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ICAR Sponsored Winter School on

Structure and Function of the Marine Ecosystem: Fisheries

01 - 21 December 2017

Fishery Resources Assessment Division
ICAR-Central Marine Fisheries Research Institute
Post Box No. 1603, Ernakulam North P.O., Kochi-682 018
Kerala, India

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Course Manual

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FOREWORD

Marine ecosystems comprises of diverse organisms and their ambient abiotic components in varied relationships leading to an ecosystem functioning. These relationships provides the services that are essential for marine organisms to sustain in the nature. The studies examining the structure and functioning of these relationships remains unclear and hence understanding and modelling of the ecological functioning is imperative in the context of the threats different ecosystem components are facing. The relationship between marine population and their environment is complex and is subjected to fluctuations which affects the bottom level of an ecosystem pyramid to higher trophic levels. Understanding the energy flow within the marine ecosystems with the help of primary to secondary producers and secondary consumers are potentially important when assessing such states and changes in these environments.

Many of the physiological changes are known to affect the key functional group, *i.e.*, the species or group of organisms, which play an important role in the health of the ecosystem. In marine environment, phytoplankton are the main functional forms which serves as the base of marine food web. Any change in the phytoplankton community structure may lead to alteration in the composition, size and structure of the entire ecosystem. Hence, it is critical to understand how these effects may scale up to population, communities, and entire marine ecosystem. Such changes are difficult to predict, particularly when more than one trophic level is affected. The identification and quantification of indicators of changes in ecosystem functioning and the knowledge base generated will provide a suitable way of bridging issues related to a specific ecosystem. New and meaningful indicators, derived from our current understanding of marine ecosystem functioning, can be used for assessing the impact of these changes and can be used as an aid in promoting responsible fisheries in marine ecosystems. Phytoplantkon is an indicator determining the colour of open Ocean. In recent years, new technologies have emerged which involves multi-disciplinary activities including biogeochemistry and its dynamics affecting higher trophic levels including fishery. The winter school proposed will provide the insights into background required for such an approach involving teaching the theory, practical, analysis and interpretation techniques in understanding the structure and functioning of marine ecosystems from ground truth measurements as well as from satellite remote sensing data. This is organized with the full funding support from Indian council of Agricultural Research (ICAR) New Delhi and the 25 participants who are attending this programme has been selected after scrutiny of their applications based on their bio-data. The participants are from different States across Indian subcontinent covering north, east, west and south. They are serving as academicians such as Professors/ scientists and in similar posts. The training will be a feather in their career and will enable them to do their academic programmes in a better manner. Selected participants will be scrutinized initially to understand their knowledge level and classes will be oriented based on this. In addition, all of them will be provided with an e-manual based on the classes. All selected participants are provided with their travel and accommodation grants. The faculty include the scientists who developed this technology, those who are practicing it and few user groups who do their research in related areas. The programme is coordinated by the Fishery Resources Assessment Division of CMFRI. This programme will generate a team of elite academicians who can contribute to sustainable management of marine ecosystem and they will further contribute to capacity building in the sector by training many more interested researchers in the years to come.

A. Gopalakrishnan
Director
CMFRI

PREFACE

World marine fisheries are passing through a crisis due to stagnation in yield from capture, increased operational costs, reduced profitability, emerging concerns of sustainability, globalization, biodiversity loss, pollution, environmental degradation, loss of critical habitats, marginalization of small scale fishers, processors, vendors, increased costs of mariculture feeds, high operation costs of marine farms, diseases and problems in brood stock management, low coastal productivity and trade concerns as well as market dynamics. Management of marine fisheries through research based interventions assumes greater importance in this context.

Marine Capture Fisheries is basically utilization of a natural resource. Assessing the abundance of an invisible resource and monitoring its dynamics through indirect methods are vital for providing policy support targeted at an informed fisheries governance. This is extremely important for management of an open access, multi-species, multi gear, migratory resource. Therefore, this task is also a challenge to those involved in the task of natural resource management. Ensuring sustainability in an open access natural resource is an onerous task.

Information on marine environment, its ecosystem structure and function is imperative for an ecosystem based management. Enormous data is required for understanding marine ecosystems. Data collection in an oceanic environment is tedious and expensive. So as to enable wide use of *in situ* data, various organizations are hosting their databases on World Wide Web. But often marine fisheries research and management lack *in situ* environmental time series data. Both modelled and Satellite Remote Sensing (SRS) data validated for time and space can be used to fill such gaps. Implementation of complex numerical models is frustrated by lack of data inputs whereas simple models ignore some complexities in the marine ecosystem. As a result model outputs have not been analysed to the extent they deserved. In case of SRS, algorithms for data retrieval vary spatially and temporally depending on the nature of optical constituents present, especially in coastal waters. But modelled and SRS data can permit at least qualitative inferences when we address some of the major unresolved questions in fisheries biology. With the advent of improved computing facilities and SRS, last two decades have seen increased activity in both ecosystem modelling and ocean biology from space. The results are used for operational and applied marine fisheries research. This winter school on 'Structure and Function of the Marine Ecosystem: Fisheries' discusses some of the applications and illustrates them with particular case studies.

Grinson George
Course director

December, 2017

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CHAPTER 01

INDIAN MARINE FISHERY RESOURCES - PRESENT STATUS

T. V. Sathianandhan

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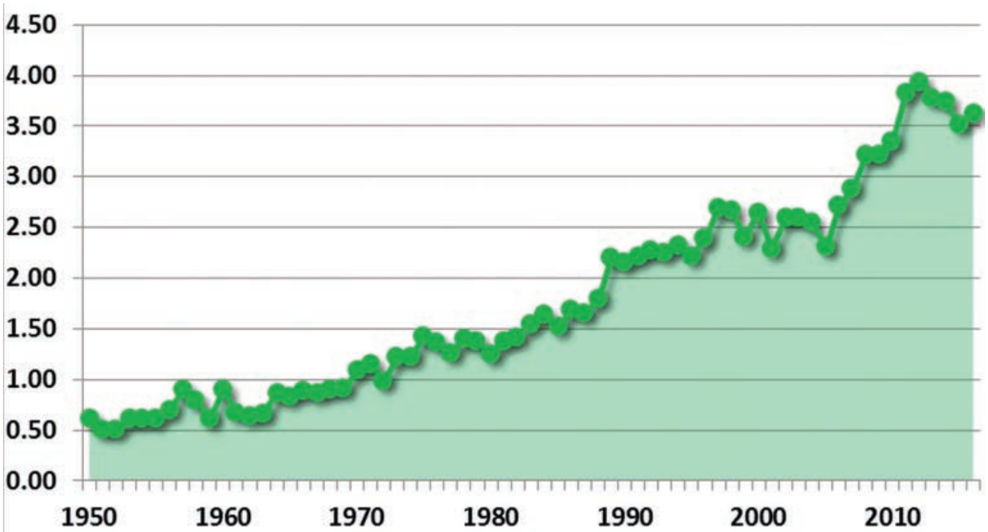
India being a tropical country is blessed with highly diverse nature of marine fishery resources in its 2.02 million square kilometer Exclusive Economic Zone with an estimated annual harvestable potential of 4.414 million metric tonnes. The marine fisheries sector provide livelihood to nearly 4.0 million people of India and meets the food and nutritional requirements of a significant proportion of the population. Also, it contributes to export earnings of the country. Sustainable harvest of the marine fishery resources are necessary as over-exploitation of the resources is likely to harm the diversity and cause reduction in the availability of some of the resources. Monitoring of the harvest of the diverse marine fishery resources of the country is being carried out regularly by CMFRI since its inception through a scientific data collection and estimation system from all along the Indian coast leading to fish stock assessment for deriving management measures to keep the harvest of the resources at sustainable levels.

Marine fisheries is an important source of food, nutrition, employment and income generation. In India, four million people depend for their livelihood on marine fisheries sector which provides employment to nearly one million fishermen and contributes significantly to the export earnings of the country and balance of trade. The sector contributes to an economic wealth valued at nearly Rs. 65,000 crores annually. The marine fisheries of the country consist of small-scale and artisanal fishers belonging mechanized, motorized and non-mechanized sectors and a range of other stakeholders, including governmental and non-governmental agencies. The marine fisheries resources are not in-exhaustive and over-exploitation would lead to loss of biodiversity and reduced availability of resources for our future generations. Uncontrolled harvest will result in depletion of the resources. Management and regulations are necessary for sustainable harvest of marine fishery resources.

India is one among the top marine fish producing countries of the world and at present the country is at 7th position in global marine capture fish production after China, Indonesia, USA, Russia, Japan and Peru. The global marine fish catch remains almost stagnant after 1990 whereas the marine fish production in India showed a steady increase from 2.3 million tonnes in 1990 to 3.94 million tonnes in 2012.

Many of the world's fisheries have experienced series of environmental shifts in recent decades involving collapse or fluctuations in the dominant fish assemblages and as a result, many fisheries-dependent human communities have lost majority of their population, while the respective countries in general were growing (Hamilton and Otterstand, 1998). In a tropical country like India, wherein the marine fisheries is supported by multispecies assemblages, severe collapses in fishery are unlikely and the marine fish production of the country has been increasing from a meager of 0.05 million t to 3.94 million tonnes over the last 62 years. This is imperative, as the marine fisheries sector in India is characterised by the dominance of small scale subsistence based fishery. In many of the societies, small-scale fishermen suffer the greatest deprivations as they have low social status, low incomes, poor living conditions and little political influence (Pomeroy and Williams, 1994). Implementation of regulations in the fishery for the sustained production from the sector has to take into account its impact on the livelihood of the considerably poor fisher population. The information necessary for such inference are generated through census.

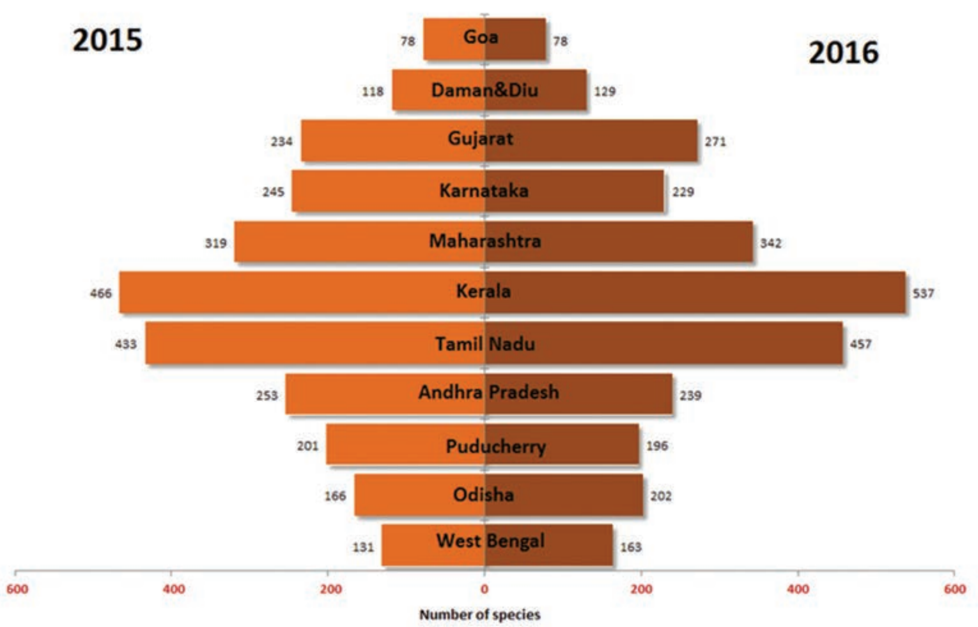


Time series plot of marine fish landings in India from 1950 to 2016 (in million tonnes)

The estimate of landings of marine fish resources along the coast in the main land of India for the year 2016 is 3.63 million metric tonnes. The contribution by the maritime states West Begal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra, Gujarat, union territories of Puducherry and Damen & Diu towards the total landings (in lakh tonnes) are 2.72 (7.5%), 1.17 (3.2%), 1.92 (5.3%), 7.07(19.5%), 5.23 (14.4%), 5.30 (14.6%), 0.61 (1.7%), 2.92 (8.1%), 7.74 (21.3%), 0.45 (1.2%), 1.17 (3.2%) respectively. The increase in landings in 2016 is mainly due to increase in marine fish landings along the coasts of West Bengal by 1.53 lakh tonnes, Karnataka by 86,000 tonnes, Gujarat by 53,000 tonnes, Kerala by 40,000 tonnes, Damen & Diu by 35,000 tonnes and Maharashtra by 27,000 tonnes. There is reduction in landings in Andhra Pradesh by 1.03 lakh tonnes, Puducherry by 34,000 tonnes, Odisha by 24,000 tonnes, Goa by 7,000 tonnes and Tamil Nadu by 2,000 tonnes.

When examined at the resource level contribution, Indian mackerel had the maximum with 2.49 lakh tonnes (6.8% of total landings) followed by oil sardine 2.45 lakh tonnes (6.7%), ribbonfishes 2.20 lakh tonnes (6.0%), penaeid prawns 2.01 lakh tonnes (5.5%) and lesser sardines 1.95 lakh tonnes (5.4%). The resources showed increased landings in 2016 are Perches by about 77,000 tonnes (81%), Hilsa shad 73,000 tonnes (354%), Ribbon fishes 43,000 tonnes (24%), Bombayduck 35,000 tonnes (31%), Squids 22,000 tonnes (24%) and Non-penaeid prawns 21,000 tonnes (14%). The resources with significant reduction in landings are Lesser sardines 61,000 tonnes (24%) and oil sardine 21,000 tonnes (8%).

