The Enigmatic Indian Oil Sardine: An Insight

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Foreword

Marine capture fisheries is an important component of the fisheries sector in India, generating livelihood avenues for an estimated 3.79 million fishers directly besides those involved in the secondary and tertiary structures concerned with fish marketing, processing and exports of fish and fishery products. Sustainable harvesting of the marine fishery resources is important in a scenario where there is large scale over-capitalisation in the sector and abrupt and long-term disruptions in environmental parameters due to climate change related processes. The Indian Oil Sardine, a major single species fishery in India accounts for 17 - 20% of the total marine fish landings. At the national level, in landing volumes it is the top ranked species during most years. Among marine fishes, its importance as a favoured table fish and rich source of fish oils creates a unique position for the Indian oil sardine in terms of its economic value. However, the resource is prone to sudden fluctuations in abundance that makes it an enigma to researchers, fishers and managers. ICAR-Central Marine Fisheries Research Institute has conducted extensive research on the resource since its inception and several aspects of its biology, fishery and stock assessment have been reported periodically. Considering the importance of this resource to the marine fisheries sector of India, it is important to compile all existing information and subsequent research insights to assist its efficient management along the Indian coast. I am happy that the scientists of the Pelagic Fisheries Division of ICAR-CMFRI have completed the task of compiling all recent information and analysed large amount of data collected pertaining to the Indian Oil Sardine in this document for the benefit of all stakeholders interested in knowing about this valuable fishery resource.

A. Gopalakrishnan
Director

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Executive summary

The Indian oil sardine, *Sardinella longiceps* Valenciennes is the most important single species marine fishery resource landed along the Indian coast in terms of volume in landings. It contributes 17 - 20% to the total marine fish landings in India, bulk of which is from the southwest coast (Kerala, Karnataka and Goa). The resource is susceptible to wide annual fluctuations and anthropogenic (overfishing), biological (spawning failure, competition from other fishes occupying the same niche and lack of food) and environmental (El Niño, rising SST, erratic rainfall and other climatic events) causes which are believed to influence the landings. While failure of the Indian oil sardine fishery in certain years has caused much concern among all stakeholders, the resource has always recovered after a few years. A combination of factors mentioned above causes these cyclic effects of glut and scarcity. The Indian oil sardine fishery and resource characteristics are being routinely assessed all along the Indian coast by the Pelagic Fisheries Division of Central Marine Fisheries Research Institute as part of the Fisheries Management Plans that are drawn up for maritime states. Since the compilation of an annotated bibliography on Indian oil sardine and a national level stock assessment published in 1992, several changes in the distribution, fishery, utilisation and marketing have taken place. Studies on probable reasons for the fluctuations in landings and management practices that are being adopted have been reviewed and discussed in this document.

The fishery for Indian oil sardine has expanded and grown over the years with several improvements/modifications in the crafts as well as gears. Demand for fresh consumption as well as preparation of value added products has encouraged exploitation of Indian oil sardine in all parts of the country, which was earlier confined mainly to the southwest coast. The annual estimated landing ranged from a mere 9 t in 1946 to an all-time high of 7,20,270 t during 2012 with an average annual landing of 1,61,960 t during 1985 - 2015 period. The west coast contributed 77% to the landing. The seines (purse seines and ring seines) with periodic technological upgradations have emerged as the most popular and efficient gear in exploiting the Indian oil sardine.

Three variants of Indian oil sardine with distinctly different morphological characteristics comprised the fishery. Variant 1, the normal Indian oil sardine formed the bulk of the landing. Variant 2, a leaner form, was more abundant along the east coast and at times formed a mixed landing with normal sardine along the west coast. Variant 3 with greater body depth was traced to the Indian oil sardine from Oman and caught off the northwest coast of India. These three variants were subjected to taxonomic, Truss, mitochondrial and microsatellite marker analysis. The Principal Component Analysis did not show significant divergence in the Indian oil sardine population in the fishery. The Oman sardine however, stood apart with its greater body depth, snout length and smaller head length. Mitochondrial cytochrome c oxidase I and control region sequences also did not show any significant variation between the three variants. However, genetic stock structure analysis using polymorphic microsatellite markers indicated signals of distinct population sub-structuring with three major sub clusters in the Indian Ocean region.

The total length and wet weight of Indian oil sardine exploited during 2000 to 2015 ranged from 42 to 237 mm and between 0.93 and 101.6 g, respectively. The mean lengths over the years in different maritime states showed a gradual increase except in Kerala. The diet of Indian oil sardine was predominantly plankton with *Coscinodiscus* sp. dominating in recent years. Sexual differentiation was observed when Indian oil sardine reached a total length of 100mm. The fish attained first maturity at 147 mm. The fecundity ranged from a few thousand numbers to over one lakh. Growth rate, diet composition and spawning dynamics had an impact on the fishery. Ageing using otoliths indicated faster growth than that inferred from length frequency analysis.

Environment had a direct impact on the growth and reproduction of Indian oil sardine. An analysis of the influence of abiotic factors on the biology of Indian oil sardine was made. Of the different parameters that affected the Indian oil sardine fishery, the impact of ENSO with its cascading effects on other environmental parameters (SST, upwelling and primary productivity) on the biological functioning (growth rate, food availability, spawning failure, etc.) was obvious.

The Indian oil sardine occupies a preferred status in the marine fishery of India. The multiple and full use of the fish has led to targeted fishing in most of the maritime states. The steep decline in landings in 2016 has led to recommendation of stronger regulatory measures like effort restrictions, landing quota and implementation of Minimum Legal Size (MLS) in Kerala. On the other hand, glut conditions resulted in discarding the landing at sea or being beach-dried and used as manure. However, the incorporation of fishmeal as an important protein component in the poultry, aqua and pet feeds has ensured full utilization of the Indian oil sardine, with assured remuneration to the fishers harvesting the resource. Hence, the onus of responsibly utilising this annual, short-lived resource lies with all stakeholders and appropriate management measures are to be suitably implemented by the fishery managers based on scientific inputs.

Fisheries management is important for ensuring sustainable exploitation of various fishery resources and even more for Indian oil sardine, which not only is an important food fish but also forms a forage fish in the marine food chain. It is also an important raw material for the fishmeal industry. The present stock status of the Indian oil sardine has been assessed using different methods (LFA, Kobe plot and CMSY). The analysis indicated that the stock is presently fully exploited and there is little scope to increase the landing by further increasing the effort. The analysis made using CMSY indicated that the stock is recovering after a steep decline during the past three years off Kerala. Based on the results obtained from the biological studies, environmental effects, genetic stock structure and stock status, management advisories are suggested. It is hoped that the insights would assist optimum utilization, conservation and sustained fishing of the Indian oil sardine resource in Indian waters.

1. Introduction

The Indian Oil Sardine (IOS), *Sardinella longiceps,* the most abundant marine fishery resource in the Indian seas, often reflects the total marine fish landing trends of the country. The fishery has played an undeniable multifaceted role in meeting the food security of a large human population for many years, provided a source of employment to the primary, secondary and tertiary fishing populations and continues to play a vital role in the economy of the coastal states.

The IOS is a small sized fish forming medium to very large shoals in the nearshore waters within a distance of 25 - 30 km and upto 50 m depth, exhibiting characteristics typical of tropical small pelagic resources. It is an 'r' growth/ reproductive strategy species with rapid growth, short lifespan, small body size, early maturity, high fecundity and variable population size in time. Large seasonal, annual and decadal fluctuations have been regularly observed in its fishery. Several reasons have been attributed to the fluctuations including human interventions (mainly fishing), biological stress and environmental conditions prevailing in the sea. Despite several theories propounded for the fluctuations, a consensus has not been reached among the researchers, and the actual reason remains an enigma. Fishery for IOS has expanded and grown over the years with several improvements/modifications in the crafts and gears. Besides being consumed in fresh form, it is used as raw material in reduction fisheries for the extraction of oil and fishmeal. This has encouraged targeted exploitation of IOS by an array of fishing gears all along the Indian coast. Several fishoil and fishmeal plants that mainly use IOS as raw material have been established recently along the east and west coasts of India. The dependency of multiple stakeholders (fishers, fish processors, consumers, industrialists and exporters) on this species has drawn the attention of fishery researchers, managers and policy makers to initiate appropriate management measures for judicious harvesting of the resource. However, the capricious nature of sardine with its seasonal, annual, inter-annual and decadal peaks and slumps in abundance and catches makes it one of the most intriguing fisheries in the country, with concerns and apprehensions on deciding the best possible practice to manage the fishery.

There are quite a few detailed studies on the IOS (Nair and Chidambaram, 1951; Nair, 1952 and 1973). However, most of the recent studies on IOS along the Indian coast are limited to assessment of the fishery, biology, habitat, etc. in nearshore waters within 50 m depth, with a few studies on aspects related to the fishery environment. Such studies on a localised basis fail to address queries on the observed fluctuations in fishery, changes in distributional range, impact of targeted fishing by several gears, influence of abiotic factors on reproduction, trophodynamics, short movements and migration. Further, the IOS fishery has undergone several structural and operational changes. Therefore, there is a need to adopt a holistic approach to address the issues in IOS fishery. This document presents a review of the earlier studies carried out on the IOS, update on its fishery, biology, stock structure, population characteristics and stock assessment based on data collected along the Indian Coast during the past two decades for the research projects of ICAR-Central Marine Fisheries Research Institute (CMFRI). The probable reasons for the fluctuating production trends, changes in distributional range, biological responses to oceanographic variables and climate change have been explored. Key biological and physical factors that would enable the forecast of the annual IOS fishery in the country are also provided to assist informed decision making.

Plate 1. Shore seine operation along Karnataka Coast

2. Taxonomy

Phylum	:	Chordata
Subphylum	:	Vertebrata
Superclass	:	Gnathostomata
Class	:	Actinopterygii
Order	:	Clupeiformes
Family	:	Clupeidae
Genus	:	*Sardinella*
Species	:	*longiceps*
Valid name	:	*Sardinella longiceps* Valenciennes, 1847
Synonyms	:	*Alausa scombrina* Valenciennes, 1847, *Clupea longiceps* (Valenciennes, 1847), *Sardinella neohowii* Valenciennes, 1847 (Source: Eschemeyer *et al.*, 2017; Froese and Pauly, 2017).

2.1. Description of the species

Type Locality: Pondicherry (Puducherry); Valenciennes, 1847. *Hist. Nat. Poiss.* Vol. XX, p. 273.

2.1.i. Diagnostic identifying characters

The IOS has a fusiform, elongate, sub cylindrical body with a rounded belly. The body depth is less than 30% of its standard length. Cycloid scales on body large, usually firm with interrupted transverse striae. Lateral line absent. A single dorsal fin with 16 - 18 rays placed before mid-point of body and pelvic fin with 9 (i+8) rays. Ventral fin is opposite to dorsal fin. Anal short with 14 - 16 rays, all fins are devoid of spines. Head length is more than greatest width of body. Snout longer than diameter of eye. Maxillary extending to below anterior part or nearly to middle of eye. Premaxillaries not protractile. Mouth rather large. Jaws nearly equal in length and no median notch present on upper jaw. Teeth feeble on palatines and tongue. Adipose eyelids broad. Opercle smooth, without radiating striae. Vertical outer edge of cleithrum covered with dorsal fold with two obtuse knobs. Pseudobranchiae present. Gills four in number. Gillrakers numerous, 150 - 255 on the lower limb of the first gill arch. Gill membranes separate, free from isthmus. Six branchiostegals present. Gill opening with two fleshy outgrowths posteriorly. Scales 46 - 48 in longitudinal series and 12 - 13 in transverse series. Body is greenish-brown along the back with golden reflections, abdomen silvery, dorsal and caudal greenish-brown, other fins pale. A large greenish-golden spot on the upper hind margin of opercle (Fig.1 and 2).

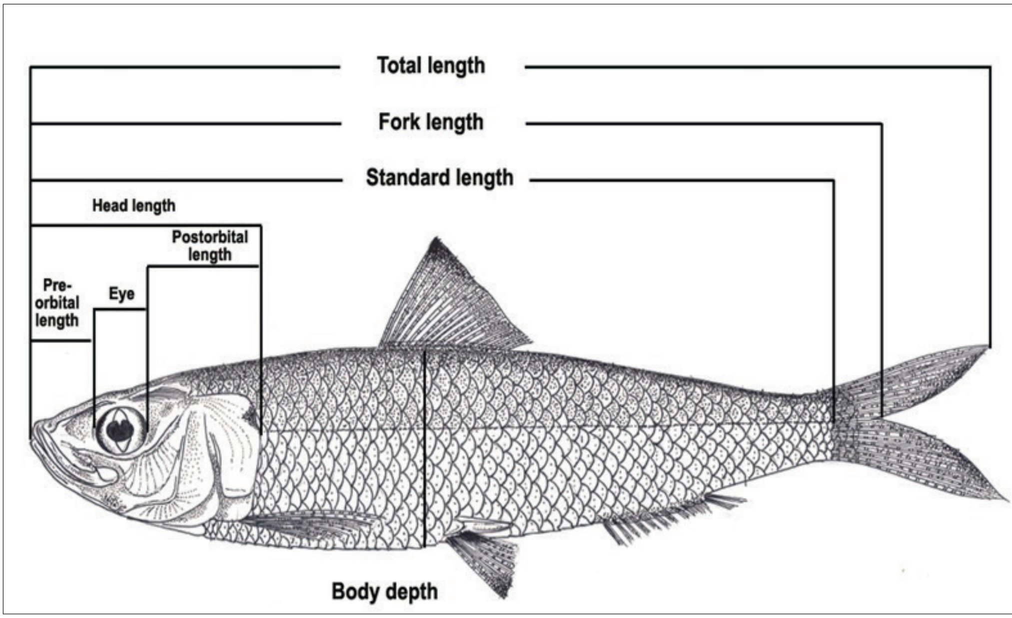


Fig.1. Line diagram of Indian oil sardine, *Sardinella longiceps* with important morphometric parameters (drawing: Yogesh Kumar K.)

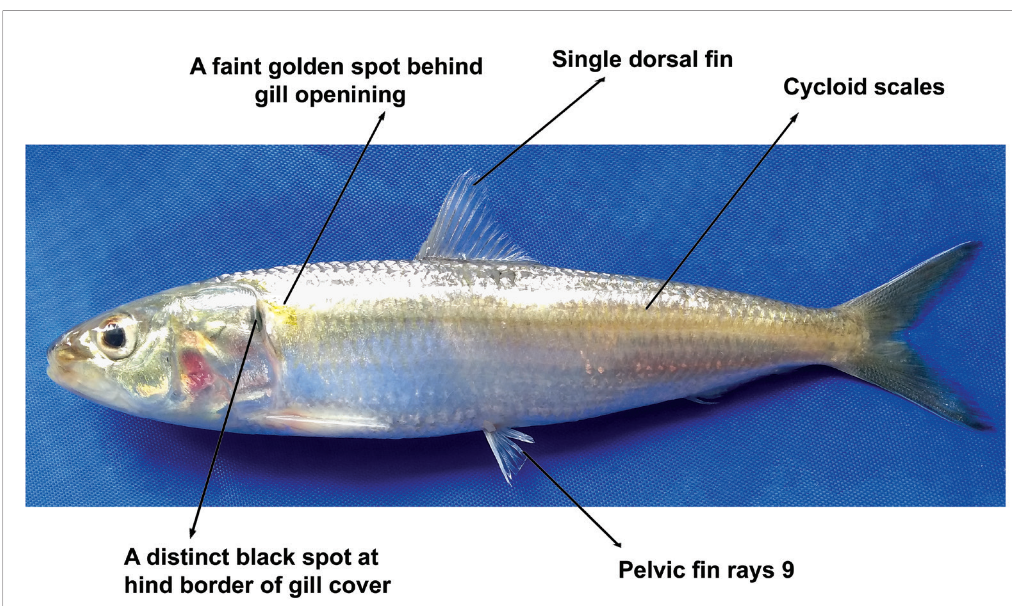


Fig. 2. The Indian oil sardine, *Sardinella longiceps*

2.1.ii. Vernacular names

Table 1. Vernacular names of Indian oil sardine used in different maritime states

State	Vernacular name
Gujarat/Diu-Daman	Tharli, Rudri
Maharashtra	Tarli, Haid, Pedvey, Padwa, Washi, Taria
Goa	Tharni, Thariae
Karnataka	Bhoothai, Baige, Tharli
Kerala	Mathi, Chala, Neichala, Nallamathi
Tamil Nadu & Puducherry	Nolali, Peichalai, Mathi,
Andhra Pradesh	Noone Kavallu, Burra Kavallu
Odisha	Nona Kavala, Disco kabala, Narikal, Nadiaphali, Nna Kavala
West Bengal	Hurhuri

Plate 2. Outboard ring seiner with Indian oil sardine catch

3. Geographical Distribution

3.1. Global distribution

The IOS has a wide distribution and occurs along the coasts of Djibouti, Egypt, Somalia, Mombasa, Seychelles, Bahrain, India, Iran, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, Sri Lanka, United Arab Emirates, Yemen, Andaman Island, Java, Bali Straits, Philippines (Nair, 1973; Soetersdal *et al*., 1999) (Fig.3). However,

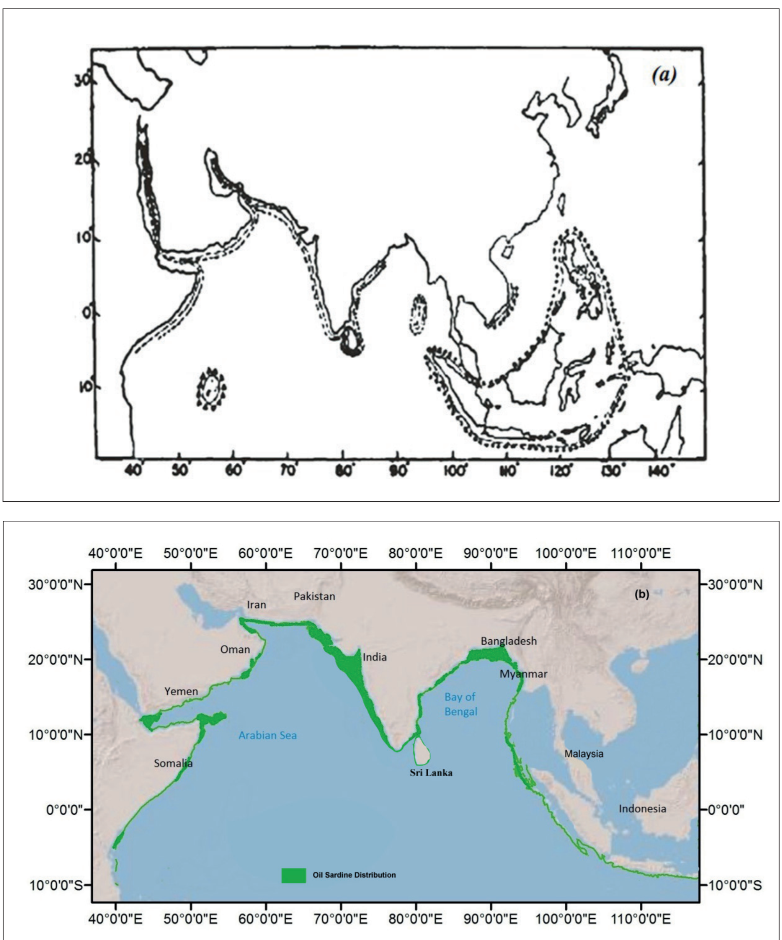


Fig.3. Distribution map of Indian oil sardine (a) Antony Raja, 1969 (b) modified based on (a) above

Willette and Santos (2013) have reported that the sardine in Philippines is *Sardinella lemuru* and not *Sardinella longiceps*. Recently, Shamsunnahar *et al*. (2017) reported the new record of IOS occurring in the sea off Bangaldesh.

3.1.i. Distribution along Indian coast

The IOS enjoys a wide distribution along the Indian Coast extending from Gujarat in the west coast to West Bengal in the east coast including the Andaman and Nicobar Islands (A&N). Occasionally they are reported to enter estuaries (CMFRI, 2002, 2005). However, exploitation at commercial levels till recently, was confined mainly to the southwest coast comprising the states of Kerala, Karnataka and Goa. The fish continues to enjoy a prominent position in the fishery of this region and specific gears have been designed to efficiently harvest the shoaling IOS. Distribution along the west coast is generally within 40 m depth zone where temperature and salinity range between 22 - 28ºC and 22.8 - 33.5 ppt, respectively (Rosa and Laevastu, 1960; Gopinathan, 1974). The fishery pattern of IOS was charted using the time series database of landings, which indicated seasonal availability of various size groups occurring in a variety of gears operated at different depths in important landing centres. While the adult stock of IOS along west coasts is observed to remain in 30 - 40 m depth, the young sardines follow an anticlockwise circulatory path between Allepey and Calicut and off Mangalore, and then move north following a clockwise circular path (Jayaprakash, 2007).

Expansion in distributional range of IOS since late 1980s as a result of sea water warming has been reported by Vivekanandan *et al*. (2009a) and increased levels of exploitation has been observed in most of the maritime states especially those on the southeast coast (Krishnakumar *et al*., 2008; Kizhakudan *et al*., 2014). The increase in Sea Surface Temperature (SST) caused by climate change along the southern peninsula could have resulted in the northward expansion of IOS to cooler areas in the north (Supraba *et al.,* 2016, 2017).

A single stock of IOS not specifically confined to any of the countries (Oman, Pakistan and Iran) exists in the region (FAO, 2011). The Gulf of Oman, an extension of the Arabian Sea with similar physical and biological conditions, facilitate free movement of IOS from the Gulf of Oman to the northwest coast of India. However, Jayaprakash (2007) mentioned that the extent of distributional range of IOS from the northern Arabian Sea to Saurashtra Coast and possibly further south would depend mainly on stock abundance in the Gulf of Oman (Fig.4).

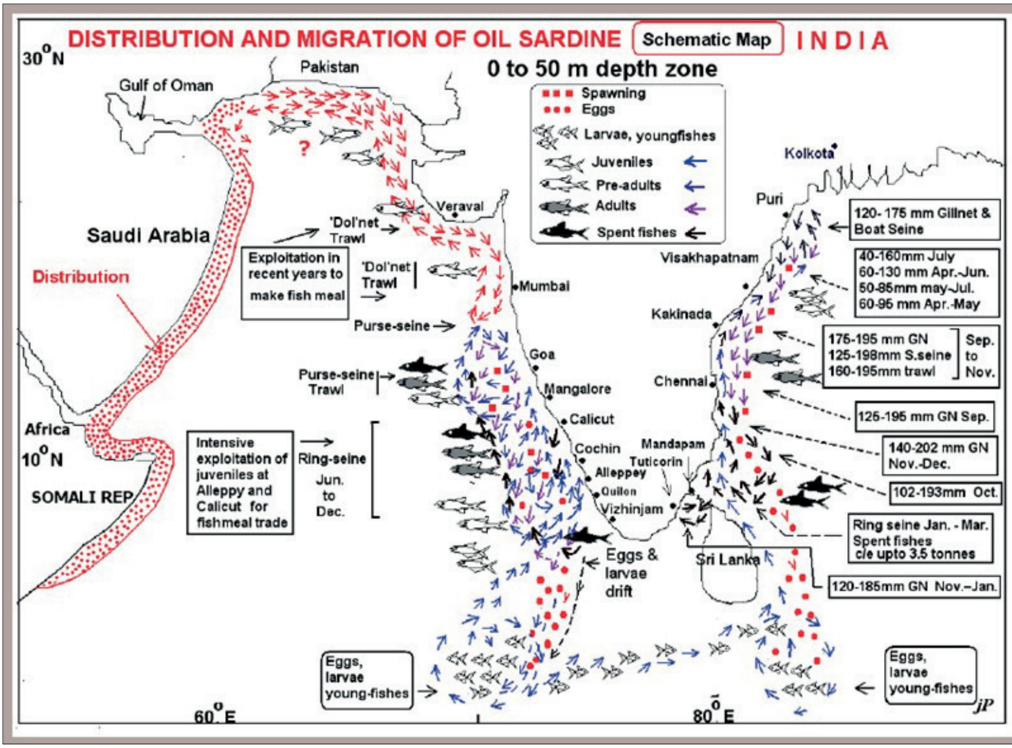


Fig.4. Map showing the distribution pattern of Indian oil sardine along Indian coast and adjacent countries (Source: Jayaprakash, 2007)`

4. Fishery

4.1. Fishing grounds

The spatial expanse of IOS fishery in the states of Karnataka, Maharashtra and Andhra Pradesh was mapped using data collected from log sheets given to crew of selected commercial fishing crafts. Mapping for Kerala was made by uing data maintained by ICAR - CMFRI (Figs. 5 - 8).

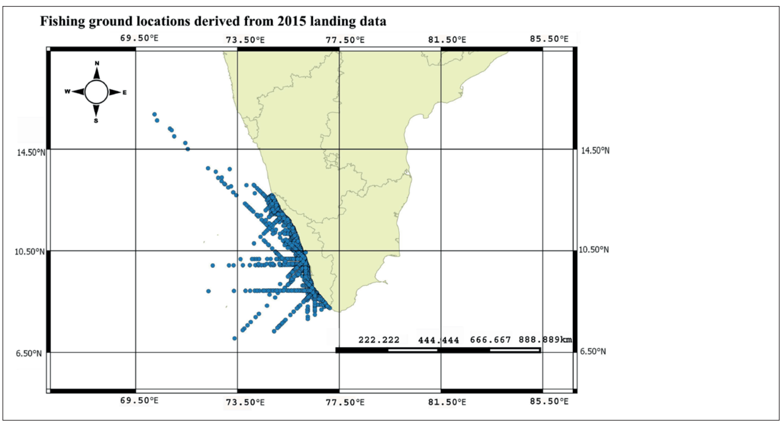


Fig.5. Spatial distribution of the Indian oil sardine exploited by ring seines in Kerala during 2015

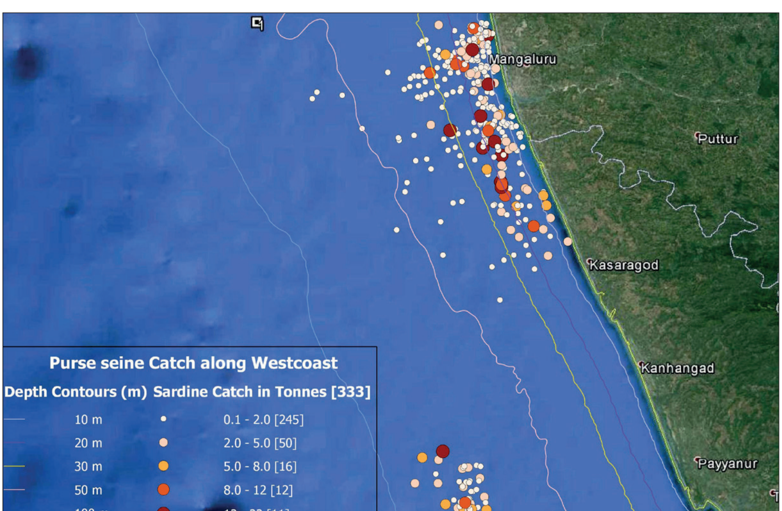


Fig.6. Spatial distribution of Indian oil sardine exploited by purse seines in Karnataka during 2010 - 2015

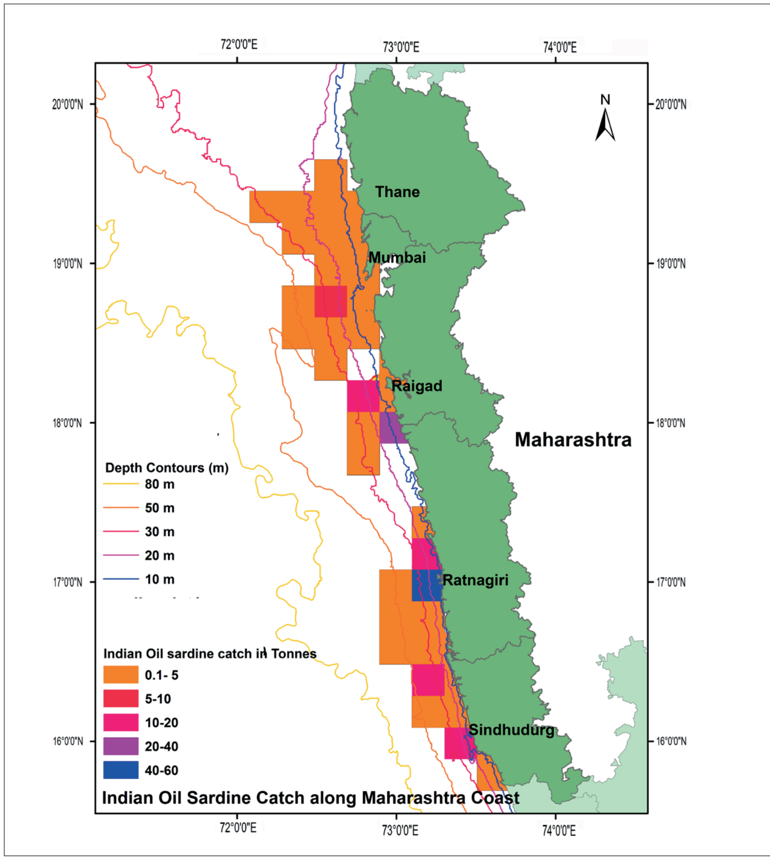


Fig.7. Spatial distribution of the Indian oil sardine exploited by purse seines in Maharashtra during 2011 - 2015

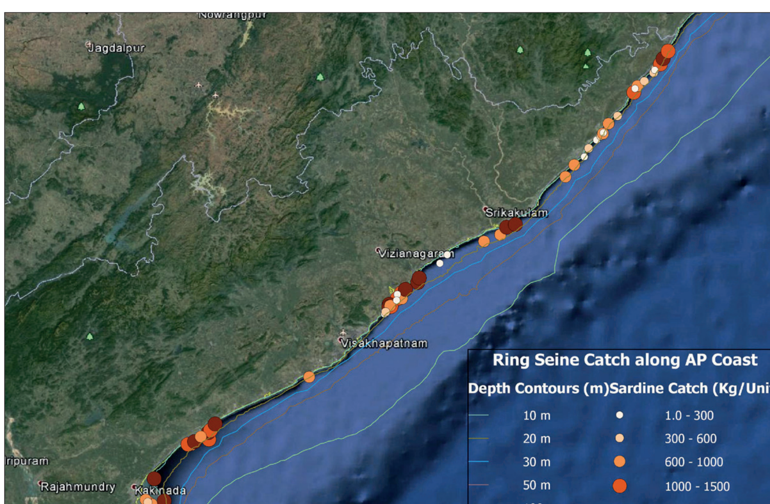


Fig.8. Spatial distribution of the Indian oil sardine exploited by trawlers in Andhra Pradesh during 2013 - 2015

The distributional maps clearly indicated that IOS is exploited from nearshore area to a maximum depth of 100m. Maximum landing was within 50 m depth zone in all states. Improved efficiency of fishing gears and endurance of crafts enable the fishers to move to areas beyond the traditional areas of operation and exploit IOS .

4.1.i. Craft and Gear

In India, an array of crafts and gears is used to exploit the IOS (Table 2). Mechanized, motorised and non-motorised craft operating varying dimensions of seines, trawls, gillnets and bagnet are used to catch the IOS. While ring seine and purse seine are the most effective gears, gillnets, bagnets and trawls are used extensively.

The seines are specially designed to catch shoaling fishes and are traditionally used along the southwest coast to efficiently catch small pelagic fishes abundant in this region. In Karnataka, the traditional shore seine, *Rampani* was replaced by purse seines (Dharmaraja and Jacob, 1980). Over the years, the trawls which were designed to catch shrimps and demersal fishes have also been suitably modified as pelagic trawls to harvest column and surface fishes. The IOS has formed part of pelagic trawl catch especially in Tamil Nadu and Andhra Pradesh. During 1980, a smaller version of the purse seines the 'ring seine' was designed by ICAR - Central Institute of Fisheries Technology (CIFT) (Panicker *et al*., 1985). This net could be operated from smaller canoes and was equally efficient in harvesting shoaling fishes. The success of ring seines in harvesting huge shoals of IOS by the fishermen in Kerala motivated fishers from all over the country especially those along the east coast to adopt this gear to catch IOS. The craft-gear types used by fishers in the maritime states of the country are given in Table 2.

Table 2. Details of crafts and gears engaged in Indian oil sardine fishery

Name of gear	Gear specifications/ Dimensions* (m)	Mesh size (mm)	Craft (OAL in m) and horsepower (hp) specifications	Reference
Kerala				
Boat seine , *Mathikkolli* (Cotton Yarn with coir ropes) *Pattenkolli* (Nylon)	50 x 56 m 42.5 x 47	17 - 18 17		Balan, 1980
Gillnet *Mathichala vala*	21 x 6.5 (per net piece); 6 pieces tied together	27		Balan, 1980
Ring seine Inboard mechanized ring seine	250 X 15 ; 630 X 100 , 300 - 600 X 50 - 60 , 600 - 1000 X 83 - 100 nets 1500 X100 700 - 1000 x 50 - 80	18 - 20 13 - 20 20	13 - 15 OAL, 9.9 hp OBM, wooden craft 25 OAL with 120 - 440 hp ; Mother boat: 20 - 22 OAL with 300 - 400 hp Carrier boat 10 - 12 OAL with 180 - 200 hp	Panicker *et al.*, 1985 Edwin & Hridayanathan, 1996 Edwin *et al.*, 2010; Dhiju, 2015
Motorised ring seine	400 - 600 x 60 - 70	20	13 - 20 OAL wooden crafts with 20 - 24 hp (OBM)	D'Cruz, 1998
Purse seine	500 - 600 x 50 - 60	13 - 20	13 - 14 OAL wooden crafts 200 hp 20 - 25 OAL wooden/steel crafts with, 250 hp	Jacob *et al.*, 1982
Trawl net	36 to 144 (L)	7 - 16	SDT: 9 - 10.9 OAL wooden crafts with 37 - 88 hp engines MDT: 13.6 - 14.5 OAL wooden/Steel, 98 - 120 hp	
Karnataka				
Trawl net	SDT: 36 (L) MDT: 144 (L)	7 - 16 (cod end) 7 - 16 (cod end)	SDT: 9 - 10.9 OAL wooden crafts with 37 - 88 hp MDT: 13.6 - 14.5 OAL Wooden/Steel, 98 - 350 hp	Rohit and Bhat, 2003 Pravin *et al.*, 2016
Purse seine	600 - 1200 x 75 - 85	16 (for anchovies), 22 - 24 (for sardines) 44 - 46 (for large pelagics)	Small: < 12 m OAL, wooden craft, 98 - 120 hp Medium: 12 - 16 m OAL, wooden craft, 108 - 240 hp Large: 16.1 - 24 m OAL,wooden/ steel, 210 - 350 hp	Pravin *et al.*, 2016

Name of gear	Gear specifications/ Dimensions* (m)	Mesh size (mm)	Craft (OAL in m) and horsepower (hp) specifications	Reference
Goa				
Gillnet	450 - 1500	18 - 30	8 - 12 OAL, wooden with 45 - 90 hp 12 - 16 OAL, wooden/steel with 120 - 240 & 300 - 400 hp	Pravin *et al.*, 2016
Purse seine	600 - 1200 x 75 - 85	22 - 46	18 - 20 OALWooden/Steel, 240 - 280 hp	
Ring seine	300 - 600 x 41.5	18 - 22	9.6 - 12.5 OAL, 8 - 25 hp (OBM)	Rohit and Bhat, 2003
Tamil Nadu (Cuddalore)				
Ring seine	700 - 1000 x 80	20	Mechanized boats	Kasim *et al.*, 2009
Puducherry				
Ring seine	400 - 600 x 50		Wood/fibreglass boats 12 - 14 OAL	Mohanraj *et al.*, 2011
Tamil Nadu (Mandapam)				
Pair trawl		Cod end 25 - 30	9.14 - 9.75 OAL with 45 - 70 hp	Marichamy *et al.*, 1992
Pair trawl		Cod end 30	14 - 16 OAL with 160 - 180 hp	Surya *et al.*, 2016
Andhra Pradesh (Kakinada)				
Ring seine	315 - 350 X 34		Fibre glass *Teppa* with 10 - 20 hp engines	Burayya, 2006
Drift gillnet	500 - 800 (L)	25 - 30mm	7 - 9 OAL wooden/fibre; 9 - 10 hp (OBM)	
Bagnet	50 - 60 (L)	20 - 60 mm	7 - 8 OAL	

*Length × height (m) L - Length

Plate 3. Glimpses of fishing activities for Indian oil sardine

In Kerala, the IOS was traditionally fished using cotton yarn based boat seines (*mathikkollivala*). These were replaced by nylon webbing (*pattenkolli*) nets during early sixties (Balan, 1980). Small indigenous canoes manned by three or four crew were operated close to the shore. Each operation brought in around 10 kg of IOS. All active menfolk in the coastal villages were engaged in the fishing activity, which included actual fishing, sorting, disposal and utilization of the landing. In addition, a traditional monofilament gillnet (*chalavala*) was also operated specifically for IOS. The introduction of the highly efficient *thanguvala*-an encircling net was a game-changer. This led to increased landings of IOS along the Kerala Coast and a gradual replacement of traditional gears. The *thanguvala* was operated between 5 to 8m from larger non-motorised or out-board motorised canoes. The impounded shoals were 'bailed out' to carrier boats and sent ashore for marketing. The crew on a *thanguvala* unit consists of 10 - 20 members depending on the size of the canoe as well as the gear. Women and children were involved in sorting the landing; traders and transporters depended on the fishery for their livelihoods. The highly efficient purse seines introduced later on operated from big mechanized fishing crafts (18 - 24 m OAL) engaging a crew of 36 to 40. However, targeted fishing for IOS remained largely limited to inshore waters upto 30 m depth that could be accessed by smaller crafts/canoes fitted with OB engines or IB engines with limited horsepower. A smaller version of the purse seine called ring seine was designed which could be operated by canoes powered by OB or IB engines. The ease as well as efficiency with which the ring seines could be operated from canoes has made this gear

Plate 4. Fishermen removing the Indian oil sardine caught in gillnet at Punnapra beach landing center

Plate 5. View of mechanized trawlers of Kerala Coast

very popular. The ring seines in Kerala are classified into two groups as IBRS (inboard ring seine) and OBRS (outboard ring seine) depending on craft size and engine horsepower. Presently, an estimated 458 IBRS and 45,685 OBRS units operate in Kerala. The IBRS and OBRS sector contributed more than 90% to the total IOS production in Kerala. While 18 - 20 crew members are engaged in an OBRS unit, 35 - 40 are engaged in an IBRS unit. The deployment of labour and wage earning in the ring seine sector of Kerala has been elaborated by Dhiju *et al.* (2012). The role of IBRS and OBRS to IOS landings in Kerala has been well recognized by the State Government and the Pelagic Fishery Bill was introduced

Plate 6. Dug-out canoes for coastal gillnet fishing

Plate 7. A view from Punnapra beach landing centre

Plate 8. Icing and loading of Indian oil sardine for interior markets

under the Kerala Marine Fishing Regulation Act, 1980 (KMFRA). With this, the ring seines are permitted to operate throughout the year including monsoon period when there is a ban on the operation of all other mechanized units such as trawls and gillnets.

