and a combination of markers is always suitable. Of late, markers developed and screened using next generation sequencing technologies are increasingly being used in fish genetics. There is an increasing global demand for aquaculture products and modern molecular methods and molecular genetics could play a major role in bringing out quality and sustainability to aquaculture.

Suggested reading

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