Among the three sectors there was 81% contribution from mechanized sector towards the total landings, motorized sector contributed 17% and the contribution from the traditional non-mechanized sector was only 2%. Mechanized trawlnets accounted for 58% of the total marine fish landings whereas mechanized gillnets and outboard ringseines contributed 8% each. The total number of species found in the landings along the Indian coast during 2016 is 817 where as it was 730 in 2015. Number of species landed in different maritime states in 2016 and 2015 are shown in the following diagram. Though Gujarat had maximum landings among all the maritime states species diversity is less compared to Kerala and Tamil Nadu.



India is one among few countries where a system based on sampling theory is used to collect marine fish catch statistics. The sampling design was developed by CMFRI in association with the Indian Agricultural Statistics Research Institute by conducting preliminary surveys. The sampling design adopted is stratified multistage random sampling, stratification being done over space and time.

Fish landings takes place at numerous locations all along the coastline in all seasons during day and night. Sampling and estimation are performed for geographical area referred as fishing zone. There are 75 fishing zones covering 9 maritime states and two coastal union territories. All the 1,511 landing centres are covered under the sample design and data collection is by qualified and trained field staff stationed at 25 locations across all maritime states. The overall operation is coordinated by the Fishery Resources Assessment Division of CMFRI.

Fish is a natural resource with capacity to rebuild. If not monitored and managed over-exploitation will lead to stock depletion and some may become extinct. Harvest of this resource needs to be maintained at sustainable level through monitoring and control. The primary objective of fish stock assessment is to provide advice on the optimum exploitation of aquatic living resources. Fish stock assessment can be described as the search for the exploitation level that in the long run gives maximum yield from the fishery. The aim of fish stock assessment is for a fishing strategy that gives the highest steady yield year after year.

The basic goal of fishery management is to estimate the amount of fish that can be removed safely while keeping the fish population healthy. These estimates may be modified by political, economic, and social considerations to arrive at an optimum yield. Overly conservative management can result in wasted fisheries production due to under-harvesting, while too liberal or no management may result in over-harvesting and severely reduced populations. Fisheries Management draws on fisheries science in order to find ways to protect fishery resources so that sustainable exploitation is possible. Fisheries Management is the integrated process of information gathering, data analysis, planning, consultation, decision making, allocation of the resources and implementation of regulations or rules to govern fishing activities with enforcement as and when necessary to ensure steady and sustainable harvest of the resources. Fisheries Management is not about managing fish but about managing people and related businesses. Fish populations are managed by regulating the actions of people. These management regulations should also consider its implications on the stakeholders.

CHAPTER

02

FISH BIODIVERSITY OF INDIAN EXCLUSIVE ECONOMIC ZONE

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Introduction

Indian fisheries have a long history, starting with Kautilya's *Arthasastra* describing fish as a source for consumption and provide evidence that fishery was a well-established industry in India and fish was relished as an article of diet as early as 300 B.C, the ancient Hindus possessed a considerable knowledge of the habit of fishes and the epic on the second pillar of Emperor Ashoka describing the prohibition of consumption of fish during a certain lunar period which can be interpreted as a conservation point of view. Modern scientific studies on Indian fishes could be traced to the initial works done by Linnaeus, Bloch and Schneider, Lacepède, Russell and Hamilton. The mid 1800s contributed much in the history of Indian fish taxonomy since the time of the expeditions was going through. Cuvier and Valenciennes (1828-1849) described 70 nominal species off Puducherry, Skyes (1839), Günther (1860, 1872, 1880) and *The Fishes of India* by Francis Day (1865-1877) and another book *Fauna of British India* Series in two volumes (1889) describing 1,418 species are the two most indispensable works on Indian fish taxonomy to date. Alcock (1889, 1890) described 162 species new to science from Indian waters.

In the 20th century, the basis of intensive studies on the different families and groups of freshwater fishes was done by Chaudhuri along with Hora and his co-workers. Misra published *An Aid to Identification of the Commercial Fishes of India and Pakistan* and *The Fauna of India and Adjacent Countries (Pisces)* in 1976. Jones and Kumaran described about 600 species of fishes in the work *Fishes of Laccadive Archipelago*. Talwar and Kacker gave a detailed description of 548 species under 89 families in his work, *Commercial Sea Fishes of India. The FAO Species Identification Sheets for Fishery Purposes - Western Indian Ocean* (Fischer and Bianchi) is still a valuable guide for researchers.

The long coastline of 8129 km^2 with an EE2 of 2.02 million sq. km including the continental shelf of 0.5 million sq. km harbors extensively rich multitude of species. Vast regions of mangroves are found along the coast of West Bengal, Orissa, Andhra Pradesh, Tamilnadu, Maharashtra, Gujarat and Andaman Islands which extends up to about 6,82,000 ha area. Coral reefs are found in the Gulf of Kutch, along the Maharashtra coast, Kerala coast, in the Gulf of Mannar, Palk Bay and the Wadge Bank along the Tamilnadu coast and around Andaman and Lakshadweep Islands. The variety of coastal ecosystems includes brackish water lakes, lagoons, estuaries, back waters, salt marshes, rocky bottom, sandy bottom and muddy areas provides a home and shelter for the mega biodiversity of India. These regions support very rich fauna and flora and constitute rich biological diversity of marine ecosystems. Diversity in the species complex, typical of tropical waters and co-existence of different fish and shellfish species in the same ground are important features of Indian Marine Biodiversity.

Species Diversity

Fin fishes

Of the 33,059 total fish species of the world, India contributes of about 2,492 marine fishes owing to 7.4% of the total marine fish resources. Of the total fish diversity known from India, the marine fishes constitute 75.6 percent, comprising of 2,492 species belonging to 941 genera, under 240 families of 40 orders. Among the fish diversity-rich areas in the marine waters of India, the Andaman and Nicobar Archipelago, shows the highest number of species, 1,431, followed by the east coast of India with 1,121 species and the west coast with 1071. Detailed taxonomy of 18 families of fishes occurring in Indian EEZ was done as shown in the Table 1. As many as 91 species of endemic marine fishes are known to occur in the coastal waters of India. As of today, about 50 marine fishes known from India fall into the Threatened category as per the IUCN Red List, and about 45 species are Near-Threatened and already on the path to vulnerability. However, only some species (10 elasmobranchs, 10 seahorses and one grouper) are listed in Schedule I of the Wildlife (Protection) Act, 1972 of the Government of India. The ecosystem goods and services provided by the fauna and flora and the interrelationship between the biodiversity and ecological processes are the fundamental issues in the sustainability and equilibrium of the ecosystem.

Table 1. List of Fish families and corresponding authors

No	Name of the Family /group	Authors
1	Flatfishes	Norman, 1934, Menon, 1977
2	Scombridae	Jones and Silas, 1962
3	Mugilidae	Sarojini, 1962
4	Clupeidae	Whitehead, 1985
5	Trichiuridae	James, 1967
6	Leiognathidae	James, 1975
7	Chirocentridae	Luther, 1968
8	Mullidae	Thomas, 1969
9	Sphyraenidae	De Sylva, 1975
10	Syngnathidae	Dawson, 1976
11	Scorpaenidae	Eschmeyer, 1969

12	Platycephalidae	Murty, 1982
13	Callionymidae	Ronald, 1983
14	Sciaenidae	Lal Mohan, 1972, 1982, Trewavas, 1977
15	Nemipteridae	Russell, 1986
16	Priacanthidae	Phillip, 1994
17	Carangidae	Sreenivasan, 1976, Joshi, 2011
18	Balistidae	Sathish Sahayak, 2015

Recent analysis indicates that 18 resource groups fall under abundant category, five fall under less abundant category and one each fall under declining, depleted and collapsed category. The resource groups under the abundant category indicates good condition of the stock. The less abundant category includes elasmobranchs, threadfins, ribbon fishes, mullets and flat fishes. Big-jawed jumper under the declining category, flying fishes under depleted and unicorn cod is in the collapsed category. While certain stocks such as those of Mackerel, Lesser Sardines, White bait, Seer fish, Coastal and oceanic tunas, Croakers, Pig face breams, Groupers, Snappers, Cat fish, Lizard fish, Silver bellies and Goat fishes are exploited all along the Indian coast. Bombay duck is caught mainly along the Gujarat and Maharashtra coast and to a lesser extent along certain pockets of Andhra, Orissa and West Bengal coasts. *Hilsa* is harvested mainly along the West Bengal coast and Gujarat coast.

Elasmobranchs

The elasmobranchs consists of sharks, sawfishes, rays, skates and guitar fishes. They are fished using different types of gears and in recent years have assumed great significance in the export market. They are exploited by a variety of fishing gears like gillnets, long lines and trawls along the Indian coast by both traditional and mechanized sectors. Though there is no directed fishing for elasmobranchs in certain places of Tamilnadu, large meshed bottom set gillnets called as 'thirukkuvalai' are operated for fishing the rays. They are all predatory feeding on a wide range from zooplankton to benthic invertebrates, bony fishes, other sharks, turtles, seabirds and marine mammals. Akhilesh *et al.* (2014) provided a checklist of 227 chondrichthyan species belonging to 11 orders and 41 families from Indian seas and it was mentioned that 27 species (12%) have questionable status with regard to their occurrence because their distributional range does not fall within Indian seas.

The Whale shark is huge, sluggish, pelagic filter-feeder, often seen swimming on the surface. Viviparous and gravid female have 300 young ones of several stages of development. The protected elasmobranchs as per the Wildlife (Protection) Act, 1972, Schedule I are *Rhincodon typus* (Whale shark), *Anoxyprisits cuspidata* (Pointed saw fish), *Prisits microdon*

(Large tooth sawfish), *Prisitis zijsron* (Longcomb sawfish), *Carcharhinus hemiodon* (Pondicherry shark), *Glyphis gangeticus* (Ganges shark), *Glyphis glyphis* (Speer tooth shark), *Himantura fluviatilis* (Gangetic sting ray), *Rhynchobatus djiddensis* (Giant guitarfish) and *Urogymnus asperimus* (Thorny ray).

Ornamental fish

The Gulf of Mannar, Palk bay, Gulf of Kutch, South West coast and the Lakshadweep and Andaman group of Islands are known to be rich in Ornamental fishery. The Wrasses, damsel fish, Surgeon, Butterfly fish, Moorish idol, Squirrel fish, Trigger fish, Rabbit fish, Parrot fish, Angels, Goat fish and Puffer fish are the major aquarium fishes represented by about 180 species. As the majority of these fishes is associated with coral reefs and those in great demand and are not very abundant, their exploitation may disturb the habitats and result in depletion of stock, if a suitable mechanism for sustainable exploitation for example sample traps, monitoring the exploitation and export are not developed. The seahorses and pipefishes are known to live in seagrass beds, mangroves and reefs in most shallower coastal waters of the temperate and tropical regions. About 300 species of ornamental fishes from 30 genera are known. CITES have listed all the seahorses in the Appendix I to stop the trade of these organisms. Indian wild Life Act 2002 also protects the seahorse by putting them in Schedule list I. Dried seahorse has got a high demand in Singapore and China for making soup and for medicinal purposes.

Ecosystem Diversity

Gujarat coast

Gujarat has the longest coastline of more than 1,600 km and the most extensive continental shelf of nearly 1,64,000 km^2, which represents nearly 20% and 32 % of India's coastline and continental shelf. The EEZ of Gujarat covers 2,14,000 km. The coast has broadly been divided into four sections: the Gulf of Kutch, the Saurashtra coast, the Gulf of Khambhat and the South Gujarat coast. The ecological importance is that India's first Marine National Park was notified in the Gulf of Kutch. In the ecological sense, the habitats exhibit considerable diversity and they include mangroves, salt marshes, coral reefs, beaches, dunes, estuaries, intertidal mudflats, gulfs, bays and wetlands. Gujarat has India's second largest extent of area under the mangroves. Gulf of Khambhat (Gulf of Cambay) is 190 km wide at its mouth between Diu and Daman, rapidly narrows to 24 km. The gulf receives many rivers, including the Sabarmati, Mahi, Narmada, and Tapti. The Gulf of Kutch is rather shallow with a depth of nearly 60 m at the mouth to less than 20 m near the head. The total gulf area is about 7,350 km^2. In the Gulf of Kutch, there are 42 islands & some islets, covering a total area of about 410.6 km^2.

About 306 fish species are listed from the sea and coastal waters of Gujarat. Some of the important group of fishes that are occurring in the Arabian sea and also ventured into Gujarat waters include sharks, rays, sea horses, catfishes, groupers, ribbon fishes, jewfishes, mullets, puffer fish, coral fish, lady fish, *etc.* Out of total 306 reported species, 23 fish species were found in the IUCN's Red Data list. Importantly, 9 of these species belong to shark families, including the whale shark, are also listed in Schedule I of Wildlife Protection Act, 1972. The fishery at present is dominated by fishes like ribbon fishes (*Trchiurus lepturus*), Bombay duck (*Harpodon nehereus*), croakers, carangids, threadfin breams, lizard fishes, tuna (*Euthynnus affinis, Thunnus tonggol, Katsuwonus pelamis, Thunnus albacores* and *Sarda orientalis*), seerfish, pomfrets, catfish, flatfishes and non penaeid prawns. The Bombay duck (*Harpodon nehereus*) fishery was dominant at Nawabunder, Rajpara and Jaffrabad along the Saurashtra coast.