A similar evolutionary trend in the gears targeting IOS has been observed in Karnataka. The *rampani*, a huge shore seine was the traditional gear used to fish IOS. Initially the *rampani* was operated without engaging crafts. Later, traditional non-motorised canoes, and then, canoes fitted with OB engines were used in the *rampani* fishery to encircle the fish shoals. The *rampani* fishery was community-based with the entire coastal village involved in fishing. While the active menfolk, numbering 250 - 300 were directly engaged in fishing, the older men, women and children involved with allied fishing activities. However, the huge *rampani* slowly became defunct and was replaced by a smaller version called the *kairampani.* This smaller gear could be operated by 70 to 90 fishermen. The introduction of purse seine, operated from large mechanized vessels, enabled the fishers to capture huge shoals farther away from the shore. The 18 - 36 crew on the mechanized purse seine could easily catch 6 - 10 t of fish within a few hours. The youth in the coastal villages preferred to work onboard the purse seiners than the labour-intense *rampani* fishing. With the introduction of OBM crafts, the *matubale* an encircling gear similar to the *thanguvala* operated in Kerala, was introduced in the coastal waters of Karnataka. The boat seine was upgraded in the late eighties to operate as the ring seine locally called the *ranibale*. Unlike in Kerala, the purse seine continues to be the dominant gear in Karnataka targeting the IOS.

Importance of Indian oil sardine in the social structure of coastal fishers

The close association of the IOS with the coastal communities of Kerala and Karnataka, is clearly reflected by the popular term by which this fish is referred to. In Kerala, while the IOS is known as '*Mathi*' it is popularly refered to as '*Kudumbapularthy*' (family provider). Several men and women are engaged in post-harvest, marketing and allied activities. The term *kudumbapularthy* therefore is very apt for IOS as the single species fishery sustains the livelihood of so many coastal fishers all round the year. In coastal Karnataka it is called as '*Bhoothai*' (Bhoo=earth, thai=mother). Fishing for IOS used to be a community activity with active involvement of all age groups in fishing as well as disposal of catch, thus forming an integral part of the social life of the coastal fishermen population.

In Karnataka, fishing with *rampani* used to be a community based activity with almost all children and active menfolk in the coastal village being involved in the operation of this huge shore seine to catch shoaling fishes, mostly sardines and mackerel, that occur close to the shore. Around 250 to 300 men were engaged in the operation of a single shore seine. Experienced fishers were able to recognize moving shoals from the shore and ably direct the operation of the rampani. At times, a single *rampani* would run over 2 - 3 km and men from adjacent villages would be engaged in its operation. The encircled shoal was slowly dragged towards the shore. When a huge shoal is impounded the fish was kept alive for nearly a week in the coastal waters. Portions of the catch would be removed periodically and marketed. The entire catch was thus fully utilized in an efficient way.

In Karnataka, the ring seine engages 18 - 25 crew depending on the size of the craft. Both the purse seine and ring seine generally have one or two carrier boats manned by 2 - 3 crew, which transport the catch to the shore. The seines alone (purse seine, ring seine and shore seine) engage around one lakh fishers. An equal number, if not more, are engaged in post-harvest, processing, marketing and transportation of the catch.

4.2. Landing trends

Trends in landings of sardines on a global level and IOS on a national level followed a similar pattern. Mechanisation and introduction of improved gears in the IOS fishery during the past three decades is clearly reflected in the seasonal and annual landing pattern of IOS on a regional and state level. Graphical comparision of the IOS landings by different gears during the recent fifteen years (2001 to 2015) with the previous fifteen year period (1985 to 2000) clearly depicted the impact of changing crafts and gears on the IOS fishery.

4.2.i. Global scenario

Sardines comprising of several species are the major contributors to the small pelagic fishery globally. The global landings of the sardine recorded a positive trend over the years despite the landing varying from 2.05 million t in 2003 to 2.58 million t in 2014 with an avarage production of 2.32 million t (FAO 2016) as indicated in Fig.9. The IOS formed a significant composition of the small pelagic landings in the Persian Gulf region, the Indian sub-continent and the East and Far East Asian regions.

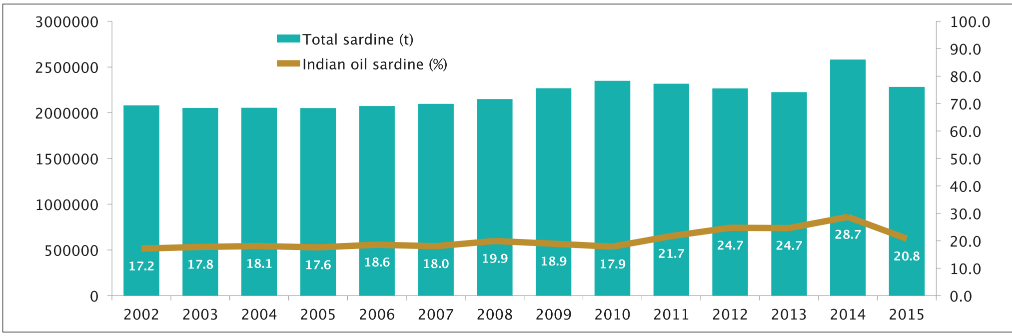


Fig.9. Global sardine landings and contribution (%) of Indian oil sardine (FAO, 2016)

4.3. Indian scenario

Historically, the three states along the southwest coast (Kerala, Karnataka and Goa) have mainly supported IOS fishery of the country. However, during the recent years, the contribution of Maharashtra, Tamil Nadu and Andhra Pradesh to the oil sardine landings has significantly increased and in Gujarat to a certain extent since late 1990s. The contribution of east coast (EC) to the total IOS landings during the 1980s was small but gradually increased over the years and reached a peak in 1994 when the contribution of this coast to the total IOS fishery was 93%. Recorded history of the IOS fishery in India dates back to 1896 (Nair and Chidambaram, 1951; Nair, 1973). The IOS landings during the late 1800 and early 1900 was also indirectly estimated by back calculation of the data available on sardine oil and guano production (Nair, 1973; Longhurst and Wooster, 1990). Various aspects of the IOS has been intensively researched earlier (Devanesan, 1943; Chidambaram and Venkataraman, 1946; Sekharan and Dhulkhed, 1963; Balan,1959,1961, 1964, 1965, 1971, 1973, 1984; Antony Raja, 1964, 1967, 1969, 1969a, 1970, 1971, 1972, 1973; Nair *et al.*, 1973; Sekharan, 1974; Rao and Dhulkhed, 1976; Balan and Reghu, 1979; Kurup *et al.*, 1987; Kumar and Balasubramanyan, 1987; Annigeri, 1989; Longhurst and Wooster, 1990; Annigeri *et al.*, 1992; Kumaran *et al.*, 1992; Madhupratap *et al.*, 1994; Ganga, 2000; Jayaprakash, 2002; Rohit and Bhat, 2003; Ganga and Pillai, 2006; Abdussamad *et al.* 2010; Chitra and Radhakrishnan, 2011; Rao *et al.* 2011; Prema *et al.* 2012; Remya *et al.*, 2013, 2015; Chakraborty *et al.*, 2015; Ganga *et al.*, 2017). An annotated bibliography on the IOS was published by ICAR - CMFRI (Girijakumari, 1990).

Plate 9. Ring seine fishing activities

4.3.i. Fishery trends

The landings data during the early period of reporting is mostly limited to the Malabar-Konkan coast where IOS was fished in good quantities. The landing over the years showed a general increasing trend but with several peaks and steep dips. A perusal of the available IOS landings data indicated the periods 1922 to 1924 had exceptionally good landings while the periods 1898 - 1900, 1908 - 1909, 1911 - 1912, 1914 - 1915, 1918 - 1919, 1941 -1949, 1963, 1994 and 2015 had poor landings. With limited preservation and marketing facilities that existed during the earlier years, huge quantities of IOS when landed, only a small part was consumed in fresh or cured condition and the rest (as much as 2,85,000 t) was converted to guano and beach manure. However, when IOS landings was very low, it has a cascading effect on the locally established fishoil and fishmeal industries.

Plate 10. View of loading of Indian oil sardine catch from ring seiner to carrier boat at mid-sea

The annual estimated landing in India ranged from a mere 9 t in 1946 to an all time high of 7,20,270 t during 2012 and an average annual landing of 1,61,960 t during 1925 - 2015. Subsequently, after 2012, the IOS landings declined to 5,96,726 t in 2013, to 5,44,684 t in 2014 and further to 2,65,667 t in 2015 (Fig.10). The IOS formed around 14% of the Total Marine Fish Landings (TMFL) of the country during 2000 - 2015. While the contribution was as high as 32% of the TMFL in 1962, it was only 2% in 1994. The landings fluctuated over the years with an overall increase in volume until 2012 after which it declined. A combination of improved efficiency of crafts and gears, use of echosounders, GPS and mobile phones aided with PFZ advisories have contributed to higher landings.

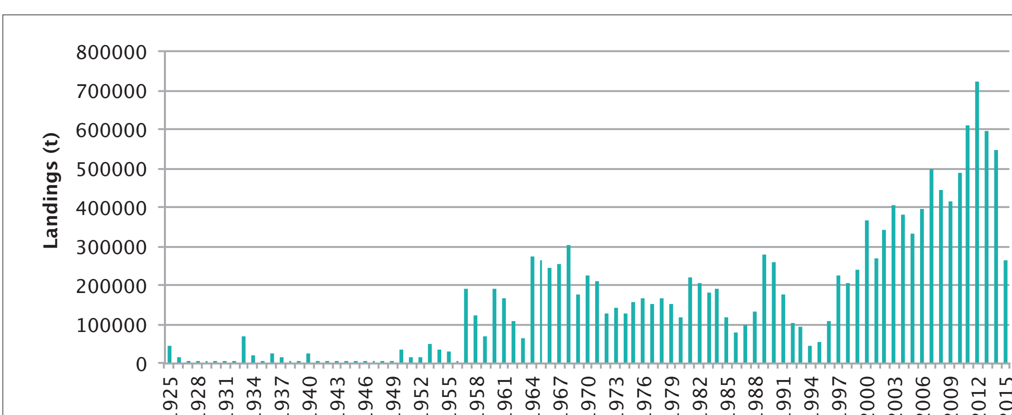


Fig.10. Annual landing trend of Indian oil sardine during 1925 - 2015

The decadal trends also fluctuated (Fig.11), but the landings during the last decade (2006 - 2015) was substantially higher than the previous decade and 2006 - 2015 decade contributed 33% of the aggregated landings during the previous nine decades (Fig.11).

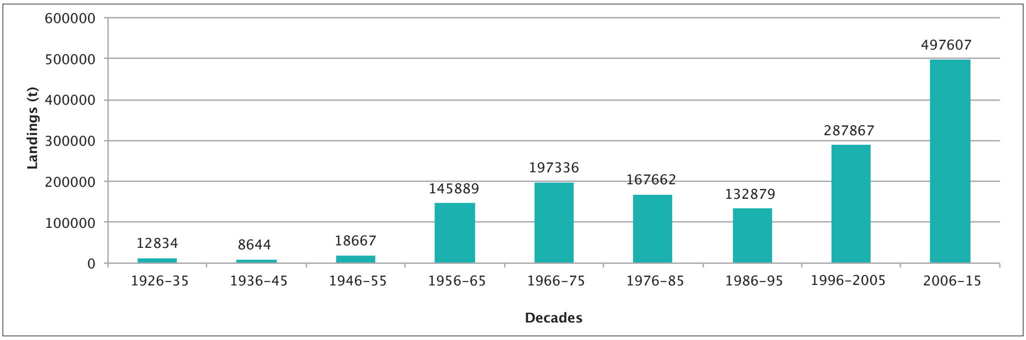


Fig. 11. Average decadal estimated Indian oil sardine landings (t) in India

The west coast (WC) recorded bulk of the IOS landings with a contribution of more than 77% to the total IOS landings of the country (Fig.12). The average landings of IOS during 1985 to 2015 along the east and west coasts were 68,566 t and 2,32,914 t respectively. In 2015, an overall decline in the landings of IOS was recorded and contribution of the east coast (EC) to the total IOS landings of the country during the year was as high as 45% (Fig.13).

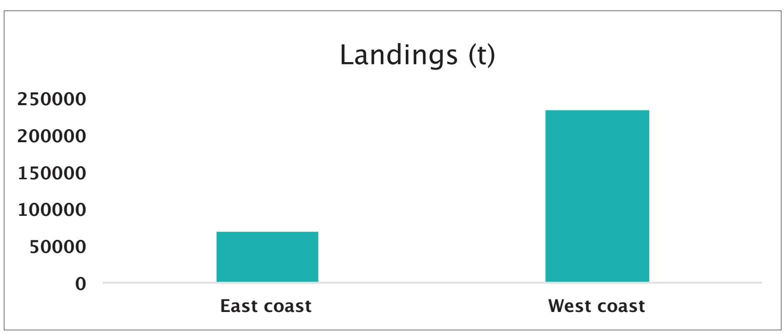


Fig.12. Contribution of east and west coasts of India to Indian oil sardine landings (Average 1985 - 2015)

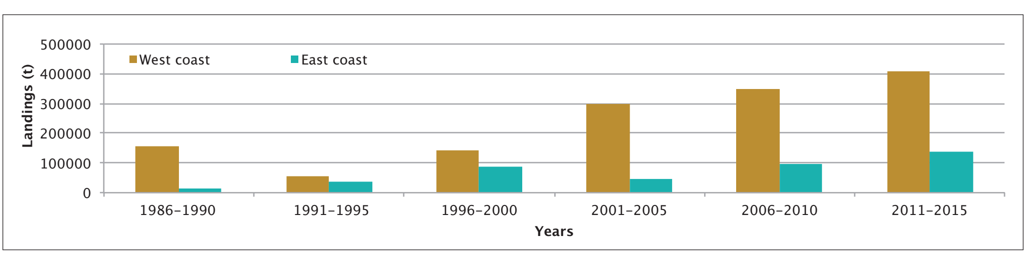


Fig. 13. Five yearly average trends in landing of Indian oil sardine along west and east coasts

In general, the IOS landings from the east coast were considerably high during 1994 - 98, 2009 and 2015 (Fig.14). The introduction of pelagic trawls and small ring seines along the east coast during the late 2000 aided efficient harvest of IOS in the area.

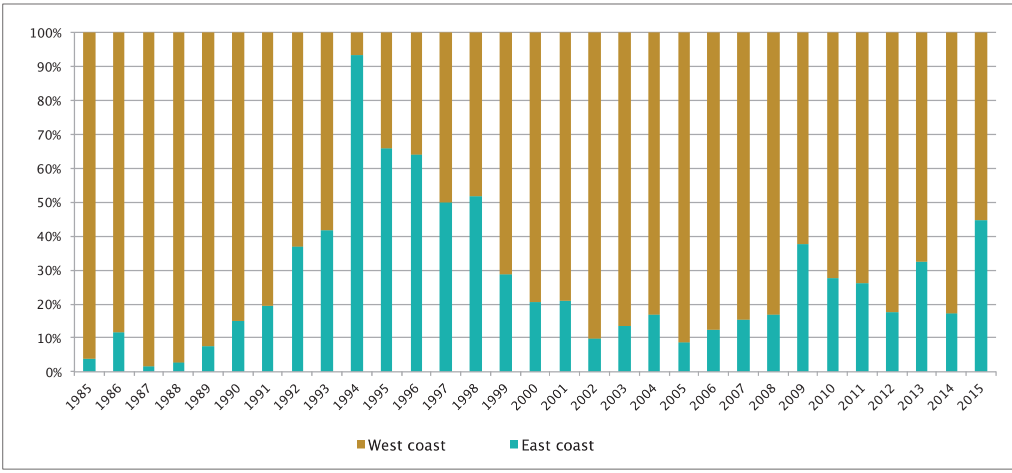


Fig.14. Contribution (%) of east and west coasts to total Indian oil sardine landing of the country

In a study on the impact of climate change in the trawl fisheries of the Tamil Nadu Coast, Kizhakudan *et al.* (2014) suggested that with rising SST trends the IOS moved to deeper (cooler) waters and the abundance was reflected in higher catches made by trawlers. IOS is mainly caught by trawls in Tamil Nadu and only in certain regions have seines been adopted in recent years. It is possible that the hitherto unexploited largely surface dwelling shoals that moved to deeper waters to avoid the rising SST (Vivekanandan, 2006; 2009a; Kizhakudan *et al.*, 2014) were caught in trawls traditionally operated in Tamil Nadu, leading to increased landing volumes along the east coast of India (Fig.15). IOS stocks are experiencing an extension in their distributional range as they are establishing themselves in areas with favorable environmental conditions (Vivekanandan *et al.*, 2009a; Vivekanandan and Krishnakumar, 2010). An increase in the eutrophic waters (indicated by chlorophyll concentration) during October to April period, from the 1980s to post 2000 years in the Arabian Sea as well as the Bay of Bengal was reported by Chaturvedi *et al.* (2013). These factors are obviously favourable for IOS, leading to an increase in their abundance and landing. The phenomenon of 'regime shifts' associated with climate change along the Indian Coast has been reported by Krishnakumar *et al.* (2006). Due to this phenomenon, IOS stocks started appearing in the fishery along the southeast coast for the first time in 1983, followed by a rapid increase in catch during 1988/89 and finally in 1998, it emerged as the single largest contributor to the total fish production from the southeast coast. Vivekanandan *et al.* (2005) reported on the phenomenon of 'fishing down the marine food, which lead to increase in the catches of fishes of the lower trophic levels (Vivekanandan *et al.*, 2009b) including IOS. The increase in catch volumes along the southeast

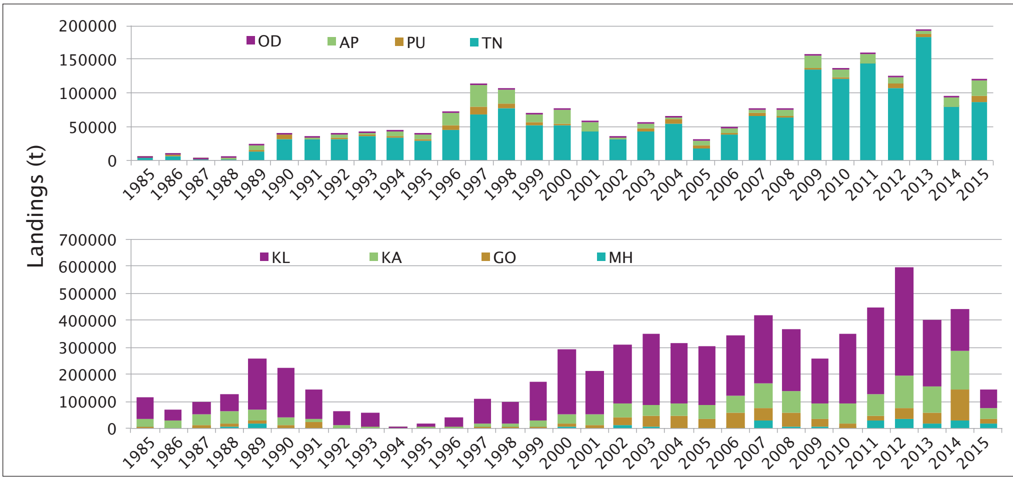


Fig.15. Trends in annual landings of Indian oil sardine in maritime states of India

coast was largely due to the 'technology creep' as well as the inherent nature of IOS stocks to show peaks in recruitment during certain years with favourable environmental conditions (Antony Raja, 1972; Longhurst and Wooster, 1990).

Jayaprakash and Pillai (2000) reported that IOS along the east coast was left to die a natural death as exploitation was minimal and sporadic due to poor demand for the fish in the local market. However, with increased demand for IOS from adjacent states especially Kerala and Karnataka (due to establishment of fishmeal plants) since early 1990s, exploitation of IOS was intensified, resulting in notable improvement in the landings along the east coast. Further, an increased removal of large predators in recent years also could have resulted in the process of 'fishing down the food web' (Vivekanandan *et al.*, 2005). Deployment of ring seine during the recent years to harvest IOS is another reason for increased landings along the east coast.

The volume of landings along the east coast has always been lower than the west coast. Interestingly, whenever a decline in total IOS landings of the country was reported, the production from states along the southwest coast had decreased and the graphic depiction of the landings along the southwest and southeast coasts formed a mirror image of each other (Fig.16). The southwest coast (Kerala, Karnataka and Goa) has always been leading in the production of the IOS. However, during the years of slump in total IOS landing, the southeast coast (Tamil Nadu and Andhra Pradesh) has recorded better landings.

Considering catch as a surrogate of distribution, the extension of IOS distribution to the northern and eastern boundaries was considered as an adaptation of IOS to rising SST caused as a result of climate change (Vivekanandan *et al.*, 2009a). Studies have indicted that sardines are affected by environmental perturbations and apparently do not have any geographical barriers in their movements along the Indian Coast (Antony Raja, 1973; Jayaprakash, 2007; Sandhya *et al.*, 2016).

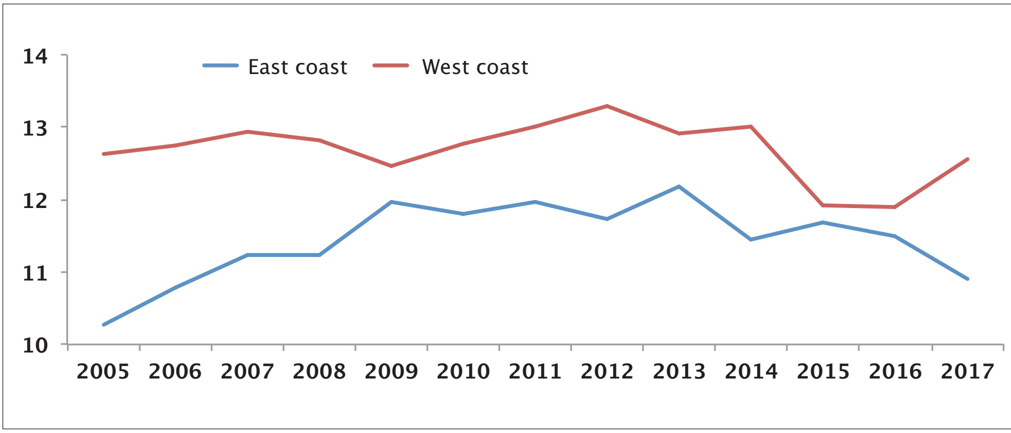


Fig.16. Annual contribution of southwest and southeast coast to the Indian oil sardine landings (2005 - 2017)

Seasonal longshore and offshore movements of *Sardinops sagax* along the South African Coast (sardine runs) has been described by Lingen *et al.* (2010). According to Freon *et al.* (2010) these runs are more in the manner of "range extension" than "migration" in that the distribution of the population among all potential habitats will be to optimize individual fitness and thereby growth of the stock. Hence, a hypothesis that the IOS may be moving within this larger regional basin resulting in this peculiar nature of landing trend is put forth. Limited studies on tagging and distribution indicated movements within a few hundred kilometers parallel to the coast and an offshore to coastal water migration for spawning and feeding only (Jayaprakash, 2007). The suggested hypothesis can be confirmed only through advanced genetic tools and tagging studies.

The Indian Ocean Dipole (IOD) has been identified as the most important driver in the inter-annual variability of the environmental factors in the Indian Ocean (Saji *et al.*, 1999). Positive IOD years (1994, 1997), negative IOD (1996, 1998, 2005) and neutral years (2000, 2001 2005) indicated that the surface circulation flows from the Bay of Bengal (BOB) to Arabian Sea (AS) during positive IOD years and *vice versa* during negative IOD years (Rayaroth *et al.*, 2016). The productivity of BOB is generally lower than the AS (Prasanna Kumar *et al.*, 2002). The shifts in the surface currents during IOD periods may be influencing the feeding conditions for the planktivorous IOS inhabiting this region, leading to their movements in tandem with these changes. Hence, a hypothesis that the IOS may be moving within this larger regional basin probably influenced by favorable environmental and feeding conditions (Prasanna Kumar *et al.*, 2002; Prakash and Ramesh, 2007) is proposed. This hypothesis too can be confirmed only through genetic tools and tagging studies.

The trends in landings, seasonal and annual variations in landing trends, gears engaged in IOS fishing in maritime states during the past thirty years (1985 - 2015) is presented in Annexure I and the annual average landings of IOS in the maritime states are depicted in Fig.17.

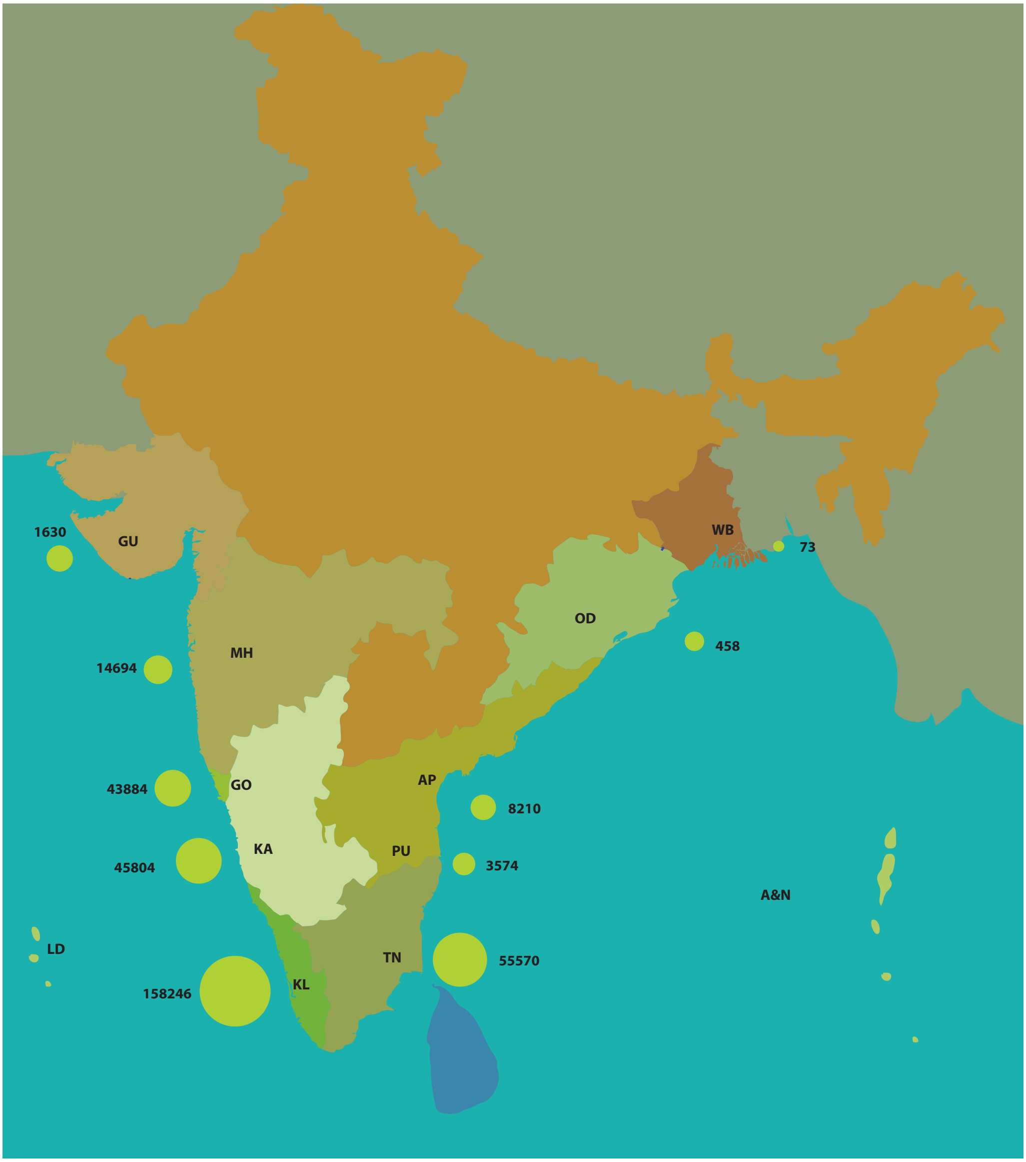


Fig.17. Indian oil sardine landings along the maritime states and Union Territories of India (average of 1985 - 2015)

The IOS landings (by volume) along the coastal states during 1969 - 1978 (Balan and Reghu, 1979) was contrasted with the IOS landings during 2007 - 2015 (Fig.18). The contribution of Tamil Nadu, which was very low during the first phase, increased to 22% during the second phase. On the other hand, the contribution of Kerala to total IOS landing declined from 79% to 44% during the respective periods.

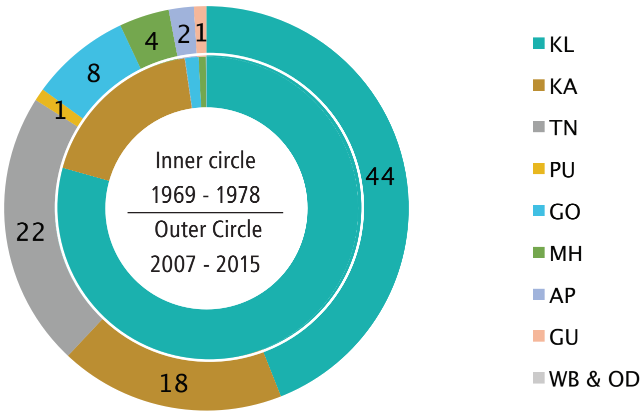


Fig.18.Changing statewise contribution to the Indian oil sardine landings during 1969 - 1978 (Inner circle) & 2007 - 2015 (Outer Circle) periods

4.3.ii. Southwest coast

The southwest coast (states of Kerala, Karnataka and Goa) contributed on an average 74.5% to the total IOS landings of the country during 1985 - 2015. The IOS formed the dominant species of marine fish landings in all these states. The major gears operated for IOS fishing in this region include the seines (inboard/ mechanized ring seine (MRS), outboard/motorised ring seine (OBRS), outboard boat seines(OBBS), purse seines (PS), gillnets (GN), outboard trawl nets (OBTN) and mechanized trawl nets (MTN) (Jayaprakash and Pillai, 2000).

Kerala

Kerala is the leading State contributing to the IOS fishery of the country with the catch ranging from a low of 1,554 t (1994) to a record high of 3,99,786 t (2012) and an average landings of 1,58,246 t during the 1985 - 2015 period. The contribution of IOS to the total marine fish landings of the state varied from 3.3% in 1994 when landings were at their historic low, to 68.7% in 1990. One of the main drivers leading to increased exploitation of IOS since 2000, was the high demand from fishmeal and fishoil industries. The steady demand from fishmeal industries encouraged intense and targeted fishing for IOS with improved seines. Moreover, the demand from these factories for less fresh or stale fish encouraged the fishermen to undertake fishing during night hours also (Jayaprakash and Pillai, 2000). Landing trends by different gears indicated ring seines to be the most important gear and accounted for about 90% of the IOS landings. An intensification of fishing effort for IOS was evident post 2008. The contribution of MRS increased to 53% during 2008 - 2015 from 17% during 2002 - 2007 with a corresponding respective decrease of OBRS from 67% to 42% (Abdussamad *et al.,* 2015). The contribution by MTN although low in landing volumes has nearly doubled and indicated the availability of IOS in deeper waters. Presence of IOS in the gut contents of offshore fishes such as ribbonfishes and tunas observed during the present study confirmed this.

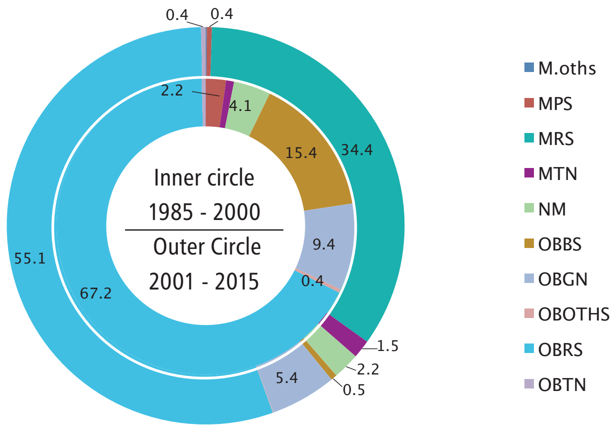


Fig.19. Gearwise (%) contribution during 1985 - 2000 and 2001 - 2015 periods in Kerala

Karnataka

The IOS landings in Karnataka ranged from 1,631 t in 1994 to 1,43,497 t in 2014 with an average of 45,804 t during 1985 - 2015. The annual contribution of the State to the total IOS landing of the country ranged from 3.5% in 1994 to 42.3% in 1987 with an average of 15.3 % (Fig.20). The MPS continued to be the major gear landing IOS but its contribution decreased from 89.8% during 1985 - 2000 to 68.2 during 2001 - 2015. The contribution of OBRS recorded a corresponding increase during the later phase (Fig.20)

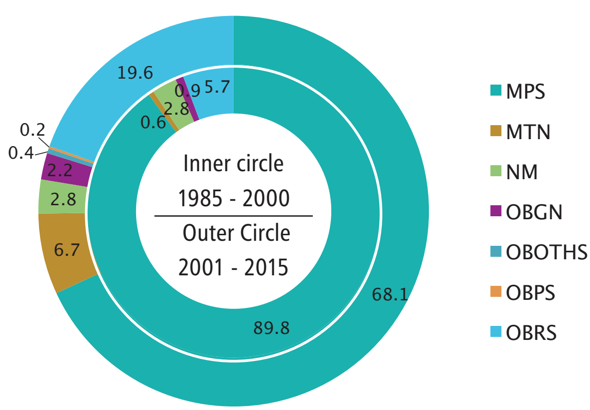


Fig. 20. Gearwise (%) contribution during 1985 - 2000 and 2001 - 2015 periods in Karnataka

Goa

In Goa, the IOS landings ranged from a mere 2 t in 1994 to 1,15,902 t in 2014 with an average of 43,884 t during 1985 - 2015 period. IOS generally formed the most dominant fish of the total marine fish landing of the State and comprised 78.9% in 2014. The percentage contribution to the total IOS landing of the country varied from 0.7 in 1986 to 27.5 in 2014 with an average of 7.9. The contribution of the OBPS in the motorised sector and the NM sector has increased in the recent years (Fig.21).

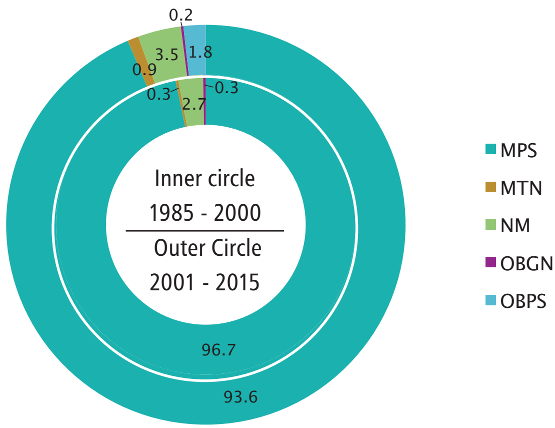


Fig. 21. Gearwise (%) contribution during 1985 - 2000 and 2001 - 2015 periods in Goa

The present fishing pattern with multiple gears enables wider coverage of fishing grounds and the catch by itself has potential to reflect abundance (Martell and Froese, 2013). However, in the present study, the landing and CPUE trends also have been analysed to understand if this would be a better indicator of IOS abundance in the fished grounds. Analysis of time series data on fishing effort, landing and CPUE for the years 1998 - 2016 by MPS, MRS and OBRS, the dominant gears landing bulk of the IOS landings along the southwest coast did not show highly significant correlations (Figs. 22 - 24).

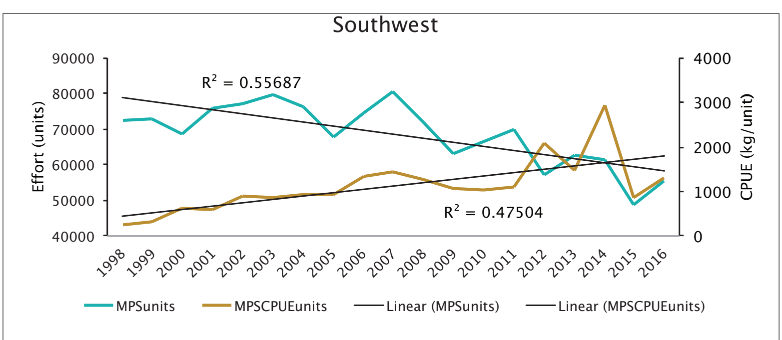


Fig 22. Trends in mechanized purse seine units and its CPUE along southwest coast

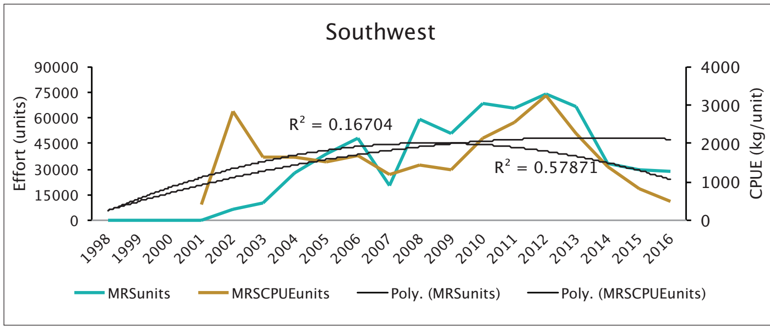


Fig.23. Trends in mechanized ring seine units and its CPUE along southwest coast

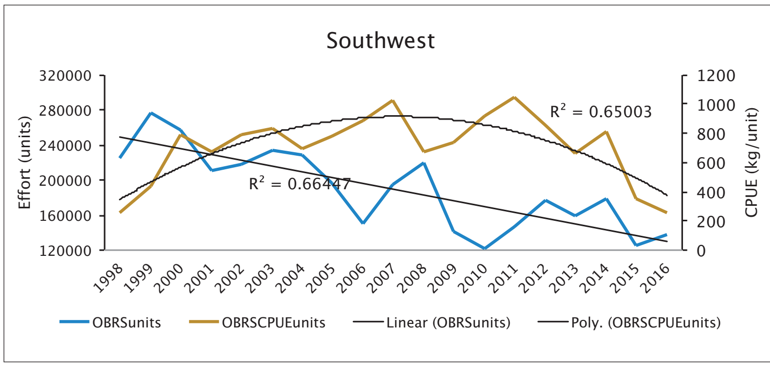


Fig.24.Trends in outboard ring seine units and its CPUE along southwest coast

While the annual fishing effort of MPS (from 72,432 units in 1998 to 55,608 units) and OBRS (from 226,037 units in 1998 to 138,093 units) gradually reduced over the 19 year period (Fig.22), the effort of MRS peaked in 2012 (70,000 units), but reduced thereafter (28,772 units in 2016) as indicated in Fig.23. The CPUE of MRS and OBRS increased until 2007 - 2012, but showed a declining trend thereafter. The CPUE of MPS alone showed increasing trend. The MPS operation is concentrated along the Karnataka-Goa coast unlike the other two gears, which are concentrated in Kerala. As all the gears fish the same IOS stock, it is likely that the CPUE of MPS also will decrease in future if proper management measures are not undertaken.

4.3.iii. Northwest coast

The northwest coast comprising states of Maharashtra and Gujarat has recorded an increase in IOS landings since the early 2000, when demand for this resource from the fishmeal and processing plants in Karnataka and Kerala increased.

Maharashtra

In Maharashtra, the estimated IOS landings during 1985 to 2015 ranged from 5 t in 1994 to 33,388 t in 2012 with an average of 14,693 t. MPS was the major contributor (53.1%) followed by MDOL (15.8 %), MTN (7.4%), OBRS (3.6

%) and non-mechanized gears (16.3%) (Annexure I). The landing trend along Maharashtra was similar to those observed in other states along the west coast with good landings during October to January and another peak during April and May (Annexure II). The average contribution of MPS to the IOS landing which was 17% during 1985 - 2000 period increased to 50.6% during 2001 - 2015. On the other hand, the contribution by non-mechanized gears decreased from 70% to 6.9% for the same periods. Significant contribution (24.4%) was made by the bagnet (MDOL) to the IOS landings during this period, though this gear traditionally targets Bombayduck and prawns (Fig.25), indicating exploitation of IOS by a wide range of gears along the northwest coast.

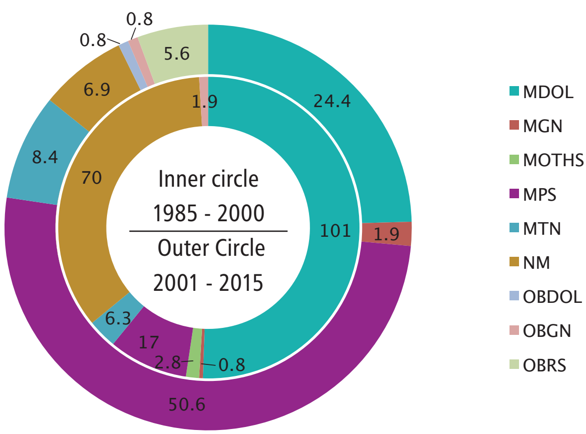


Fig.25. Gearwise (%) contribution during 1985 - 2000 and 2001 - 2015 periods in Maharashtra

Gujarat

The IOS formed a meagre, occasional and erratic fishery in Gujarat. It formed part of gillnet based fishery for the small pelagics especially in Saurashtra and south Gujarat. During the period under study, IOS landings was recorded only in 1987, 1990, 2005, 2006, 2014 and 2015 and the landing ranged from 2 t in 1990 to 6,891 t in 2014 (Annexure I). The dwindling landing in Kerala and Karnataka, and the larger size with higher oil content in the IOS occurring along Gujarat Coast yielded higher unit price for the fish in southern states. This motivated the fishers of Gujarat to target IOS in recent years. The fishery for IOS is mostly concentrated around Veraval, Porbander and Okha, owing to the existence of traders, rail and road connectivity for bulk transportation to markets in the south.

Gillnets (55 - 65 mm mesh size) operated from dug-out, plank built and fibre canoes (18 - 32 feet in length) fitted with outboard engines is the major gear that exploits IOS along the Saurashtra Coast. Though OBM have over-shadowed the traditional modes of propulsion like the oars and sails, these traditional means are still used to some extent. Incidental landing of IOS by trawls operated in the inshore waters was also recorded. At times of mass incursion of sardines to inshore waters as observed in Okha during November 2014, cast nets and scoop nets were used to catch the fish.

4.3.iv. Southeast Coast

The southeast coast encompassing the states of Tamil Nadu, Puducherry and Andhra Pradesh has contributed significantly to the total IOS landing of the country especially during the last two decades. The annual contribution of this region to the total IOS landings ranged from 1.7% in 1987 to 93.5% in 1994. With a contribution of 33% to the total IOS landings of the country in 2015, Tamil Nadu became the forerunner among the maritime states in IOS landings for the first time.

Tamil Nadu

In Tamil Nadu, the landing ranged from 876 t in 1987 to 1,82,427 t in 2013 with its contribution to the total IOS production in the country ranging from 0.9% in 1987 to 73.6% in 1994. The five yearly landings showed a quantum jump from 53,462 t during 1986 - 90 to 5,98,267 t during 2011 - 2015 with peak landings during February-March (Annexure II). Pair trawls and gillnets were the main gears used. Average (1985 - 2015) gearwise contribution to IOS landing during 1985 - 2015 was as follows: MTN (28.8 %), NM (23.5%), MRS (14.2%), OBGN (13.1%) OBRS (8.3%) and OBBN (5.2%) (Annexure I).

The declining contribution of NM gears to the IOS landing, marginal increase in OBGN contribution, substantial increase in MTN and emergence of OBRS and MRS during 1985 - 2015. (Fig. 26) indicated the rapid changes occurring in the IOS fishery along Tamil Nadu Coast.

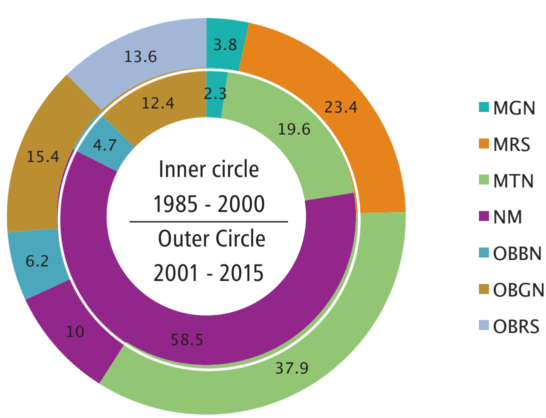


Fig.26. Gearwise (%) contribution during 1985 - 2000 and 2001 - 2015 periods in Tamil Nadu

Puducherry

The annual IOS landings along Puducherry Coast ranged from 191 t in 1988 to 11,260 t in 1997 with an average of 3,574 t. The contribution of Puduchery to the total IOS landings of the country varied from 0.1% in 1988 to 6.5% in 1996. The five yearly (total landing) trends showed highest landings of 32,268 t during 1996 - 2000 after which the fishery declined during next two succeeding periods but showed slight improvement during 2011 - 2015. The OBBN (*edavalai*) contributed 30% of landing followed by NM gears (29%), OBGN (15 %), OBRS (9%) and OBPS (7%) (Annexure I). The monthly landing trend in Puducherry was different from that observed in Tamil Nadu with peak landings during August-September (Annexure II). This is due to the introduction of mechanized seines, the most efficient gear for exploiting shoaling fishes, whereas, in Tamil Nadu the trawls continue to be the major gear exploiting the IOS. While comparing the fishery for IOS during 1985 - 2000 and 2001 - 2015 periods in Puducherry, it is evident that the contribution of both the mechanized and motorised sector has increased while the NM sector has steeply declined (Fig.27). There has been a significant increase in the fishing pressure and targeted fishing for IOS as reflected in the increased contribution by seines

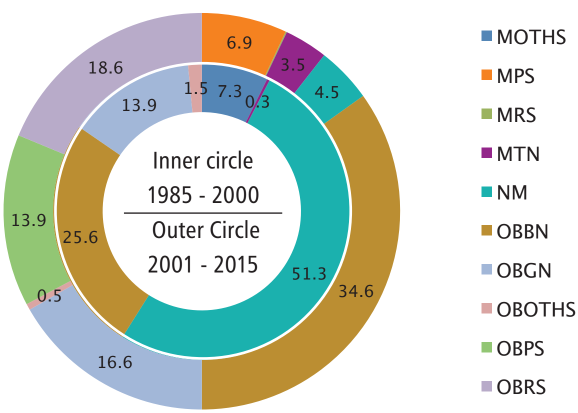


Fig.27. Gearwise (%) contribution during 1985 - 2000 and 2001 - 2015 periods in Puducherry

Andhra Pradesh

In Andhra Pradesh, the total IOS landing ranged from 146 t in 1987 to 31,968 t in 1998 with an average of 8,210 t. The contribution of the State to the total IOS landing of the country varied from 0.1% in 1987 to 17.2% in 1996. The five yearly landing showed that the production increased from 9,429 t during 1986 - 1990 to 1,02,662 t during 1996 - 2000 and thereafter the landings ranged between 27,735 t and 62,649 t in the succeeding periods. Exploitation was mainly by gillnets and trawls with peak landings during August-September.

The average (1985 - 2015) gearwise contribution to the IOS fishery was NM (49%), OBOTHS (16.6%), OBRS (16.1 %), OBBS (5.7%) and OBGN (5.4 %) as indicated in Annexure I. However, a comparison of the fishery during the two phases (1985 - 2000 and 2001 to 2015) indicated that the landing by NM has reduced sharply from 83.2 to 24.7% while the OBRS which appeared in the second phase (2001 - 2015) contributed 30.9% to the IOS landing of the State (Fig.28).

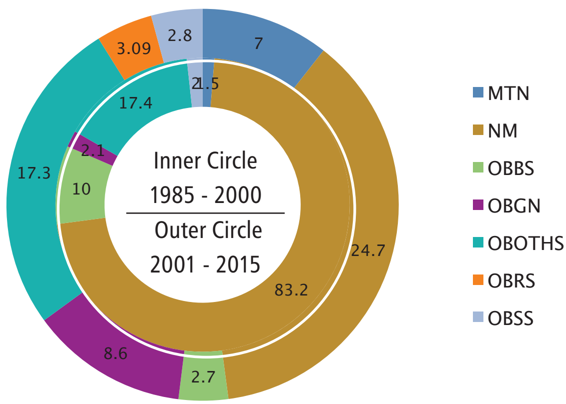


Fig.28.Gearwise (%) contribution during 1985 - 2000 and 2001 - 2015 periods in Andhra Pradesh

4.3.v. Northeast Coast

Odisha and West Bengal comprising the maritime states of the northeast region contributed minimally to the total IOS landing of the country.

Odisha

In Odisha the landing fluctuated between 1 t in 1987 and 2,617 t in 2012. The main gears exploiting IOS were NM (54.6%), OBGN (20.5%) and OBRS (14.3%). The percentage contribution to the total IOS landings of the country during most years was <0.5 %. The landings have however showed a progressive increase from 43 t during 1986 - 1990 to 1,290 t during 2011 - 15 (Annexure I). Though IOS is regularly landed, it is not a major fishery in the State. May and June were the most productive months (Annexure II). Steep decline in the contribution of the NM sector and increased contribution by OBGN and MTN was observed in later years. OBRS operation started only in the second phase and contributed 18.2% to the landing (Fig.29).

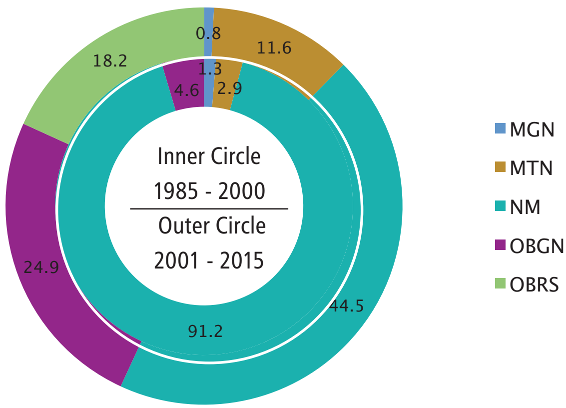


Fig.29. Gear-wise (%) contribution during 1985 - 2000 and 2001 - 2015 periods in Odisha

West Bengal

The IOS fishery in West Bengal was also very low, erratic and absent in some years. The landings increased from from 1.6 t in 1986 - 1990, it rose to 138 t in 1996 - 2000 but decreased to 25 t in 2001 - 2005 and marginally increased to 79 t during 2011 - 2015 periods (Annexure I). Gearwise trends during 1985 - 2000 period to 2001 - 2015 indicated that the contribution of MTN increased from 31 to 81.5% and OBGN from 7.6 to 15% while that of NM reduced from 28.4% to 7.1% and MGN operations were stopped (Fig.30).

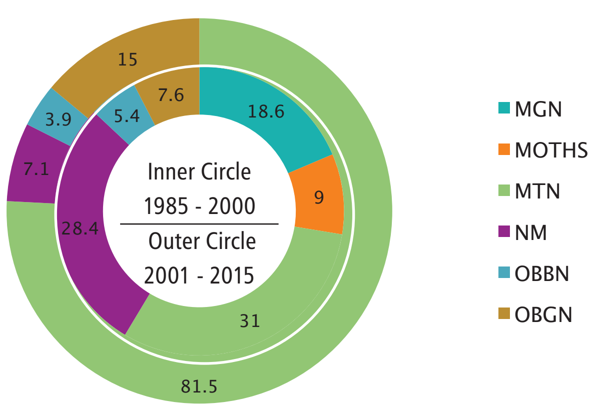


Fig.30. Gearwise (%) contribution during 1985 - 2000 and 2001 - 2015 periods in West Bengal

Plate 11. Landings of adult Indian oil sardine at Beypore, Kerala

5. Value chain and socioeconomics of Indian Oil Sardine fishery

The IOS is a highly favoured table fish in Kerala and Karnataka and large quantities are sold in fresh form. It is also ideal for extraction of oil and preparation of protein rich fishmeal. During periods of abundance, huge quantities are caught and landed resulting in glut. Being rich in oil, the fish is highly perishable and cannot be stored for long durations. Madhavan *et al.* (1974) have reported on the 'belly bursting' phenomenon and have noted that it is a serious problem during freezing of small sized IOS with less fat. Further, if ice storage prior to freezing exceeds three days, IOS lose their acceptability as table fish. During glut, part of the catch is canned and the rest is taken by fishmeal plants for extraction of oil and preparation of fishmeal (Surya *et al.*, 2016). On the other hand, when landing is moderate or less in Kerala, the entire landing is marketed locally for consumption in fresh condition. Further, during times of acute scarcity and when the demand supply gap is high, IOS is procured from Karnataka, Goa, Maharashtra, Tamil Nadu and Andhra Pradesh (Shyam *et al.*, 2015 ; Roul *et al.*, 2016) and occasionally from Oman (Prakasan *et al.*, 2015) to meet the high local demand for IOS in fresh form for consumption (Figs. 31 and 32).

In Kerala, the IOS formed nearly 30% of all fish consumed (Shyam *et al.*, 2015). However, a certain portion of the IOS catch is also used in dry fish trade where fish purchased at ₹ 25 per kg is dried for 3 - 5 days and

Fig.31. Repacking imported Indian oil sardine from Oman to meet demand in domestic markets of Kerala in 2015

Fig. 32. Fresh locally sourced Indian oil sardine being sold in domestic markets in Kerala

later sold for ₹ 100/kg (Shyam *et al.*, 2016). In Karnataka, 34% of the IOS landed is retailed in fresh condition for direct consumption in local markets and interstate traders take about 8% of the landing. A portion (8%) of the remaining landing in fresh condition is used to produce value added products such as canned sardine (in brine or tomato sauce) and the rest (50%) of the landing in any condition (fresh, partly spoilt or decayed) is used for extraction of oil and preparation of fishmeal. The fishmeal is in good demand for preparation of poultry feed, aquafeed and petfeed. The preference for IOS in fresh condition in Goa is less as compared to Kerala and Karnataka. Therefore, only a small part of the IOS landing is used for local consumption and part of the landing landed in fresh condition is sent to Karnataka and Kerala when there is a good demand. The remaining landing if any is generally used as manure or sent to fishmeal plants.

In Gujarat and Maharashtra, the IOS is not a preferred fish. In Gujarat, till recently the IOS had its place among the low value bycatch; generally termed as "*kutta*" and was used for fishmeal production. It was also used for production of fishoil for treating wooden canoes and boats. With the advent of freight systems and cold chains in the domestic fish trade and high demand and high prices offered in Kerala, transportation from Saurashtra in Gujarat gained momentum since 2015. Consequently, the price of IOS in Gujarat increased from ₹5 to ₹70 per kg.

The preference for IOS along the East coast is very low. Part of the catch when landed in good condition, is iced and sent to Kerala and Karnataka for consumption whenever there is a demand, while some portion is used as bait in smallscale hook and line and troll operations. Rest of the landing was reluctantly (as the high oil content of the fish takes several hours to dry and the odour emanating from drying process remains for several days) beach-dried and then sent for preparation of poultry feed. However, with the demand for IOS in any condition increasing from the fishoil and fishmeal plants during recent years, the landing is transported to these plants (Das *et al.,* 2013). The disposal of IOS landing in Odisha and West Bengal is similar to that in Tamil Nadu and Andhra Pradesh. In recent years, fishmeal plants have been established in Tamil Nadu and Andhra Pradesh as well to gainfully use the IOS landed along the East coast.

5.1. Marketing and price spread in Indian Oil Sardine trade

Small-sized fishes like the IOS play a vital role in meeting the nutrition of countries all over the world (Isaacs, 2016). Similarly, in India with small marine fishes such as IOS are a source of protein rich food for the coastal population with fishing being an important economic activity of the region. Along the Indian coast, while the increase in volume of landings of IOS was 19.7% and 6.3% during 1995 - 2004 and 2005 - 2014 respectively, growth in monetary value was to the tune of 24.1% and 9.7% respectively (Aswathy and Narayanakumar, 2017). Inspite of disposition of large amounts of IOS to low-value markets such as fishmeal plants, higher appreciation of overall monetary value in recent years indicates substantial increase in the price of IOS in recent years. This is mainly due to people’s recognition of the high nutritional value (like omega 3-fatty acid) of IOS as well as the steep escalation in the price of high-valued fishes such as seerfish and pomfrets.

The price spread or Gross Marketing Margin (GMM) is low when market is efficient. In the case of IOS, it ranged from ₹ 6 per kg in Goa to ₹26 per kg in Karnataka with a national average of ₹17 per kg during 2000 - 2008 (Sathiadas *et al.*, 2011). The Fishermen’s Share in Consumer’s Rupee (FSCR), another parameter used for assessing marketing efficiency, indicated a national average of 51.4% for IOS, ranging from 30% in Karnataka to 68% in Maharashtra during 2000 - 2008. Aswathy *et al.* (2017) estimated an average FSCR of 55.8, 61.8 and 68.5% during 2014 - 15 in Uttara Kannada, Udupi and Dakshina Kannada districts in Karnataka respectively. Volatile price trends (higher price fluctuations at the Point of first sales) of IOS indicated the prevalence of distress sales by fishermen due to lack of infrastructure facilities and basic amenities for hygenic handling (Sathiadas *et al.*, 2011). Returns from the landings can be improved by adopting proper catch utilization strategies. These include introduction of appropriate harvest control rules, Minimum Support Price (MSP) and improved supply chain with adequate cold storage and transportation facilities. Development of value added and nutraceutical products such as Polyunsaturated Fatty Acid (PUFA) concentrates and PUFA emulsions from IOS also offer tremendous potential (Kajal *et al.*, 2015).

5.2. Disposal, market linkages and revenue generated in Karnataka: a case study

A rapid study on the disposal and market linkages of IOS in Karnataka during 2016 indicated that the entire landings of IOS, is fully utilized with no wastage. Of the total IOS landings, an estimated 42% reaches the domestic market for fresh consumption. The fishmeal and fishoil plants take up 48% while the processing plants, cutting sheds and inter-state traders together account for the

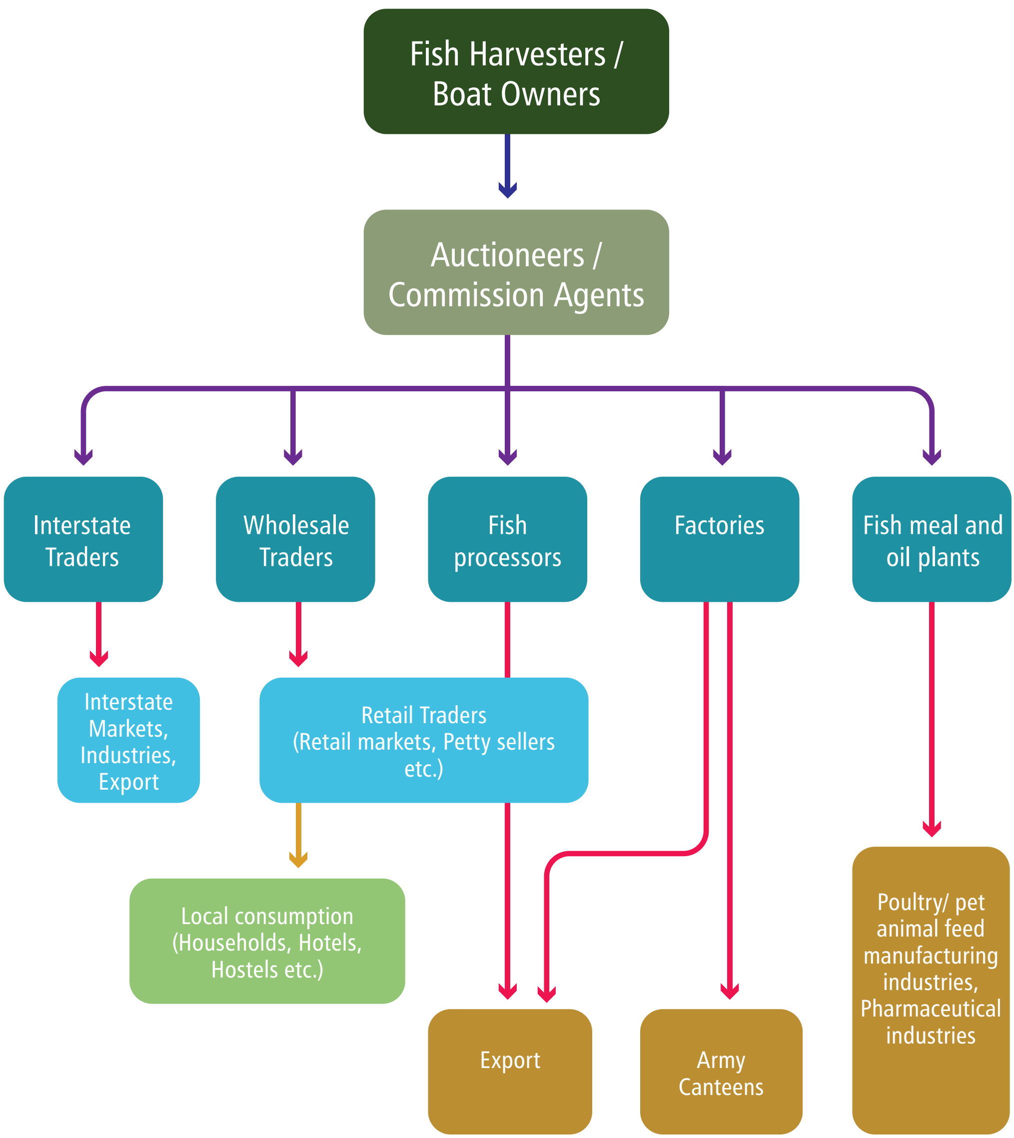


Fig.33. Existing market linkages for Indian oil sardine landed in Karnataka

remaining 10%. The IOS thus passes through several linkages and reaches either the domestic fresh fish market, processing plants or fishmeal plants (Fig.33).

Although marketing linkages for IOS are many, maximum revenue was generated through sale for fresh consumption at ₹ 80/kg. The processing plants procured IOS at ₹ 60/kg and fishmeal plants procured IOS (in any condition-fresh, partially or fully spoiled) at maximum price of ₹14/kg. A total revenue of ₹ 2900.1 million was generated through disposal of 62,609 t of IOS landed in Karnataka during 2016, of which ₹ 2103.7 million (72.5%) was generated by sale for fresh consumption in domestic as well as interstate trade. The purchase of IOS by processing plants (10% of landings, 6,260 t) generated ₹ 375.7 million. The fishmeal plants purchased the remaining 48% of the catch (30,052 t) at ₹ 420.7 million.

Table 3. Estimated revenue generated from Indian oil sardine fishery in Karnataka during 2016

Disposition of landing	Total quantity (t)	Price (₹/kg)	Revenue generated (million ₹)
Fresh consumption (42% of total landings) (Local + Interstate sale)	26295	80	2103.7
Processing (10% of total landings) (Processing plants+Canning+ Fish cutting)	6261	60	375.7
Fish meal plants (48% of total landings)	30052	14	420.7
Total	62609	14 - 80	2900.1

Plate 12. Interior view of fishmeal plant

Reduction of IOS to fishmeal (which in turn is used for preparation of aquafeed/ poultry feed or pet feed) happens only when there is a glut in landings. However, if the entire IOS could be handled properly and used for direct consumption it would have fetched a higher price. Had all the IOS landed in Karnataka during 2016 been used for domestic consumption or processed as value added product, the revenue generated would have been close to ₹ 4884.1 million, which is ₹1984 million more than what was actually realized.

Plate 13. Oil extraction from Indian oil sardine

6. Biology

The length range, mean, reproductive biology and trophodynamics of the IOS have been continuously monitored by ICAR - CMFRI through regular sampling from major landing centres particularly located along Kerala, Karnataka, Maharashtra, Tamil Nadu and Andhra Pradesh and analyzing the time series data generated.

6.1. Length distribution

The size of IOS landed along the Indian coast ranged from 40 mm to 229 mm (Tables 4,5 and Annexure III). However, the largest recorded size of IOS along the Indian coast that measured 272 mm in total length and weighed 159 g (wet weight) was from the landings at Malpe Fisheries Harbour in Karnataka (Rohit, 2003). The length distribution of IOS along the west coast ranged between 56 and 218 mm with a wider range during during October-November. The wide length range indicated the presence of recruits as well as adults in the fishery and high exploitation of all size groups by seines during these months. In Karnataka, the mean length during all months as well as most years except 2012 and 2013 was well above the size at first maturity. In Kerala, the annual mean size of IOS during 2000 - 2015 was close to or > L_m except in 2009. In Andhra Pradesh, smaller sizes (TL less than L_m) were more abundant during January to March, July, September and November. Smaller annual mean sizes ($<L_m$) predominated till 2008 and thereafter larger mean sizes were recorded. This is probably because, the shore seine and non-mechanized gears mainly contributed to the IOS fishery till 2008 and thereafter the mechanized sector especially ring seines and pelagic trawls operating in deeper areas also started contributing significantly to the IOS fishery (Ref. Craft and Gear section 4.1.i). In Tamil Nadu, the highest monthly mean length was during April-May, which coincides with the peak spawning season. Although the annual mean size was below size at first maturity (L_m) in the earlier years (2002 to 2006) later it was higher and around 150 mm. IOS landings in Gujarat mainly by gillnets had only large sized fishes with a very narrow size range (Annexure III).

Size Based Indicators (SBI) were evaluated as a predictor for fishery success (Mohamed *et al.*, 2008) using time series data of L_{mean}, L_{range}, L_{max} and L_{min} of IOS which showed only poor fit for the first three parameters and moderately good fit for the last parameter. In general, the present observations indicated that IOS landed along the west coast had higher mean lengths as compared to those landed on the east coast. Fishing operations (type of gear used and season of fishing) and biological influences caused by multiple broods with different growth rates (Yohannan, 1979) influence the length distribution in the catch. Gears such as purse seines and trawlnets are non-selective and catch all size groups. The IOS catch by gillnet, on the other hand, is limited by the mesh size.

Table. 4. Monthwise length range (mm) and mean size of Indian oil sardine landed in different states

Month	Karnataka	Kerala	Tamil Nadu	Andhra Pradesh
January	72 - 210 (160)	90 - 200 (127)	96 - 181 (129)	80 - 199 (116.6)
February	76 - 211 (162)	70 - 205 (173)	100 - 192 (144)	100 - 169 (118.9)
March	78 - 210 (160)	55 - 205 (150)	115 - 168 (137)	50 - 209 (129.7)
April	96 - 208 (172)	60 - 205 (163)	110 - 162 (121)	130 - 219 (155.2)
May	100 - 218 (171)	85 - 205 (132)	122 - 194 (147)	40 - 209 (141.7)
June	82 - 209 (174)	80 - 205 (187)	81 - 204 (146.2)	40 - 219 (173)
July	NA	85 - 205 (148)	56 - 206 (146.4)	40 - 209 (111.1)
August	91 - 216 (170)	75 - 205 (145)	41 - 195 (146.1)	120 - 219 (173)
September	73 - 214 (164)	120 - 205 (131)	66 - 225 (146.9)	60 - 229 (136.2)
October	56 - 216 (159)	140 - 210 (146)	111 - 220 (146.7)	50 - 209 (141.1)
November	58 - 218 (156)	95 - 205 (135)	100 - 204 (150.9)	80 - 209 (135.5)
December	92 - 212 (156)	95 - 210 (152)	76 - 197 (151)	80 - 219 (145.2)

*values are average for the years 2010 - 2015, mean size in parenthesis NA - Data Not Available

Table. 5. Annual length range (mm) and mean size of Indian oil sardine landed at different states

Year	Karnataka	Kerala	Tamil Nadu	Andhra Pradesh
2000	85 - 215 (142.3)	40 - 210 (107)	NA	50 - 209 (129.7)
2001	90 - 215 (141.8)	55 - 205 (147)	NA	40 - 209 (88.1)
2002	70 - 215 (148)	90 - 210 (149)	81 - 180 (111.8)	40 - 219 (116.5)
2003	70 - 215 (143.1)	70 - 210 (149)	96 - 175 (139.8)	80 - 159 (119.3)
2004	65 - 215 (146.5)	55 - 205 (142)	76 - 175 (128.1)	60 - 109 (82.9)
2005	55 - 210 (151.1)	60 - 210 (149)	56 - 180 (125.3)	80 - 199 (134.2)
2006	70 - 205 (153.4)	85 - 205 (157)	41 - 185 (114.4)	50 - 169 (96.3)
2007	90 - 205 (164)	80 - 205 (151)	76 - 200 (157.1)	80 - 129 (138.9)
2008	90 - 205 (146.2)	85 - 205 (143)	61 - 195 (144.2)	90 - 199 (150.6)
2009	90 - 205 (147.3)	95 - 180 (128)	55 - 225 (153.1)	90 - 209 (142.6)
2010	85 - 205 (149.1)	120 - 200 (185)	52 - 198 (164.9)	50 - 219 (125.6)
2011	95 - 215 (148.1)	95 - 210 (163)	122 - 196 (157)	80 - 219 (157.6)
2012	95 - 210 (138.3)	95 - 210 (153)	136 - 192 (167.2)	80 - 229 (153.5)
2013	95 - 210 (135.6)	100 - 205 (152)	100 - 220 (157.7)	70 - 219 (143.2)
2014	120 - 210 (161)	90 - 200 (148)	93 - 202 (167.9)	90 - 229 (158.2)
2015	105 - 210 (164)	100 - 190 (134)	109 - 196 (159.8)	NA

*values in parenthesis indicates mean, NA - Data Not Available

6.1.i. Length-Weight relationship

Analysis of IOS samples collected from different maritime states indicated an isometric growth pattern with 'b' value in the length-weight relationship close to 3. The estimated 'a' and 'b' values in the length-weight relationship formula ($W=aL^b$) is a=0.013, b=2.896. The 'W' is the wet weight in grams, 'L' is the total length of fish in centimetre and 'a' and 'b' are constants (Fig.34). The estimated length-weight relationship did not differ between males and females. Antony Raja (1967) observed that the relationship varied significantly among fishes collected during different seasons and maturity groups but not among the sexes and suggested appropriate consideration of this factor while converting estimated weights of fish landed to numbers or *vice versa*.

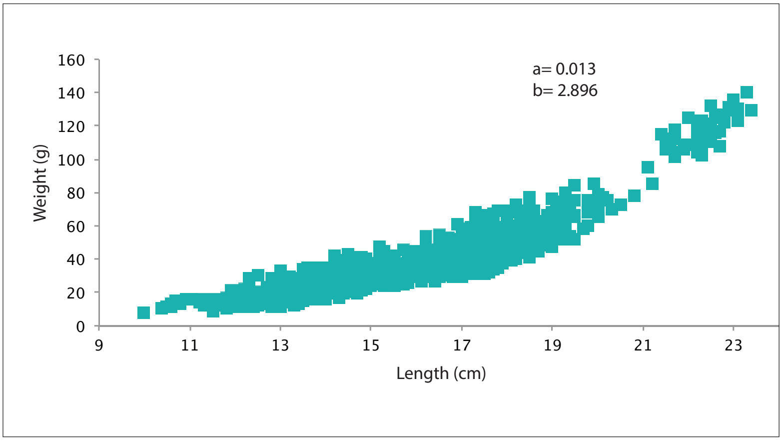


Fig.34. Length-weight relationship of Indian oil sardine

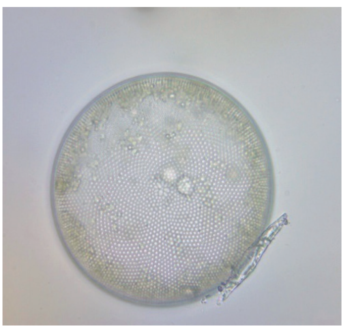
6.2. Food and feeding

The IOS feed extensively on phytoplankton and the extremely fine straining; well developed gill rakers efficiently filter the planktonic food items from the surrounding marine environment (Kagwade, 1967). Several studies on the food and feeding of IOS and its planktivorus feeding nature are available (Chidambaram,1950; Nair and Subramanyan,1955; Dhulkhed, 1962, 1970, 1972; Noble, 1964; Qasim and Jacob, 1972; Rohit and Bhat, 2003; Vivekanandan *et al.,* 2009; Remya *et al.*, 2013; Supraba, *et al.* 2016, 2017). Hornell (1910) recorded 'mud' as a food constitutent and subsequently Hornell and Nayudu (1924) concluded that this consists of plankton (infusorians and dinoflagellates) and decaying leaf/vegetable debris brought by river run-off during monsoon, which enhances the productivity of coastal waters. Kagwade (1967) had also attributed nutritive value to the detritus/muddy matter that occurred seasonally in sardine diets. While the diet analysis in later years was in conformity with the earlier reports, a shift in the ranking of the phytoplankton species constituting the diet was observed. Kagwade (1967) observed *Coscinodiscus* sp., *Biddulphia* sp., *Fragilaria oceanica, Pleurosigma* sp. and *Nitzschia* spp., throughout the year in the guts sampled, as a 'common' food item of the IOS. Dinoflagellates, tintinnids and copepods were observed in the gut by Dhulkhed (1962). In a later study, Remya *et al.* (2013) indicated a broad diet width of plankton with 29 species of diatoms, 6 species of dinoflagellates besides tintinnids and copepods as common food items and showed seasonal variations in frequency of occurrence. However, Remya *et al.* (2013) highlighted that *Fragilaria oceanica*, the food item that was considered to be the favourite diet and an indicator of abundance of IOS (Nair and Subrahmanyan, 1955), occurred only in 30, 18 and 6%of the IOS stomachs examined in the pre-monsoon (February-May), monsoon (June-September) and post-monsoon (October-January) seasons respectively. Dominance of the diatom *Coscinodiscus* spp. which is reported to be more tolerant to higher temperatures (Subrahmanyan, 1959, 1959a,b; Subrahmanyan and Sarma, 1960) was reported during the later years (Kumar and Balasubrahmanyan, 1987; Rohit and Bhat, 2003; Supraba, *et al.* 2016 and 2017). Bensam (1964) has reported that juveniles of IOS fed more on planktonic crustaceans than on phytoplankton. The major diet components of oil sardine are given in Figs. 35 and 36. A variety of phytoplankton with a dominance of *Coscinodiscus* sp., *Ceratium* spp, *Skeletonema* spp., *Pleurosigma* and *Navicula* besides copepods (highest Index of Preponderance) constituted its diet on the northwest coast (Table 6).

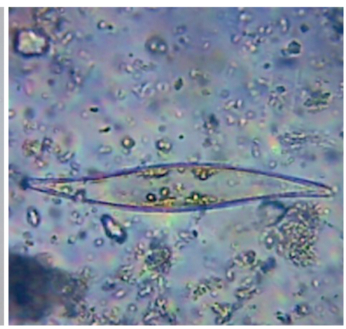
Table 6. Index of Preponderance (IOP) of food items in the gut of Indian oil sardine sampled in Maharashtra during 2015

Food item	Annual IOP	Food item	Annual IOP
Amphipods	0.02	Ostracod	0.10
Biddulphia sp.	0.58	*Peridinium* sp.	0.14
Ceratium sp.	4.49	*Planktoniella* sp.	0.14
Chaetoceros sp.	1.47	*Pleurosigma* sp.	5.84
Cirripede larva	0.03	Polychaete	0.04
Copepod	38.53	*Prorocentrum* sp.	0.48
Coscinodiscus sp.	26.80	*Protoperidinium* sp.	0.48
Crustacean parts	0.13	*Pyrophacus* sp.	1.89
Cyclotella sp.	0.06	*Rhizosolenia* sp.	0.12
Dinophysis sp.	0.89	*Skeletonema* sp.	9.76
Eucampia sp.	0.00	Stomatopod	0.01
Fish scale	0.01	*Surirella* sp.	0.28
Fish skeletal remains	0.00	*Thallassiosira* sp.	1.51
Fish eggs	0.00	*Thallassionema* sp.	0.19
Foraminifera	0.84	*Thallassiothrix* sp.	0.85
Fragilaria sp.	0.01	Tintinnid	0.40
Melosira sp.	0.01	*Triceratium* sp.	0.01
Debris	0.05	Gastropod	0.01
Navicula sp.	2.01	*Acetes* spp.	0.02
Nitzschia sp.	1.79	Lamellibranch	0.01

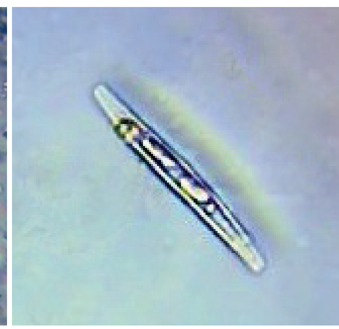
Among phytoplankton, diatoms (*Coscinodiscus* sp., *Fragilaria* sp., *Rhizosolenia* sp., *Biddulphia* sp., *Chaetoceros* sp., *Triceratium* sp., *Skeletonema* sp., *Nitzschia* sp., *Planktoniella* sp., *Thallassiosira* sp., *Thalassiothrix* sp., *Thalassionema* sp., *Melosira* sp., *Tetrahedral* sp., *Pleurosigma* sp., *Navicula* sp., *Bacteriastrum* sp., *Asteromphalus* sp. and *Cyclotella* sp.) dominated followed by dinoflagellates (*Ceratium* sp., *Peridinium* sp., *Surirella* sp. *Protoperidinium* sp., *Ornithocercos* sp., *Dinophysis* sp., *Pyrophacus* sp., *Ditylum* sp. and *Prorocentrum* sp.). Blue green algae represented by *Trichodesmium* sp. and *Oscillatoria* sp. were also observed in the diet. The zooplankton in the gut were mainly represented by copepods, amphipods, cladocera, fish eggs, crustaceans, crustacean larvae, polychaete worms and bivalves.