Mumbai coast

The Maharashtra coast that stretches between Bordi/Dahanu in the North and Redi/Terekhol in the South is about 720 km long and 30-50 km wide. The shoreline is indented by numerous west flowing river mouths, creeks, bays, headlands, promontories and cliffs. There are about 18 prominent creeks/estuaries along the coast many of which harbor mangrove habitats. Bombay duck fisheries form the mainstay of the commercially important fisheries of the coast from Ratnagiri to Broach. The coastline between Bombay and Kathiawar is found to be productive for Sciaenids, *Leptomelanosoma indicus (=Polynemus indicus), Polynemus* spp., perches and eels. The Gulf of Cambay and North Bombay coast are also rich in Bombay duck fisheries. About 285 species have been reported from the coast. Major finfishes along this coast was Bombay duck, ribbonfish, sharks, pomfrets, lizardfish, catfishes, oil sardine, anchovy, barracudas, fullbeaks, sailfish, Cobia, wolf herring, groupers, whitefish and mackerel.

Konkan coast

The Konkan coast stretches like a beautiful chain of 720 km formed from the coastal districts of the states of Maharashtra, Goa and Karnataka. Many river mouths, creeks, small bays, cliffs and beaches, interspersed with historic forts, lend an alluring charm to this landscape. Konkan is also rich in coastal and marine biodiversity. Mangrove forests, coral reefs, charismatic marine species like dolphins, porpoises, whales, sea turtles, many species of coastal birds and other fauna make the Konkan coast a veritable treasure trove biological diversity. The Malvan Marine Sanctuary has spread over 29 km^2; the sanctuary is rich in coral and marine life. The Karwar group of islands with its unique rocky with sandy shore supports a wide range of fauna. There are more than 170 different species of food fishes landing in the coast and is famous for its large shoals of mackerel, *Rastrelliger kanagurta* dominating the coasts of Karnataka. Oil sardine along with *Sardinella fimbriata,* anchovies, clupeids, ribbonfishes, seerfishes, *Lactarius lactarius*, carangids, pomfrets, croakers, catfish, whitefish, flatfishes, silver bellies also contribute much to the fisheries of both the coasts.

Malabar Coast

Characteristic features of the Malabar Coast are the upwelling, southwest monsoon, northeast monsoon, mud-bank along the southwest coast and high coastal production. Upwelling occurs in the region between Kanyakumari and Karwar during the onset of southwest monsoon. It starts in the southern region first and then extends northwards with the progress of southwest monsoon. Southwest monsoon season is the period when mud-banks are formed in some places along the southwest coast of India especially the Kerala coast. Mud banks of the Alleppey region is formed by the subterranean mud and the Vembanad lake system provides the mud for this. The mud-banks between Parapanangadi and Tanur are the aggregation of coastal mud. The mud-banks at Chellanam, Narakkal, Valappad, Elathur, Quilandy, Muzhuppilangadi, Kottikalam, Anjur, Adakathubali, Kumbala, Uppala and Ullal are formed by the sediments and organic debris discharged from river and estuaries. Mud-banks at Vypeen are formed from dredging operation. Along the southwest coast in India the maximum production of phytoplankton takes place during the southwest monsoon months.

The peak of plankton biomass is observed during peak southwest monsoon and pre-monsoon periods that is during and after upwelling, while the abundance of fish eggs and larvae shows peak during the pre-monsoon. Thus, it is well known that the intensity of southwest monsoon plays an important role in the fluctuation of the fishery resources especially the pelagic fishes. The fish diversity occurs at the mud banks are characteristic of the fishing grounds off the south-west coast of India. About 50 species of fish were recorded from these regions. Fishes of the families Carcharhinidae, Clupeidae, Dussumieriidae, Engraulidae, Chirocentridae, Bagridae, Hemiramphidae, Sphyraenidae, Mugilidae, Polynemidae, Ambassidae, Terapontidae. Sillaginidae, Lactaridae, Siganidae, Carangidae, Gerridae, Leiognathidae, Pomadasydae, Sciaenidae, Trichiuridae. Scomberesocidae, Stromateidae, Cynoglossidae, Chirocentridae and Drepaneidae were come across in the landings.

Lakshadweep

The Union territory of Lakshadweep consists of 36 islands covering an area of 32 km^2 of which 10 islands are inhabited, 20,000 km^2 of lagoons and 4,000 km^2 oceanic zones. Among the fishes of Lakshadweep, those of ornamental value are abundant. Of the 603 species of marine fishes belonging to 126 families that are reported from the islands, at least 300 species belong to the ornamental fish category. Oceanic species of tuna such as Skipjack and Yellowfin tuna constitute the major tuna resources from Lakshadweep Islands. The main economy of the islanders is dependent on the tuna catch and fishing is done for nearly six months of the year from October to April. The most common species of sharks that occur in Lakshadweep are the Spade-nose shark/Yellow dog shark, and the Milk shark. The Blacktip Shark and Hammerhead shark are also commonly found in the waters around Lakshadweep.

Gulf of Mannar

The Gulf of Mannar located in the Southern part of the Bay of Bengal with a string of 21 islands which has been declared as a marine National Park under the Wild Life (Protection) Act 1972 by the Government of India. The reserve covers 10,500 km^2, which comprises of a variety of sensitive marine habitats like coral reefs, mangroves and sea grasses, and could be considered as one of the most productive ecosystems. The core area of the reserve is comprised of a 560km^2 of coral islands and shallow marine habitat. The Gulf of Mannar alone produces about 20% of the marine fish catch in Tamil Nadu. A total of 1,182 species belonging to 476 genera in 144 families and 39 orders was reported from GOM ecosystem. The finfish resources, mainly comprises of small pelagics, barracudas, silverbellies, rays, skates, eels, carangids, flying fish, full beaks and half beaks. The demersal finfish resources, mainly associated coral reefs are threadfin breams, grouper, snappers, emperor and reef associated fishes. Further, large pelagic species like skipjack tuna, yellowfin tuna, bigeye tuna, kawakawa, frigate tuna and seer fish, bill fishes, eagle rays are most abundant in offshore and oceanic areas, but also occur in coastal waters are found in certain areas of the Gulf of Mannar.

Palk Bay

Palk Bay is situated on the southeast coast of India encompassing the sea between Point Calimere near Vedaranyam in the north and the northern shores of Mandapam to Dhanushkodi in the south. The Palk Bay itself is about 110 km long and is surrounded on the northern and western sides by the coastline of the State of Tamil Nadu in the mainland of India. The coastline of Palk Bay has coral reefs, mangroves, lagoons, and sea grass ecosystems. Elasmobranchs are the largest group of fishes and are well represented in the fishery wealth of the Ramewaram Island on the Palk Bay side. This is one of the best fishing grounds for smaller sardines, silver bellies, common white fish and half beaks, mullets and sciaenids. The common fishes found in this area also include Sharks, Rays, Skates, Tiger-sharks and Hammer-headed sharks.

Coromandel Coast

Seer fishes are most abundant in the Coromandel Coast of Tamil Nadu along with miscellaneous fisheries formed of trichiurids and percoids. The flying-fish fishery is an important seasonal fishery on the east coast of India extending from Madras to Point Calimere along the Coromandel Coast. Three species of flying-fish, *viz*., *Hirundichthys coromandelensis, Cheliopogon spilopterus* and *C. bahiensis*, are generally found in these waters, but more than 90% of the catch consists of *C. coromandelensis*.

Deep-sea fish diversity

A first authentic record of the deep-sea fishes from India was by Alcock in the book *A Descriptive Catalogue of the Indian deep-sea fishes in the Indian museum* based on the fishes collected during the explorations in the Indian Ocean by *RIMS Investigator* (1889-1900). Then comes the results of R.V. *VARUNA* cruises (1962-1968) showed the presence of *Anodontostoma chacunda*, *Atropus atropos*, *Benthodesmus tenuis*, *Brachirus orientalis*, *Chlorophthalmus agassizi, C. corniger*, *Carangoides malabaricus, Caranx kalla, Centropristis investigatoris, Chascanopsetta lugubris, Chlorophthalmus corniger*, *Cubiceps natalensis, Cynoglossus bilineatus*, *C. semifasciatus, Decapterus russelli*, *Drepane punctata*, *Epinnula orientalis, Goniolosa manmina*, *Grammoplites scaber*, *Himantura urnak*, *Holocentrum rubrum*, *J. diacanthus, Johnius dussumieri*, *Kowala coval*, *L. argentimaculatus*, *L. bindus*, *L. johni*, *L. kasmira*, *L. malabaricus*, *Lactarius lactarius*, *Leiognathus splendens*, *Lepidopus caudatus*, *Lepturacanthus savala*, *Megalaspis cordyla*, *Myripristis murdjan, Nemipterus japonicus*, *Netuma thalassinus*, *Opisthopterus tardoore, Otolithes argentatus, P. sexifilis, Parastromateus niger*, *Paseneopsis cyanea*, *Pastinachus sephen*, *Pellona ditchela*, *Polymixia nobilis, Polynemus plebius*, *Pomadasys hasta*, *Psenes indicus, Pseudorhombus arsius, Rexea prometheoides, Rhynchobatis djiddensis, Saurida tumbil*, *Scoliodon palasorrah, Scyllium hispidum, Sillago sihama*, *Solea elongata, Sphyraena acutipinnis*, *Synagrops japonicus*, *Synodus indicus*, *Thrissocles mystax*, *T. malabarica, Trichiurus lepturus and Tylosurus crocodilus* from the depth zone of 1 to 450m.

A checklist of fishes of Indian EEZ was published based on the surveys of FORV *Sagar Sampada* in the EEZ of India during 1985-'87. This list is arranged alphabetically by families and genera. The list contains 242 species belonging to 87 families with both conventional and nonconventional fish fauna of the Indian EEZ with the scientific and common names of fishes, details of the depth of occurrence, depth of fishing, position and the gear were also included. The study by Hashim (2012) reported and the occurrence of 188 species of deep-sea fishes from Indian EEZ during the exploratory surveys. Deep sea fish species like *Psenopsis cyanea, Bembrops caudimacula, Chlorophthalmus bicornis*, *C. agassizi*, *Uranoscopus archionema, Gavialiceps taeniola*, *Priacanthus hamrur* and *Neoepinnula orientalis* were found to be the most abundant during the study. Hashim (2012) observed a highest diversity in Arabian Sea (4.95) followed by Andaman Waters (4.12) and Bay of Bengal (3.55).

Biodiversity conservation

The exploited marine fisheries resources from the Indian EEZ area have been reached maximum from the present fishing grounds up to 200 m depth. The coastal fisheries faces several threats such as indiscriminate fishing, habitat degradation, pollution, social conflicts, the introduction of highly sophisticated fishing gadgets with a need for management measures and conservation of marine biodiversity to maintain sustainable use of marine biodiversity. A total of 65 species of fishes is under the threatened category of IUCN from the Indian seas (Table 2).