Coscinodiscus sp. (Coscinodiscaceae)

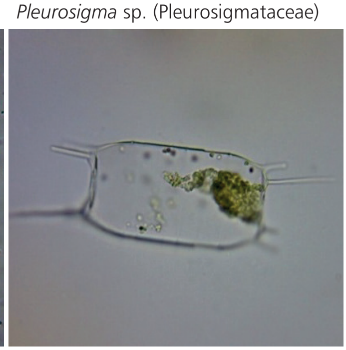


Pleurosigma sp. (Pleurosigmataceae)



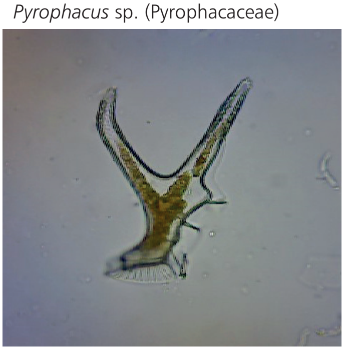
Nitzschia sp. (Bacillariaceae)

Pyrophacus sp. (Pyrophacaceae)

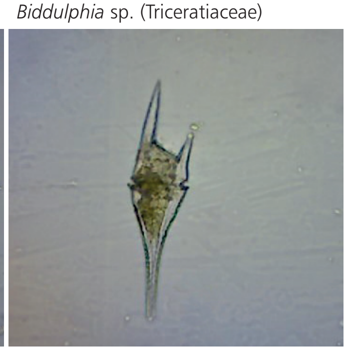


Biddulphia sp. (Triceratiaceae)

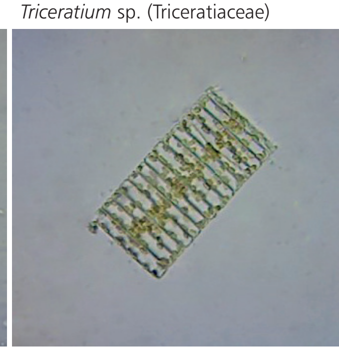
Triceratium sp. (Triceratiaceae)



Dinophysis sp. (Dinophysiacea)



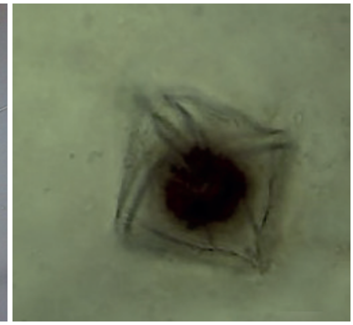
Ceratium sp. (Ceratiaceae)



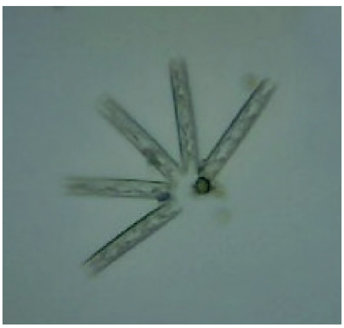
Fragilaria sp. (Fragilariaceae)

Navicula sp. (Naviculineae)

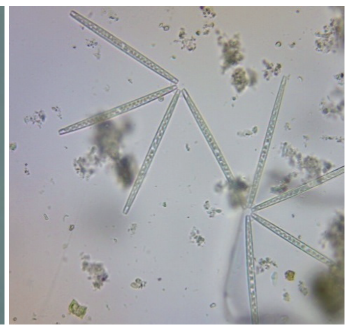
Rhizosolenia sp. (Rhizosoleniaceae)



Peridinium sp. (Peridiniaceae)



Thalassionema sp. (Thalassionemataceae)

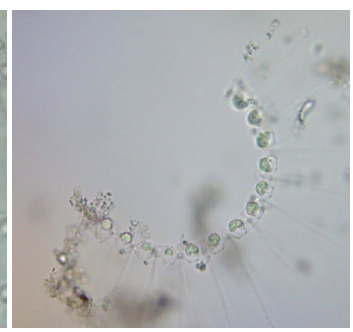


Thalassiothrix sp. (Thalassionemataceae)

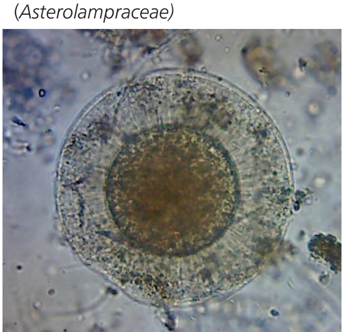
Skeletonema sp. (Skeletonemataceae)

Asteromphalus sp. (*Asterolampraceae)*

Cyclotella sp. (Stephanodiscaceae)



Chaetoceros sp. (Chaetocerotaceae)

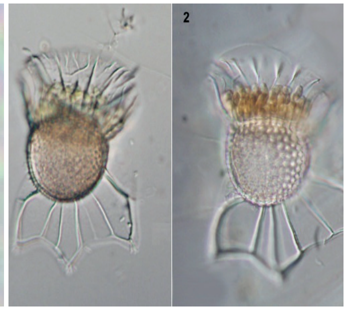


Planktoniella sp. (Thalassiraceae)

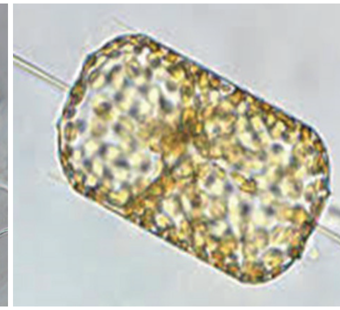
Thalassiosirra sp. (Thalassiraceae)

Surirella sp. (Surirellaceae)

Prorocentrum sp. (Prorocentraceae)



Ornithocercos sp. (Dinophysiaceae)



Ditylum sp. (Lithodesmiaceae)

Fig.35. Major phytoplankton diet component of Indian oil sardine

Copepod

Amphipod

Lucifer sp.

Cladocera

Decapod larvae

Chaetognatha

Gastropod

Foraminifera

Tintinnid

Cirripede larvae

Acetes spp.

Ostracoda

Fig.36. Major zooplankton diet component of Indian oil sardine

The average monthly and annual feeding intensity of IOS during 2000 - 2015 was studied. Feeding intensity was gauged by the distension of stomach and was classified based on physical observation of the stomach as empty (food absent or present in trace amounts), half full (food occupied half to three fourth of the stomach volume) and full (food content occupied more than three fourth to entire stomach volume and stomach was fully distended). All stages of feeding conditions were observed during all months in all years from Kerala and Karnataka along the west coast and Tamil Nadu and Andhra Pradesh along the east coast of India. Results of feeding intensity are given in Annexure IV.

Annual and monthly feeding intensity of IOS in Kerala indicated a dominance of empty stomachs. Fishes with half full and full stomachs were observed in all months and years. Generally, higher feeding intensity was observed in September and December coinciding with post spawning months. Higher numbers of well fed fish were observed in 2012 off Kerala Coast. A combination of favorable environmental factors and feeding conditions resulted in a good condition factor in female spawners during the peak spawning period. Favourable feeding conditions for the fish facilitates lipid deposition and high condition factor that ensures higher reproductive success (Gopakumar, 1974). Incidentally, the environmental conditions were favorable in 2012 as opposed to 2014 when the effects of El Niño had set in.

A similar feeding intensity pattern was observed in Karnataka with good feeding intensity in May as the fish prepares to spawn during June-August period. During the years 2005 to 2007 period, good feeding conditions continued which extended until 2010 indicating availability of plenty of food items. Along the east coast (Tamil Nadu and Andhra Pradesh), good feeding condition was observed during all months and years (Annexure IV).

6.3. Reproductive biology

The resilience of a fish population to exploitation is largely dependant on the reproductive traits (size/age at maturity, fecundity, spawning time, strategy, duration, etc.) (Morgan, 2008). A sound understanding of the reproductive biology of a fish species is crucial for providing scientific advice for fisheries management. Sexes in IOS are separate but cannot be easily distinguished externally. Though George (1959) has suggested a method to identify mature males and females in the field, it is still very difficult to distinguish the sexes externally. Visual differentiation of male and female gonads can be observed when IOS attains a minimum length of 10 cm (TL). Males and females were equally distributed on an annual basis with some changes in the Male: Female (M:F) ratio on a monthly basis (Table 7) and comparable to earlier reports (Dhulkhed, 1968; Antony Raja, 1969a; Rohit and Bhat, 2003).

Table 7. Monthly sex ratio (Male: Female) of Indian oil sardine observed in the landings of different maritime states during 2007 - 2014.

Months	Karnataka	Kerala	Andhra Pradesh
January	1:1.10	1:1.15	1:1.30
February	1: 1.28	1:1.17	1:0.97
March	1:1.06	1:.86	1:2.38
April	1:1.06	1:1.08	NA
May	1:1.18	1:0.01	1:1.85
June	1:0.92	1:0.92	1:0.70
July	NA	1:1.32	1:1.38
August	1:0.86	1:1.12	1:1.43
September	1: 0.97	1:1.03	1:1.12
October	1:1.04	1:0.93	1:1.69
November	1:1.14	1:1.07	1:0.37
December	1:1.00	1:1.01	1:0.71
Annual	1:0.95	1:1.06	1:1.35

NA - Not Available

6.3.i. Maturity stages

The maturity stages of male and female gonads were classified as per the ICES scale and adopted with suitable modifications (Antony Raja, 1964) (Fig 37). The gonads were classified into seven stages where stage I and II were grouped as immature, III & IV as maturing, V and VI as mature and VII (a & b) as partially and fully spent stages. Spent recovery stage (IIb) is somewhat similar to stage II but the ovaries are dark red or brownish, with a flattened appearance and oviducts much wider and shorter. Usually the total length of

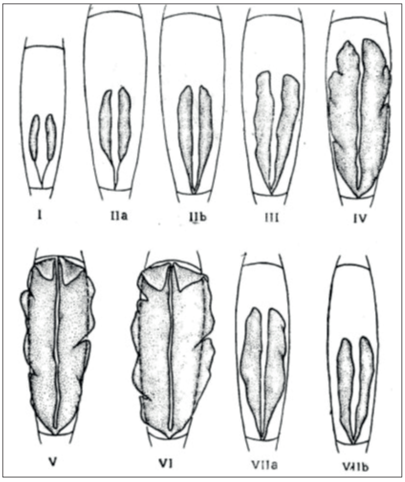


Fig.37. Diagrammatic representation of different maturity stages (adopted from Antony Raja, 1964)

these fishes measures above L_m. All stages of maturity were observed in the collections made during the present study. Photographs of immature (Stages I & II), maturing (stages III & IV), mature (stage V), spent (stages VII a & VIIb) are given in Fig.38 and hydrated egg (stage VI) in Fig.39.

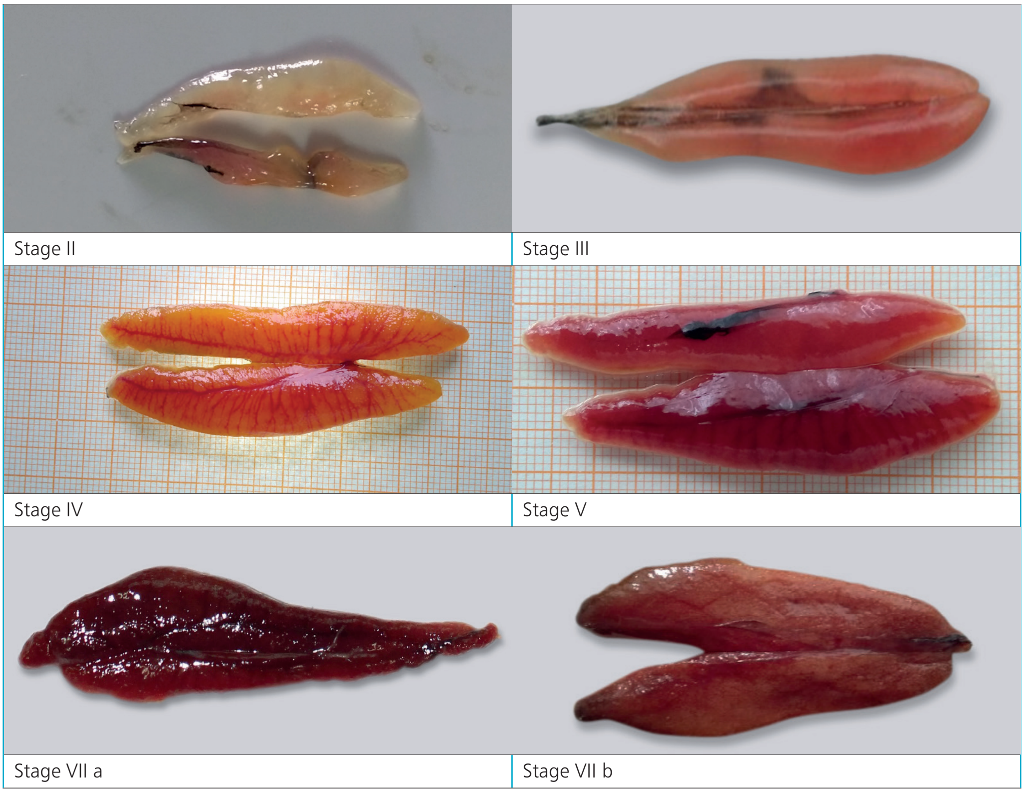
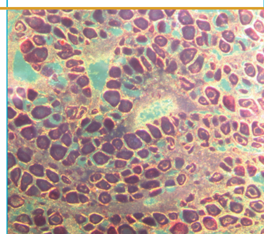
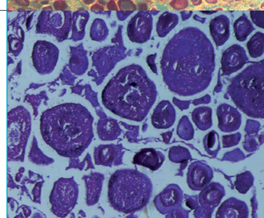
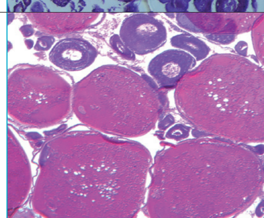
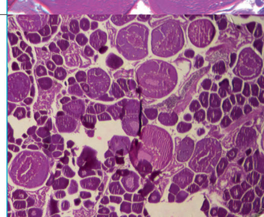
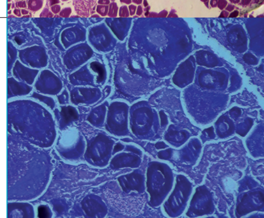


Fig.38. Maturity stages in female gonads of Indian oil sardine

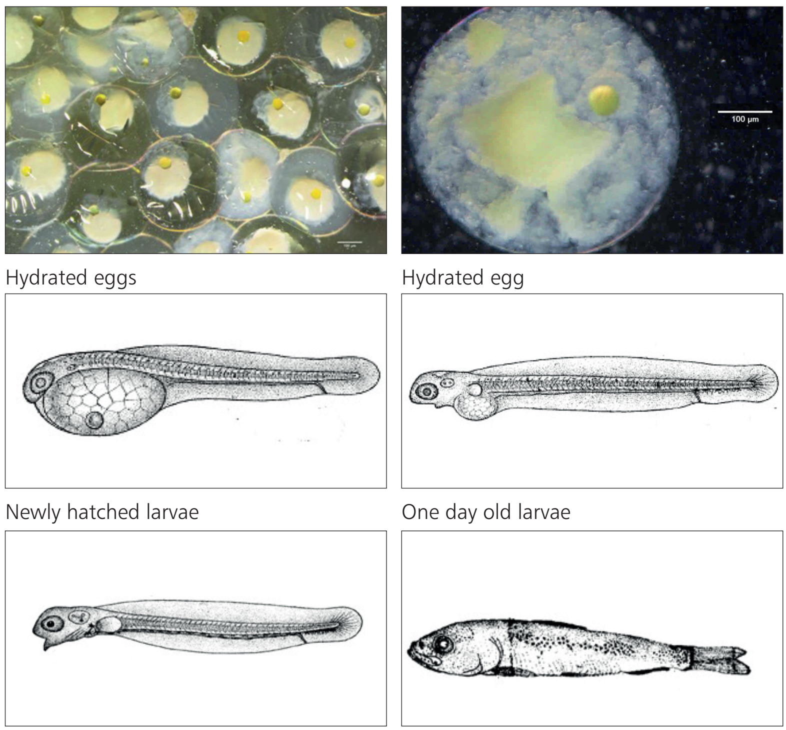
Different stages of female gonad were subjected to histological analysis and the results presented in Table 8.

Table 8. Macroscopic and microscopic features of female gonads

Gonad stage	Histology	Description
Immature (Stage I Stage II)		Ovaries soft, cylindrical and translucent, pink coloured and smooth with no blood vessels. Oviduct is long and transparent with ovarian bodies that look like detached stubs, which progressively grow longer, and the length of the oviducts reduce. Transparent ova cannot be easily recognised. Oocytes in early stages of development (Perinucleolus stage) with large nucleus; several nucleoli with densely staining cytoplasm and no lipid droplets (pre-vitellogenic phase) present.
Maturing (Stage III Stage IV)		Developing ovary with oocytes showing small lipid granules in the cytoplasm, yolk granules gradually increased and became densely packed. Some of the lipid droplets have coalesced to form a large oil globule (migratory nucleus stage).
Matured/ Ripe (Stage V Stage VI)		The fusion of lipid droplets and coalescence of yolk globules to form yolk plates results in translucent, golden coloured ova characterised as a spawning ovary with hydrated (HYD) oocytes. Imminent spawning indicated in gonads with presence of ripe, transparent, sago like eggs.
Partially Spent (Stage VII a)		Partially spent, post spawn ovary showing hydrated oocytes, Post-ovulatory follicles (POF) and pre-vitellogenic oocyte pool.
Fully spent (Stage VII b)		Spent ovary with old POF and pre-vitellogenic oocytes. Ovary has a typical collapsed, flabby and dark red coloured appearance with few eggs inside.

6.3.ii. Spawning and larval stages

A few reports on the spawning grounds of IOS are available. Possible spawning grounds have been delineated based on occurrence of oozing spawners or planktonic eggs off Quilandy (Devanesan, 1943), Tanur-Tellicherry belt (Nair, 1959, 1973), Kasaragod and Cochin (Anon., 1976) and Vizhinjam (Lazarus, 1985). The fully ripe eggs are transparent with a diameter of 1 - 1.2 mm with a single spherical yellow oil globule of about 0.1mm diameter (Nair, 1959). Ripe eggs of IOS collected off Kochi during the present study period are given in Fig.39. The larval stages of IOS have been described (Nair, 1973; Anon., 1976) and are reproduced below (Fig.39). According to these descriptions, mouth is well formed by day 2 while in a 3-day-old larva, complete absorption of yolk is seen. This period of total consumption of yolk coincides with the ‘critical first feeding’ necessary to ensure the survival of larvae (Hjort, 1914).The smallest size recruited to the fishery is around 6 cm (TL) size (Fig.40).



Hydrated eggs | Hydrated egg

Newly hatched larvae | One day old larvae

Two day old larvae | Juvenile 38 mm TL

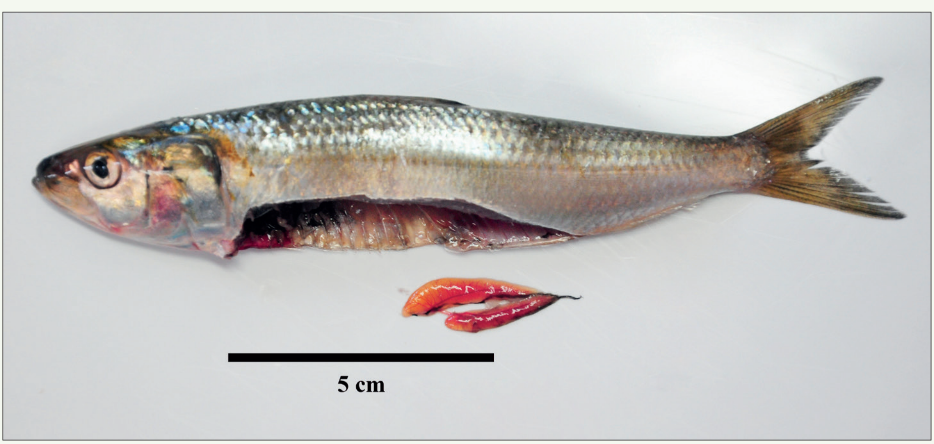
Fig.39. Hydrated eggs and larval stages of Indian oil sardine (Source: Nair, 1973, Anon., 1976 & Lazarus, 1985)

Fig.40. Juvenile Indian oil sardine (6.5 cm) collected from ring seine at Kochi

Disruption in spawning and atresia of ovary

During 2014 delayed maturity of gonads was observed in samples collected off Kochi and fishes as large as 170 mm had immature/early maturity stages. Most of the fishes had empty stomach. Spawners were not observed during frequent sampling at fish landing centres during 2015, which was corroborated by fishermen surveys indicating serious retardation of normal spawning and reduced recruitment. Gonads sampled during 2014 - 2015 indicated some pertubations in the normal spawning. It was concluded that this delayed maturation and poor feed conditions were due to impact of El Niño that induced unfavorable environmental conditions (See Annexure V).

Antony Raja (1964) indicated July-September as the peak spawning period which occasionally may be advanced or prolonged by a month. Breeding time in fishes is cued to favorable environmental factors that will enhance larval survival by ensuring a favorable food supply to the newly hatched larva. Photoperiod, temperature and seasonal rainfall are considered as important environmental drivers which are transduced into the endocrine processes, thereby regulating reproductive cycles in fish and IOS in particular (Antony Raja, 1972; Lam, 1983; Pankhurst and Porter, 2003). Wind and current patterns are important factors that ensure that the larvae are retained within the 'optimal recruitment window'(Longhurst and Wooster, 1990). Physiological setback in the spawning rhythm due to unfavourable environmental conditions, primarily failure of monsoon has been reported to cause atretic ovaries. In this condition, the ovaries have ruptured ova and vascular hypertrophy with flabby darkish red/brownish colour and a typical bimodal distribution of oocytes. In such conditions, only a certain portion of the ovaries is affected and what exactly triggers this is only a portion of the fishes is not clear (Antony Raja, 1964). Insulin like growth factor I (IGFI) is an important component of the complex system driving growth and reproduction in fishes. The synthesis and release of IGFI is stimulated by the growth hormone (GH) produced in the anterior pituitary gland and forms the GH - IGFI axis in fishes, controlling reproduction. This is affected by environmental factors (food availability, temperature, photoperiod and salinity) and can impair many physiological processes in fish including reproduction (Reinecke, 2010). Fluctuations in chlorophyll biomass due to precipitation induced river run-off variations which impact the fisheries of planktivorous fishes like sardines have also been reported (Abdellaoui *et al.*, 2017). Similar environmental cues prevailing in the coastal waters could have led to delayed maturation and spawning failure during the peak spawning period in 2014 and 2015.



An adult Indian Oil Sardine (170 mm TL) with immature gonads (IIa) showing signs of delayed maturation

6.3.iii. Length at first maturity

Length at first maturity (Lm) is the length at which 50% of the fishes of a particular species attain maturity and qualify to spawn. It is an important parameter influencing fecundity and resilience of fish populations (Zachariah *et al.*, 2016). In the present publication, fishes with gonads in stage III and above were considered for determining L_m. Samples collected from different States were pooled and L_m was estimated using the Logistic curve (King, 1995). The estimated L_m was 147 mm (Fig.41). Earlier, Hornell and Nayudu (1924) and Devanesan (1943) reported the size at first maturity for IOS as 150 mm while Bensam (1968) estimated it as 135 - 145 mm. In general, length range between 120 - 169 mm has been recorded as L_m by various investigators (Antony Raja, 1964; Dhulkhed, 1964, 1968; Radhakrishnan, 1965; Annigeri, 1969; Balan, 1971; Kumar and Balasubramanian, 1989; Devaraj *et al.*, 1997; Rohit and Bhat, 2003; Nair *et al.*, 2016).

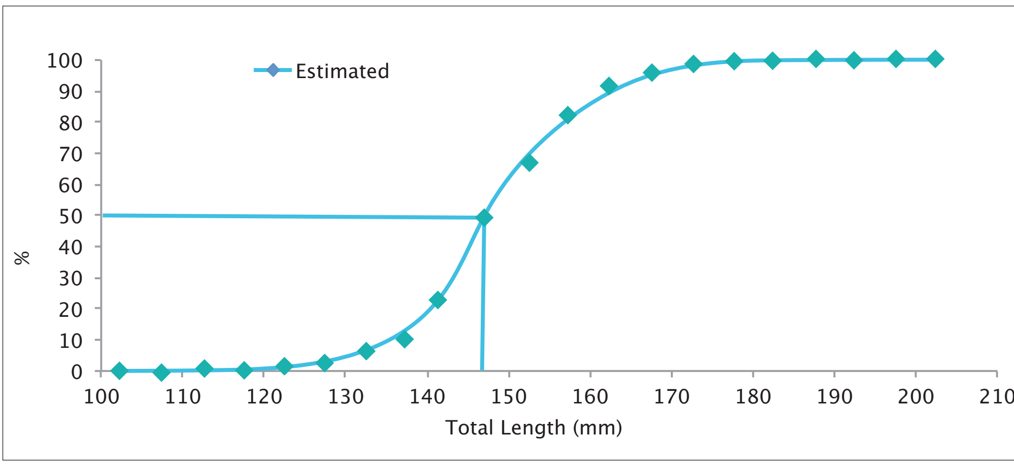


Fig.41. Length at first maturity of Indian oil sardine

Size range and monthly mean size of IOS along the west coast (Table 4) indicated a protracted spawning and recruitment periods. In Kerala, the annual mean size was close to or above L_m. Similarly, the mean size during most months was also above L_m.

6.3.iv. Fecundity

The absolute fecundity estimated per mature fish of size range 150 - 180 mm (TL) along west coast ranged from 12,631 to 75,000 eggs (Nair and Chidambaram, 1951; Nair, 1959; Antony Raja, 1972). Antony Raja (1971) found very poor relationship of either length or weight of IOS with fecundity. However, he recorded higher values of fecundity in two-year-old fishes as compared to younger fishes. In a series of observations for the period 1960 - 1965, Antony Raja (1972) recorded absolute fecundity values ranging from 17,950 to 45,077.

Deshmukh (2010) estimated the fecundity of IOS ranging from 45,000 to 75,000. Abdussamad *et al.* (2010) estimated the absolute fecundity of IOS collected from Tuticorin in Tamil Nadu as 58,950. During the present study the fecundity ranged from 60,807 to over one lakh (1,10,160) in the samples collected from the southwest coast (Table 9). However, it was only around 45,000 during the stock resuscitation process in 1998 following the population crash in 1994 (CMFRI, 2005). The fecundity of IOS estimated for samples collected during 2014 from Kochi was low ranging from 11,000 to 14,000 as against an average of 37,000 - 47,000 recorded during the earlier years.

Table 9. Absolute fecundity of Indian oil sardine

Year	Karnataka		Kerala	
	Range	Average	Range	Average
2011	21043 - 48898	33676	15600 - 51672	37179
2012	19213 - 96000	57606	14317 - 110160	45279
2013	37680 - 124485	61484	16988 - 99318	47305
2014	60807 - 94708	23423	11804 - 13420	12631

6.3.v. Spawning season

The spawning season of IOS was determined by analyzing the monthly distribution of gonad maturity stages and values of the Gonado Somatic Index (GSI). Along the southwest coast, mature and spent gonads were observed throughout the year indicating year round spawning. The peak spawning coincided with the southwest monsoon (June-August) (Annexure V). A higher GSI was observed during June-July (Fig.42). Along the east coast, peak spawning period of IOS was October-November. Prolonged spawning season is typical of small pelagics living in a highly volatile tropical ecosystem and the "bet hedging" strategy helps to maximize the chances of larval survival by providing an optimal recruitment window (Cury and Roy, 1989; Lambert *et al.*, 2003). The protracted spawning season of IOS and intense activity during June to September has been reported along southwest coast of India by several earlier workers (Hornell, 1910; Hornell and Nayudu, 1924; Devanesan, 1943; Devanesan and Chidambaram, 1953; Sekharan and Dhulkhed, 1963, 1968; Antony Raja, 1972; Balan and Abdul Nizar, 1988; Prabhu and Dhulkhed, 1967; Jayaprakash and Pillai, 2000; Rohit and Bhat, 2003)

Seasonal occurrence of adults and immature fishes in the fishery was analysed for the period 2001 - 2015 to understand changes if any in seasonal spawning activity of IOS. Though, shifts in spawning seasons in fishes such as threadfin breams due to the impact of warming of sea have been reported, such changes were not observed in the case of IOS along the southwest coast. From the data analyzed during the present study, it appears that the main spawning activity is influenced by rain and cooler temperature but apparently the stability of the period of occurrence and onset of the southwest monsoon largely negated any effect of higher SST trends. Changes in hydro-meteorological characters such as rainfall/drought affect the river runoff volumes and can change the seawater temperature and phytoplankton biomass in the sea (Abdellaoui *et al.*, 2017; Prasanna Kumar *et al.*, 2010) which can affect predominantly phytoplankton feeding fishes such as IOS. The productivity of the coastal habitat, which is a major spawning and nursery ground for the IOS has an important bearing on ensuring that the spawners have adequate energy resources to start the gonad development process and the first hatched larvae have the preferred planktonic food items of desired quality and quantity (Antony Raja, 1969; Gopakumar, 1974).

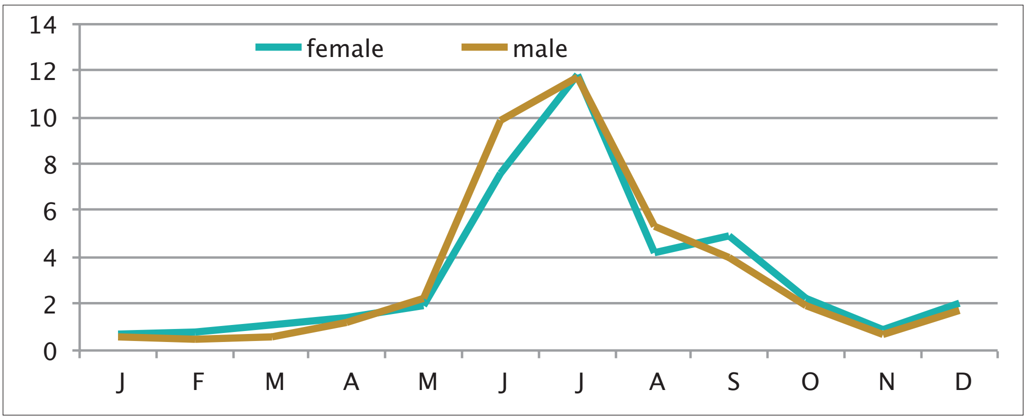


Fig.42. Plot of Gonado-Somatic Index of Indian oil sardine in Karnataka

6.3.vi. Juvenile composition

The life history milestones of the IOS are presented in Fig.43. IOS below 14 cm TL were considered as juveniles for the present study. The juvenile component

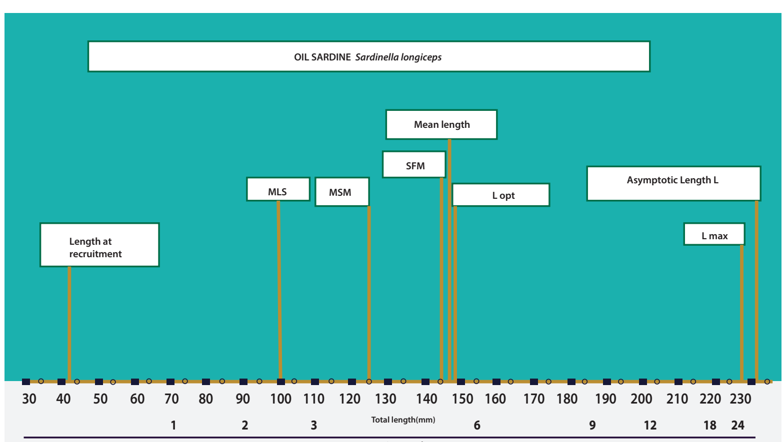


Fig.43. Diagrammatic presentation of the life history milestones in Indian oil sardine

MLS - Minimum Legal Size, MSM - Smallest Size at maturity, SFM - Size at first maturity, Lopt-Optimum length for capture was further subgrouped as fishes below 10 cm, the size fixed as Minimum Legal Size (MLS), fishes between 10.1 to 14 cm and fishes with TL >14.1 cm (adult). Juveniles (<14 cm) were observed during all months in the fishery with variations in percentage occurrence in different states (Table 10).

Table 10. Monthly composition of juveniles* (<14 cm) in the fishery

Months/States	Kerala	Karnataka	Goa	Gujarat	Tamil Nadu	Andhra Pradesh
January	60.0	53.4	73.0	1.0	8.2	22.4
February	96.3	56.0	78.3	1.2	1.2	52.8
March	82.9	58.7	69.7	2.0	0.2	61.1
April	-	17.0	72.3	0.2	0.3	80.1
May	70.6	30.8	42.7	1.6	2.7	82.5
June	0	20.2	4.7	-	19.2	65.3
July	12.1	-	-	-	21.1	85.7
August	62.1	5.9	4.4	-	17.8	38.8
September	93.5	41.8	16.8	-	7.2	78.0
October	97.9	49.9	14.5	0.2	5.1	85.1
November	42.3	74.5	28.7	1.7	7.3	35.7
December	42.1	68.8	84.5	0.0	9.6	73.3

* Percentage of estimated numbers landed

The annual contribution of juveniles in the landings has declined considerably in recent years, predominantly due to the awareness created to the fishermen on causes leading to growth overfishing as well as introduction of regulations like MLS (Mohamed *et al.*, 2014; Rohit *et al.*, 2016; Sivadas *et al.*, 2017). The proportion of fishes with TL <10 cm during 2010 - 2014 ranged from negligible numbers in 2015 to 16.6% in 2014. Proportion of juveniles between 10.1 to 14 cm ranged from 48.8% in 2010 to 65.3% in 2014 (Fig.44). This indicated that there was considerable fishing pressure on the new recruits, before they

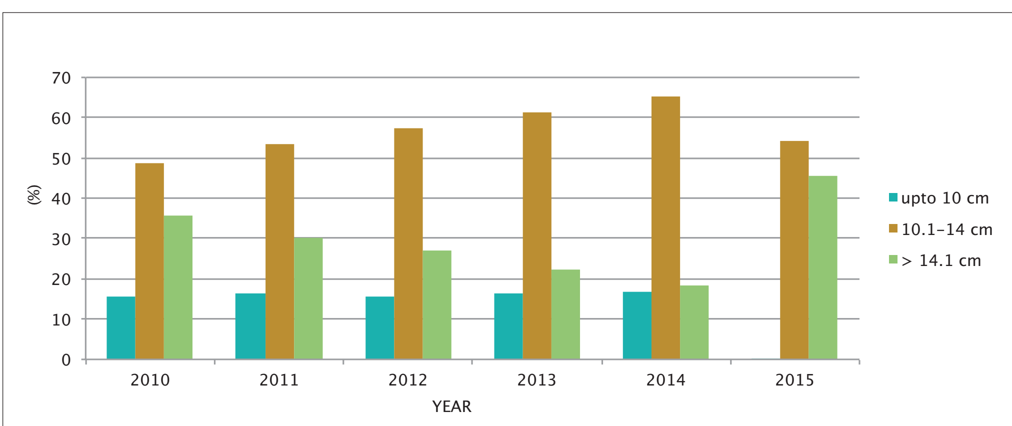


Fig.44. Composition (%) of three size categories of Indian oil sardine landed along southwest coast of India during 2000 - 2015.

attain sexual maturity at around 15 cm. Fishing of very small juveniles (<10cm) rampant during the early 2000 has reduced significantly in the recent years.

However, it may be necessary to introduce a higher MLS with a seasonal effect whenever there are signs of a strong decline in the abundance in the fishing grounds caused by unfavorable environmental conditions. Such measures when implemented should preferably be when fish of < 10 cm are recruited to the fishery in large numbers (August-September) so as to increase the number of fish surviving upto their first spawning (Hill,1990). The annual fishery of IOS is dependent on the recruits of the same year (0 year class) and studies have indicated that the brood recruited during this period shows the fastest growth rate and is responsible for the success of the fishery in that particular year (Antony Raja, 1970; Yohannan, 1979). This may be a more acceptable alternative to the stakeholders rather than the imposition of a total ban on the fishery that was enforced by the British Government to deal with the serious collapse of the IOS fishery during 1940s (Nair, 1952).

7. Stock assessment

Stock assessment of IOS was made using the length based FiSAT software and CMSY method.

7.1. Age and growth

Growth of IOS was studied by tracing progression of mode in the population using length frequency (LF) data and by reading growth inscriptions on otoliths (Fig.45). Length frequency data from all maritime states for the period 2010 - 2015 were collected and analyzed. The von Bertalanffy growth parameters L_∞, K (annual) and t_0 estimated from pooled length frequency data using FiSAT software were 23.43 cm, 1.57 and - 0.11 year respectively. The growth equation showed that the fish grows fast and attains 19.3 and 22.7 cm by the end of first and second year respectively. Length at age data developed from otolith analysis was comparable with the length-based method but indicated much faster growth during the initial months than the above estimates (Table 11 and Fig.46). The annual K was higher at 1.76 and fish attained 20.1 cm and 22.9 cm respectively at the end of first and second year (Table 12).

Table: 11 Growth of Indian oil sardine based on length frequency and otolith inscriptions

Age (month)	Estimated TL(cm) based on otolith rings	Estimated TL(cm) based on LF analysis
1	6.8	6.1
2	9.0	8.3
3	11.0	10.1
6	15.4	14.4
9	18.3	17.4
12	20.1	19.3
15	21.3	20.7
18	22.1	21.6
21	22.5	22.2
24	22.9	22.6
30	23.2	23.0
36	23.4	23.3

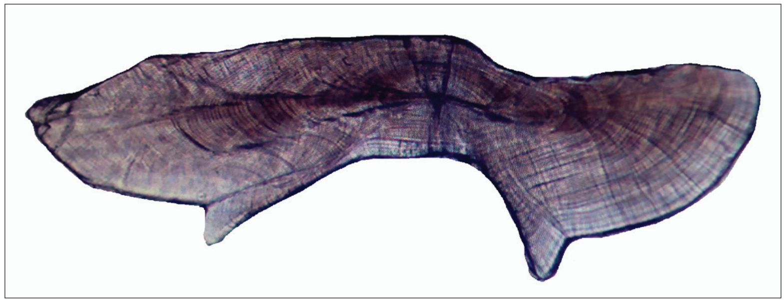


Fig.45. Cross section of Indian oil sardine otolith showing growth rings

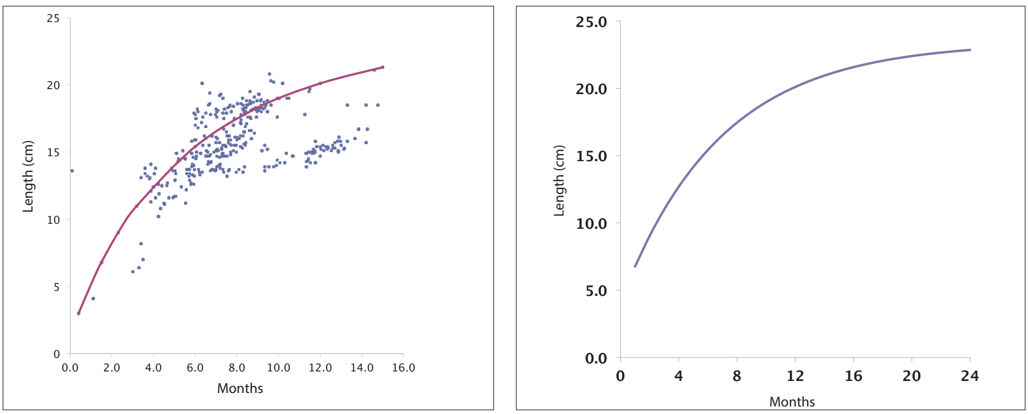


Fig.46. Growth curves of Indian oil sardine (a. otolith based age at length data; b. LF based modal progression)

Table 12. Growth parameters of Indian oil sardine

Growth parameters	Modal progression	Otolith
L_∞	23.43	23.43
K	1.57	1.76
t_0	- 0.11	- 0.11
M	1.339	1.339
a	0.013	0.013
b	2.896	2.896
M/K	0.853*	0.761

* used in stock assessment

Antony Raja (1970) indicated rapid growth in length during the first two months, when about 70% of first year growth is attained. According to him the fish reaches a length of 60 - 65 mm in the first month and 95 - 110, 110 - 125, 125 - 140 and 150 - 160 mm at the end of 2, 3, 6 and 12 months respectively and attains maturity by the end of first year. Yohannan (1998) observed a period of fast growth rate during June-August when the water is highly productive due to plankton blooms caused by upwelling. Antony Raja (1970) concluded that differential growth rates prevail among the broods during the spawning peak June-August along the southwest coast of India. Fastest growth rates occurred during the first three months and the first brood attains the size of 140 mm within 6 months while the later broods take longer time. The growth recorded in different locations are summarised in Table 13. Growth rates are often density dependent and fastest growth rates have been recorded during 1963 - 64 and lowest during 1961 - 62 and 1964 - 65 (Antony Raja, 1970). It is apparent that growth estimates are higher in recent years when the stock biomass has also declined considerably (Ganga *et al.*, 2017). Further increase in SST could have resulted in faster growth rates by altering metabolism in the fish.

Table 13. Estimated growth of Indian oil sardine

L_∞ (mm)	K(Annual)	Age (year)			Location & Reference
		0.5	1	2	
221	0.75	117	168	180	West Coast, Annigeri *et al.*, 1992
200	2.1	130	175	200	Malabar Coast, Yohannan, 1998
228	0.90		136	191	Karnataka Coast, Rohit and Bhat, 2003
234	1.57	144	193	226	Indian Coast, Present study

7.2. Recruitment pattern

The occurred recruitment defined as the smallest size recorded in the fishery indicated that recruitment was round the year with peaks (as percent of total fish recruited over an annual cycle) during certain months. Along the west coast recruitment occurred mainly during May-August and along east coast it was during February-April. Maximum recruitment (59 - 66%) along southwest coast (Kerala, Karnataka and Goa) occurred during May to August. On the northwest coast, along Maharashtra and Gujarat Coasts it was during May-August and July-September respectively. Along the northeast coast (Andhra Pradesh and Tamil Nadu), it was during February-April (Table 14). Spawning and recruitment are cued to ensure maximum survival of the recruits provided favourable feeding conditions, a critical requirement for newly hatched larvae exists. Phytoplankton maxima occur during February-April followed by a secondary peak during November off Visakhapatnam (Ganapati and Murthy, 1955; Vijayakumaran *et al.*, 1996). Hornell and Nayudu (1924) and George (1953) reported that the phytoplankton maxima occurred during May-September off Calicut on the west coast. The periods of phytoplankton maxima along these areas synchronised with the peak IOS recruitment to the fishery.

Table 14. Monthly recruitment (%) pattern of Indian oil sardine along the Indian coast

Month	WC	EC	AP	TN	KL	KA	GO	MH	GJ
January	0	1.2	0.2	2.2	1.7	1.8	1.8	0.1	0.5
February	0.5	13.6	13.3	14	5.6	4.1	4.1	1.2	1.6
March	3.2	19.5	12.7	26.3	12.1	11.5	11.5	2.5	1.9
April	6.4	26.1	31.3	20.8	11.7	7.7	14.7	5.1	5.1
May	11.6	9.9	9	10.8	10.2	10.5	20.5	11.8	8.2
June	17.4	6.6	11.2	1.9	20.4	22.8	30.8	17.3	12.2
July	21.2	9.8	6.2	13.5	15.2	17.6	7.6	30.3	20.7
August	18.3	6.4	7.2	5.6	12	13.8	6.8	16.1	20.1
September	6.9	3.3	5.2	1.3	10.4	9.1	1.1	11	22.9
October	6.4	1.4	2.7	0.2	0.4	0.9	0.9	3.8	4.1
November	8.1	1.2	1	1.4	0.3	0.2	0.2	0.8	2.6
December	0	1.1	0	2.2	0	0	0	0	0

7.3. Mortality and exploitation rates

Mortality occurs due to natural causes and fishing. Natural and fishing mortality were estimated using Pauly's empirical formula and the catch curve in FiSAT. Natural mortality (M) was estimated as 1.34 (Table 15). The fishing mortality (F) and total mortality (Z) along the Indian coast during 2010 - 2015 was 5.371 and 6.71 respectively. The mortality estimates showed that major loss from the stock was due to fishing and it varied considerably between east and west coasts and between maritime states. Mean F varied between 2.27 and 8.4 between maritime states. It was 3.72 along the east coast and 5.79 along west coast. The high fishing mortality value for the west coast is due to intensive and targeted fishing for the species. It was the highest in Goa followed by Tamil Nadu, Karnataka, Maharashtra and the lowest in Gujarat and Andhra Pradesh.

7.4. Yield per recruit

The relative yield/recruit analysis showed that the optimum Exploitation ratio (E_{opt}) in Indian waters was 0.70 and maximum Exploitation ratio (E_{max}) possible without affecting the stock was 0.782 (Fig.47). The current Exploitation ratio (E_{curr}) for the Indian coast is 0.80, which is higher than E_{max} (Table 15). While the Exploitation rate along the east coast was, lower (0.74) than E_{max}, it was higher than E_{opt}. However, along west coast it was 0.81, which is much higher than E_{max}.

The E_{curr} indicated that the resource on a national level is being exploited at level higher than E_{max}. The situation is same in all the maritime states except Gujarat on west coast and along Tamil Nadu, on east coast indicating heavy pressure on the resources and a need for lowering the fishing effort. Along the coasts of Andhra Pradesh and Gujarat, it was lower than E_{opt} which is ideal for the stock and offers scope for increasing the production through increased effort. However,

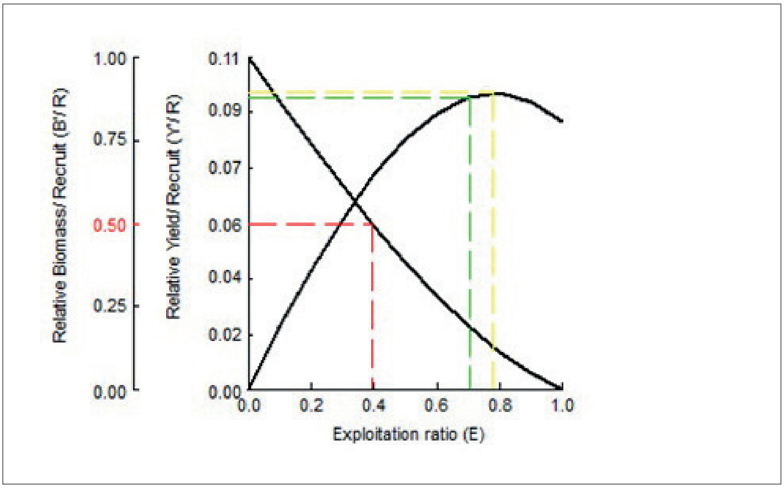


Fig. 47. Exploitation ratio and relative yield/recruit curve of Indian oil sardine

the IOS is short lived, highly fecund with medium resilience and maintaining fishing rates at high levels will adversely affect the long term sustainability of the stock (Zacharia *et al.*, 2016). During times of sudden environmental eventualities like El Niño it would take long time for depleted fish stocks to revive and would adversely affect the livelihoods of fishermen.

Table 15. Mortality and Exploitation ratio of Indian oil sardine

Area	F	Z	E_{curr}
India	5.371	6.71	0.800
West coast	5.791	7.13	0.812
East coast	3.721	5.06	0.735
Andhra Pradesh	2.701	4.04	0.669
Tamil Nadu	5.921	7.26	0.816
Kerala	5.101	6.44	0.792
Karnataka	5.701	7.04	0.810
Goa	8.421	9.76	0.863
Maharashtra	5.231	6.57	0.796
Gujarat	2.271	3.61	0.629

M* value is 1.339

7.5. Virtual Population Analysis

Virtual Population Analysis (VPA) showed that fishing mortality in the population due to fishing starts when IOS attained a TL of 60 mm. However, F remained low upto 100 mm. The F was moderate in the IOS population with a TL ranging between 100 - 150 mm size group and high for fishes over 150 mm indicating that fishing targeted large sized adults (Fig.49). The moderately high fishing mortality among 100 - 150 mm IOS indicated that they were also under considerable fishing pressure, whereas small juveniles < 100 mm were not targeted.

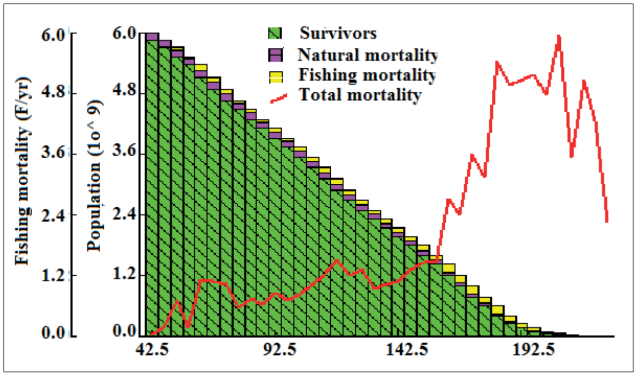


Fig.48. Size wise mortality rates of Indian oil sardine

7.5.i. Probability of capture

Size at capture is an indicator of the intensity of fishing pressure on the stock. Estimates of probability of capture indicated that size at first capture (L_{50}) is lower than the size at maturity (147 mm) along the Indian coast except in Maharashtra and Gujarat (Table 16). Therefore, the '0' year class mainly supports the fishery in most states and recruitment into the fishery in these states would determine the fishery success during the year.

Table 16. Size at capture of Indian oil sardine along the Indian Coast

Area	L_{25}	L_{50}	L_{75}	L_c/L_∞
India	114	133	142	0.61
West coast	108	127	136	0.54
East coast	126	142	156	0.58
Andhra Pradesh	102	132	162	0.56
Tamil Nadu	102	109	116	0.42
Kerala	104	118	130	0.50
Karnataka	112	125	130	0.53
Goa	117	120	123	0.51
Maharashtra	155	161	167	0.69
Gujarat	178	189	197	0.81

7.5.ii. Lcohort analysis

The annual stock, spawning biomass and recruitment numbers were estimated using the Lcohort module in FiSAT software. The spawning stock biomass (SSB) indirectly indicates the sustainability of an exploited fish stock and is used as a biological reference point. The SSB estimates varied between 30.7 and 67% (of total stock biomass) in the major IOS fishing states (Table 17). At national level it was 49.8%, for west coast, it was 49% and for east coast it was 50.2%. It was lowest in Goa (30.7%) followed by Tamil Nadu (35.1%) and Karnataka (40.2%). An SSB of 20% is considered as a normal precautionary standard for most species to sustain the stock (Pope, 1983; Goodyear, 1993; Gabriel *et al.*, 1989; Mace and Sissenwine 1993). The present estimates suggest that though fishing pressure is high in most states, SSB is sufficiently high to support stock replenishment.

Table 17. Average annual stock status of Indian oil sardine for the period 2010 - 2015

Area	Standing stock (t)	Spawning stock (t)	Recruitment (in '000 numbers)	Yield (t)	SSB (%)
India	276102	137509	41673	598289	49.8
West Coast	206301	101029	32220	457165	49.0
East Coast	66119	33191	9850	141124	50.2
Andhra Pradesh	6507	4362	823	9898	67.0
Tamil Nadu	43581	15284	9814	126034	35.1
Kerala	86601	39065	18816	276632	45.1
Karnataka	35129	14111	7456	104408	40.2
Goa	13933	4281	1054	47695	30.7
Maharashtra	8362	4059	878	21539	48.5
Gujarat	8086	8086	1248	6891	100.0
Other states/UT	-	-	-	5192	-

7.6. Maximum Sustainable Yield

The Maximum Sustainable Yield (MSY) for IOS fishery along the Indian coast was estimated using Thompson and Bell prediction model. The estimated MSY for the Indian Coast was 6,38,516 t. The west coast was more productive with a share of 76% (4,84,983 t) of the potential. Among the maritime states, Kerala was the most productive with a MSY share of 43.8 % (2,79,866 t), followed by Tamil Nadu and Karnataka with a share of 21.1 and 17% respectively (Table 18).

Table 18. Average yield and estimate of MSY for Indian oil sardine

Area	Average yield (t) 2010 - 2015	MSY (t)	% of National MSY
India	598289	638516	100.0
West Coast	457165	484983	76.0
East Coast	141124	153533	24.0
Andhra Pradesh	9898	10101	1.6
Tamil Nadu	126034	134414	21.1
Kerala	276632	279866	43.8
Karnataka	104408	108447	17.0
Goa	47695	50745	7.9
Maharashtra	21539	21619	3.4
Gujarat	6891	24306	3.8
Other states	5192	9018	1.4

Table 19. Estimated Biological Reference Points (BRPs) of Indian oil sardine

Area	E_{curr}	B_{curr}	B_{MSY}	E_{curr}/E_{MSY}*	B_{curr}/B_{MSY}
India	0.800	659744	809127	1.02	0.815
West Coast	0.812	532511	685287	1.04	0.777
East Coast	0.735	127233	123840	0.94	1.027
Andhra Pradesh	0.669	15507	8281	0.85	1.873
Tamil Nadu	0.816	83581	101272	1.04	0.825
Kerala	0.7926	348601	429265	1.01	0.812
Karnataka	0.810	127829	174526	1.04	0.732
Goa	0.863	23933	45556	1.10	0.525
Maharashtra	0.796	18362	29023	1.02	0.633
Gujarat	0.629	13786	6917	0.80	1.993

*E_{MSY} = 0.782

The results obtained from the Thompson and Bell analysis indicated that fishing pressure is high in most states with E_{curr}/E_{MSY} ratio higher than 1 and B_{curr}/B_{MSY} ratio lower than 1.

7.7. Stock status

The results of stock assessment are pictorially represented in Fig.49. On the X-axis, the plot represents the current biomass (B_{curr}) relative to biomass at MSY levels (B_{MSY}). The Y-axis represents the current exploitation rate (E_{curr}) relative to exploitation rate at MSY level (E_{MSY}). The plot gives a clear graphical indication of the status of the stock and offers a simple way in which managers can quickly infer if the stock is in "good" or "bad" shape, depending on the quadrant where the point referring to the country, coast or the maritime state falls. A value below 1.0 on the X-axis means that the biomass is exploited above desirable levels and the stock is overfished. On the other hand, a value above 1.0 on the Y-axis indicates fishing mortality is above desirable levels and that "overfishing is occurring" (Anon 2007, 2009).

The plotted result indicated that fishing pressure was high above the maximum limit along the west coast, whereas it was below the maximum limit along the east coast. Among the maritime states, the resource was optimally exploited only along Andhra Pradesh and Gujarat and in all other states; the fishery exceeded the optimum limit.

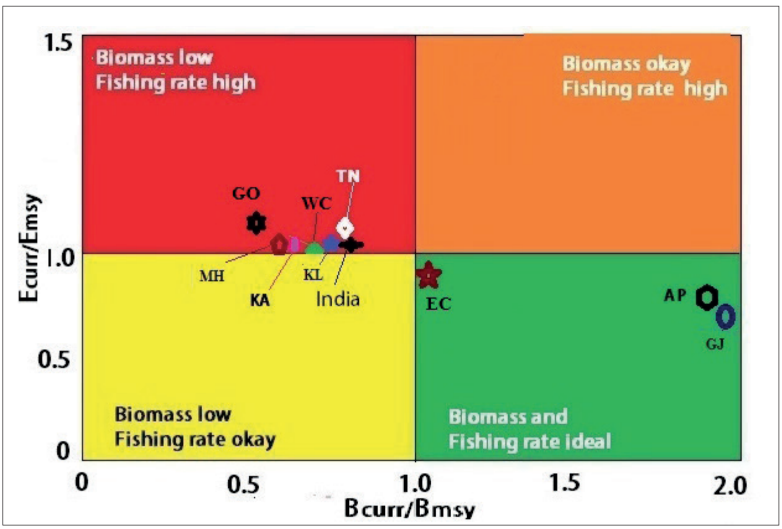


Fig. 49. Stock status of Indian oil sardine depicting the biomass and exploitation level

7.8. Catch-MSY

The Catch-MSY (CMSY) method (Martell and Froese 2013; Froese, 2017; Froese *et al.*, 2017) was applied to the IOS fishery along the southwest coast for the period 1995 - 2015 to validate the results on stock status obtained from Virtual Population Analysis. The CMSY results (Table 20) indicated that the MSY was around 2.55 lakh t (CI 2.3 - 2.9 lakh t) for the southwest coast, which broadly agreed with the estimates of MSY of 4.7 lakh t estimated for the entire west coast (including the northwest coast of Maharashtra and Gujarat) using the Thomson and Bell model (Table 18). Both results indicated high fishing pressure and declining biomass after the year 2000 (Fig.50). In 2015, the B/B_{MSY} had reached very low level of 0.534. This may be due to very high fishing mortality since 2000, during which the F/F_{MSY} was as high as 2.5 (Figs.51 and 52).

In Kerala, the over capacity of ring seines and targeted fishing for IOS almost throughout the year resulted in high exploitation levels during the later years, which could have contributed to growth overfishing. Fishing trips for IOS by the seine fleet is by choice, depending on market demand and availability of shoals. Fishermen abstain from fishing when market demand in general is low or when very young fish with only low market value is available in the fishing grounds. Fishermen in Kerala perceiving decreased abundance of sardine in the normal fishing grounds, targeted fishing for IOS declined considerably leading to a lowering of fishing pressure on the stock in 2015.

In Karnataka, the purse seine which is the main gear exploiting pelagic resources, two specific nets are operated, one targeting IOS with mesh size of 22 - 24 mm and the other targeting large pelagics with mesh size of 45 mm and above. The large meshed purse seines '*kotibalae*' are operated both during day and night. With '*kotibalae*' getting good landings of large pelagics and a higher price for the catch, more than 90% of the purse seine fishers use '*kotibalae*'. This has reduced targeted fishing pressure on IOS in these two states along the southwest coast (Fig.52). Therefore, if favourable environmental conditions return, recovery of the fishery is possible.

Table 20. Results of CMSY analysis for Indian oil sardine exploited off southwest coast of India

Metric	**Estimate**	**Confidence limits (95%)**
MSY ('000 t)	255	226 - 289
B_{MSY}('000 t)	1520	1211 - 1908
F_{msy}	0.168	0.143 - 0.198
B/B_{msy} (for 2015)	0.534	
F/F_{msy}(for 2015)	0.938	

The relatively high fishing pressure that the stock has been subjected to since 2009 which continued upto 2012 led to exploitation beyond the MSY levels during 2012. The demand for IOS for production of fishoil and fishmeal also induced fishers to continue targeted fishing of the IOS stock. Small pelagic fishes like sardines exhibit high variability in their annual population levels with high turnover rates, strong year classes followed by weak recruitment and *vice versa* (Antony Raja, 1973; Balan, 1984; Kawaski, 1991). The exploitation level is now declining as fishermen have temporarily reduced their fishing trips for catching IOS as they perceived reduced abundance in the normal fishing grounds. This reduction in fishing pressure may have to continue for another 2 - 3 years or until occurrence of favourable environmental conditions. Historically the landings have bounced back from around 40,000 t in 1994 to > 1 lakh t within a span of 2 years (1996). Ban on fishing to allow the IOS stock to recover has precedence with the regulations introduced by the British to tide over the severe failure of the IOS fishery during 1943, which was revoked after two years and has not been re-introduced since. A blanket ban on fishing can affect the livelihoods

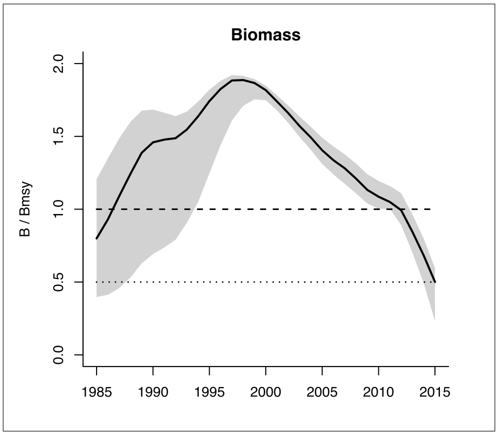


Fig.50. Biomass Reference Point (B/B_{MSY}) for Indian oil sardine along the southwest coast

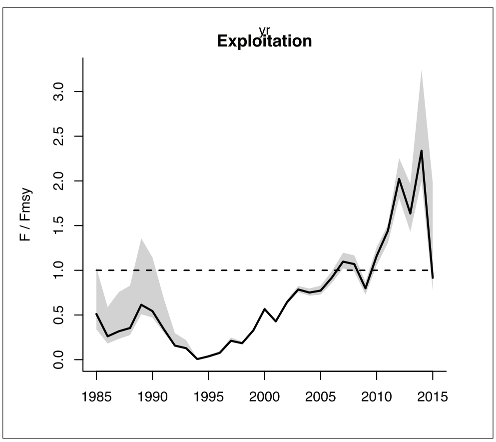


Fig.51. Exploitation Reference point (F/F_{MSY}) of Indian oil sardine ($F/F_{MSY}>1.0$= over fishing) along the southwest coast

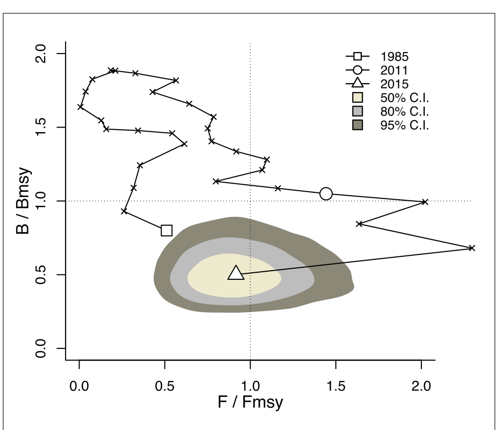


Fig.52. Reference points for biomass (B/B_{MSY}) and fishing levels (F/F_{MSY}) of Indian oil sardine on the southwest coast during 1985 - 2015

of several fishermen in a multi gear, seasonal type of fishing activities pursued by the coastal fishers for whom IOS is a highly valued fish. The effects of El Niño during 2014 on the ocean dynamics and weather disruptions have been documented. Environmental disruptions caused by El Niño are cyclic and will gradually fade (Dinesh *et al.*, 2016). Hence, a precautionary approach to the fishery is recommended with reduced fishing effort and adherence to regulations on avoiding fishing of juveniles, using recommended mesh size in the nets deployed and engine horsepower of crafts that can lower the fishing mortality rates and allow the fishery to rebuild quickly.

8. Morphotypes of Indian Oil Sardine

8.1. Morphological divergence

Three visible morphotypes of the IOS having the same meristic counts were recognized - 'normal' (Variant 1), 'lean' (Variant 2) and 'broad' (Variant 3 - Oman sardine) (Fig.53) from Indian and neighbouring coasts. Detailed analysis was carried out to find out whether the morphotypes of the IOS were significantly different. Morphometric measurements were subjected to truss analysis. The head length differed among the three morphotypes (Table 21). In the normal sardine the head length is more (31.9 ± 2.8) and in the case of the Oman sardine, the body depth is higher (24.2 ± 0.4). Reasons ranging from ecological effects, poor food availability and the IOS fishery possibly comprising of different stocks, have been attributed for differences in morphometric characters observed by earlier workers (Antony Raja, 1969; Antony Raja and Hiyama, 1969).

Table 21. Morphometric measurements of Indian oil sardine

Measurement	Normal	Oman	Lean
Total length (TL) in mm	162 ± 19.2	221.4 ± 5.2	156 ± 1.1
Standard length (SL) in mm	138 ± 17.3	195.6 ± 5.2	130 ± 0.8
Body depth as % SL (mm)	22.2 ± 1.2	24.2 ± 0.4	20.9 ± 0.5
Head length (HL) as % SL	31.9 ± 2.8	30.5 ± 0.5	28.8 ± 0.9
Snout length (as % HL)	25.8 ± 1.5	26.8 ± 1.5	24.7 ± 0.9
Eye diameter (as % HL)	18.2 ± 1.4	18.8 ± 1.1	20.2 ± 1.7

8.1.i. Truss analysis

The truss morphometrics study was done on 875 IOS samples collected from major fish landing centres at seven locations *viz*., Visakhapatnam, Chennai, Thoothukudi on the east coast and Kozhikode, Kochi (Kerala), Mangalore and Mumbai (Table 22) along the west coast to conclude if there was any significant morphological divergence in the IOS morphotypes contributing to the fishery. Samples were also collected from fish markets where the IOS sourced from Oman was being sold (Prakasan *et al.*, 2015).

Variant 1

Variant 2

Variant 3

Fig. 53. Morphotypes of Indian oil sardine

Table 22. Sampling locations and sample size for truss analysis

Locality	Numbers sampled
Visakhapatnam	116
Chennai	20
Tuticorin	171
Mangalore	247
Mumbai	110
Kochi, Kozhikodu (Kerala)	179
Oman	32
Total	875

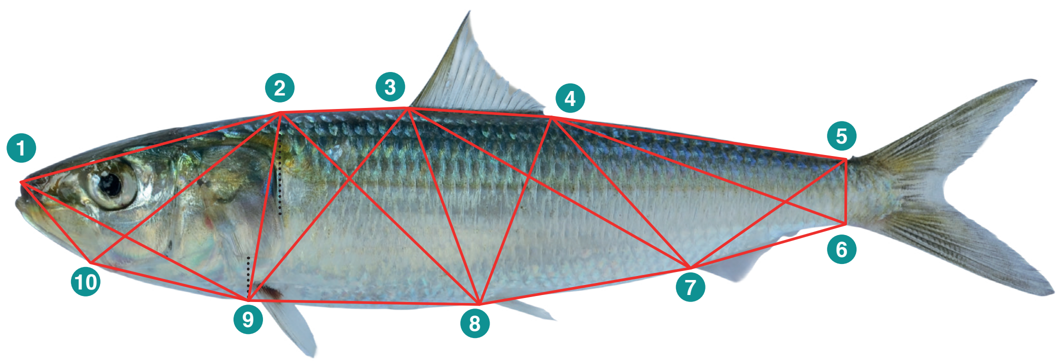


Fig.54. Truss landmarks and distances recorded

Based on the 10 landmarks, distances were measured (Table 23, Fig.54). The data were log-transformed to reduce the correlations of the means and variances (Sokal and Rohlf, 1969). Statistical analysis of the Truss landmark measurements (Table 24) were carried out in two stages. In the first stage, PCA was performed on the entire data set pooling samples from different locations. PC 1 was a measure of general size while PC II contains information on shape as well as size. In order to obtain a shape component free from the effect of size, the algorithm of Humphries *et al.* (1981) was deployed. The size-free shape component (sheared PC II) estimated for each samples were plotted against PC I to get the stock discrimination characters (Fig.55). Based on the important characters identified, samples pooled across all maritime states in India were subject to Discriminant Analysis.

Table 23. Truss landmarks and distances recorded

Landmark number	Definition
1	Tip of upper snout
2	Operculum posteriormost edge
3	Origin of dorsal fin
4	Insertion of dorsal fin
5	Point of origin of caudal fin (upper lobe)
6	Point of origin of caudal fin (lower lobe)
7	Origin anal fin
8	Origin pelvic fin
9	Origin pectoral fin
10	Anterior border of eye

Table 24. Landmarks and distance measures with PC values derived for Indian oil sardine

Landmarks	Description	PC I	PC II	Sheared PC II	Sheared PC III
P1 - P2	Head length	- 0.1760	- 0.0024	0.0996	0.0087
P1 - P10	Snout length	- 0.2091	0.9043	0.9282	0.1597
P1 - P9	Head length	- 0.1881	0.1722	0.2625	0.0820
P2 - P10	Head length	- 0.1894	- 0.0783	0.0396	0.0051
P9 - P10	Head length	- 0.1789	- 0.1620	- 0.0411	0.0517
P2 - P3	Pre dorsal fin region	- 0.2487	0.0208	0.1624	0.2044
P2 - P9	Body depth	- 0.2170	- 0.0771	0.0567	0.0451
P2 - P8	Body depth	- 0.2314	- 0.0692	0.0720	0.1422
P8 - P9	Pre dorsal fin	- 0.2331	- 0.0356	0.1031	0.1064
P3 - P8	Body depth	- 0.2365	- 0.1554	- 0.0019	0.0994
P3 - P9	Body depth	- 0.2383	- 0.0554	0.0884	0.0817
P3 - P4	Dorsal fin base	- 0.2158	- 0.0561	0.0747	- 0.0144
P3 - P7	Body depth	- 0.2339	- 0.0269	0.1113	- 0.0507
P8 - P7	Pre anal fin region	- 0.2487	0.1207	0.2516	- 0.2616
P4 - P8	Body depth	- 0.2500	- 0.1566	0.0047	0.0752
P4 - P7	Body depth	- 0.2420	- 0.0608	0.0857	0.0029
P4 - P5	Body depth	- 0.2240	- 0.0354	0.0979	0.1334
P4 - P6	Caudal length	- 0.2205	- 0.0572	0.0764	0.1289
P5 - P7	Caudal depth	- 0.1987	- 0.0754	0.0476	0.3087
P6 - P7	Caudal length	- 0.1919	- 0.1372	- 0.0115	0.3559
P5 - P6	Caudal depth	- 0.1825	0.0694	0.1675	0.1251

PCA of 875 adults (Variant 1 - 414; Variant 2 - 429; Variant 3 - 32) revealed that 81% of the total variation in the multivariate data was explained by the first three principal components mentioned in

Table 24. All the first factor loadings (PC I) were negative and nearly of the same magnitude, indicating that all the 21 characters contributed equally to the total variation. Approximately 77% of the total variance was explained along the first two principal component axes, which alone were taken into consideration to identify morphometric characters of importance. PC II highly correlated with snout length. Head length (P1 - P9) and body depth (abdominal region, P8 - P7) also were indicators of shape difference showing higher values. When grouping of IOS was done, samples clustered together in the centre as a homogenous group. Only the IOS from Oman available in Indian markets clustered separately. A few numbers from Mumbai and Mangalore grouped with the samples collected from Oman. The results of Truss analysis did not indicate a significant morphological divergence among the IOS samples from the various centres. The Oman sardine (variant 3), which has a higher body depth, clustered at one end (Fig.55).

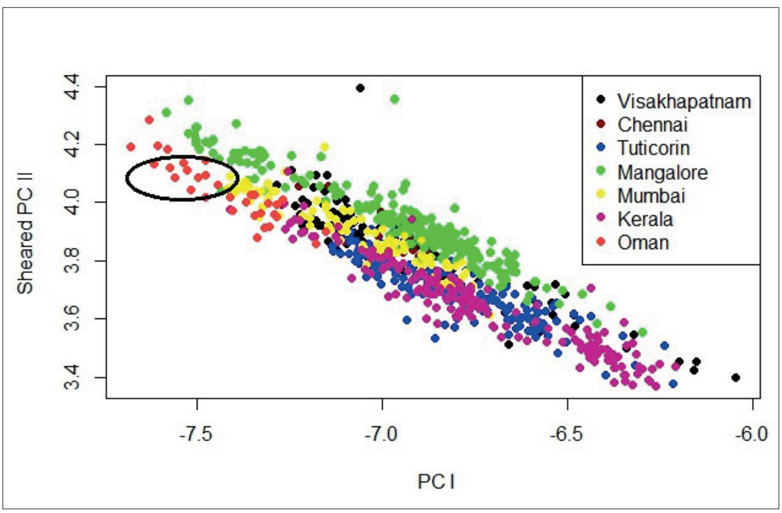


Fig.55. Truss based stock discrimination of different morphotypes of Indian oil sardine from different states

Hornell and Nayudu (1924) based on morphometric measurements of head and body length, believed that different races were absent in Malabar and South Kanara Coast. On the other hand, Devanesan and Chidambaram (1943) suggested the presence of three distinct races along the west coast of India, based on the head and total length ratio as well as pectoral fin rays count of IOS. Nair and Chidambaram (1951) too expressed doubts on the IOS fishery being supported by a single stock and suggested further careful examination. The morphometric characters of IOS exhibit a general level of variability as discerened from various taxonomic descriptions but certain characters such as ratio of head length, height and girth to body length and the vertebral count show stability (Antony Raja, 1969; Antony Raja and Hiyama,1969). Annigeri (1978) inferred different sub-populations of IOS along north Kanara coast of Karnataka based on differences in vertebral counts. This study confirmed the presence of a single stock of IOS contributing to the fishery. The morphometric characters which differed among the samples, were mainly the snout length, head length and body depth. Remya *et al.* (2015) also reported phenotypic homogeneity for IOS of the southwest and southeast coasts. Recent genetic studies using microsatellite markers have indicated stock divergence with a possibility of a separate stock in the northwest coast (Sandhya *et al.,* 2017). Stock definition requires stable differences in shape (Cadrin, 2013) with related biological parameters (growth parameters, spawning characteristics, *etc*). Current information indicates differences in the growth and reproductive characteristics of IOS occurring off Indian and Oman coasts (Al-Anbouri, 2012, 2013; Al-Jufaili, 2011).

8.1.ii. Analysis of Similarities (ANOSIM) on linear morphometric characters

ANOSIM on log-transformed morphometric ratios of 94 IOS specimens belonging to three different morphotypes were made by Sandhya *et al.* (2016b) to assess whether they were significantly divergent. PCA of log-transformed ratios of 17 linear morphological characters (as percentage of standard length) (Table.25) showed distinct clustering (Fig.56) with PC I and PC II explaining 50.7% and 17.6% of the total morphological variation respectively indicating that the ANOSIM analysis is a powerful tool in differentiating the three distinct morphotypes of IOS. The differences in depth at dorsal, anal base length, caudal width, distance from pelvic to anal origin, depth at anal origin and eye diameter accounted for 52% of the variation between variant 1 and 2 in the analysis. 56% of the variation between variant 2 and 3 was explained by differences in caudal width, distance from pelvic to anal origin, anal base length, depth at dorsal and depth at anal. Differences in caudal width, eye diameter, anal base length, depth at anal, distance from pelvic to anal origin accounted for 50% of the variation between variant 1 and 3.

Table 25. Morphological characteristics measured in three variants of Indian oil sardine (average values as percentage of standard length)

Morphometric characteristics	Variant 1	Variant 2	Variant 3
Head length**	30.8	28.7	27.46
Snout length**	6.76	5.87	5.92
Eye diameter **	6.05	4.94	5.08
Inter orbital width **	6.62	5.46	7.0
Distance from snout to 1st dorsal**	47.36	44.01	45.85
Distance from snout to pectoral*	29.43	27.6	27.95
Distance from snout to pelvic**	54.76	51.28	54.38
Distance from snout to anal origin**	78.14	70.7	78.06
Distance from pelvic to anal origin**	23.59	20.05	26.13
Caudal width**	8.0	6.9	9.7
Depth at first dorsal**	24.42	19.03	24.76

Morphometric characteristics	Variant 1	Variant 2	Variant 3
Depth at anal origin**	14.0	12.11	15.72
First dorsal height**	12.25	10.7	11.62
First dorsal base length**	13.46	11.6	13.43
Anal base length**	13.19	10.7	13.35
Pectoral length	14.7	14.0	14.9
Pelvic length	7.7	7.59	8.23

**Highly significant P < 0.01, *Significant P < 0.05.

8.1.iii. Species level identification of the morphological variants with Mitochondrial DNA markers

The three variants of IOS were further analysed genetically to examine whether they belonged to the same species. Mitochondrial cytochrome c oxidase I (mtDNA

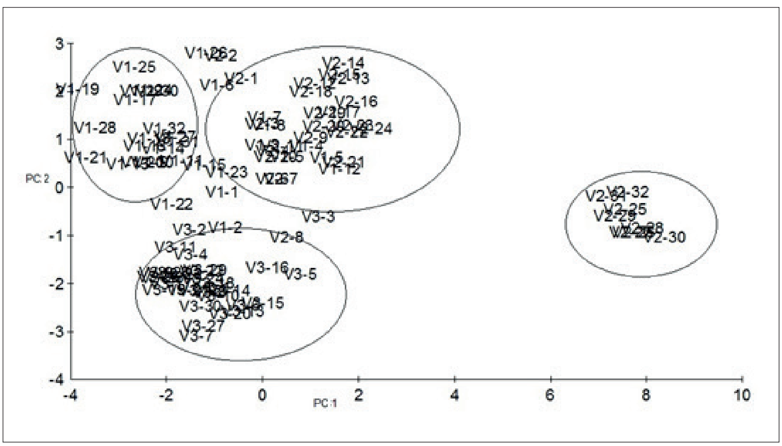


Fig. 56. Principal Component Analysis plot of the first versus second principal components of morphological characters in 94 Indian oil sardine specimen

COI) partial sequence analysis did not show any significant variation between the three variants. The Kimura2P genetic distance values based on DNA barcodes (COI, 655bp) were very low ranging from 0.1 - 0.2% indicating that the three morphotypes belonged to the same species *Sardinella longiceps* (Figs.57 and 58). Based on the analysis, Sandhya *et al.* (2016a) inferred that variant 3 (Oman sardine) is confined to the waters of Gulf of Oman and variant1 mostly along the west coast and variant 2 mostly along the east coast.