Table 2. Threatened fishes from the Indian seas (1,2)

	Species	Family	Threat Category
1	*Aetobatus flagellum*	Myliobatidae	Endangered (EN)
2	*Aetomylaeus maculatus*	Myliobatidae	Endangered (EN)
3	*Aetomylaeus nichofii*	Myliobatidae	Vulnerable (VU)
4	*Alopias pelagicus*	Alopiidae	Vulnerable (VU)
5	*Alopias superciliosus*	Alopiidae	Vulnerable (VU)
6	*Alopias vulpinus*	Alopiidae	Vulnerable (VU)
7	*Anoxypristis cuspidata*	Pristidae	Endangered (EN)
8	*Balistes vetula*	Balistidae	Vulnerable (VU)
9	*Carcharhinus albimarginatus*	Carcharhinidae	Vulnerable (VU)
10	*Carcharhinus hemiodon*	Carcharhinidae	Critically Endangered (CR)
11	*Carcharhinus longimanus*	Carcharhinidae	Vulnerable (VU)
12	*Carcharhinus obsucurus*	Carcharhinidae	Vulnerable (VU)
13	*Carcharhinus plumbeus*	Carcharhinidae	Vulnerable (VU)
14	*Carcharias taurus*	Odontaspididae	Vulnerable (VU)
15	*Carinotetraodon travancoricus*	Tetraodontidae	Vulnerable (VU)
16	*Centrophorus squamosus*	Centrophoridae	Vulnerable (VU)
17	*Chaenogaleus macrostoma*	Hemigaleidae	Vulnerable (VU)
18	*Cheilinus undulatus*	Labridae	Endangered (EN)
19	*Cromileptes altivelis*	Serranidae	Vulnerable (VU)
20	*Epinephelus lanceolatus*	Serranidae	Vulnerable (VU)
21	*Epinephelus marginatus*	Serranidae	Endangered (EN)
22	*Etroplus canarensis*	Cichlidae	Endangered (EN)
23	*Glaucostegus granulatus*	Rhinobatidae	Vulnerable (VU)
24	*Glaucostegus typus*	Rhinobatidae	Vulnerable (VU)
25	*Glyphis gangeticus*	Carcharhinidae	Critically Endangered (CR)
26	*Gymnura zonura*	Gymnuridae	Vulnerable (VU)
27	*Hemigaleus microstoma*	Hemigaleidae	Vulnerable (VU)
28	*Hemipristis elongata*	Hemigaleidae	Vulnerable (VU)

29	*Himantura gerrardi*	Dasyatidae	Vulnerable (VU)
30	*Himantura leoparda*	Dasyatidae	Vulnerable (VU)
31	*Himantura polylepis*	Dasyatidae	Endangered (EN)
32	*Himantura uarnak*	Dasyatidae	Vulnerable (VU)
33	*Himantura undulata*	Dasyatidae	Vulnerable (VU)
34	*Hippocampus histrix*	Syngnathidae	Vulnerable (VU)
35	*Hippocampus kelloggi*	Syngnathidae	Vulnerable (VU)
36	*Hippocampus kuda*	Syngnathidae	Vulnerable (VU)
37	*Hippocampus trimaculatus*	Syngnathidae	Vulnerable (VU)
38	*Hyporhamphus xanthopterus*	Hemiramphidae	Vulnerable (VU)
39	*Isurus oxyrinchus*	Lamnidae	Vulnerable (VU)
40	*Lamiopsis temminckii*	Carcharhinidae	Endangered (EN)
41	*Makaira nigricans*	Istiophoridae	Vulnerable (VU)
42	*Manta birostris*	Myliobatidae	Vulnerable (VU)
43	*Mobula mobular*	Myliobatidae	Endangered (EN)
44	*Monopterus fossorius*	Synbranchidae	Endangered (EN)
45	*Monopterus indicus*	Synbranchidae	Vulnerable (VU)
46	*Nebrius ferrugineus*	Ginglymostomatidae	Vulnerable (VU)
47	*Negaprion acutidens*	Carcharhinidae	Vulnerable (VU)
48	*Oostethus insularis*	Syngnathidae	Vulnerable (VU)
49	*Plectropomus areolatus*	Serranidae	Vulnerable (VU)
50	*Pristis pectinata*	Pristidae	Critically Endangered (CR)
51	*Pristis pristis*	Pristidae	Critically Endangered (CR)
52	*Pristis zijsron*	Pristidae	Critically Endangered (CR)
53	*Rhina ancylostoma*	Rhinobatidae	Vulnerable (VU)
54	*Rhincodon typus*	Rhincodontidae	Vulnerable (VU)
55	*Rhinobatos obtusus*	Rhinobatidae	Vulnerable (VU)
56	*Rhinoptera javanica*	Myliobatidae	Vulnerable (VU)
57	*Rhynchobatus djiddensis*	Rhinobatidae	Vulnerable (VU)
58	*Sphyrna lewini*	Sphyrnidae	Endangered (EN)
59	*Sphyrna mokarran*	Sphyrnidae	Endangered (EN)
60	*Sphyrna tudes*	Sphyrnidae	Vulnerable (VU)
61	*Sphyrna zygaena*	Sphyrnidae	Vulnerable (VU)
62	*Stegostoma fasciatum*	Stegostomatidae	Vulnerable (VU)
63	*Taeniurops meyeni*	Dasyatidae	Vulnerable (VU)
64	*Thunnus obesus*	Scombridae	Vulnerable (VU)
65	*Urogymnus asperrimus*	Dasyatidae	Vulnerable (VU)

Source : 1. Froese, R. and D. Pauly. Editors. 2017. FishBase. World Wide Web electronic publication. www.fishbase.org.
2. The IUCN Red List. 2017: www.iucnredlist.org

Human activities are the major causes for the loss of biodiversity and degradation of marine and coastal habitats, which needs immediate attention and comprehensive action plan to conserve the biodiversity for living harmoniously with nature. Some of the measures such as control of excess fleet size, control of some of the gears like purse seines, ring seines, disco-nets, regulation of mesh size, avoid habitat degradation of nursery areas of the some of the species, reduce the discards of the low value fish, protection of spawners, implementation of reference points and notification of marine reserves are required for the protection and conservation of marine and coastal biodiversity.

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CHAPTER

03

FUNDAMENTALS OF OCEAN COLOUR REMOTE SENSING

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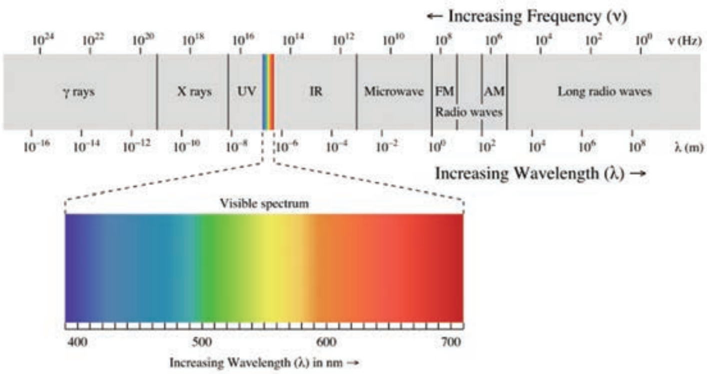
Remote sensing refers to collection of information about an object without being in direct contact with the object. Remote sensing aids in measuring remote areas which are inaccessible by any other means and offer less expense than *in-situ* measurements. Remote sensing facilitates creation of long time series and extended measurement. This has the advantage that several parameters can be measured at same time and satellite-based remote sensing measurements allow global observations. Remote sensing has its own advantages and disadvantages. The limitation includes indirect measurements of large areas which are not of interest to the user. The automated instrument degradation creates retrieval errors and are affected by several factors/processes, and not only by the object of interest. Additional assumptions and models are needed for the interpretation of the measurements and before using these models in oceanographic studies, it is extremely important to validate the performance of the various ocean colour algorithms with *in-situ* observations (Swirgon *et al.*, 2015).

Two different types of remote sensing include active and passive remote sensing. Passive remote sensing measures naturally available energy *viz.* solar light which are either attenuated scattered and reflected. In active remote sensing, the sensor emits visible radiation towards target and reflected radiation in emitted bands are detected and measured. These type of sensors can work day and night and can use wavelengths not available from natural sources. LIDAR comes under this category of active ocean colour remote sensing.

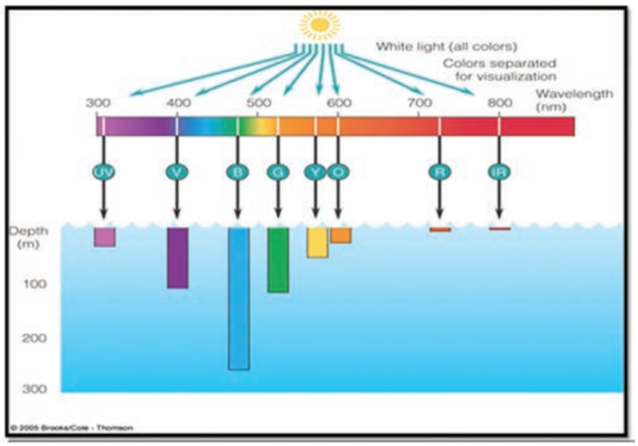


(Image courtesy: https://commons.wikimedia.org)

Fig. 1. Illustration of the Visible spectrum of the light

Solar light is an electromagnetic radiation where waves are fluctuations of electric and magnetic fields, which can transport energy from one location to another (Figure 1). When sunlight strikes the ocean, some of it reflects off the surface back into the atmosphere. The amount of energy that penetrates the surface of the water depends on the angle at which the sunlight strikes the ocean. Near the equator, the sun's rays strike the ocean almost perpendicular to the ocean's surface. Near the poles, the sun's rays strike the ocean at an angle, rather than directly. The direct angle of the sun's rays to the surface of the water at the equator means that more energy penetrates the surface of the water at the equator than at the poles.

Water absorbs almost all of the infrared energy from sunlight within 10 centimetres of the surface. Visible red light has slightly more energy than invisible infrared radiation and is more readily absorbed by water than other visible wavelengths. Light with longer wavelengths is absorbed more quickly than that with shorter wavelengths. Because of this, the higher energy light with short wavelengths, such as blue, is able to penetrate more deeply (Figure 2). The depth of the water not only affects the colours of light that are noticeable underwater, it also affects the intensity, or amount of light. Within the first 10 m, water absorbs more than 50 percent of the visible light energy. Even in clear tropical water only about 1 percent of visible light, mostly in the blue range, penetrates to 100 m. Light attenuation is the gradual decrease in light intensity as it travels through matter.



(Image courtesy : http://ksuweb.kennesaw.edu/~jdirnber/oceanography/Lectures()ceanogr/LecOceanStructur/0620B.jpg

Fig. 2. Illustration showing penetration of visible spectrum in the ocean

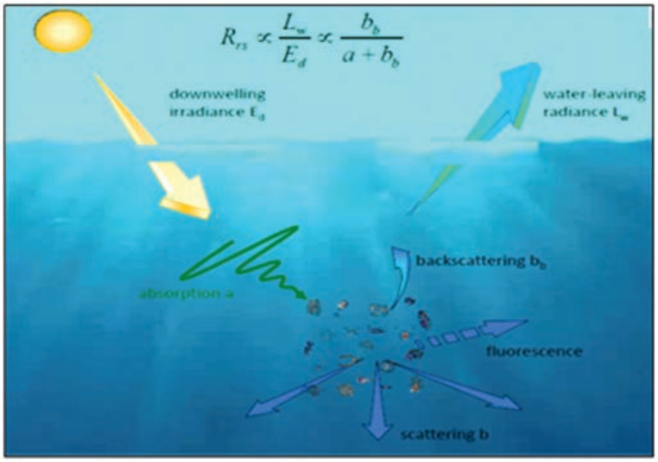
Ocean colour is the colour of ocean resulted due to the change in the characteristics of the incident solar radiation after interacting with the Optically Active Substances (OAS) prevailing in the water column. Ocean Optics is the branch of physics concerned with the interactions of light with ocean as the light propagates through the ocean. The incoming solar radiation is affected by several factors *viz.* scattering by inorganic suspended material, scattering from water molecules, absorption by the Dissolved Organic Matter, absorption by Phytoplankton and reflection off the bottom. These factors/substances that modify the incoming radiations are known as optically active substances. These can be categorized into two properties- Inherent and apparent optical properties. Inherent Optical Property (IOP) is an optical property of the water body which is totally independent of the spatial distribution of the radiation and Apparent Optical Property (AOP) is an optical property of the water body that is dependent upon the spatial distribution of the incident radiation. Absorption (a) and scattering ($b = b_f + b_b$) are the main IOP's and reflectance (R_{rs}) and attenuation (K_d) form the AOP which are interlinked. 'b_f' and b_b represents forward and backward scattering, 'μ_d' represents average cosine of downwelling light (Morel *et al.*, 2006).

$k_d = (a + b_b) / \mu_d$ ....(1)

$R_{rs} = (f/q)\,(b_b / a + b_b)$.........................(2)

Downwelling solar irradiance penetrating through the air-water interface into the water and from the subsurface layer into deeper layers is absorbed and scattered on its way by water itself as well as by OAS in the water (Figure 3). Partial radiation are also back scattered and reflected. These leaves the ocean surface as water leaving radiance (L_w) and is measured by ocean colour satellites. Remote sensing reflectance corresponds to the fraction of downwelling radiance (E_d) and upwelling radiance (L_w) which is further affected by the IOP of oceans.

After leaving the ocean, these radiations are again exposed to scattering and reflection by various substances present in the atmosphere such as aerosols, water vapour, dust particles *etc*. Hence, there is need for accurate measurement of these radiances top of atmosphere (TOA). Ocean colour algorithms incorporated with various atmospheric corrections serve the functions. The accurate retrieval of Chlorophyll in case 2 waters also requires the selection of a suitable atmospheric correction scheme (Minu *et al.*, 2014b). In turbid waters, sensor-derived R_{rs} at blue wavelengths is often biased downward and sometimes even negative. This problem often results from assumptions that water-leaving radiance is negligible at near-infrared (NIR) bands (Siegel *et al.* 2000).



(Image courtesy : http://classroom.oceanteacher.org/course/view.php?id=190)

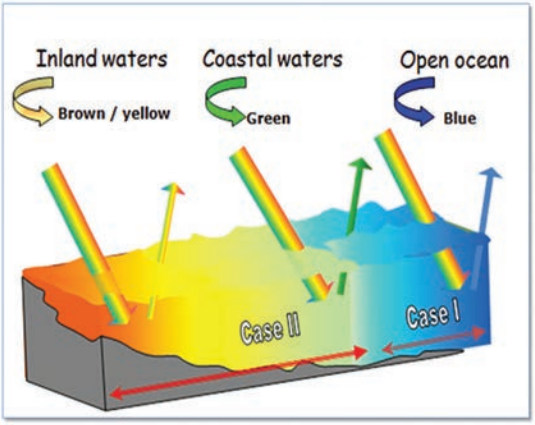
Fig. 3. Illustration showing the modifications of underwater light

For the ocean–atmosphere system, top-of-atmosphere (TOA) reflectance, $\rho_t(\lambda)$, as measured by the satellite sensor, can be written as a linear sum from various contributions (ignoring whitecaps and sun glint):

$\rho_t(\lambda) = \rho_r(\lambda) + \rho_a(\lambda) + t(\lambda)\rho_w(\lambda)$...........(3)

where $\rho_r(\lambda)$, $\rho_a(\lambda)$, and $\rho_w(\lambda)$ are the reflectance contributions from molecules (Rayleigh scattering), aerosols (including Rayleigh-aerosol interactions), and ocean waters, respectively, and $t(\lambda)$ is the diffuse transmittance of the atmosphere.

The concentration of OAS determines the magnitude and shape of in- water R_{rs}. The difference can be mainly observed in the blue wavelength region of visible spectrum. Oceanic waters are partitioned into Case I and Case II waters (Figure 4). Case I waters are waters in which phytoplankton are the principal agents responsible for the variations in optical properties of water whereas Case II waters are influenced by phytoplankton and other substances that vary independently of phytoplankton notably, inorganic particles in suspension and yellow substances.



(Image courtesy : www.incois.org)

Fig. 4. Illustration of interaction of visible radiation

Ocean colour algorithms are developed inorder to retrieve different oceanic parameters using water leaving radiance derived from satellite data incorporating reliable atmospheric correction models. These algorithms can be empirical / semi-empirical. Empirical algorithms are based on statistical relationship with less intensive computations and are easy to implement operationally. The derived relationships can be applied to other regions also. Semi-empirical algorithms are based on radiative transfer solutions and offer intensive computations with *in-situ* data to train the models. Radiative transfer theory is based on the assumption that as a beam of radiation travels, it loses energy to absorption, gains energy by emission, and redistributes energy by scattering. The equation that connects the IOPs and the radiance is called the radiative transfer equation (RTE) and is expressed as

$L_T(\lambda) = L_w(\lambda)T(\lambda) + Lg(\lambda)\,T(\lambda) + L_a(\lambda) + L_r(\lambda) + L_b(\lambda)$ .... (4)

Where L_T(ë) is the radiance reaching remote sensor and L_w is the water leaving radiance

$L_w(\lambda) = L_{ww}(\lambda) + L_{wp}(\lambda) + L_{wCDOM}(\lambda) + L_{ws}(\lambda) + L_{wb}(\lambda)$ .... (5)

Subscripts 'g' for sky-glitter, 'a' for aerosols, 'w' for water, 'p' for phytoplankton, CDOM for coloured dissolved organic matter (gelbstoff), 's' for inorganic suspended sediments and 'b' for reflection off the bottom.

As phytoplankton concentration increases, the reflectance in the blue decreases and in the green it increases slightly. Thus a ratio of blue to green water reflectances are used to derive quantitative estimates of pigment concentration. Empirical algorithms are developed based on this principle. Each sensor is assigned a default chlorophyll algorithm. The default algorithm varies by sensor based on available spectral bands. The default algorithms by sensor is given by equation (4) and the wavelength of each algorithm / sensor is provided in the table 1:

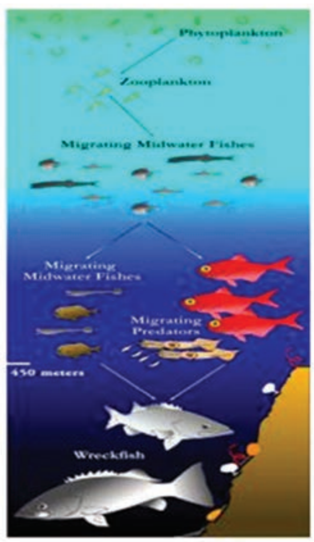
$$log_{10}(chlor\_a) = a_0 + \sum_{i-1}^{4} a_i log_{10?} \left(\frac{R_{rs}(\lambda_{\text{blue}})}{Rrs\ (\lambda_{green})} \right)^i \text{.........................(6)}$$

Table 1. Operational algorithms and respective wavebands.

Ocean colour algorithm	Sensor	blue	green
OC3C	CZCS	443>520	550
OC4	SeaWiFS	443>490>510	555
OC4E	MERIS	443>490>510	560
OC4O	OCTS	443>490>516	565
OC3M	MODIS	443>488	547
OC3V	VIIRS	443>486	550

Applications of Ocean Colour Remote Sensing

Ocean colour remote sensing has wide applications and is applicable for societal benefits. The societal benefits include coastal zone protection and management, fisheries-detection and management *etc*. Coastal zones are prone to pollution and sedimentation due to anthropogenic activities. High chlorophyll concentration indicates harmful algal blooms and quantification of CDOM and TSM performs as good indicators of coastal pollution. Figure 5 shows the trophic relation of fishes with zooplankton and phytoplankton. Cross-trophic level models linking phytoplankton to ûsh production enables long term forecasting of potential fishery zones (PFZ) (Dulvy *et al.*, 2009). Indian National Centre for Ocean Information Services (INCOIS) at Hyderabad disseminates PFZ advisories along the coastal states of India. Species specific advisories for Tuna are also delivered as operational product by INCOIS.



(Image courtesy : IOCCG 2009)

Fig. 5. Illustration of trophic relation of fishes with zooplankton and phytoplankton

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CHAPTER 04

SATELLITE OCEAN COLOUR SENSORS

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1. Introduction

The 70% of the earth's surface is covered by the ocean and the life inhabiting the oceans play an important role in shaping the earth's climate. Phytoplankton, also known as microalgae, are the single celled, autotrophic components of the plankton community and a key part of oceans, seas and freshwater basin ecosystems. They are significant factor in the ocean carbon cycle and, hence, important in all pathways of carbon in the ocean. Phytoplankton contain chlorophyll pigments for photosynthesis, similar to terrestrial plants and require sunlight in order to live and grow. Most of them are buoyant and float in the upper part of the ocean, where plenty of sunlight is available. They also require inorganic nutrients such as nitrates, phosphates, and sulphur which they convert into proteins, fats, and carbohydrates. In a balanced ecosystem, phytoplankton are the base of the food web and provide food for a wide range of sea creatures (NOAA). The measurement of phytoplankton can be indexed as chlorophyll concentration and is important as they are fundamental to understanding how the marine ecosystem responds to climate variability and climate change.

In open ocean waters, the ocean colour is predominantly driven by the phytoplankton concentration and ocean colour remote sensing has been used to estimate the amount of chlorophyll-a, the primary light-absorbing pigment in all phytoplankton. The marine ecosystem captures the visible part of the solar spectrum (400nm - 700nm) for photosynthesis with the help of the pigment molecules (principally chlorophyll) contained in phytoplankton. As they absorb and scatter light from the sun, phytoplankton exert a profound influence on the submarine light field, including the flux upwards across the water surface. As their concentration increases, the colour of the ocean changes from blue to green. Such shifts in ocean colour and the abundance of phytoplankton (chlorophyll concentration) can be mapped by measuring the light reflecting from the sea with optical sensors on-board earth-orbiting satellites. The technique is called ocean-colour radiometry or ocean colour remote sensing, and has proved to be one of the most fruitful of remote-sensing technologies.

For the last few decades, satellite data was used to estimate large-scale patterns of chlorophyll and to model primary productivity across the global ocean from daily to inter-annual timescales. Such global estimates of chlorophyll and primary productivity have been integrated into climate models illustrating the feedback between ocean life and global climate processes (Dierssen *et al.*, 2013). The applications of ocean colour remote sensing are extensive, varied, and fundamental to understand and monitor the global ecosystem. They are being used for monitoring of harmful algal blooms, critical coastal habitats, eutrophication processes, oil spills, and a variety of hazards in the coastal zone. Major applications of ocean colour data are as follows (Ocean Optics Web Book).

- Mapping of chlorophyll concentrations
- Measurement of inherent optical properties such as absorption and backscatter
- Determination of phytoplankton physiology, phenology, and functional groups
- Studies of ocean carbon fixation and cycling
- Monitoring of ecosystem changes resulting from climate change
- Fisheries management
- Mapping of coral reefs, sea grass beds, and kelp forests
- Mapping of shallow-water bathymetry and bottom type for military operations
- Monitoring of water quality for recreation
- Detection of harmful algal blooms and pollution events

2. Ocean Colour sensors

Ocean colour (OC) is an oceanic Essential Climate Variable (ECV), which is used by climate modellers and researchers. Remote sensing of ocean colour from space began in 1978 with the successful launch of NASA's Coastal Zone Color Scanner (CZCS) and it was a milestone in the history of satellite ocean colour remote sensing. Since then, more than twenty ocean colour satellite sensors have been launched *viz.* MOS, OCTS, POLDER, SeaWiFS, OCI, OCM, OSMI, MERIS, CMODIS, COCTS CZI, OSMI, GLI, POLDER-2, MODIS_AQUA, MISR, POLDER-3, MERSI, HICO, OCM-2, GOCI and VIIRS (www.ioccg.org/sensors_ioccg.html). More ocean colour sensors are planned over the next decade by various space agencies. These sensors capture continuous global ocean colour data (e.g. chlorophyll concentration, primary production), which provide significant benefits for research in areas such as biological oceanography and climate change studies. According to the current framework for ocean colour remote sensing, the satellite sensor first measures the intensity of the upward spectral radiation at the top-of-atmosphere (TOA). The varying intensities are then used to retrieve the water-leaving radiance after atmospheric correction, leading to the further retrieval of the optically active marine components (e.g. phytoplankton, minerals and coloured dissolved organic matter). The characteristics of past, current and scheduled ocean colour sensors are furnished in Table 1, Table 2 and Table 3 respectively. Among them, a short description on CZCS, SeaWiFS, MODIS, MERIS and OCM are briefly explained in the following sub-sections.

2.1 CZCS

The Coastal Zone Colour Scanner (CZCS) was the first instrument devoted to the measurement of ocean colour. The CZCS was a multi-channel scanning radiometer aboard the Nimbus 7 satellite, launched on 24 October 1978, and became operational on 2 November 1978. Though it was an experimental mission intended to last only one year, the sensor continued to generate valuable time-series data over selected test sites until 22 June 1986. The sensor resolution was 800m with six channels. The mission was success providing many lessons to the science community regarding calibration, validation and atmospheric corrections of an ocean colour remote sensing system. CZCS laid the foundations for

Table 1. Historical Ocean-Colour Sensors (Source: IOCCG)

SENSOR / DATA SOURCE	AGENCY	SATELLITE	OPERATING DATES	SWATH (KM)	SPATIAL RESOLUTION (M)	# OF BANDS	SPECTRAL COVERAGE (NM)	ORBIT
CZCS	NASA (USA)	Nimbus-7 (USA)	24/10/78 - 22/6/86	1556	825	6	433-12500	Polar
CMODIS	CNSA (China)	SZ-3 (China)	25/3/02 - 15/9/02	650-700	400	34	403-12,500	Polar
COCTS CZI	SOA (China)	HY-1A (China)	15/5/02 - 1/4/04	1400 500	1100 250	10 4	402-12,500 420-890	Polar
GLI	NASDA (Japan)	ADEOS-II (Japan)	14/12/02 - 24/10/03	1600	250/1000	36	375-12,500	Polar
HICO	ONR, DOD and NASA	JEM-EF Int. Space Stn.	18/09/09 - 4/12/14	50 km Selected coastal scenes	100	124	380 - 1000	51.6o, 15.8 orbits p/d
MERIS	ESA (Europe)	ENVISAT (Europe)	1/3/02 - 9/5/12	1150	300/1200	15	412-1050	Polar
MOS	DLR (Germany)	IRS P3 (India)	21/3/96 - 31/5/04	200	500	18	408-1600	Polar
OCI	NEC (Japan)	ROCSAT-1 (Taiwan)	27/01/99 - 16/6/04	690	825	6	433-12,500	Polar
OCM	ISRO (India)	IRS-P4 (India)	26/5/99 - 8/8/10	1420	360/4000	8	402-885	Polar
OCTS	NASDA (Japan)	ADEOS (Japan)	17/8/96 - 29/6/97	1400	700	12	402-12,500	Polar
OSMI	KARI (Korea)	KOMPSAT-1 / Arirang-1 (Korea)	20/12/99 - 31/1/08	800	850	6	400-900	Polar
POLDER	CNES (France)	ADEOS (Japan)	17/8/96 - 29/6/97	2400	6 km	9	443-910	Polar
POLDER-2	CNES (France)	ADEOS-II (Japan)	14/12/02 - 24/10/03	2400	6000	9	443-910	Polar
POLDER-3	CNES (France)	Parasol	Dec 2004 - Dec 2013	2100	6000	9	443-1020	Polar
SeaWiFS	NASA (USA)	OrbView-2 (USA)	01/08/97 - 14/02/11	2806	1100	8	402-885	Polar

Table 2. Current Ocean-Colour Sensors (Source : IOCCG)