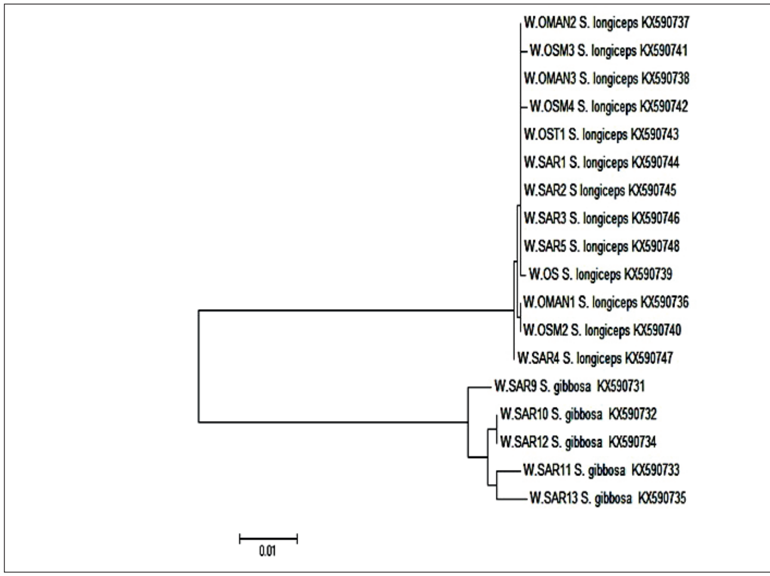


Figure.57. Phylogenetic tree showing morphologically divergent sardines clustered in the same clade.

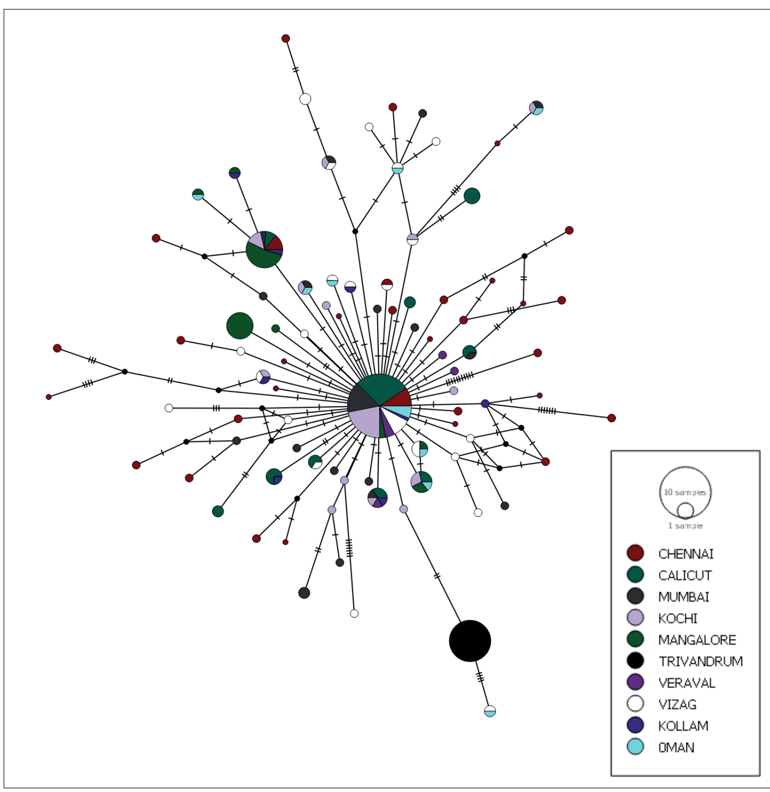


Fig.58. Haplotype network diagram constructed using mitochondrial COI (655bp) sequences. (*Haplotypes are represented in circles and colours indicate geographical locations. Mutational steps are indicated in vertical stripes.)*

9. Genetic stock structure and diversity analysis

Sustainable management of pelagic resources requires deeper understanding of intra and inter-specific genetic diversity patterns and hence it is imperative to understand the different mechanisms underpinning biodiversity at different levels (Santamaria and Mendez, 2012). Traditionally, marine fishes are considered to be low genetically differentiated and weakly adapted due to the absence of geographical barriers (Smedbol *et al.*, 2002; Poulsen *et al.*, 2006). However, recent studies using advanced markers have indicated genetically differentiated and spatially structured patterns in marine fishes (Teacher *et al.*, 2013; Scherag *et al.*, 2016). The genetic differentiation is mainly contributed by biological characteristics of marine fishes like natal homing (Svedang *et al.*, 2007), larval retention (Cowen *et al.*, 2006), historic events (Bradbury *et al.*, 2008), oceanic current patterns (Cowen *et al.*, 2006) and environmental factors like temperature and salinity gradients (Larsen *et al.*, 2012). IOS is one of the commercially important small pelagic fish and plays a significant role in ocean ecology. Preliminary studies have been carried out to understand the intra-specific diversity patterns and stock structure of IOS from Indian waters using enzyme loci (Venkita Krishnan, 1993), cytogenetic, biochemical, morphometric tools (Mohandas, 1997) and allozymes (Menezes, 1994). These studies indicated the possible presence of distinct stocks in Indian waters, but these investigations were limited by reduced sample size and geographical coverage. A detailed investigation on stock structure and intra-specific diversity patterns of IOS along its range of distribution was made using mitochondrial and polymorphic microsatellite markers (Sandhya *et al.,* 2016a, Wilson *et al.*, 2017).

Genetic stock structure and diversity analyzed using mitochondrial DNA (mtDNA) markers (control region partial sequence 758bp) in IOS collected from Gulf of Oman and all along the Indian coast (Veraval, Mumbai, Mangalore, Calicut, Kochi, Trivandrum, Chennai and Vizag) revealed high levels of genetic diversity as indicated by haplotype variation (Sandhya *et al.*, 2016). The high levels of haplotype variation associated with low levels of nucleotide variation in addition to unimodal mismatch plots indicated a demographic expansion in IOS populations historically (Fig.59). The approximate period of spatial and demographic expansion of IOS also coincided with late Pleistocene epoch, a period characterized by frequent El Niño events and influx of warm waters into the Indian Ocean. Historic effective population sizes were also found to be very high. Mitochondrial markers could not distinguish any signals of distinct genetic stock structuring among IOS populations from Gulf of Oman and all over the Indian coast, even though interesting insights were derived into the historic patterns of diversity.

Mitochondrial markers are maternally inherited unlike nuclear microsatellites and hence the resolving power to detect signals of population structure is considered low especially in marine pelagic fishes with large effective population sizes. Hence, genetic stock structure analysis of IOS was also carried out using 6 polymorphic microsatellite markers (Wilson *et al.*, 2017). The results indicated signals of distinct population sub-structuring with three major sub clusters (Fig.60) in the Indian ocean region with maximum genetic subdivision between

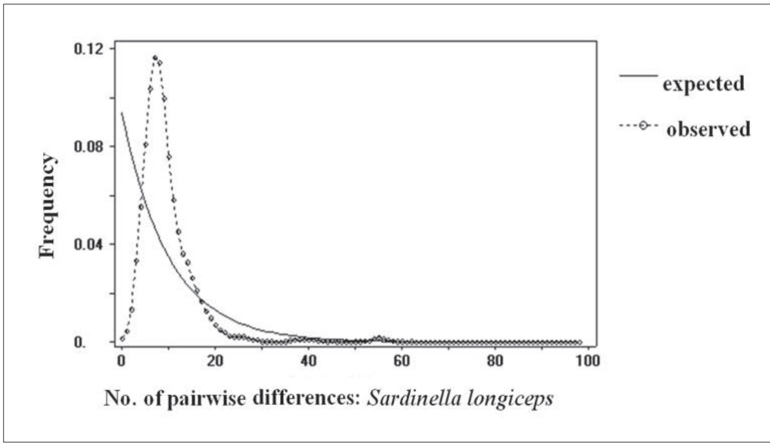


Fig. 59. Mismatch distribution for Indian oil sardine indicating demographic expansion constructed using control region sequences

Gulf of Oman and Indian coastline followed by another major subdivision within the Indian coastline between northwest coast of India versus other parts (Wilson *et al.*, 2017).

Signals of geographic connectivity and gene flow were present in all the other regions. Oceanographic and environmental parameters (temperature, salinity,

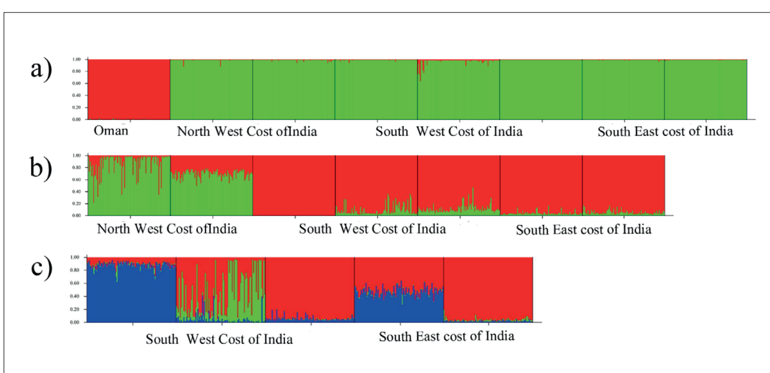


Fig.60. Graphical results of STRUCTURE analysis of six microsatellite loci in Indian oil sardine populations. Vertical lines represent probability of individual membership in simulated clusters. a) Plot for K = 2 (including all the samples), b) Plot for K = 2 (excluding Oman samples), and c) K = 3 (Excluding Oman and Northwest coast of India samples).

pH and local currents) vary between geographical locations, which might have contributed to the population sub-structuring of IOS (Fig.61). Even though patterns of mixing are present along southwest and southeast coasts of India, the presence of a meta-population structure in IOS cannot be ruled out.

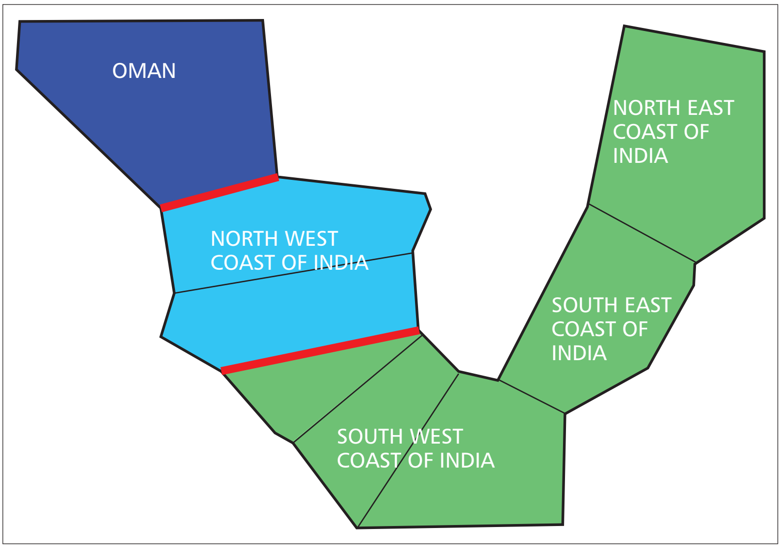


Fig.61.Genetic barrier to gene flow (red lines) among Indian oil sardine (calculated using FST and RST matrix based on the samples from 8 locations).

10. Proximate composition of Indian oil sardine

Studies conducted earlier on the proximate composition of IOS from Indian seas have indicated that on a wet weight basis the moisture content ranged from 65.5 to 77.4%, crude fat from 9.2 to 14.3%, crude protein from 17.1 to 18.1% and ash content from 1.7 to 2.9% (Madhavan *et al.*, 1974a). Proximate composition of normal, lean and Oman sardines (sardine from Omani waters) made during the present study is given in Table 26. The results were comparable to the earlier studies with an average moisture of 71%, crude protein 18.5%, crude fat 4.9% and crude ash 5.3%. On the other hand, in the Oman sardine samples collected from fish markets in Kochi, the moisture content was relatively low at 53.5% and protein content (19.5%) was comparable to that of normal sardine (18.5%). The protein content of the lean sardine was very low (12.7%) and differed significantly from that of normal and Oman sardine. The fat content was significantly high (22 - 29%) in Oman sardine (Table 26). A recent study by Mohanty *et al.* (2016) on the fatty acid composition of IOS suggested that this high fat fish (>8%) had an average Saturated Fatty Acids (SFA) content of 39.4%, Monounsaturated Fatty Acid (MUFA) 24.1% and Polyunsaturated Fatty Acid (PUFA) 26.8% with an ω_3/ω_6 fatty acids ratio of 4.3. Chitra-Som and Radhakrishnan (2011) reported that among PUFAs the EPA content in IOS was higher than DHA and highlighted the health benefits from consumption of oil sardine. Kajal *et al.* (2015) reported on the fatty acid composition of crude and solvent extracted sardine oil and concluded that sardine oil extracted from native IOS can be a potential substitute for the imported PUFA supplements currently used as food supplements in India. Udari *et al.* (2015) have described the development of ω_3 enriched instant soup powder from IOS.

Table 26. Proximate composition (%) of Indian oil sardine

Sample type	Dry matter	Moisture	Crude protein	Crude fat	Crude ash	Crude fibre	Acid insoluble ash	Nitrogen free extract
Normal sardine	26.7 - 31.4	68.6 - 73.3	17.5 - 19.5	3.7 - 12.6	1.2 - 7.0	0.0 - 0.3	0.0 - 0.3	0.0 - 0.5
Oman sardine	43.5 - 49.4	50.6 - 56.5	19.1 - 20.1	22.1 - 29.1	0.8 - 0.9	0.13- 0.2	0.0 - 0.1	0.2 - 0.5
Lean sardine	28.5	71.5	12.7	4.6	1.3	0.1	-	-

11. Environment and its influence on recruitment and fishery trends

Marine ecosystems are highly dynamic and influence the environment on temporal and spatial scales. The response to changes in the ocean current pattern that triggered nutrient cycles and affected productivity patterns have been documented in several studies globally. However, biological responses to these processes are extremely complex and perhaps not fully understood. Climatological and hydrological parameters are reported to influence abundance and the distribution of IOS, thereby causing fluctuations in the catches (Day, 1889; Thurston, 1900; Hornell, 1910; Sundara Raj, 1934 - 1940; Devanesan, 1943: Chidambaram, 1950; Nair and Chidambaram, 1951; Sekharan, 1962: Sekharan and Dhulkhed, 1963, Bannerji, 1967; Bennet, 1968; Murty and Varma, 1964; Murty and Vishnudatta, 1976; Murty and Edelman, 1971; Murty, 1965, 1966; Rao *et al.,* 1973; Manjusha *et al*., 2013; Vivekanandan, 2017). The favourable temperature range for IOS is reported to be between 27 and 28º C (Gopinathan, 1974). Global warming has contributed to the changes in the fishery and biology of marine fishes, including IOS (Vivekanandan, 2013). Seasonal or unusual variations in wind speed and chlorophyll concentration also influence IOS catch (Srinivasarangan and Chidambaram, 1985; Piontkovski *et al*., 2014). Surges in recruitment during 1962 - 1964 and 1973 - 75 along the Kerala Coast have corresponded to periods of increasing total IOS abundance (Antony Raja, 1972, 1973). There is also a cyclical pattern where increased recruitment leads to a higher adult population, followed by a decrease in recruitment and lower adult population subsequently (Longhurst and Wooster, 1990). Krishnakumar *et al*. (2006) have reported 'regime shifts' that is associated with climate change phenomenon during 1983 and 1988/89, when IOS stocks started appearing in the fishery along the southeast coast for the first time. This was followed by a rapid increase in landings and finally in 1998, IOS emerged as the single largest contributor to the total fish production from the southeast coast.

Recruitment is the number of juveniles entering the fishery at one given point of time. Longhurst and Wooster (1990) indicated remarkably constant recruitment cycles for IOS with occasional surges. Recruits per Spawning Stock Biomass (RSSB) anomalies were investigated for the possible influence of environmental factors on IOS recruitment in the southwest coast of India. Recruitment strength (in numbers) during 2001 to 2015 was determined from a Length at age model which considered the length composition of the commercial fishery catch and total landings of the seine fishery, based on the assumption that catches are a proxy for actual abundance in the sea (Longhurst and Wooster, 1990). Recruits were defined as the fully recruited length group entering the fishery (usually around 3 months after hatching) and estimated on an annual basis. Relationship between SSB and recruitment was established using regression analysis, which had the highest effect with a 3 month lag and was used for further analysis following Longhurst and Wooster (1990) method. The monthly RSSB anomaly was also computed as the difference between the RSSB value and the expected RSSB divided by the standard deviation of the RSSB values.

The survival rates during the early life stages of the fish determines the success of marine fisheries (Stevens, 1977), which in turn is critically influenced by the 'first feeding' phase of marine fish larvae (Hjort, 1914). In the present document, a suite of environmental factors that could potentially influence survival of the fish during its early life history stages (larvae) such as Real Time Temperature (RTT), Chlorophyll *a* (Chl *a*), upwelling index and rainfall off Karnataka were selected and interactions with IOS fishery analysed. Time series data were taken from secondary sources. Oceanographic data was gathered using satellite remote sensing (SRS) real time data for wind, temperature, Chlorophyll *a*, and rainfall data provided by IMD (Box averaged values, grids selected for Karnataka 12^o N to 15^o N, 73^o E to 74.5^o E) for the analysis. Chlorophyll *a* was obtained from Ocean Colour Climate Change Initiative (OC-CCI) available at www.oceancolour.org. Wind and temperature data from Asia-Pacific Data Research Center (http://apdrc.soest.hawaii.edu/) website. Coastal offshore Ekman Mass Transport derived from the along shore component of wind was used as the upwelling index for this study. Strong negative values of the Ekman Mass Transport represent the strong offshore mass transport and consequently upwelling along the west coast of India. For the calculation of coastal Ekman Transport, monthly SRS data from European Remote Sensing (ERS), Quick Scatterometer (QuickScaT) and Advanced Scatterometer (ASCAT) wind products were used following Shah *et al*. (2015) and Hareesh *et al*. (2016). Temperature at 5 m depth from Simple Ocean Data Assimilation (SODA)-assimilated model output was also used.

The longterm data on climatological parameters studied were taken from the following sources: Temperature data from ICOADS; rainfall from IMD, interannual changes in phytoplankton abundance from SeaWiFS satellite data, multivariate ENSO index and UPI from http://oceanview.pfeg.noaa.gov and current speed and direction from oceanmotion.org of NASA.

The Generalized Additive Model (GAM) which allows additive effects to be modelled without specifying a single equation for each environmental effect was fitted to the RSSB anomalies for IOS to identify potential non-linear effects of environmental factors (Hastie and Tibshirani, 1990).

GAM followed the general formulation:

$$E[y] = a + s(X_1) + \ldots + s(X_n) + \varepsilon$$

where E[y] is the expected value of the response (dependent) variable y, here RSSB, *a* is the intercept parametric term which represents the mean of the response variable, *s* is the smoothing function based on the thin plate regression spline, *Xi* are the independent variables and ε the error term. The Gaussian error distribution with the identity link function was used for independent variables smoothing and fitting of GAM. Further data exploration and analysis were carried out with the package R 3.2.2 version and the associated mgcv package (R core team, 2015). A pseudo-R^2 value (Swartzman *et al*., 1992) was also computed to provide an indication of the overall goodness-of-fit of the selected model.

The lagged and contemporaneous variables were investigated to identify time-lagged physical changes in oceanographic and atmospheric conditions that could affect IOS recruitment success. The degree of collinearity between explanatory variables was tested with correlation plots of variables and variance inflation values (Zurr *et al.,* 2009).

Correlations between the variables were less than 0.8 and variance inflation values were less than 1.5 for all the pairs, indicating no collinearity among the explanatory variables. The Chl *a* concentration during 2001 - 2015 ranged from 0.136 to 1.959 mg m^3 with an average value of 0.33 mg m^3. The RTT varied from 27.63 to 30.52°C (Table 27). The monthly RTT means peaked in April and May and Chl *a* measurements during August-September (Table 28). In general, Chl *a* concentration remained high from July to September during the period except in 2009 and 2015. In these years, peak Chl *a* concentration was observed in October.

Table 27. Range of parameters used for modelling RSSB (off Karnataka)

	RTT (°C)	Chl *a*	Upwelling index	Rainfall (mm)
Min	27.63	0.136	-1550	0.025
Max	30.52	1.959	64	1628.725

Table 28. Monthly averaged values of explanatory variables during 2001 - 2015 in Karnataka

Month	RTT (°C)	Chl *a* (mg m^{-3})	Upwelling Index (m^2 $second^{-1}$)	Rainfall (mm)	RSSB
January	28.29	0.33	-439.56	1.54	1.41
February	28.39	0.29	-567.19	2.40	0.46
March	29.09	0.27	-452.63	28.90	1.28
April	29.72	0.29	-434.50	46.60	0.36
May	29.94	0.37	-536.31	182.97	0.83
June	29.17	0.40	-554.81	948.83	0.51
July	28.25	0.73	-1095.88	1010.82	0.29

Month	RTT (°C)	Chl *a* (mg m^{-3})	Upwelling Index (m^2 $second^{-1}$)	Rainfall (mm)	RSSB
August	27.93	1.04	-1002.38	734.75	0.31
September	28.16	0.91	-541.50	388.33	1.05
October	28.76	0.66	-166.69	200.13	38.44
November	28.99	0.39	-116.94	62.61	30.53
December	28.69	0.34	-230.13	13.28	4.06

Of the four environmental variables considered, the strongest GAM relationship existed between three months lagged Chl *a* and contemporaneous upwelling index, although, in both cases, a high proportion of variation was not explained by the GAMs (Table 29). The effect of RTT and rainfall were not significant for RSSB of sardine. The shape of the RSSB anomaly response to the Chl *a* and upwelling index was non-linear and highest recruitment success occurred when Chl *a* values were between 1.2 - 1.7 mg m^3 (Fig. 62). RSSB anomaly had a concave response to Chl *a*. RSSB anomaly had a convex response to upwelling index between -500 to 0 which indicated that moderate upwelling does have a positive effect on IOS recruitment while the extreme events had a negative effect (Fig. 63).

Table 29. Important variable identifed as explanatory variable and their statistical signifcance

Explanatory variable	Estimated degrees of freedom	p-value	Deviance explained
Model I			
Chl *a*	3.5	<0.001*	11%
Model II			
Upwelling Index	2.8	<0.001*	10.7%

*Indicates significant p values at significance level of 0.01

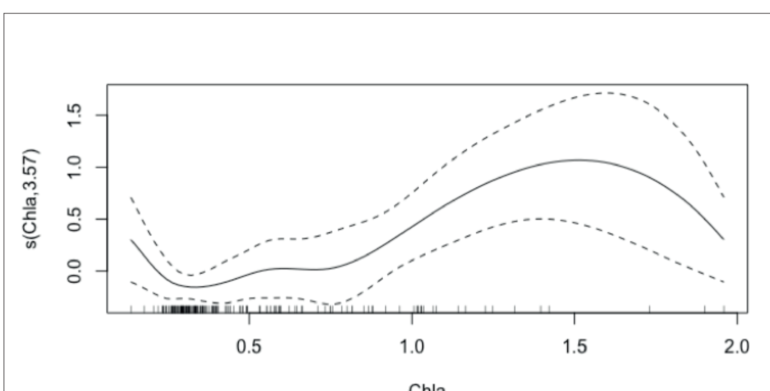


Fig.62. Relationship between Chl *a* and the recruitment success for Indian oil sardine using GAM model.

The dotted lines correspond to the 95% confidence intervals. Black thin bars correspond to the observed values.

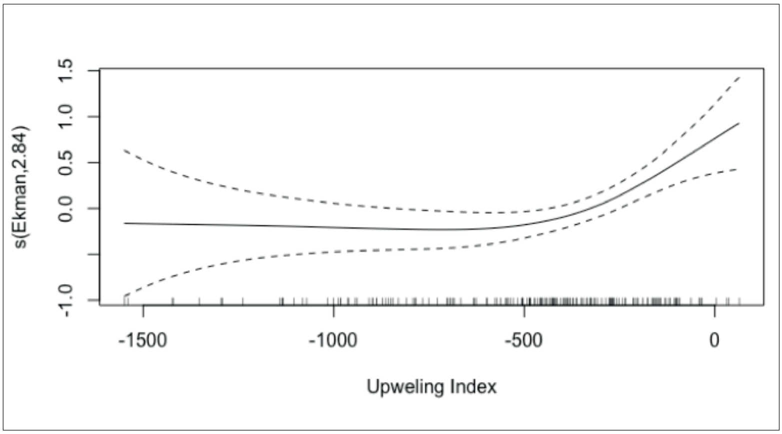


Fig.63. Relationship between Upwelling Index and the recruitment success for Indian oil sardine using GAM model. The dotted lines correspond to the 95% confidence intervals. Black thin bars correspond to the observed values.

Monthly recruitment in numbers during 2001- 2015 off Mangalore (Fig.64) indicated a significant decline after 2012. It was low during the 2001- 2006 period in comparison to the peaks in 2008 and 2012. Reasons for reduced recruitment could be due to spawning failure (failed egg development) or skipped spawning (partial resorption of eggs) (Rideout *et al*., 2005) in addition to the influence of factors including high/low population density (detected by individuals by pheromones), temperature regimes and low condition factor which is primarily affected by feeding conditions and diet composition (Jorgensen *et al*., 2006; Morgan and Lilly, 2006). Therefore, correlations between maturity data, SSB and annual recruitment indices along with environmental indices would help in developing prediction models.

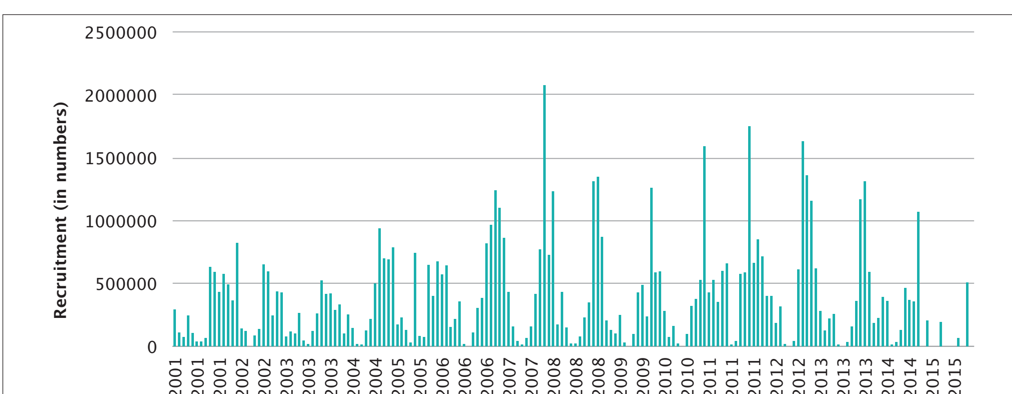


Fig.64. Recruitment trends off Mangalore Coast during 2001-2015 period

11.1. Influence of ENSO (El Niño Southern Oscillation) on Indian oil sardine fishery

The most prominent large scale climate variability on Earth is the El niño Southern Oscillation (ENSO) cycle (Glantz, 1996; Mc Phaden, 1999; Trenberth and Caron 2000; Mc Phaden, 2004) involving the entire tropical Pacific Ocean and global atmosphere (Philander, 1999). ENSO is characterized with unusually warm (El Niño) and cold (La Niña) phases which begins in the tropical Pacific (McPhaden, 2004) as a result of a dynamic interaction of atmospheric response to SST fluctuations (Trenberth 1997, Trenberth and Caron 2000) oscillating approximately every 3 - 7 years (Fig.65).

The intensity of El Niño is classified based on SST anomalies exceeding the normal threshold by +0.5°C. The changes brought about by ENSO impact rainfall and

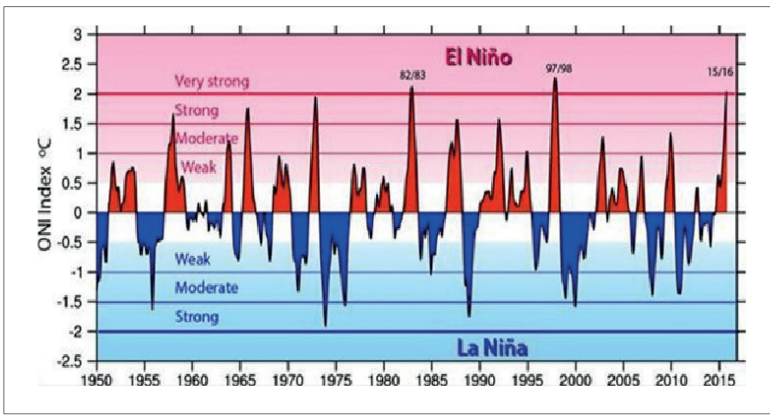
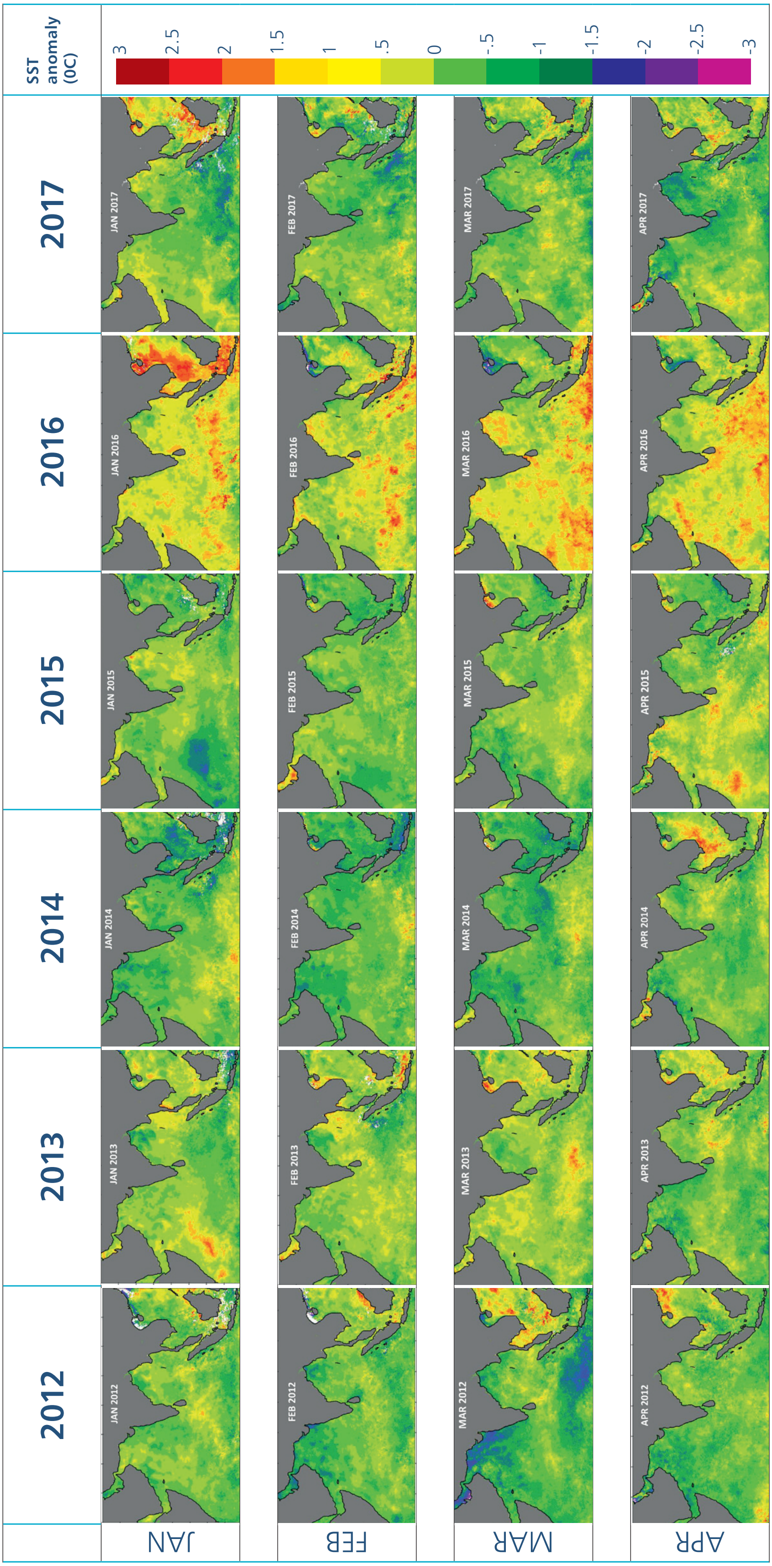


Fig.65. El Niño (Red) and La Niña (Blue) phases in the east central tropical Pacific Ocean (Source: National Centre for Atmospheric Research)


SST anomaly (0C)
3
2.5
2
1.5
1
.5
0
-.5
-1
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2017
JAN
FEB
MAR
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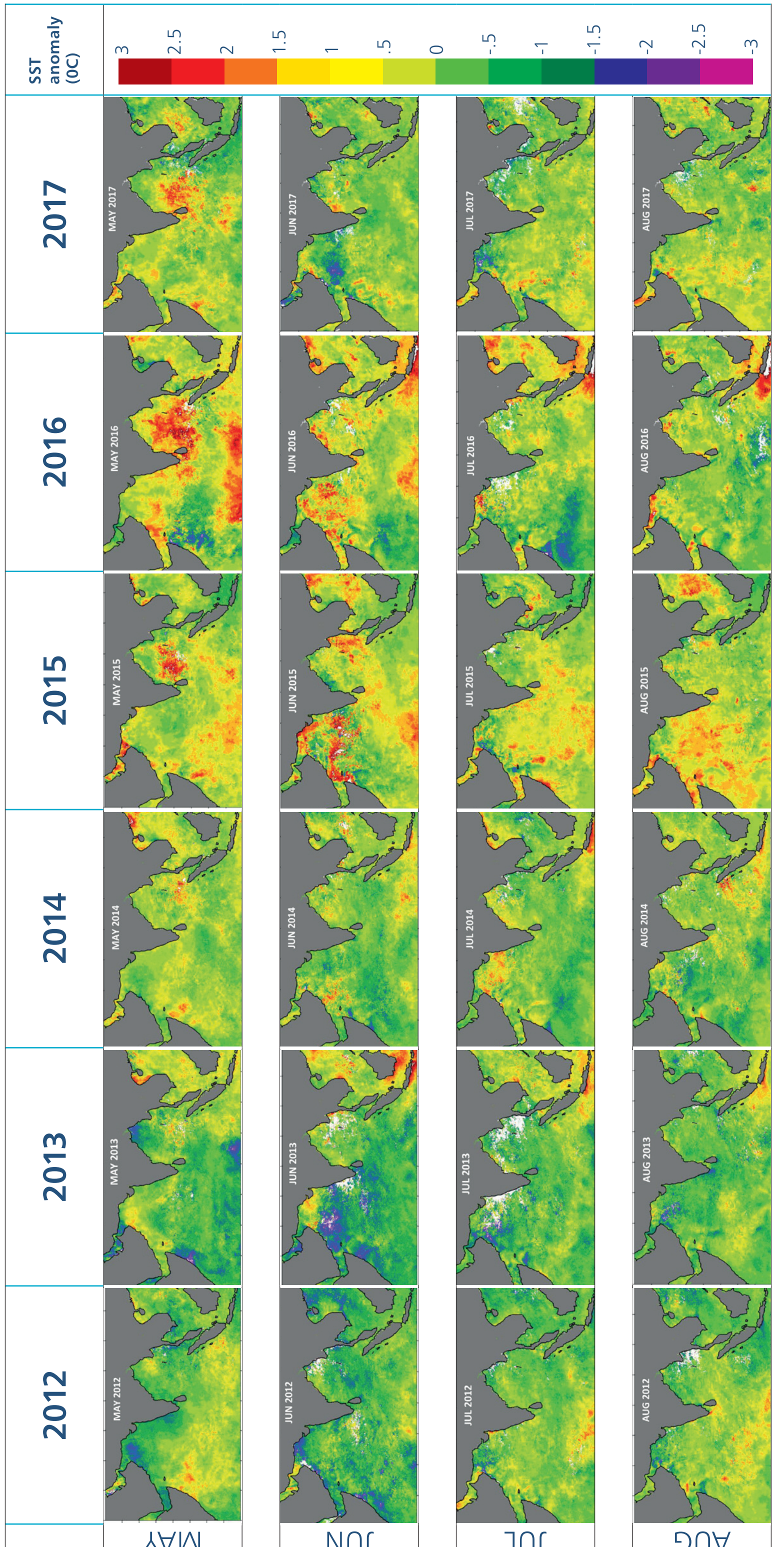
SST anomaly (0C)
3
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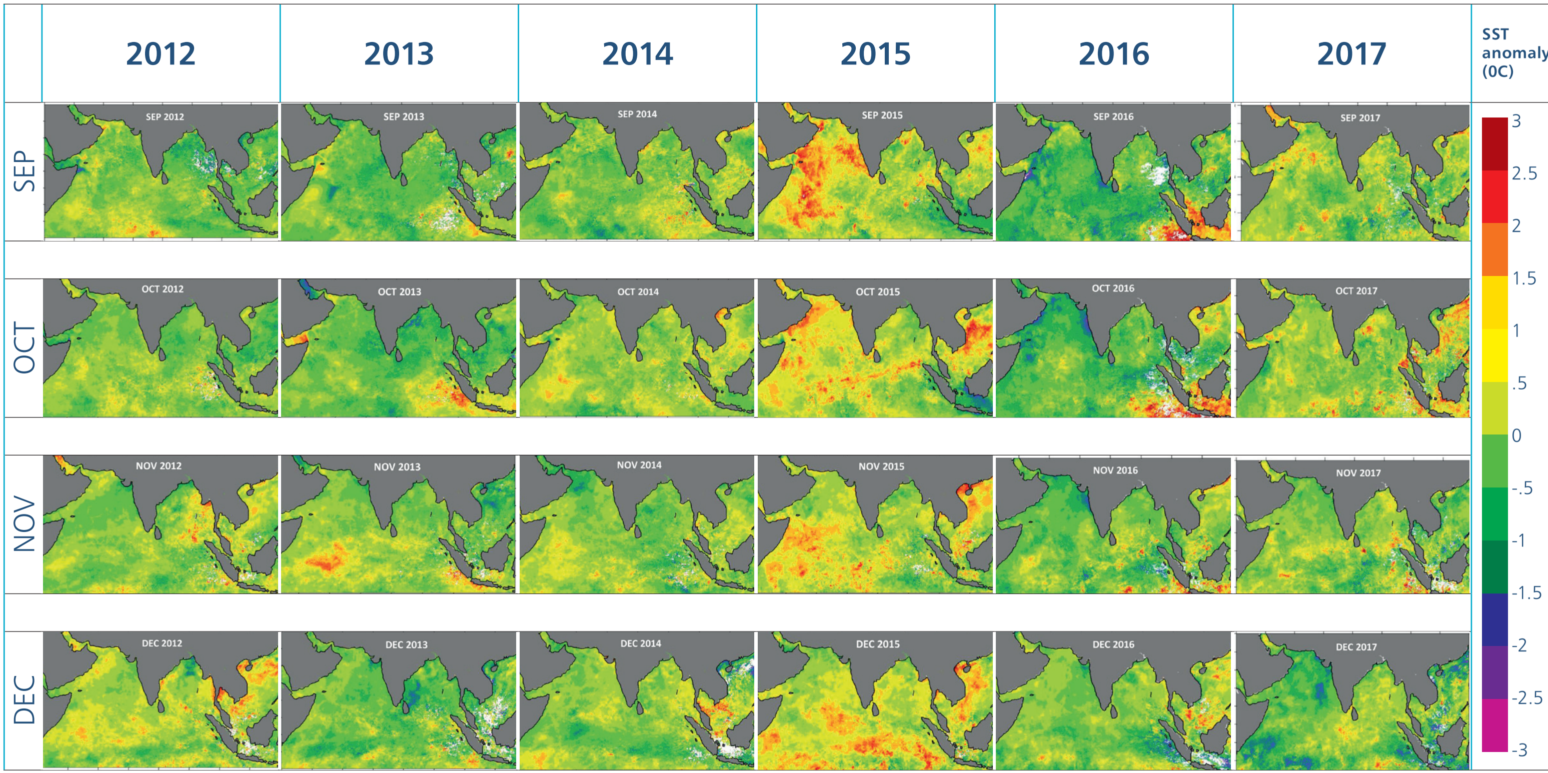

Plate 14. Monthly SST anomalies along the Indian Coast during 2012 - 2016

have a cascading effect on other environmental parameters (SST, thermal fronts, Chl *a*, ONI). Prasanna Kumar *et al*. (2002) have reported decadal anomaly of the summer monsoon rainfall (June-September period) along the Indian coast where it was highest during the post 1995 period. It resulted in declining rainfall volume, increasing number of heat spells on land and a disruption in the decadal cycle of SST in the Arabian Sea.