SENSOR / DATA LINK	AGENCY	SATELLITE	LAUNCH DATE	SWATH (KM)	SPATIAL RESOLUTION (M)	BANDS	SPECTRAL COVERAGE (NM)	SPECTRAL RESPONSE FUNCTION	ORBIT
COCTS CZI	SOA (China)	HY-1B	11 April 2007	3000 500	1100 250	10 4	402 - 885 433 - 695		Polar
GOCI	KARI/KIOST (South Korea)	COMS	26 June 2010	2500	500	8	400 - 865		Geostationary
MODIS-Aqua	NASA (USA)	Aqua (EOS-PM1)	4 May 2002	2330	250/500/1000	36	405-14,385	SRF-link	Polar
MODIS-Terra	NASA (USA)	Terra (EOS-AM1)	18 Dec 1999	2330	250/500/1000	36	405-14,385	SRF-link	Polar
OCM-2	ISRO (India)	Oceansat-2 (India)	23 Sept 2009	1420	360/4000	8	400 - 900		Polar
OLCI	ESA/ EUMETSAT	Sentinel 3A	16 Feb 2016	1270	300/1200	21	400 - 1020	SRF-link	Polar
VIIRS	NOAA (USA)	Suomi NPP	28 Oct 2011	3000	375 / 750	22	402 - 11,800	SRF-link	Polar
VIIRS	NOAA/NASA (USA)	JPSS-1	18 Nov 2017	3000	370 / 740	22	402 - 11,800	SRF-link	Polar

Table 3. Scheduled Ocean-Colour Sensors (Source : IOCCG)

SATELLITE	AGENCY	SENSOR / DATA LINK	LAUNCH DATE	SWATH (KM)	SPATIAL RESOLUTION (M)	# OF BANDS	SPECTRAL COVERAGE (NM)	ORBIT
HY-1C/D (China)	CNSA (China)	COCTS CZI	2018	3000 950	1100 250	10 4	402 - 12,500 433 -885	Polar
GCOM-C	JAXA (Japan)	SGLI	Dec 2017	1150 - 1400	250/1000	19	375 - 12,500	Polar
HY-1E/F (China)	CNSA (China)	CZI	2021	2900 1000	1100 250	10 4	402 - 12,500 433 - 885	Polar
EnMAP	DLR (Germany)	HSI	2019	30	30	242	420 - 2450	Polar
OCEANSAT-3	ISRO (India)	OCM-3	2018-2019	1400	360 / 1	13	400 - 1,010	Polar
Sentinel-3B	ESA/ EUMETSAT	OLCI	2018	1265	260	21	390 - 1040	Polar
SABIA-MAR	CONAE	Multi-spectral Optical Camera	Sept 2021	200/2200	200/1100	16	380 - 11,800	Polar
GeoKompsat 2B	KARI/KIOST (South Korea)	GOCI-II	March 2019	1200 x 1500 TBD	250/1000	13	412 - 1240 TBD	Geostationary
PACE	NASA	OCI	2022/2023	2000	1000	hyperspectral (5 nm from 350 to 890 nm + 6 in NIR-SWIR)	350-2250 nm	Polar
GISAT-1	ISRO (India)	HYSI-VNIR	*(planned)	250	320	60	400-870	Geostationary (35,786 km) at 93.5°E
ACE	NASA	OES	>2020	TBD	1000	26	350-2135	Polar
GEO-CAPE	NASA	Coastal Ocean Color Imaging Spec (Name TBD)	>2022	TBD	250 - 375	155 TBD	340-2160	Geostationary
HyspIRI	NASA	VSWIR instrument	>2022	145	60	10 nm contiguous bands	380 - 2500	LEO, Sun Sync.

subsequent satellite ocean colour sensors, and formed a cornerstone for international efforts to understand the ocean's role in the carbon cycle. It also provided oceanographers with new insights into the biological and chemical properties of ocean water masses.

2.2 SeaWiFS

Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) was the only scientific instrument on GeoEye's OrbView-2 (AKA SeaStar) satellite, and was a follow-on experiment to the CZCS. The satellite was launched 1 August 1997, SeaWiFS began scientific operations on 18 September 1997. The spacecraft occupied a sun-synchronous orbit at an altitude of 705 km with an equatorial crossing time at 12 pm. The sensor resolution was 1.1 km in Local Area Coverage (LAC) and 4.5 km Global Area Coverage (GAC). The instrument was specifically designed to monitor ocean colour characteristics such as chlorophyll-a concentration and water clarity. During its operational period, the spacecraft telemetry became invalid due to failure of GPS, SeaWiFS interface and battery. As a result, there are gaps in data collection during 1 January 2008- 12 April 2008. In order to make data available at same accuracy, the spacecraft orbit altitude changed from 705 to 690 km. Unfortunately, the sensor failed its operation on 14 December 2010.

2.3 MODIS

MODerate- resolution Imaging Spectroradiometer (MODIS) are the series of EOS sensors launched by NASA on TERRA (December 1999) and AQUA (May 2002) satellites. MODIS is one of the most successful sensor in the ocean colour series and it is operational till date. Unlike SeaWiFS, MODIS records SST also with a spatial resolution of 1.1 km. The instruments capture data in 36 spectral bands ranging in wavelength from 0.4 μm to 14.4μm and at varying spatial resolutions (2 bands at 250 m, 5 bands at 500 m and 29 bands at 1 km). The instrument image the entire Earth every 1 to 2 days. They are designed to provide measurements in large-scale global dynamics including changes in Earth's cloud cover, radiation budget and processes occurring in the oceans, on land, and in the lower atmosphere. MODIS is succeeded by the VIIRS instrument onboard the Suomi NPP satellite launched in 2011 and future Joint Polar Satellite System (JPSS) satellites (http://modis.gsfc.nasa.gov).

2.4 Ocean Colour Monitor (OCM) and OCM-2

Ocean Colour Monitor (OCM) and OCM-2 on board OCEANSAT-1 and OCEANSAT-2 respectively were launched by the Indian Space Research Organisation (ISRO) and designed to map the ocean colour, especially in Indian waters. OCM was the first satellite sensor employed for oceanographic studies in the Indian waters. The OCM sensor was launched on 26 May 1999 and it operated successfully till August 2010. OCM-2, the successor of OCM launched on 23 September 2009, and is currently operational. In OCM, the sensor is a solid state camera which collects data on atmospheric aerosols, suspended sediments and chlorophyll concentration, detect and monitor phytoplankton blooms. It operates in eight spectral bands. OCM provides a spatial resolution of 350 meters and a swath of 1420 km, and capable of covering the whole country every two days. The main applications are measurement of chlorophyll, detection of algal blooms, identification of potential fishery zones, delineation of ocean currents and eddies, observation of pollution and sediment inputs into the coastal zone and their impact on marine food, *etc.* (ISRO, 1999).

2.5 MERIS

Medium Resolution Imaging Spectrometer (MERIS) was launched in March 2002 and one of the main instruments on-board the European Space Agency (ESA)'s ENVISAT platform. The MERIS instrument was a moderate resolution wide field-of-view push-broom imaging spectro-radiometer capable of sensing in the 390 nm to 1040 nm spectral range. The instrument had a swath width of 1150 meters, providing a global coverage every 3 days at 300 m resolution. The primary objective of MERIS was to observe the colour of the ocean, both in the open ocean (clear or Case I waters) and in coastal zones (turbid or Case II waters). These observations were used to derive estimates of the concentration of chlorophyll and sediments in suspension in the water. In addition, this instrument was useful to monitor the evolution of terrestrial environments, such as the fraction of the solar radiation effectively used by plants in the process of photosynthesis, amongst many others applications (LAADS-DAAC). ESA formally announced the end of ENVISAT's mission on 9 May 2012.

3. Ocean Colour Climate Change Initiative (OC-CCI)

The European Space Agency (ESA) initiated Climate Change Initiatives (CCI) for all Essential Climate Variables (ECV). The Ocean Colour CCI (OC-CCI) is the one of them that related to a 'living' variable and having the goal of providing stable, long-term, satellite-based ECV data products. They utilise data archives of from ESA's MERIS and NASA's SeaWiFS, MODIS and possibly CZCS (after careful evaluation) sensors. The OCCCI presents an integrated approach by setting up a global database of in situ measurements and by inter-comparing OC-CCI products with pre-cursor datasets. The availability of *in-situ* databases is fundamental for the validation of satellite derived ocean colour products. A global distribution *in-situ* database was assembled, from several pre-existing datasets, with data spanning between 1997 and 2016 (OC-CCI web).

The OC-CCI project aims to:

- Develop and validate algorithms to meet the Ocean Colour ECV requirements for consistent, stable, error-characterized global satellite data products from multi-sensor data archives.

- Produce and validate, within an R&D context, the most complete and consistent possible time series of multi-sensor global satellite data products for climate research and modelling.
- Optimize the impact of MERIS data on climate data records.
- Generate complete specifications for an operational production system.
- Strengthen inter-disciplinary cooperation between international Earth observation, climate research and modelling communities, in pursuit of scientific excellence.

An inter-comparison analysis between OC-CCI chlorophyll-a product and satellite pre-cursor datasets was done with single missions and merged single mission products. Single mission datasets considered were SeaWiFS, MODIS-Aqua, MERIS and VIIRS; merged mission datasets were obtained from the GlobColour (GC) as well as the Making Earth Science Data Records for Use in Research Environments (MEaSUREs). OC-CCI product was found to be most similar to SeaWiFS record, and generally, the OC-CCI record was most similar to records derived from single mission than merged mission initiatives. Results suggest that CCI product is a more consistent dataset than other available merged mission initiatives (see Figure 1). In conclusion, climate related science, requires long term data records to provide robust results, OC-CCI product proves to be a worthy data record for climate research, as it combines multi-sensor OC observations to provide a > 15-year global error-characterized record. The

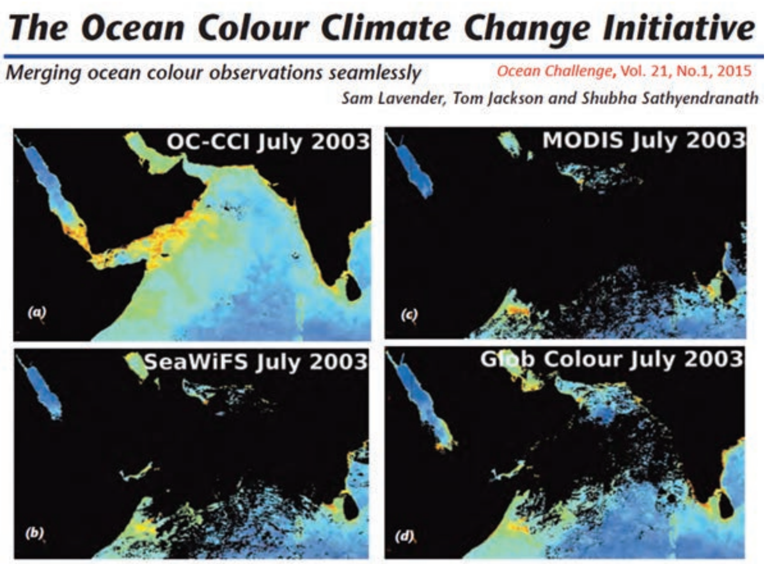

Fig. 1. Inter-comparison analysis between OC-CCI chlorophyll-a product with MODIS, SeaWiFS and GlobColour

data can be accessed by several options, including FTP and composite browser, is available in http://www.oceancolour.org/. A screen shot of the website is shown in Figure 2.

Fig. 2. screen shot of OC-CCI web portal

The OC-CCI project completed its third year with the release of version 3.1 product to the international science community following internal quality control and analysis. The project is maintained through the participation of the different consortium members: Plymouth Marine Laboratory (Science lead) (UK), Telespazio VEGA (UK), Brockmann Consult (Germany), Helmholtz-Zentrum Geesthacht (Germany), Joint Research Centre (EU), HYGEOS (France), Nansen Environmental and Remote Sensing Centre (Norway) and Foundation of the Faculty of Sciences of the University of Lisbon (Portugal) but enhanced with new CRG members (University of Reading) and user engagement (Sam Lavender through VEGA). In addition to European partners, OC-CCI has identified partners in the USA (National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, Naval Research Laboratory), Japan (Hokkaido University) and Canada (Bedford Institute of Oceanography). Additional international expertise is sought through interaction with the International Ocean Colour Coordination Group (IOCCG).

4. International Ocean-Colour Coordinating Group (IOCCG)

The IOCCG is an international Committee of experts with representatives from national space agencies as well as the ocean colour user community and was established in 1996. IOCCG promotes the application of remotely-sensed ocean-colour data through coordination, training, association between providers (space agencies) and users (scientists), advocacy and provision of expert advice. Objectives include developing consensus and synthesis at the world scale in the subject area of satellite ocean colour radiometry, establishing specialised scientific working groups to investigate various aspects of ocean-colour technology and its applications, and addressing continuity and consistency of ocean colour radiance datasets. The IOCCG also has a strong interest in capacity building, and conducts and sponsors advanced ocean colour training courses in various countries around the world (IOCCG). An overview and various activities of IOCCG are schematically represented in Figure 3.

Fig. 3. An overview and various activities of IOCCG (source: IOCCG)

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CHAPTER 05

PHYTOPLANKTON FUNCTIONAL TYPES

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What are functional types ?

The term "functional types" emerged from biogeochemical studies. It represents the group of organisms that share common characteristic role in biogeochemical functions. In ecology, a functional type or group represents an aggregation of organisms according to some well-defined property that sets a role or "function" for them in a system. Phytoplankton Functional types (PFT) are defined as a group of organisms (irrespective of taxonomic affiliation) that carry out a particular chemical process such as calcification, silicification, nitrogen fixation, or dimethyl sulfide production; they are also referred to as "biogeochemical guilds". For example, in Nitrogen-Phytoplankton-Zooplankton (NPZ) models, P and Z are representatives of functional types, *i.e.*, producers and consumers. This aggregation is acceptable for some applications, but may be too coarse or even inappropriate for others.