The impact area of El Niño along the Indian coast in recent times was along southwest coast, especially off Kerala (Fig.66). The monthly change in SST along the Indian Coast during 2012 to 2016 is provided in Plate 14. Observation on the behavioural response of IOS to ENSO phenomenon during 2010 - 2017 along the Kerala Coast provided a clear cue to the processes, which cause seasonal fluctuation in abundance and catch. The period 2010 - 2013 was largely a La Niña period. During this period, normal growth, sexual maturation, timely spawning and recruitment with high resilience to heavy fishing pressure were noticed. Fishery was within 50m depth zone and catches remained high. With the onset of El Niño by 2014, changes in the behavioral and distributional patterns of IOS was observed. The IOS moved to deeper waters as evidenced from its increased abundance in the guts of predatory fishes caught from deeper waters. Considerable proportion of the stock also appeared to migrate and exhibit range extension to the adjacent waters, as increased landings of IOS was recorded in Tamil Nadu while it declined in Kerala (Fig.16). Similar inverse relationship in IOS landings between Kerala and Tamil Nadu noticed during earlier years were attributed to 'regime shift' (Krishnakumar *et al*., 2006, 2008). Changes in biological characteristics during the initial period of El Niño was more striking, and expressed as growth retardation (Section 9.1) and shrunken ovaries with reduced fecundity (Section 8.3). The condition factor (CF) of female IOS spawners remain below three during peak spawning months (June- August) of study period except in 2007 and 2011 (Fig 67). With the intensification of El Niño (expressed as ONI Index) the ovaries failed to develop. This consequently led to

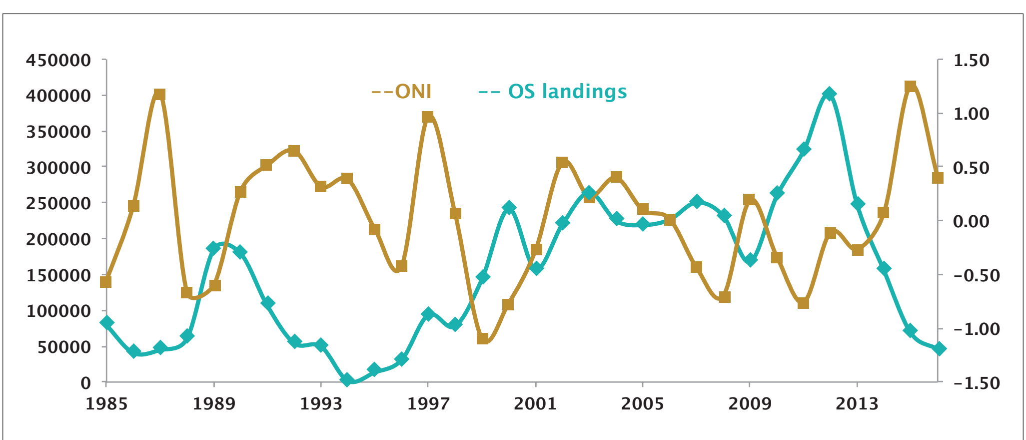

Fig.66. Interannual variability of Indian oil sardine landings (t) and Nino Index along Kerala coast

severe spawning failure during 2014 - 2015 period and adversely affected the recruitment process of IOS. Meanwhile the targeted fishing for IOS continued unabated resulting in considerable removal of the available stock. High fishing mortality combined with poor recruitment due to spawning failure or poor spawning (Fig. 69) and other related El Niño phenomenon, led to depletion of stock to an extremely low level. With the weakening of El Niño since 2016, normal spawning activity resumed and marginal improvement in IOS landings was recorded in 2017.

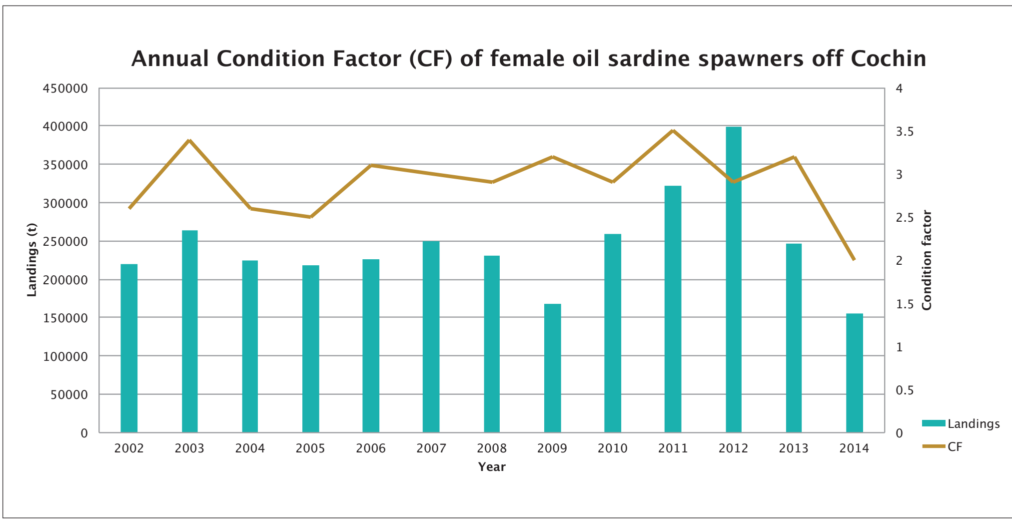

Fig.67. Annual trends in landings and condition factor (2002-2014) of Indian oil sardine caught off Kerala coast

Extreme events such as ENSO and cyclones are major environmental drivers, which influence recruitment success in IOS population. The inherent attributes of IOS such as high fecundity, low survival rate, small size, short generation turnover time and protracted spawning period has helped it to flourish in abundance after a population crash. Our observations indicate that IOS decline is a natural phenomenon obviously in association with the onset and retreat of El Niño. Considering the medium to high resilience capacity of IOS (Zacharia *et al.*, 2016) and historical fishery trends, the IOS fishery along the southwest coast of India is expected to revive in a span of 2 - 3 years.

Generally, the recruitment number of a species is related to fecundity or SSB as a proxy of egg production (Myers and Barrowman, 1996; Morgan, 2008). However, other biological factors (age-length structure of the stock, condition factor of spawners, predation or non-fishery mortality) also have important roles to play. When the stock is depleted to a considerably low level, rebuilding to the original healthy levels requires longer periods, the time depending on the level of depletion and persistence of adverse conditions. Since the factor(s) causing

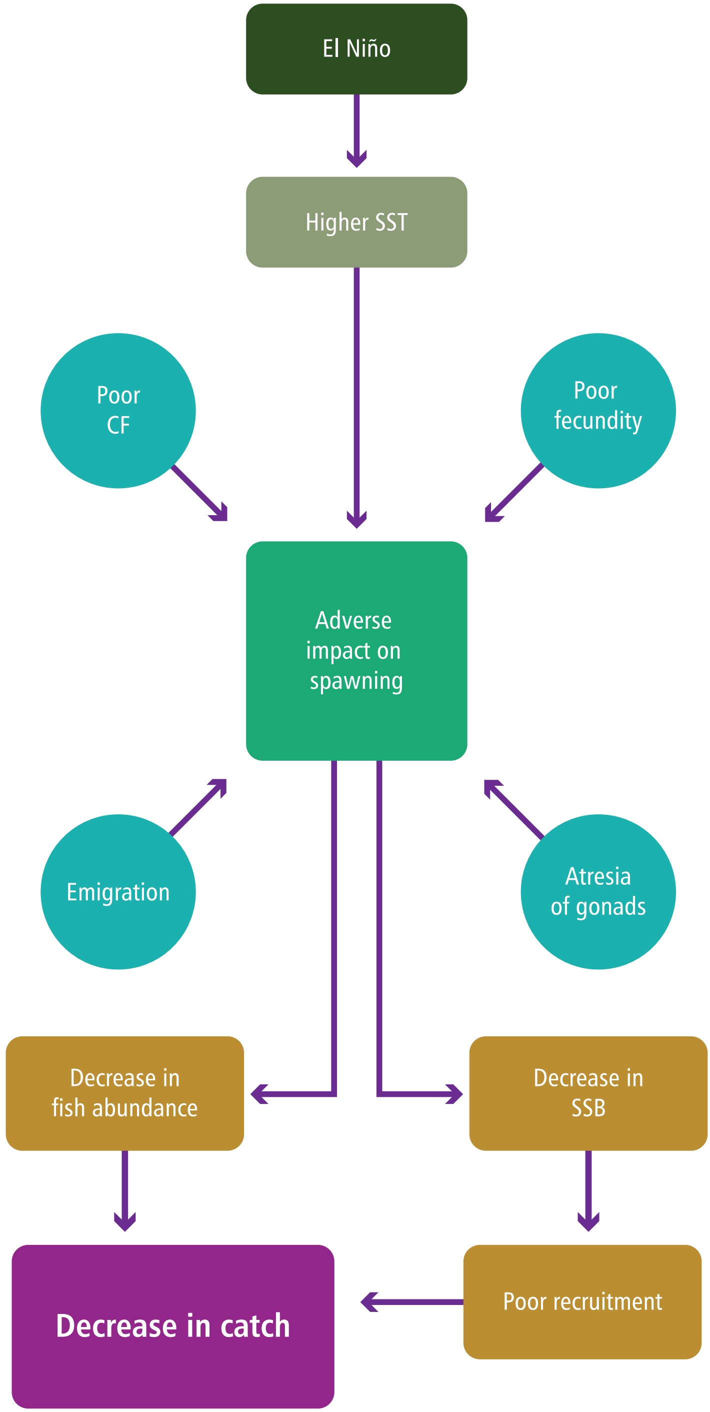

Fig.68 Sketch depicting interactions between various eco-biological factors on the fishery of Indian oil sardine

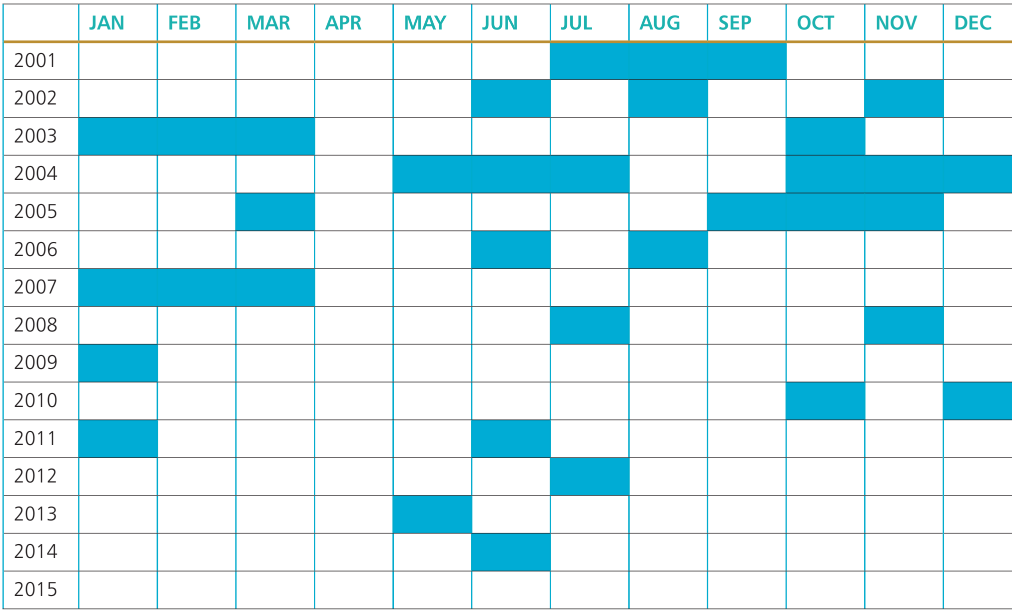

Fig.69 Monthly occurrence of spent stages of spawners indicating spawning activity off Cochin during 2001-2015

IOS fluctuation are primarily environment driven, impact could be minimised by regulating fishing mortality, based on the scientific monitoring of the onset of ENSO and biological behaviour of the species. Partial or full closure of the fishery depending on extent of biological change would help to minimise decline of stocks and reduce the time required for stock revival.

12. Postulates on Indian Oil Sardine landing fluctuations

Seasonal, annual, decadal and periodic fluctuations in landings are inherent characteristics of IOS. The reasons for such events could be a single or a combination of several environmental factors with its staggering effects on the fishery, trophodynamics and reproductive physiology of IOS. Several studies made to understand the dynamics leading to the unpredictable high and low landing patterns have still not zeroed in to a specific cause. However, postulates ranging from overfishing to the existence of several stocks contributing to the fishery were propounded as the probable reasons for the capricious nature of the IOS fishery. The different postulates made by earlier researchers have been reviewed and discussed in the light of the knowledge gained during the present study.

Overfishing is one of the oldest and continued reasons for reduced landings (Day, 1865; Sundara Raj, 1934 - 1940; Devanesan, 1943; CMFRI, 2017 and 2017a). On the other hand, Bannerji (1967, 1968) suggested that overfishing need not necessarily be the reason for reduced landings especially when accessibility of the existing gear brings only portions of the stocks under exploitation and the yield is not close to MSY. It is evident from the present study, the number and types of gears engaged in IOS fishery has increased over the years. Modifications made in the seines have improved the efficiency of the purse seines and ring seines. Exploitation levels of IOS were high during the later years and during 2010 - 2015 it ranged from 96.6% (India) to 98.8% (Kerala) of the estimated MSY (Table 18). This could have contributed to high exploitation resulting in decline of landings in some years. Hence, a precautionary approach along with adoption of specific management measures (limiting present effort and landing as well as introduction of new units; declare closed season and strict implementation of MLS) are to be adopted for sustainability of the fishery in the long run.

Lack/absence of traditionally favoured food items (*Fragilaria oceanica)* is another reason that has been believed to influence the availability of adult and juvenile IOS in the fished areas *(*Chidambaram, 1951; Panikkar, 1952; Nair and Subrahmanyan, 1955 and Noble, 1964) and scarcity of copepods and cladocerans (Nair and Chidambaram, 1951; Bensam,1967; Devaraj and Vivekanandan,1999). On the other hand, IOS is reported to have mixed diet consisting of *Coscinodiscus* sp., *Fragilaria oceanica, Pleurosigma* sp., certain dinoflagellates and copepods with no specific preference or consistency for a particular food item (Dhulkhed, 1964, 1970; Kagwade, 1967; Bensam, 1967; Noble, 1969). Increasing SST, an impact of climate change, has led to a change in the plankton species composition (Marinov *et al*., 2010). In the absence or decreased quantity of the traditionally believed food item, the IOS has substituted it with smaller sized higher temperature tolerant species (*Coscinodiscus* sp.) and other mixed plankton.

When fishery mainly depends on ‘0’ year class (Antony Raja, 1969 and 1971) or leans more on older year classes (Bennet, 1968), selective and excess removal of these year classes could be a reason leading to fluctuations observed in the IOS fishery. The present study has revealed that the IOS fishery is supported by all size groups with the ‘0’ to ‘1’ year class dominating the landings in all states. The rapid growth and short life span of IOS and attainment of maturity in its first year makes it safe to be exploited in the first year itself. However, measures such as implementation of MLS and fishery closures during peak breeding season to prevent recruitment and growth overfishing are recommended.

Antony Raja (1969, 1971 and 1972) has related fluctuations to spawning and survival rate of spawn in the same season, which in turn is dependent on atresia of gonads. Spawning failure was observed in 2014 and 2015 and reasons for such a phenomenon are attributed to the combined effect of biotic and abiotic factors influencing the reproductive biology of IOS.

Possible existence of heterogeneity of IOS stocks is also attributed as a reason for the fluctuations (Cushing, 1967; Dhulkhed and Rao, 1976; Dhulkhed and Nagesh, 1976). TRUSS and molecular studies indicated that the morphometrically different oil sardine phenotypes observed in the fishery belonged to the same stock. Mitochondrial DNA marker studies too indicated the existence of a single stock. Microsatellite DNA markers however indicated presence of a separate stock for the Oman region, another for northwest region and the third for the rest of India.

The changes in the mean sea level resulted in fluctuations on IOS landing (Chidambaram and Menon, 1945; Antony Raja, 1969; Murty and Edelman, 1971; Longhurst and Wooster, 1990; Thara, 2011). Similarly, a close relationship of sunspot activity, rainfall patterns, El Niño frequency and intensity showed close correspondence with IOS landings (Anderson, 1989; Srinath *et al*., 1998; Jayaprakash, 2002). We observed a combined influence of rainfall, RTT, Chl *a* and upwelling index on the RSSB thereby affecting the landings of IOS.

Existence of an inverse relationship between IOS and Indian mackerel abundance would influence the landing trends (Nair and Chidambaram, 1951; Devaraj and Vivekanandan, 1999). In the present study, an inverse relationship between landing rates of IOS and Indian mackerel was observed in some years but, correlation between the landing rate anomalies of these two fisheries was not significant on an annual basis.

Regime shifts caused by a strong El Niño closely followed by a strong La Niña or vice versa leads to loss of resilience in the ecosystem and leads to alteration in distribution and production of IOS (Madhu Pratap *et al*., 1994; Krishnakumar *et al.*, 2006, 2008) and the fish may opt for a demersal or bathypelagic phase when surface waters are warm (Antony Raja, 1973). Higher SST during 2015 and 2016 have resulted in lower landings and could have possibly influenced migration and distributional expanse of IOS along the west and east coasts. Sathianandan and Alagaraja (1998) have put forth a postulate on the existence of 21 and 11 year cycles in IOS fishery trends. We have observed a erratic trend in the landings, which is in tune with environmental cues. With abrupt environmental disruptions associated with the global climate change becoming more frequent, these cycles may no longer be existing.

The IOS exhibits all the characteristics of a small tropical fish with annual, seasonal and decadal landing fluctuations. Of the different climate related events that affected the IOS fishery, the impact of ENSO with its cascading effects on other environmental factors (SST, upwelling and primary productivity) and on the biological functioning (growth rate, food availability, spawning failure, etc.) was the most obvious. In addition, the local preference for the fish in fresh condition, the fishing patterns and the marketing facilities existing in the region too played an important role in exploitation and utilization of the IOS.

13. Management Measures

The natural fishery resources, however abundant, if not managed judiciously with appropriate conservation measures, will lead to reduction, depletion, collapse and at times disappearance. Therefore, in the interest of the IOS fishery, a few management measures in place have to be strengthened and continued with additional measures to be enforced. Management measure to protect the IOS were prevalent as early as 1940s. The IOS landing had crashed to very low levels in 1941. This led the erstwhile Government of Madras to promulgate a legislation to prevent the capture of IOS juveniles and spawners in 1943. The clauses under this legislation were prohibition of i) use of highly destructive boat seine (*Mathikollivala*) during sardine season (August-April), ii) use of gillnet (*Mathi chalavala*) during spawning period (August-September) and iii) landing of IOS below 15 cm exceeding a total weight of one maund (37 kg) from any single boat during the fishing season. This legislation was further modified in 1945 to prohibit use of the above mentioned gears throughout the season and the landing of immature IOS (Nair, 1973). The legislation however lapsed in 1947.

The Marine Fishing Regulation Act (MFRA) is in place since the 1980s and all the maritime states have several management/regulation measures for marine fisheries. Relevant regulations on the zonation/demarcation of the fishing areas for different categories of gear types, closed fishing season, restrictions on the use of destructive fishing gears, *etc*. are clearly indicated in the MFRAs. The ICAR-CIFT has developed a model ring seine (length 600 m and depth 60 m with 22 mm mesh size) for the IOS and mackerel fisheries (Edwin *et al*., 2010; Dhiju, 2015). This model gear would avoid excessive fishing pressure and growth overfishing by ring seines in Kerala. In addition, the Expert Committee for registration of fishing vessels (Kurup *et al*., 2009), recommended mesh size regulation of 22 mm or more in the bunt and body regions, a maximum gear dimensions of <600 m (length) X <60 m hung depth for all new/replacement ring seines, an OAL of <20 m for the fishing crafts and engine horsepower of <65 hp for canoes operating ring seines.

13.1 Practices / Control measures in place for conservation and management of Indian Oil Sardine

i. Closed fishing season: All the coastal states follow a closed fishing season coinciding with the peak spawning season of IOS and the period immediately after that.

ii. MLS is in force in Kerala (since 2015, Kerala GO (P) No. 40/15/F&PD) and observers keep strict vigilance at the landing centres. With strict enforcement, the Kerala fishers especially those operating the highly efficient ring seines abstain from fishing when small sized (<10 cm) sardines are abundant in the fishing grounds. In other coastal states, a similar decision is being contemplated where the MLS will be enforced either at the landing centre or at the procurement stage at fish processing, fishmeal and fish drying yards. Implementation of MLS for IOS at procurement stages in Karnataka will have wide implications on IOS fishing patterns in all maritime states as most of the fishmeal plants are situated in Karnataka.

iii. Most landing centres observe weekly, monthly or occasional holidays (local festivals) which help in reducing the overall fishing effort.

iv. Operation of pair trawls, which target pelagic fishes including small sized fishes, is banned in all states.

v. Operation of ring seine the most efficient gear exploiting IOS fishery is banned in Tamil Nadu and Andhra Pradesh.

vi. Operation of seines using any kind of light to attract fish is banned in all maritime states (Govt. of India order no F.No.21001/3/2014- FY (Ind) dated 29 August 2016).

vii. Trawling during night is banned in most maritime states under MFRAs.

viii. Mesh size regulation for major gears engaged in IOS fishing is mentioned in the MFRAs and follow up amendments.

Based on the review and results of the present study and considering the importance of the IOS fishery to the the marine fisheries sector of the country in terms of volume, value, employment generation and food security; the following measures are suggested in addition to those already in place for sustainable IOS fisheries:

i. Optimum fleetsize of different craft/gear categories engaged in IOS fishing needs to be estimated and overcapacity issues have to be addressed.

ii. The optimum boat length to engine hp ratio may be adopted.

iii. Optimum gear size to craft length (as per the craft-engine combination recommended by ICAR-CIFT) needs to be strictly followed.

iv. Fishing licenses should clearly specify the gear that may be operated in mechanized craft.

v. Innovations in fishing method/ modifications of the gears may be permitted only after approval from the Fisheries Department before it is put to commercial practice.

vi. During years of low abundance of IOS, seasonal landing limits to be reintroduced, effort (number of units as well as fishing trips per unit) to be further regulated and MLS may be raised to 14 cm.

vii. Targeted fishing for oil sardine may be limited or closed partially during the peak El Niño years depending on the biological conditions of the species such as growth retardation, poor gonadal development to preserve future spawners.

viii. Fisheries institutions may closely monitor the occurrence and intensity of El Niño along the Indian coast and forewarn the potential adverse impact on the IOS fishery in areas of high risks.

ix. Technology enabled (echosounder fitted) fishing boats to avoid capture of IOS juveniles.

x. ITKs from traditional fishers (ban on night fishing, fishing during monsoon) may be incorporated in fisheries management advisories.

xi. Optimum mesh size suggested for each gear type has to be strictly enforced. The use of square mesh codends in fish trawls to be made mandatory.

xii. Updates and advisories on IOS stock health to be provided by research institutes to stakeholders from time to time to enable them to take appropriate actions.

xiii. Post harvest facilities, market linkages and cold chains to be improved to ensure that the IOS reaches the consumers in good condition.

xiv. Fish oil and fish meal plants largely depend on IOS as raw material irrespective of its size or condition (partially or completely spoilt). This marketing avenue has been the driving force for targeted fishing for IOS in all the maritime states. Therefore the following points may be addressed as in National Policy on Marine Fisheries (NPMF), 2017:

    a. Establishment of new fishmeal and fishoil plants dependent heavily on IOS must be permitted only after careful consideration of the availbility and stock health of the resource.

    b. Production quotas based on the capacity of existing fishmeal plants may be fixed.

    c. A minimum price for IOS that is procured by the plants as raw material may be fixed, to ensure a fair deal for the fishers and encourage a healthy demand supply chain.

xv. A precautionary approach, with regular reviews of the fishery and sound management practices would ensure the continued wellbeing of this imporant fishery.

xvi. IOS is a plankton grazer and inturn is an important prey for larger carnivores and predators. To ensure that fisheries do not compromise the wider biodiversity and functioning of marine ecosystems, an Ecosystem Approach to Fisheries Management (EAFM) may be adopted to ensure longterm fisheries sustainability across a broader range of species and the ecosystem.

xvii. Co-management with the participation of all stakeholders in the supply chain, from producer to consumer including the auxiliary industries such as fishmeal plants would result in better management, monitoring, optimum utilization and conservation of the IOS stock.

14. Future research plans

The document gives a detailed account of the IOS fishery and advisories that are to be adopted for resource sustainability. However, further studies on the following lines need to be taken up to monitor the fishery and resolve some of the questions that still remain unanswered so that the IOS fishery is well managed and a forecasting system is devloped:

Detailed analysis of diet of IOS, phytoplankton, picoplankton coupled with *in situ* fishery surveys to understand the relationship that exists between availability of suitable food in the sea and the success of fishery.

Complete life history and related habitats of the IOS needs to be studied so that seasonal MPAs may be declared in the critical spawning areas.

Identify and map the spawning /nursery grounds through egg/larval surveys.

In situ growth studies to be conducted in confined environment to sort out the ambiguities regarding growth parameters obtained from otolith imaging and length frequency analysis.

Disruptions in spawning and gonad development and the reasons thereof have to be studied in detail.

Detailed studies on migration of oil sardine using modern methods may be taken up.

Stock characterization using advanced genetic tools to be continued.

The enigma on fluctuations observed in IOS landings if resolved would lead to the development of a sound forecasting fishery model, which would immensely benefit the small-scale fishers whose income is depenedent on this dominant species. This document provides insights not only for a sustainable future for IOS fishery but also for the nutritional and financial security of the coastal dwellers.

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Annexure I

Landing trend of Indian Oil Sardine and contribution by different gears

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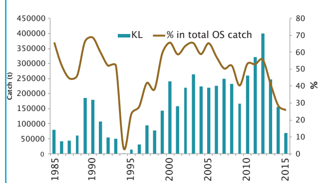
<tr><td>KL</td><td>
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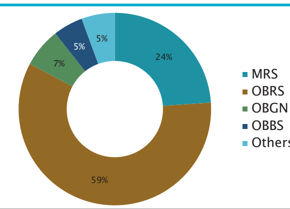
</td><td>
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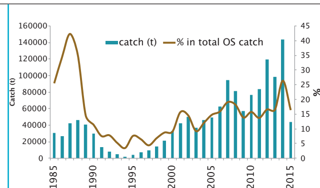
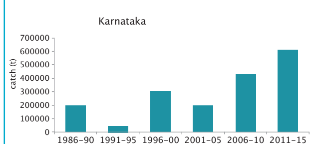
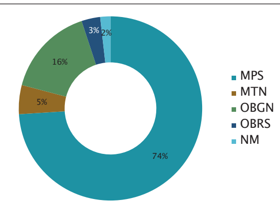
<tr><td>KA</td><td>
</td><td>
</td><td>
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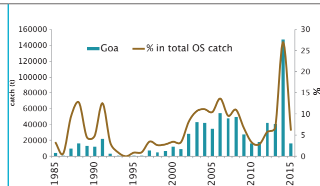
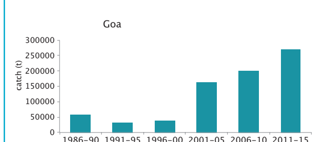
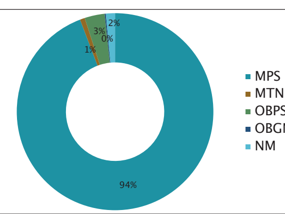
<tr><td>GO</td><td>
</td><td>
</td><td>
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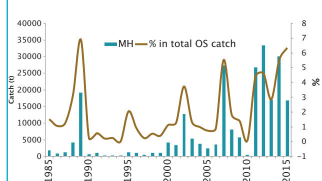
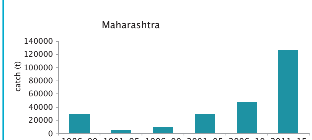
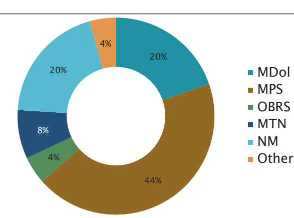
<tr><td>MH</td><td>
</td><td>
</td><td>
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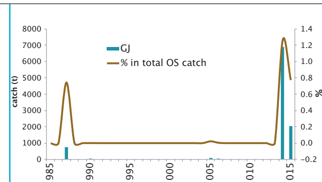
<tr><td>GJ</td><td>
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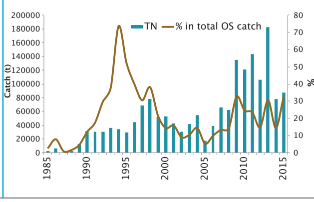
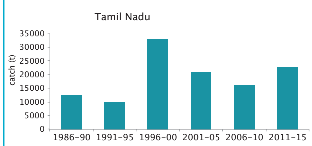
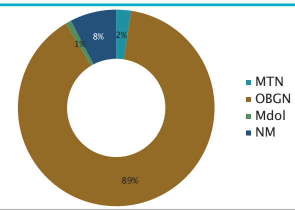
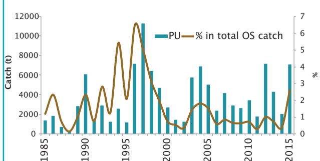
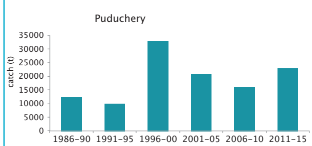
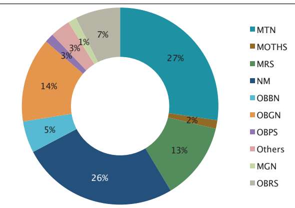
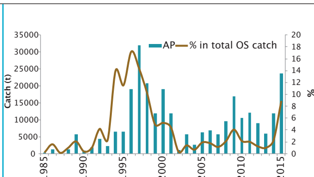
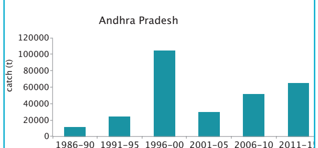
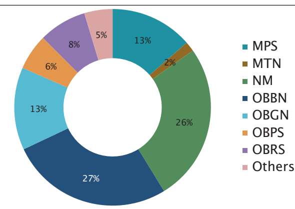
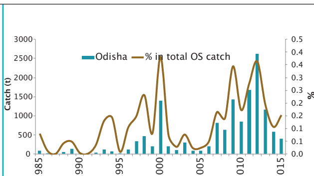
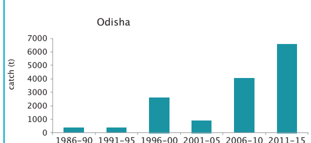
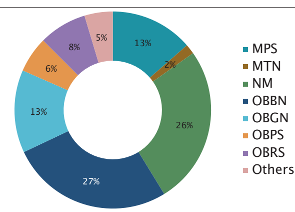
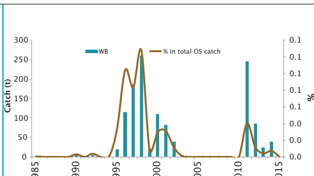
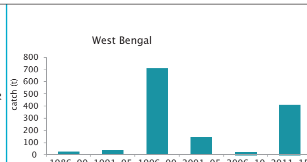
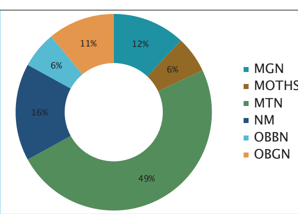
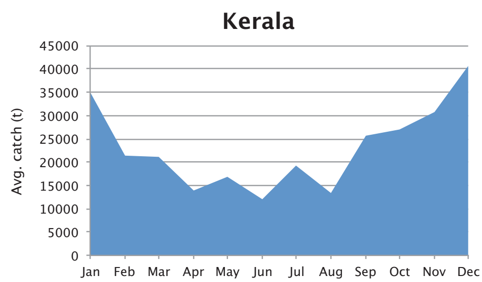
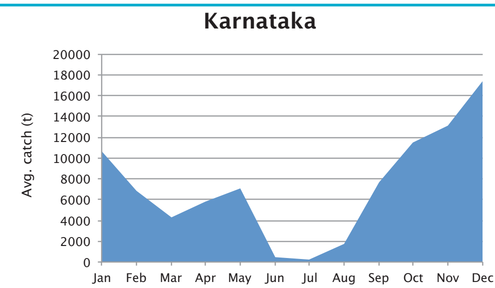
TN			
PU			
AP			
OR			
WB			

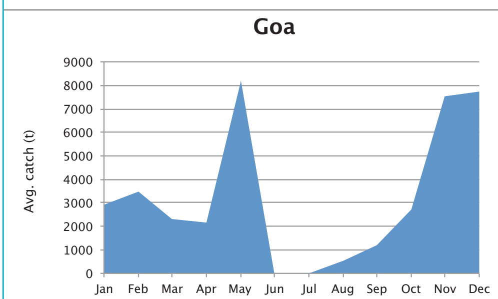
Annexure II

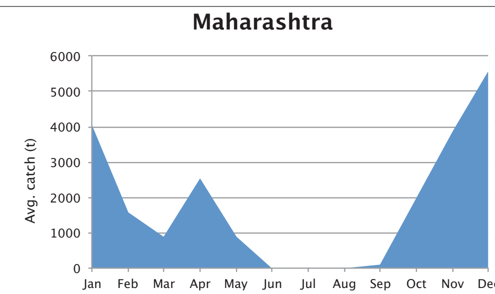
Seasonal patterns in Indian Oil Sardine landing along the Indian coast

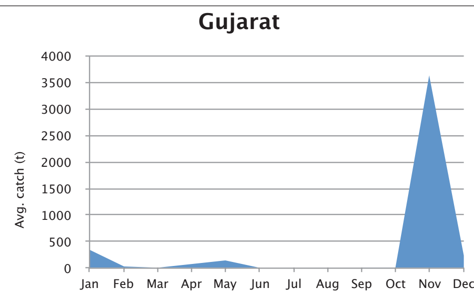
West coast



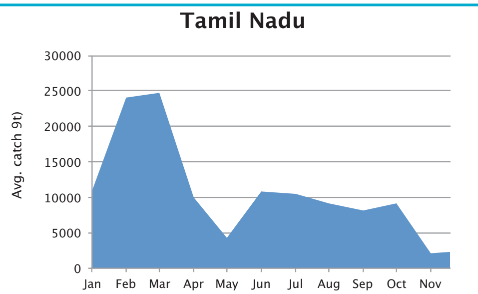


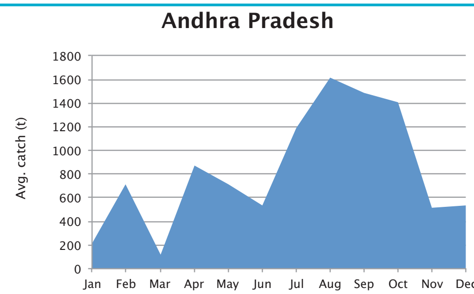


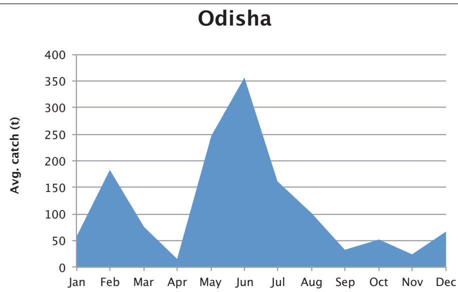




East coast

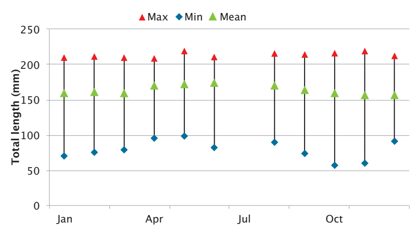
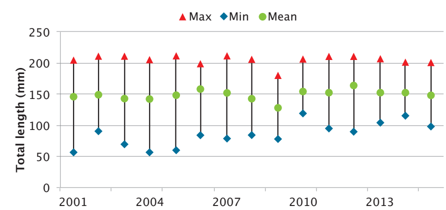
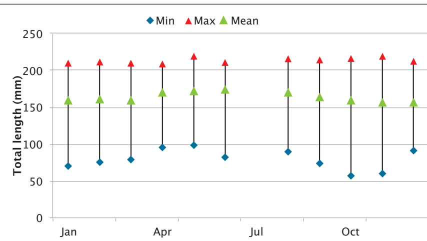
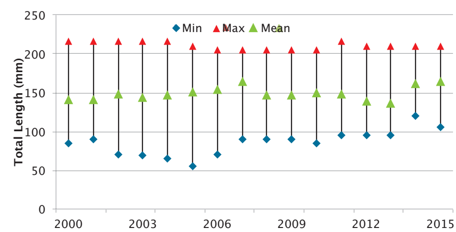
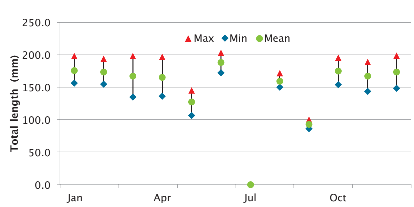
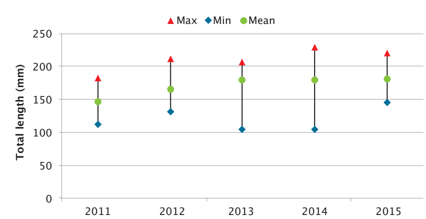
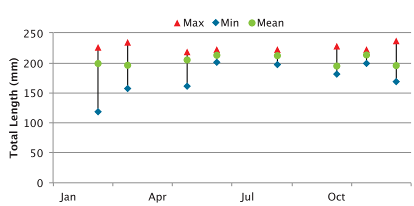
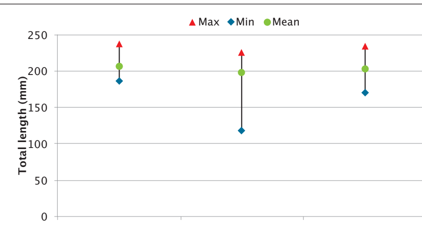

Tamil Nadu
Avg. catch 9t)
30000
25000
20000
15000
10000
5000
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov

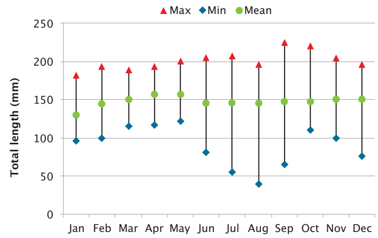
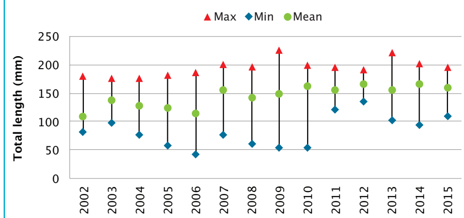

Andhra Pradesh
Avg. catch (t)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


Odisha
Avg. catch (t)
400
350
300
250
200
150
100
50
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Annexure III

Size range and mean (TL in mm) of the Indian Oil Sardine

State	Monthly length range (mm)	Annual length range (mm)
KL		
KA		
MH		
GU		

<table>
<tr><th>State</th><th>Monthly length range (mm)</th><th>Annual length range (mm)</th></tr>
<tr><td>TN</td><td>
</td><td>
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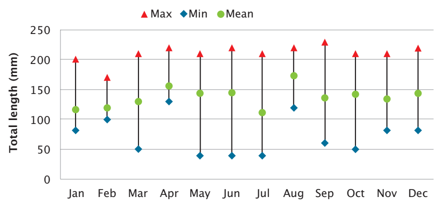
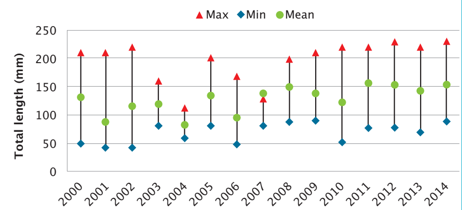
<tr><td>AP</td><td>
</td><td>
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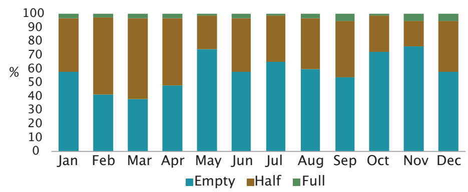
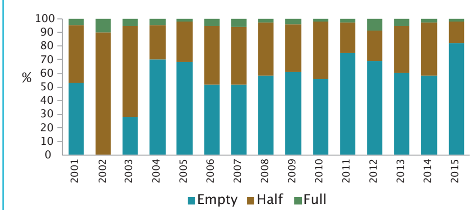
Annexure IV

Annual and average monthly quantitative assessment (feeding intensity) of Indian Oil Sardine in various maritime states

<table>
<tr><th>State</th><th>Average monthly feeding intensity</th><th>Annual feeding intensity</th></tr>
<tr><td>KL</td><td>
</td><td>
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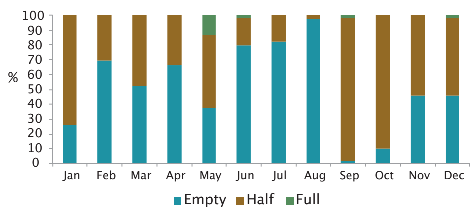
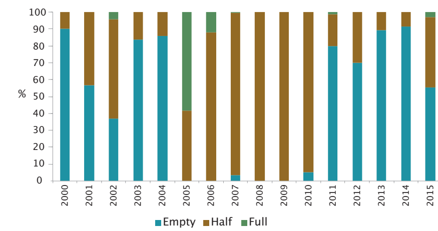
<tr><td>KA</td><td>
</td><td>
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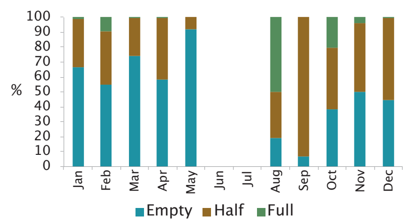
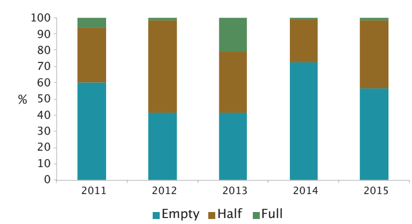
<tr><td>MH</td><td>
</td><td>
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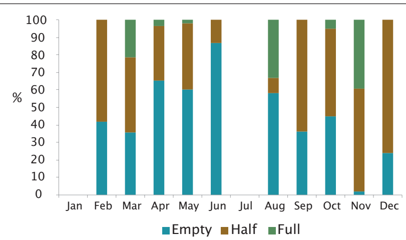
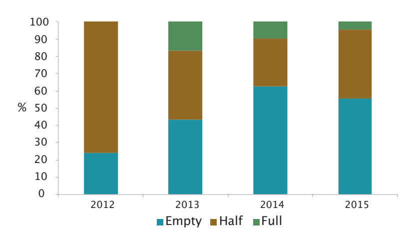
<tr><td>GU</td><td>
</td><td>
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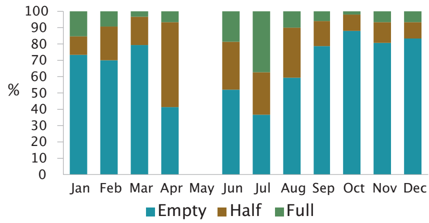
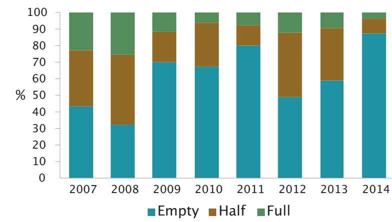
<table>
<tr><th>State</th><th>Average monthly feeding intensity</th><th>Annual feeding intensity</th></tr>
<tr><td>TN</td><td>
</td><td>
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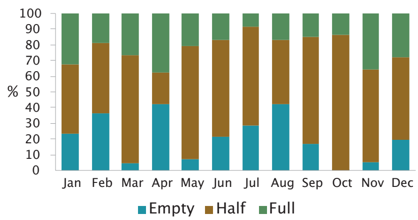
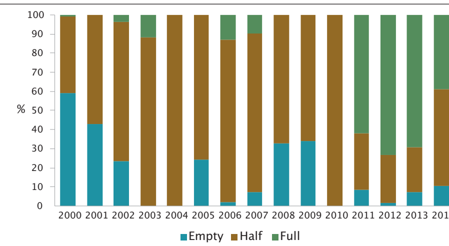
<tr><td>AP</td><td>
</td><td>
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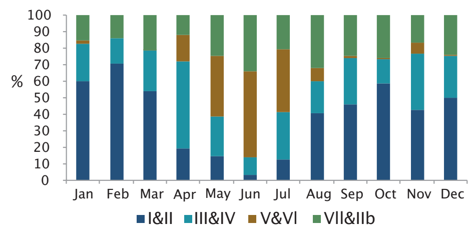
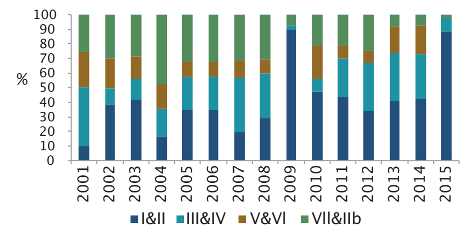
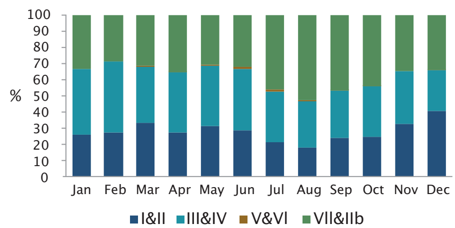
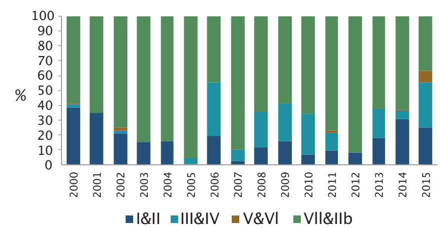
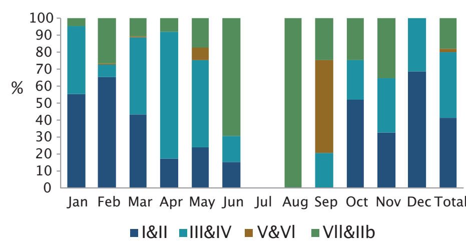
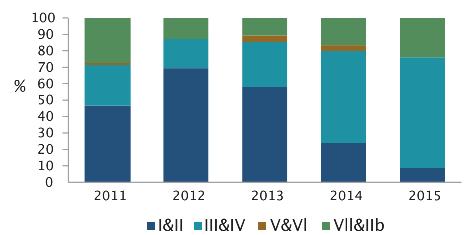
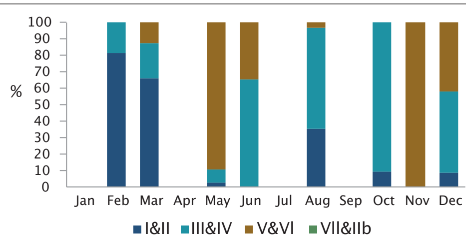
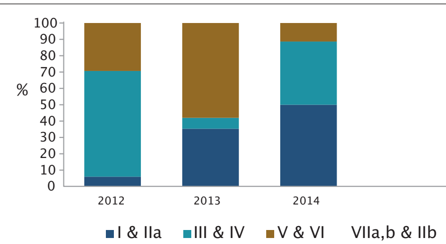
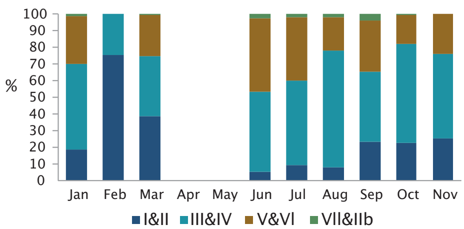
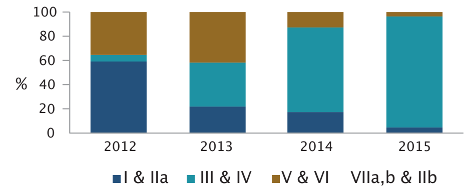
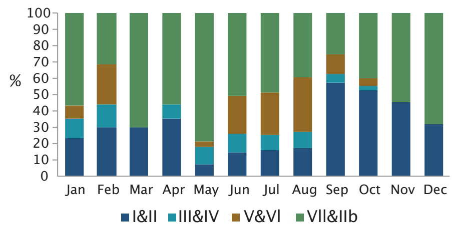
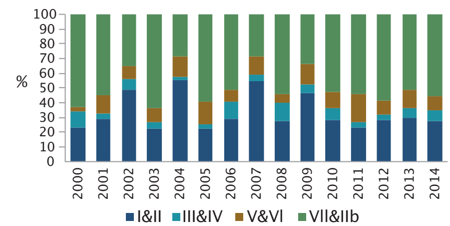
Annexure V

Annual and average monthly quantitative assessment (maturity stages) of Indian oil sardine in various maritime states

State	Average Monthly maturity stages	Annual Maturity stages
KL		
KA		
MH		
GU		

State	Average Monthly maturity stages	Annual Maturity stages
TN		
AP		

A poet's lamentation on Indian oil sardine (In Malayalam)

മത്തീ നിനക്കെന്തുപറ്റി?

ഡോ. സി. രാമചന്ദ്രൻ, ളാക്കാട്ടൂർ (Principal scientist, CMFRI, Kochi- 18)

മത്തീ നിനക്കെന്തുപറ്റി – എന്റെ
മത്തീ നിനക്കെന്തുപറ്റീ?!
ഉത്തരം തേടി ഞാൻ ശാസ്ത്ര വിജ്ഞാനത്തി
നുത്തുംഗ കേന്ദ്രത്തിലെത്തി ...... !
"മൊത്തത്തിലുച്ചത്തിലൊന്നു ചിന്തിക്കിൽ
അച്ചുതാ, ശങ്കകളേറെ.
എങ്കിലും ചൊന്നിടാം ഓരോ പ്രകാരത്തി
ലെങ്കൾക്കു ബോധിച്ച പോലെ . . . . .
ചാളയെന്നും വിളിപ്പേരുള്ള മത്തിയെ
ചാലേയറിവതിന്നാദ്യം
ശാസ്ത്രീയനാമമതെന്തന്നറിക നീ
ബോധമൊന്നും പോകവേണ്ട !
സാർഡിനെല്ലാ ലോഞ്ചിസെപ്സെന്ന് ലാറ്റിനിൽ
ചാളക്ക് ശാസ്ത്രീയ നാമം,
നീണ്ട തലയുള്ള മത്തിയെന്നർത്ഥത്തിൽ
പേരിട്ടതോ വാലൻസിയെൻസ്സും[1]
വാച്ചമോദത്തിൽ കടൽപ്പരപ്പിൽ നീണ്ട
കാഴ്ചയായ് നിന്നതിന്നാലോ
ചേർച്ചയിൽ 'മത്സ്യ'[2]മെന്നാദ്യ-
മുരച്ചതിൻ മൂലമോ മത്തിയാം ശബ്ദം?
മിന്നുന്നതൊന്നിനെ മീനെന്ന് നിർണ്ണയം
ചൊന്നതോ വെൺതമിഴ്ഗാത്രം
വേദമന്ത്രപ്പൊരുൾ[3] കോർത്തവരാ-
മോദമേറെക്കഴിച്ചിരുന്നെന്നോ?
ഉത്തമാംഗത്തിനും ഹൃത്തിനും മത്തിയൊ
രുത്തമ[4]മെന്നവർ കണ്ടു.
പാരം പരവശനായ് മുനി നീട്ടിയ
നാരായ വേരാണ് മത്തി!"
'ഒത്തോരവതാരമൂർത്തിയായ് വാഴിച്ച
മത്തിക്കിതെന്തോന്നുപറ്റി?
പേരു പെരുമയും 'വിക്കി'[5]യിലുണ്ടെടോ
കാരണമെന്തെന്നു ചൊല്ലൂ'
"പേരും പെരുമയുമൊക്കെ പഠിപ്പത്
കാരണത്തിൻ വഴിത്താര്
കാര്യമറിയാതെ കാരണമില്ലെടോ
കാറാതെയൽപം ക്ഷമിക്കൂ . . . .

ഞാറ്റുവേലക്കാറ്റ് മൂപ്പിച്ചപൊന്നുകൾ
പാറ്റുവാൻ വന്നു പായ്ക്കപ്പൽ
ആഴക്കടൽ താണ്ടിത്തീരമണയുവാൻ
ഊഴം ഗണിച്ചവരെന്നാൽ
ആഴിപ്പരപ്പിൽ നിറഞ്ഞ പുലപ്പി[6]നാൽ
ആവാതെ നാവികർ നിന്നൂ[7]!
കരപോലെ തന്നെ കടൽപ്പരപ്പായ് നല്ല
തിരയായ് ഘനം വെച്ച മത്തി
അരിമണിക്കും പോലുമില്ലയീനാട്ടിലി-
ന്നൊരുകാല വൈദോഷമെത്തി.
വാഴ്ന്നുവോനല്ലയോയേറെ നാളെങ്ങളാ
മേഴകൾ തൻ മാംസ്യതോഴൻ,
ആരോ വിളിച്ചു ‘കുടുംബം പുലർത്തി’യെ-
ന്നാരോമലേയതുസത്യം!
ശ്രീമൂല വൈഭവാലാമസോണിൽ നിന്നു-
മാമൂലമെത്തിയീ നാട്ടിൻ
ദാരിദ്ര്യശോകമകറ്റും മരച്ചീനി-
യാരുദ്രമിന്നങ്ങു നിൽപൂ!
(നളനഷ്ട ദുർഭഗം പേർത്തുപഴിക്കുന്ന
ദമയന്തിയെന്ന കണക്കേ!)
തെങ്ങിന്റെ മൂട്ടിലൊരിക്കൽ വളമായി
മങ്ങിയ ചാളക്ക് മോക്ഷം
നൽകിയതോ സ്നേഹകമ്പോള[8]മുള്ളതിൽ
പുൽകിയ ധ്വര തന്റെ ബുദ്ധി!
പിന്നെ മലബാറ് കണ്ടതോ ചാളതൻ
പൊന്നൊലുക്കൊത്ത ദിനങ്ങൾ
ചാളത്തടികളിൽ പോയവർ പോയവർ
ചാലേ നിറച്ചൂ വലകൾ
കോളൊത്തു വന്നതിൻ സ്നേഹപ്രവാഹത്തിൽ
മാലോകരാമോദമാളീ!
പുന്നക്കയും നല്ല കൊപ്രയുമാട്ടുന്ന
മണ്ണിൽ നിറഞ്ഞു മീനെണ്ണ
എണ്ണകയറ്റി ബേപ്പൂരിന്നുരുവുകൾ
എണ്ണമില്ലാതാഴി താണ്ടി
എത്തി ‘ഡേ’[9] മൽസ്യകുടുംബ ചരിതത്തിൻ
പുസ്തകമാദ്യം രചിച്ചൂ
ഉത്തരദേശക്കടലുകൾ നേരിട്ട
വർദ്ധിച്ച ചൂഷണം കണ്ടു.
മത്തിയില്ലാതെയായ് ഒത്ത ദുരാഗ്രഹ
ചിത്തം വെടിഞ്ഞു വിവേകം
കത്തിപ്പിടിപ്പിച്ച് വേണ്ട നിയന്ത്രണ-
തത്വങ്ങളൊന്നായ് മൊഴിഞ്ഞു.
കണ്ണിവലിപ്പം[10] വളർക്കെ കുറയ്ക്കയാ -
ലുണ്ണികളില്ലാതെ വന്നു
ഉണ്ണുവാനില്ലാതെ മറ്റിനം മീനുകൾ
കണ്ണുവെട്ടിത്തരം പാത്തു.
ഒന്നുമറ്റൊന്നിനെത്തിന്നുന്നൊരാഴിയിൽ
വന്നൂ ദുരന്തങ്ങളൊന്നായ്
ചിന്നുമുഡുക്കൾ മനുഷ്യകുലത്തിന്റെ
‘ഉന്നതി’ കണ്ടു രസിച്ചു!
മാറും ഋതുക്കൾ തൻ തോളത്തു കേറിയാ -
ണോരോ ത്ധഷവും ചരിപ്പൂ
കാലപ്രവാഹവും നീരൊഴുക്കിന്നൊത്തു
ചാലിച്ചതല്ലേ പൊലപ്പും ?
വഞ്ചി, വലയതുമൊക്കെയെടുത്തു നൽ-
തഞ്ചവും നോക്കി പ്രയാസാൽ
വെള്ളത്തിലഭ്യാസ പാടവത്തിൽ തിര-
ത്തള്ളലിൽ കൊല്ലലിന്നായി
കയ്യും തലയും മറന്ന് വലപ്പാട്
പെയ്യും പെയ്ത്തൊക്കെ നോക്കി
ഹയ്യാ വലിച്ചോ തിരിച്ചോ വലിച്ചോന്ന്
കൊയ്യുന്നതാണിന്നു രീതി
കുഞ്ഞനും പൊണ്ണനും തന്തയും തള്ളയും
ഒന്നൊഴിയാതൊക്കെ വാരി
കഞ്ഞിക്കരിയെന്ന പേരും പറഞ്ഞിട്ട്
ഞഞ്ഞഞ്ഞ പിഞ്ഞഞ്ഞ കഷ്ടം!
പൊന്നുതരുന്നൊരാത്താറാവിനെ-
യിന്നു കൊല്ലരുതെന്ന് പറവാൻ
വിണ്ണിലെ മായിക കാവ്യ പ്രവാചകർ
മണ്ണിലേക്കെന്നൊന്നിറങ്ങും?
പൊടിമീനുമില്ലാതെയായപ്പൊഴല്ലയോ
കൊടിയതാം തന്ത്രങ്ങൾ പാർത്തൂ!
കൊല്ലിവലകൾ നിരോധിച്ചുകൊണ്ടുള്ള
നല്ലോരെഴുത്തോല വന്നു
നാടുകൂടിക്കടക്കോടതി[11] വെച്ചാറേ
പാലിച്ചിടാൻ സ്വയം ചട്ടം
ഓടങ്ങളാഴിയിൽ പോകാൻ ദിനങ്ങളും
ജാല[12]തിൻ കണ്ണിക്കരുത്തും
ഏതേതുമേതൊക്കെയെന്നും പിഴയ്ക്കായി
ഏകേണ്ടതെത്രയാണെന്നും
തീരുമാനങ്ങളെടുത്തവർ ധീവരർ
ശ്രീ കുരുംബാപാദമൂലേ

II

വിട്ടുപോകിന്ത്യയെന്നുച്ചം മുഴങ്ങവേ
കെട്ടഴിഞ്ഞു ജാക്ക്[13] നാട്ടിൽ
വർണ പതാകയുയർന്നു., തിടം വെച്ചു
ധർണകൾ, ചട്ടമഴിഞ്ഞു.

III

വാർത്ത പടർന്നതാ തീരത്തുറകളിൽ
‘‘മത്തി അപ്രത്യക്ഷമായി!’’
ചാത്തന്റെ കോപമോ മൂത്തോത്തിയാർക്കുള്ള
ചാർത്ത് പിഴച്ചതോ പാരിൽ ?
കാലിയായ് മത്തിയമേരിക്ക തന്നിലെ
കാലിഫോർണ്യാവിലും ഓർത്താൽ
കോലാഹലം പിന്നെയെന്തിന്നു കൂടണം
കോലത്തു നാട്ടിലെ മൂഢാ!
പത്തു പതിനൊന്ന് വർഷങ്ങൾ കൂടുമ്പോൾ
മത്തികാട്ടുന്നൊരീക്കൂത്തിൻ
ഒത്തരഹ്യമറിയുന്നതിന്നായി
ഒത്തുകൂടി ശാസ്ത്ര വൃന്ദം.

വൃദ്ധിക്ഷയങ്ങൾ തൻമൂലമറിയുവാൻ
ശ്രദ്ധയോടെ ജീവചക്രം
മൊത്തമഴിച്ചു കഠിനം പഠിച്ചവർ
ശുദ്ധശാസ്ത്രത്തിന്റെ തോഴർ[14]
തീറ്റയും[15], ചാറ്റലും, സൂര്യ കല[16]യുമായ്
കൂട്ടിസിദ്ധാന്തങ്ങളെത്തീ
കാറ്റിന്റെ മുന്നിൽ കരിയിലയെന്നപോൽ
ഏറ്റമില്ലാതാർത്തു മത്തി!
പാണ്ടിനാടും പിന്നെ ദൂരെയൊമാനതും
താണ്ടി നാട്ടിൽ ചാളയെത്തീ
ആഗോള താപനമാണെന്നു ചൊന്നവർ-
ക്കാകവെ ഹാലൊന്നിളകീ!
തെല്ലുപോലും ബാക്കിവെക്കാതെ വാശിയിൽ
ജെല്ലികൾ[17] തിന്നതാണെന്നും
അല്ലിടവപ്പാതി പറ്റിച്ചതാണെന്ന്
ചൊല്ലുവോരും കുറവില്ല . . . .

IV

കരനീരു[18] നോക്കിപ്പുലപ്പു സ്വപ്നം കണ്ട്
കരയുന്ന മീനാളനൊപ്പം
അരികത്ത് ശ്വാസമടക്കിയരുമയായ്
ഉരയുന്നു മത്തി രഹസ്യം
‘‘ബാറുകൾ പൂട്ടിയ കേരളതീരത്ത്
ബോറാണു ജീവിതം, ഇഷ്ടാ
ചാറിനുപോലും വരില്ല ഞങ്ങൾ
അറുബോറാണിവിടം, വരട്ടേ!!’’

കുറിപ്പ്:

1. *Sardinella longiceps* (Valenciennes, 1847)
2. മദി ഹർഷേ ഇതി മത്സ്യ (തത്വമസി, പേജ് 157)
3. ഋഗ്വേദത്തിൽ ‘മീൻ’എന്ന പ്രയോഗം
4. ഒമേഗാ-3- ഫാറ്റി ആസിഡുകളുടെ കലവറ യാണ് മത്തി
5. വിക്കിപ്പീഡിയ
6. മീൻകൂട്ടം (മീനാളരുടെ ഭാഷ)
7. 1320-ൽ സിലോൺ തീരത്തു വന്ന (ഫിയോ ഓ ഡോറിക്കിന്റെ അനുഭവസാക്ഷ്യം-ഫ്രാൻസിസ് ഡേ. 1865. ഫിഷസ് ഓഫ് മലബാർ p.viiii)
8. ബ്രിട്ടീഷ് ഭരണകാലത്തെ വർദ്ധിച്ച മീനെണ്ണ കയറ്റുമതി
9. ഫ്രാൻസിസ് ഡേ (Francis Day)
10. വലക്കണ്ണിയുടെവലിപ്പം (mesh size)
11. കടൽക്കോടതികൾ മലബാറിൽ ഇന്നുമുണ്ട്
12. വല
13. യൂണിയൻ ജാക്ക്
14. ഡോ. ആന്റണി രാജ, ഡോ.ചിദംബരം, ഡോ. ബാലൻ, ഡോ. യോഹന്നാൻ തുടങ്ങിയവരെ അനുസ്മരിക്കുന്നു.
15. പ്ളവകങ്ങൾ (planktons)
16. Sunspot Activity
17. ജെല്ലി ഫിഷ്
18. Ocean current

A poet's lamentation on Indian oil sardine
What ails thee, Oh dear Sardine?

by C. Ramachandran (Principal scientist, CMFRI, Kochi- 18)

"What ails thee Oh dear Sardine
What ails thee? What ails thee?"

It was In search of an answer
Did I seek the lofty researcher-
"Abound though reasons many
Its legends still worth a litany"

Known in God's own country as "mathy"or chala
May be the former rooting for "matsya"[1]
Someone watching a sea full, thick and vast-
"The why" thy name was stuck in the past.

Vedas mention "meen" too for fish
Borrowed perhaps, from the world of Tamil
"That which glitters" yelled the ascetic Rishi
Did their taste buds turn equally mushy?

Good for the head and heart they found
If not, how the lass[2] caught him spellbound!"
(Is Artedi of the Vyasa lineage?
Is "Ich-the(y)ology" of an Indian heritage?)

"Wiki has these and other stories in plenty
Like, the fish was the Lord's first avatar
But waste not my time as if we are in a bar
Tell me straight why my fish went so scanty"

"Essential my friend , a deep sense of history
Before you fathom a fallen fishery

"Well behind, long ago, the monsoon clouds
Afar came a boat full of sailors and traders
And Lo, they had to wait for days off the bay
For It was sardines all their way[3]…..

Such was our seas with sardines so abundant
It's our bad fate, and times my dear friend
She lost the glory ; we hope she's still fecund
To redeem thy sobriquet, as the destitute called,
"Home maker" of the masses, from times untold

Oh See the cassava so much never in agony-
Like a forlorn Nala who lost his Damayanthi!
Remember, the king's gift that was shipped from Amazon
That kept for long the famines off our zone-

For a long time used as a manure mere
She did come out of an outcast stock
When gone were the whales ; driven by the oil shock
Let us thank the British manoeuvre sure

Like Mushrooms soon spawned on the Malabar coast
Oil extractors for export , with salt and fast
That made the coast rich and jubilant
Sardine the white gold; and fisherfolk triumphant.

Those "Urus" from Beypore used to sail coconut oil
Ferried fish oil instead ,without fail
Never were fishing done with so much fury
That other traders wilted by the sardine jamboree

Then to sketch fishes came a surgeon Day4
A marvel we fish scholars refer even today
Seen the Wick's herring cross the finishing line
Suggested he ways to keep it at bay

Fishing done without a break for the fish
Saw the nets narrow the size of the mesh
Soon all themselves were found in a mess
Stochastic playing a game of chess
Or Was it a game of snake and ladder
Destiny if, en masse you fish the harder

Dancing on the shoulders of mighty seasons
No Fish can wait for human survival reasons

It is Nature that sets the aquatic rhythm
Rules that a trillion of our neurons can't fathom
Even by robots that shuttle Moon or Mars
On life under water , are we still an ass!

Fish for fishers is a hope against hope
Bereft of the hope you cease to be one
Sea makes them blind, tomorrow never on top
Stone age genes wrecking John to John[5].

While the flying Jack counted days to quit
Sardine threw the fishermen out of wit
There came experts and Commissions to study
To mend ways to make the harvest steady

British thus banned the "mass-killing net"
Catching the "babies" made illegal quiet[6]
For, playing truant was the iconic clupeid
Though fishermen felt their wings were clipped

But the wise fishers thought otherwise
Their own court[7] declared overfishing a vice
Those hesitant to comply risked a wrath divine
As if, where science fumble let faith intervene …
Word of the Raj and word of the god
Did save the sardines, hand in hand
Inscrutable are the ways of the clupeid
Mid nineties came again the vanishing prank

Puzzled all , but there was'nt much furore
As it happened a decade or so later
"Collapse" grabbed all the press headlines
Hooked on the beach they ripped their fate lines

Latched on a newly found solidarity[8]
Fishers pondered the serendipity
Which in fact was a circularity[9]
Scholarly so viewed a minority

Warming seas to teeming jelly fish
Pundits waged an erudite skirmish
It is finishing that we do; and not fishing
"Catch less care more" will see ourselves thriving
Many pressed the bells of an ichthyo- famine
And a few found the argument utterly mean
'Five percent protein and the rest big politics"[10]
Back came the clupeid; braiding a new aesthetics-
Aping the tragedy of an iconic cod
An Elegy I planned but penned an ode!!!!!

Notes

1. "mada ithi harshayathe ithi matsyaha" (that which is frolicking in water) goes the etymology in Sanskrit.
2. Sathyavathy, who seduces Parasara Rishi parenting Vyasa
3. Experience of Friar Odoric (1320) quoted by Day (1865)
4. Francis Day , author of Fishes of Malabar
5. John Cleghorn, (1854) UK, who coined the term Overfishing, John Crosbie, fisheries minister who declared moratorium for the Canadian Cod (1992)
6. Devanesan, D.W. 1943. 'A Brief Investigation into the Causes of the Fluctuation of the Annual Fishery of the Oil-Sardine of Malabar, Sardinella Longiceps
7. Kadakkodathy of Malabar coast (Ramachandran,2006)
8. Events Post –Meenakumari Commission Report
9. Mc Clatchie et al 2017.
10. Editorial in Science after the cod fishery collapse

Acronyms/Abbreviations

Acronyms	Abbreviations
ANOSIM	Analysis of Similarities
A&N	Andaman and Nicobar
AP	Andhra Pradesh
ASCAT	Advanced Scatterometer
ASWP	Arabian Sea Warm Pool
B	Biomass
Bcurr	Current Biomass
BMSY	Biomass at Maximum Sustainable Yield
CF	Condition Factor
CGR	Compound Annual Growth Rate
Chl *a*	Chlorophyll a
CIFT	Central Institute of Fisheries Technology
CI	Confidence Interval
Cm	Centimeter
CMFRI	Central Marine Fisheries Research Institute
CMSY	Catch-MSY
CPUE	Catch Per Unit Effort
CO2	Carbon dioxide
COI	Cytochrome C Oxidase I
DHA	Docosahexaenoic Acid
DNA	Deoxyribonucleic Acid
E	Exploitation rate (F/Z)
EAFM	Ecosystem Approach to Fisheries Management
EC	East Coast
Ecurr	Current Exploitation ratio
Emax	Maximum Exploitation ratio
Emsy	Exploitation ratio at MSY level
ENSO	El Niño Southern Oscillation
EPA	Eicosa Pentaenoic Acid
Eopt	Optimum Exploitation ratio
ERS	European Remote Sensing
FAO	Food and Agricultural Organization
F	Fishing Effort
F	Instantaneous rate of fishing mortality
FiSAT	FAO-ICLARM Stock Assessment Tools
FMSY	Fishing mortality at Maximum Sustainable Yield
FSCR	Fishermen’s Share in Consumers Rupee
G	Gram/s
GJ	Gujarat
GMM	Gross Marketing Margin
GO	Goa
GSI	Gonado Somatic Index
HL	Head Length
HYD	Hydrated
IBRS	Inboard Ring Seines
ICAR	Indian Council of Agricultural Research
ICES	International Council for the Exploration of the Sea
ICOADS	International Comprehensive Ocean Atmosphere Data Set
IMD	Indian Meteorological Department
IOD	Indian Ocean Dipole
IOP	Index of Preponderance
IOS	Indian Oil Sardine
IPCC	Intergovernmental Panel on Climate Change
K	von Bertalanffy Growth coefficient
KA	Karnataka
Kg	Kilogram
KL	Kerala
Km	Kilo meter
KMFRA	Kerala State Marine Fishing Regulation Act
L∞	Asymptotic length
Lc	Length at first capture

LF	Length Frequency
Lm	Length at first maturity
Lmean	Mean Length
Lmin	Minimum Length
Lmax	Maximum Length
Lopt	Optimum length for capture
Lr	Length at recruitment
Lrange	Length range
Lt	Length at age t
M	Instantaneous rate of natural mortality
MDOL	Mechanized Dol Net
MDT	Multi-Day Trawl
MEI	Multivariate ENSO Index
M:F	Male: Female ratio
MFRA	Marine Fishing Regulation Act
Mg	Milligram/s
MGN	Mechanized Gillnet
MH	Maharashtra
MLS	Minimum Legal Size
MOTHS	Other Mechanized Gears
MPA	Marine Protected Area
MPS	Mechanized Purse Seine
MRS	Mechanized Ring Seine
MSY	Maximum Sustainable Yeild
MTN	Mechanized Trawl Net
MUFA	Monounsaturated fatty acids
NM	Non mechanized
NE	Northeast
NW	Northwest
OAL	Overall Length
OBBN	Outboard Bagnet
OBBS	Outboard Boat Seine
OBDOL	Outboard Dol net
OBGN	Outboard Gillnet
OBM	Outboard Motorised
OBOTHS	Other outboard fitted crafts
OBPS	Outboard Purse Seine
OBRS	Outboard Ring Seine

OC-CCI	Ocean Colour Climate Change Initiative
OD	Odisha
ONI	Ocean Nano Index
PCA	Principal Component Analysis
PC	Principal Component
PD	Puducherry
POF	Post Ovulatory Follicles
PUFA	Poly Unsaturated Fatty Acids
RSSB	Recruitment-Spawning Stock Biomass ratio
RTT	Real Time Temperature
SBI	Size Based Indicators
SE	Southeast
SFA	Saturated Fatty Acids
SFM	Size at First Maturity
SL	Standard Length
Sp.	Species
SODA	Simple Ocean Data Assimilation
SST	Sea Surface Temperature
SpSB	Spawning Stock Biomass
StSB	Standing Stock Biomass
SRS	Satellite Remote Sensing
SW	Southwest
T	Ton
t0	Age at zero length
TL	Total Length
TMFL	Total Marine Fish Landings
TN	Tamil Nadu
UPI	Upwelling Index
VPA	Virtual Population Analysis
WB	West Bengal
WC	West Coast
WMO	World Meteorological Organisation
$W\infty$	Asymptotic weight
Y	Yield
Y/R	Yield per recruitment
Z	Instantaneous rate of total mortality

Legend to Figures

Legend to Plates

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An Insight

The Indian Oil Sardine supported by single species and accounting for the bulk of the marine fish catch dictates the marine fishery landings trends of the Country. This small pelagic fish despite its capricious nature, occupies a unique and significant position in the social and economic structure of the coastal fishers. However, the reason leading to sudden fluctuations with its staggered effects on the multiple stakeholders dependent on the Indian oil sardine remains an enigma till date. This book provides an insight to the research work carried out in the county on the Indian oil sardine, reasons for the capricious nature and measures to be adopted to forecast the fishery and minimize impacts of unexpected fluctuations.

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