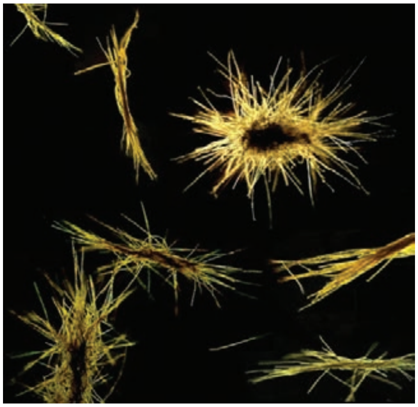
Common Phytoplankton functional types and its Distribution

In pelagic zone, phytoplankton are the dominant diverse group of unicellular microalgae, metabolically and physiologically similar to higher plants. Phytoplankton play a major role in indicating the ecology of the region and it highly contributes as a major primary producer in the food web. These organisms are key partners of carbon and nutrient cycles in the ocean. Diatoms, cyanobacteria, dinoflagellates and coccolithophores are the most dominant phytoplankton taxa in the marine waters. These groups are named as "phytoplankton functional types". Phytoplankton community structures vary from one place to another depending upon various environmental factors resulting in heterogeneous distribution patterns. The major factors that influence the distribution of phytoplankton are: (1) environmental conditions (e.g. temperature and nutrient concentrations), (2) interspecific relationships (*i.e.,* predation and competition), and (3) dispersal (Follows *et al.*, 2007). The distribution and species composition of phytoplankton determines the structure and functioning of the marine food web. Phytoplankton functional types are classified based on size into Pico plankton, Nanoplankton and Net plankton; based on groups, they are classified as Cyanobacteria, PicoEukaryotes, Diatoms and Dinoflagellates; based on ecological functions, plankton are classified as Silicifiers, Calcifiers, Nitrogen fixers and DMS producers.

Phytoplankton based on size classes:

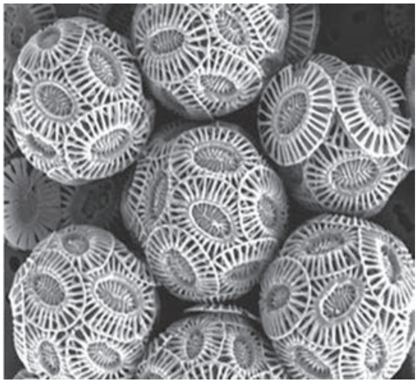
Size of phytoplankton ranges from ~0.6 μm to > 200 μm. The phytoplankton size classes are classified into picoplankton (0.2-2 μm), nanoplankton (2-20 μm) and microphytoplankton (20-200 μm). These broad size classes occupy different physical and chemical niches based on their nutrient-uptake ability, light-harvesting efficiency and sinking rate through the euphotic zone.

Nitrogen Fixers



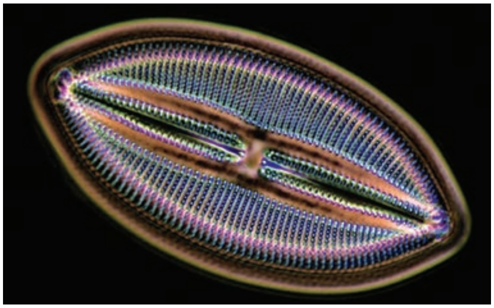
Nitrogen is an essential component for phytoplankton growth. Phytoplankton takes up nitrogen in the form of nitrite, nitrate and ammonia. Nitrogen fixing phytoplankton are also called as Diazotrophs, belong to the class cyanobacteria (blue green algae). For example, *Trichodesmicum*, bloom causing genera of blue green algae (See Image 1, source:https://alchetron.com/Trichodesmium). These organisms are capable of utilizing dissolved nitrogen gas in seawater. These functional types are symbionts, present along with other phytoplankton groups. These groups are known to contribute to nitrogen fixation. When nitrogen fixation is high,the oceanic primary production may vary from nitrogen-limited to phosphorus limited and hence affects the phosphorus cycle.

Calcifiers



Coccolithophores belong to the phylum Prymnesiophyceae. In the process of biomineralization, calcium compounds react with Hydrogen carbonate to form calcium carbonate and dissolved carbondioxide ($Ca + 2HCO_3 \longrightarrow CaCO_3 + H_2O + CO_2$). They produce calcium carbonate shells called coccoliths and are referred to as calcifying phytoplankton. Coccolithophores are the most abundant primary producers and a large contributor to the primary productivity of both the tropical and subtropical oceans. Calcifiers are estimated to produce about 0.6 and 1.2 GT calcite carbon per year. (Coccolithophores: See Image 2, source: http://rwotton.blogspot.in/2016/04/jo-athertons-anthropocene)

Silicifiers



Diatoms possess silica frustules that surround and protect the cells and are commonly known as Silicifeirs. This phytoplankton belongs to the class, Bacillariophyceae. The presence of silica frustules makes this phytoplankton negatively buoyant. They sink into the deeper waters of the ocean contributing to the transportation of carbon and nitrogen from surface to deeper waters. Other phytoplankton such as chrysophytes, silicoflagellates, and xanthophytes are also known to be silicifiers (Brownlee and Taylor,2002). SeeImage3, source:https://sites.google.com/site/botany317/session2/eukaryotes/session3/heterokonts/diatoms).

DMS producers

Phytoplankton taxa of classes: Dinophyceae, Haptophyceae (including Coccolithophores), Chrysophyceae, Pelagophyceae and prasinophyceae are referred to as DMS producers. These phytoplankton populations produce dimethyl sulfoniopropionate (DMSP) a volatile organic compound. The processes related to cell decay and grazing are involved in the transformation of DMSP to Dimethyl sulphide (DMS) in the water. DMS is responsible for the characteristic smell in the seawater. DMS is thought to play a role in the Earth's heat budget by decreasing the amount of solar radiation that reaches the Earth's surface.

Role of Phytoplankton Functional types

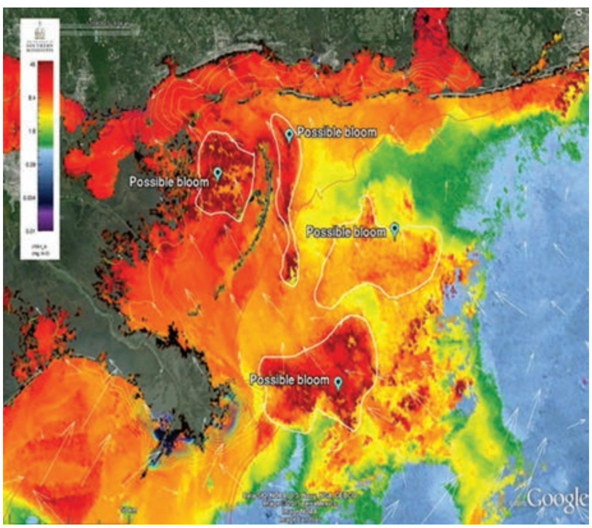
Phytoplankton play an important role in the global carbon cycle. They are responsible for fixing carbon into organic material during the process of photosynthesis. The amount of carbon emission on an annual scale is estimated to about 7 GT per annum and the process is comparable to the net production by terrestrial plants at the global scale (Longhurst, 1995). Phytoplankton functional types are major primary producers involved in the biogeochemical processes of nitrogen, phosphorous and other elements present in the surface waters of the ocean. Phytoplankton are the source of food supply for the fishery resources of the marine ecosystem. Phytoplankton composition influences the food webs and the type of fish that live in a delineated region or environment. For example, some phytoplankton functional types such as flagellates favor the growth of clupeids. Thus, phytoplankton types are also relevant in studies of fish ecology, and hence are an important ingredient in efforts towardsan ecosystem-based strategy for sustainable management of fisheries. Phytoplankton leads to harmful algal blooms, if their occurrence is in very high concentrations. This creates a low-oxygen *i.e.*, hypoxia condition creating negative impact on the fisheries environment. Dinoflagellates and diatoms are the functional types implicate harmful algal blooms in the coastal and oceanic systems.

Studying the phytoplankton diversity in the oceans at large regional scale still remains as an intractable problem. There, the remotely-sensed PFT information serves to be very useful for understanding the various ecological and biogeochemical processes in the ocean. steady rise in sea surface temperature has the potential to extend the geographic ranges of PFTs such as nitrogen fixers and picoplankton, whereas increases in ocean acidity (increase in atmospheric carbon-di-oxide levels), tend to lower the abundance of some other species.

Methods of measuring Phytoplankton Functional types

Phytoplankton identification and characterization are based on several approaches such as using microscopy studies, chromatography techniques for characterizing the functional types based on pigments, cytometry, genetic sequential molecular methods and through remote sensing. Microscopic techniques rely on optical lenses and human eyes or cameras to identify the phytoplankton species. High performance Liquid Chromatography techniques rely on detectors for absorption and fluorescence signals of phytoplankton pigments. Flow-cytometry incorporate photomultipliers or diodes to detect scattering and fluorescence properties of individual phytoplankton cells. Optical properties have the potential to be incorporated with *in situ* technologies, which provides improve space-time coverage in accessing the PFTs in the sea.

Satellite remote sensing datasets are also used to identify and characterize the phytoplankton communities. Mapping and case studies on Harmful algal blooms of Coccolithophores, Diatoms and different species of cyanobacteria at different regional scales were also carried out based on spectral band signals and validated algorithms. Phytoplankton functional types were also studied by determining the size structures of the phytoplankton communities using two approaches: abundance based approach and spectral based approach. Abundance based approach uses the expected size structure of the phytoplankton at a given pixel, based on *in situ* correlations between



size structure and phytoplankton abundance. Spectral-based approaches are more direct, as they rely on observing distinct optical signatures (absorption, reflectance and backscattering). An example ocean colour satellite image from Visible Infrared Imaging Radiometer Suite coupled with modeled data to delineate the possible phytoplankton bloom is presented in the Image 4 (source: Ocean Weather Laboratory).

Each method has both advantages and disadvantages in characterization of phytoplankton communities. Hence, integrated approaches from different methodologies can lead to more comprehensive assessments and understanding of the PFTs on a synoptic scale. In future, expansion and advances in *in situ* sensors and deployment modes emphasizing high resolution time series sites and numerous mobile platforms will be advancing approaches to address the technical limitations to address the technical limitations to study these microscopic organisms.

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CHAPTER

06

PHYTOPLANKTON TAXONOMY, IDENTIFICATION AND ENUMERATION

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Introduction

Phytoplankton are microscopic, free floating organisms and is the principal primary producers of the oceans. Their size range from 0.2 µm to 2 mm. Phytoplankton contains primary pigments and accessory pigments such as chlorophyll (Chl), carotenoids *etc.* which strongly absorbs the blue and red light of the visible spectra. Phytoplankton also influences the total scattering properties of sea water. Due to their relatively large size, the larger phytoplankton species contributes relatively little to backscattering in the visible spectrum. The principal phytoplankton taxonomic groups include:-

Class Bacillariophyceae	-	Diatoms
Class Pyrrophyceae	-	Dinoflagellates
Class Prymnesiophyceae	-	Coccolithophores
Class Chrysophyceae	-	Silicoflagellates
Class Euglenophyceae	-	Euglenoid flagellates
Class Chlorophyceae	-	Green algae
Class Cyanophyceae	-	Blue-green algae
Class Haptophyceae	-	Brown colored Phytoflagellates (Kennish 2001).

Class Bacillariophyceae (Diatoms)

The class Bacillariphyceae comprises diatoms with fascinating shapes and ornate patterns. The common shapes include rounded (centric) and elongated (pennate). Diatoms are embedded in an outer wall made of silica and known by the frustules. The shape of diatoms are like a lab Petri dish or a soap box, with one valve larger in diameter (the "epivalve") and the other one overlapping the reversed second valve (the "hypovalve"). Some diatoms attach to each other, while some others attach end to end at an angle to form colonies. Diatoms reproduces by asexual or vegetative reproduction. **Sexual** reproduction producing auxospores and resting spores are also reported. The visible accessory pigmentation in diatoms are of golden colour.

Centric diatoms are characterized by their radial symmetry are common to the surface waters. Many centric diatoms have projecting spines, which increases their surface area in relation to the volume of water holding them up, which helps them stay buoyant. Pennate diatoms have elongated valves and are more likely to be found on shallow bottoms. Pennate diatoms have a groove on their underside, called a "**raphe**," which secretes mucus.

Class Pyrrophyceae (Dinoflagellates)

This name's Greek origin means "spinning tail;" so named because these microscopic organisms have flagella–tiny tails made of protein strands. As the name indicates these are embedded with 2 (dino) flagella. These whip-like flagella helps them to propel in the water and are sometimes used for attachment . The two flagella are dissimilar in size, one wrapped around the body and one extending outward from the body. In dinoflagellates, the accessory pigments are coloured of red to reddish brown. The outer wall of dinoflagellates are made of cellulose. Dinoflagellates are differentiated into two owing to the presence or absence of armoured plates. Some dinoflagellates have thick armoured plates that fit together, like the armour of medieval knights and these plates can slide apart or over each other. Others are unarmored or naked. Bioluminiscence is another peculiarity of dinoflagellates.

Class Prymnesiophyceae (Coccolithophores)

Coccolithophores surround themselves with a microscopic plating made of limestone (calcite). These scales, known as coccoliths, are shaped like hubcaps and are only three one-thousandths of a millimeter in diameter.

Class Chrysophyceae (Silicoflagellates)

Small single-celled flagellates and flagellated colonies. Common in oligotrophic clear waters and humic waters. The algae coming under this family is commonly known as golden algae. The cells are naked or covered by scales, lorica or cell wall. The flagellate cell usually possesses two heterodynamic flagella. This algal family is unicellular or colonial. The pigments are chlorophyll-a, -c and fucoxanthin; this fucoxanthin which give the characteristic colour. It stores energy in the form both as carbohydrate and oil droplets. Presence silica deposition vesicle, flagella apical and unequal in length. Asexual reproduction by binary fission, sporogenesis. Sexual reproduction reported in some members. The lifecycle is haplontic in chrysophyceae.

Class Euglenophycea (Euglenoid flagellates)

The euglenophyceans are basically unicellular flagellate. The cell is usually naked, but some species such as Trachelomonas (Euglenales) possess lorica deposited by iron and magnesium. The most unique feature of the Euglenophyceae is the presence of proteinaceous strips, pelicler strips beneath the cell membrane. The species with many flexible pellicler strips. In the Euglenophyceae, a photosynthetic genus, as well as many colorless phagotrophic or osmotrophic species are present. The green chloroplast is originated via secondary endosymbiosis with a green plant at the common ancestor of the Eutreptiales and Euglenales.

Class Chlorophyceae (Green algae)

Chlorophyceae (chloros, green; phyceae, algal organisation) is commonly known as green algae. Green algae are characterized by the presence of green plastids known as chloroplast. This containing a starch storing region called pyrenoids. The members of Chlorophyceae generally grow in fresh water (about 90%) and the rest in saline water, terrestrial habitat *etc.* The fresh water members such as Volvox, Oedogonium, Spirogyra *etc.* grow in ponds, pools and lakes. Flagella are 1-many, equal in size and inserted either apically or sub-apically. The flagella show typical 9+2 arrangement when viewed under E.M. The cells are eukaryotic in nature. The cell wall is mainly made up of cellulose, which comprised of hydroxyproline glyco-sides or xylans and mannans. The flagellate cells have eye-spot or stigma in the anterior portion, which remain inser-ted at one side of the chloroplast.

Class Cyanophyceae (Blue-green algae)

Members of the class Myxophyceae (Cyanophyceae) are commonly known as blue green algae. The name blue green algae is given because of the presence of a dominant pigment c-phycocyanin, the blue green pigment. In addition, other pigments like chlorophyll a (green), c-phycoerythrin (red), â-carotene and different xanthophylls are also present. The members of this class are the simplest living autotrophic prokaryotes. Nucleus is of prokaryotic nature *i.e.*, devoid of nuclear membrane and nucleolus, Absence of well-organised cell orga-nelles, and Pigments are distributed throughout the chromoplasm (the outer part of proto-plasm). Locomotion is generally absent, but when occurs, it is of gliding or jerky type.

Class Haptophyceae (Brown colored Phytoflagellates)

Unicellular, mostly marine, mostly photosynthetic. Around 80 genera, 500 species (= relatively low diversity). Ecologically important component of phytoplankton communities at all latitudes. Mostly nannoplankton (2-20 micron) size fraction. Mostly motile with 2 flagella. Characteristic feature: presence of a haptonema. Two smooth flagella, equal or unequal in length. Almost all haptophytes are photosynthetic (one species isn't), but most may actually be mixotrophic. All haptophytes contain chlorophylls a and c, as well as ?-carotene, diatoxanthin and diadinoxanthin. In this they resemble heterokonts.

Characters for phytoplankton identification

Phytoplankton are identified based on thier:-

- Cell shape / size
- Mode of life (solitary, colonies, filaments...)
- Organelles : presence / absence

- Plastids: colour, number, shape, ultrastructure
- Cell covering (frustule, scales, theca, cyst...)
- Flagella (number, length, insertion)
- Reserve substances (nature, localisation)
- Other characters (stigma, haptonema, pseudopods, ...)

Sample Collection, Preservation and Enumeration

Sampling Design

Offshore and inshore sampling designs differ according to seasons, locations, depths, substrates, purpose of monitoring and available manpower and equipments. To detect early phases of phytoplankton blooms, frequency of sampling becomes important because blooms can develop over a period of 2 to 3 weeks or be transported into an area. Monitoring of sentinel filter feeding species is also beneficial, e.g., bivalves and tunicates.

Sample Collection

Before sampling begins, the manpower involved has to be thorough in sampling design (transects and adaptive sampling), frequency, collection methods, variables to be measured, data recording and storage, and the best approach to meet the goals of the program. Repetitive sampling at fixed stations is desired for statistical analysis of data (plankton, nutrients, salinity, temperature, *etc.*). Processing enough sample volume is also important. Distance between stations can be critical because of oceanographic conditions. Sampling for planktonic blooms and conditions should involve sampling or profiling with depth because the water column is 3 dimensional. It may also involve monitoring "seed" beds in the benthos to determine and even predict timing of blooms. Sampling for benthic algal blooms requires collecting substrate, e.g., sediments, on a routine basis. Processing requires removal of HA cells for analysis.

Equipments for collection of samples include Bucket, weighted, bottle or Niskin sampler. The bottles used for collecting live samples has to be properly labeled. The label should contain Station Identification No, Latitude/Longitude, Depth at which sample was collected, name of fixatives used and date of sampling. Latitude /Longitude can be identified using GPS unit. A data log sheet also has to be maintained specifying all the details collected for the sample. This may include pH, temperature (using thermometer) *etc.* Lead weighted bottles can be used for collection of phytoplankton samples upto 40m depth. For collecting of sample at depths <200m, Niskin sampler can be used. This uses weights or ropes on wire to trigger the closing of openings in this sampler. The sample collection can be assisted with a portable data profiler which is able to measure pH, Dissolved Oxygen, Conductivity, TDS, Salinity, ammonium, Nitrate, chloride, Temperature *etc.* When the sampling platform is a Ship, CTD and rosette sampler will serve the purpose.

Fixatives used for sample preservation

Unacidified (Neutral Lugol's Iodine) Solution

1gm potassium Iodide, 0.5 gm Iodine, Dissolve in 3ml of distilled water dilute to 50ml. Use 2%in volume/volume for final concentration.

Gluteraldehyde

25% gluteraldehyde buffered with sodium acetate to a 10% solution. Use in a 1:10 ratio with sample.

Methods for collecting samples

The bottle in which sample is collected has to be rinsed with water sample at the collection point. The samples are collected from discrete depths and transferred to the properly labelled sampling bottles. The bottles are stored in coolers separately for live samples and fixed samples.

Enumeration

1. Using Utermohl Method

The sample bottle is gently inverted nearly 15 times . 10-100ml of sample is measured and transferred to the Utermohlchamber. The chamber is kept idle for 24 hours. The phytoplankton cells are allowed to settle in the chamber. Minimum 30 fields are examined. The phytoplankton are identified upto species level and enumerated. Afterwards, the entire chamber is examined to know the presence of any phytoplankton that is not encountered in the fields. The chamber is examined under inverted microscope. The table below shows the data sheet.

Serial Number	Phytoplankton species	Numerical abundance	Total Number
1	Skeletonema	~~1111~~ ~~1111~~ 11	12
2	Chaetoceros	1111	4
3	Coscinodiscus	~~1111~~	5

Calculation

Cells/Litre=1000*(C*A)/ F*FA*V

Calculation cells/Litre at 100X magnification

Cells/Litre=1000*(C/V)

C = Number of cells counted

A = Area of chamber bottom

F = Number of fields counted

FA = Area of Field view

V = Volume settled

2. *Using Nunc Method*

The bottle containing samples are inverted nearly 15 times. About 3ml of sample is measured using a pipette. The samples are transferred to Nunc chamber. Cells are allowed to settle for 30 minutes. The cells are identified and enumerated for entire bottom of chamber using inverted microscope. For dense samples, reduced volume (0.3 ml - 0.03 ml) are used for enumeration. Sterile filtered seawater is added to the chamber to level out the sample.

The advantage of Using Nunc chamber is that resolution of cells and morphologyare right upto the edge of the chamber side without distortion, optical transects can be counted easily, and cells can be moved easily for further analysis. The disadvantage includes use of limited volume of sample and higher cost. Limited number of usage of Nunc chambers is also a drawback.

3. Using Sedge-wick Rafter

Sedgewick rafter slides are used for examining 1ml of sample. The slide is designed to occupy 1ml of sample and partitioned into 1000 grids each with an area of $1mm^3$. Identification and enumeration is done in 4x4 grids or on random selection. A minimum of 3 such grids are examined under microscope. The average number is then calculated and scaled for 1ml.

$$N = \frac{(n*v*1000)}{V}$$

Where N = number of cells per litre
n = number of cells per millilitre
V = total volume filtered
v = volume of sub-sample

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CHAPTER

07

ALGAL CULTURE METHODS

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Stock Culture

All algae culture systems require a set of 'stock' cultures, usually of about 250ml in volume, to provide the reservoir of algal cells from which to start the larger-scale cultures which will be used for feeding.

Stock cultures are kept in small flasks, such as 500ml borosilicate glass, flat-bottomed boiling flasks fitted with cotton-wool bungs. Two types of culture medium can be used:

a) Erdschreiber culture medium, which is difficult to prepare but very reliable; and

b) simpler, but less reliable culture medium

Sub culture

Stock cultures must be sub-cultured frequently. Sub-culturing involves inoculating some cells from an old stock culture into fresh culture medium, so that the cells can continue to grow and divide and remain healthy. If sub-culturing is not carried out, the algal cells in the stock culture will eventually die. It is important to take precautions to prevent contaminants from the air entering the stock cultures when sub-culturing.

To start a new stock culture, about 20ml of algae are taken from a stock culture which has been growing for 6 to 7 days and poured into a flask containing 250ml of fresh culture medium. After removing the cotton-wool bungs, and before and after pouring, the necks of both flasks should be passed through a gas flame, such as that from a Bunsen burner or spirit lamp, to kill the new stock culture should be put about 20cm from a fluorescent lamp that is lit continually. The air temperature around the culture should be less than 25°C. Note that stock cultures do not require an air/CO_2 supply.

After sub-culturing, the remainder of the old stock culture can be used to start a batch culture of up to 10 litres. If the stock culture is not required immediately, it may be kept for up to 3 weeks on a shelf in a north-facing window (away from direct sunlight), But after this time it should be discarded.

Types of Culture

There are many different ways of culturing algae. These range from closely-controlled methods on the laboratory bench top, with a few litres algae, to less predictable methods in outdoor tanks, containing thousands of litres, in which production relies on natural conditions. Several methods have been developed at Conwy, for the production of algae for use as food for various marine animals.

There are certain requirements for all methods. A culture must be inoculated, and the algae left to grow and divide. The rate of growth and division varies with different types of algae left to grow and divide. The rate of growth and division varies with different types of algae and also depends on how well the various culture conditions necessary for growth have been met. When there are sufficient algal cells in the container for feeding, one of the three culture methods below may be followed:

Batch culture

Batch culture is a system where the total culture is harvested and used as food. If required, another culture can be set up to replace it.

Semi-continuous culture

Semi-continuous culture is a system where part of the culture is harvested and used as food, and the amount taken is replaced with fresh culture medium (clean sea water and nutrient salts). After allowing 2-3 days for the remaining cells to grow and divide, the process is repeated. Semi-continuous cultures may be operated for up to 7 to 8 weeks.

Continuous culture

This falls into two categories:

i) *turbidostat* culture, in which the number of algal cells in the culture is monitored and, as the cells divide and grow, an automatic system keeps the culture density at a pre-set level by diluting the culture with fresh medium; and

ii) *chemostat* culture, in which a flow of fresh medium is introduced into the culture at a steady, pre-determined rate.

With both types, the surplus culture overflows into a collecting container, from which it can be taken and used as food.

With semi-continuous and continuous culture methods, the number of food cells produced (the yield) varies with the density of the culture. For each type of algae, the greatest yield is obtained by maintaining the culture at an optimum density. This optimum density can be determined experimentally and is given for each of the culture systems as described in the following section.

Some culture methods

Batch culture (small volumes of up to 10 litres)

Where small volumes of algae culture are required, for example, of 2 litres to 10 litres per day, production is most conveniently achieved in flasks. An example of a batch culture system for producing 3 litres of food per day from a culture of *Chaetoceros calcitrans* is given below and is described as daily procedures.

A set of three, 250 ml stock cultures is started by inoculating from one existing 250 ml stock culture on each of 3 successive days. The new stock cultures are grown at a temperature of about 21°C, and at a distance of 15 to 20 cm from a 65 watt fluorescent tube. After 3 days, and then daily, each of these stock cultures is used in turn to inoculate a new 250 ml stock culture then daily, each of these stock cultures is used in turn to inoculate a new 250 ml stock culture and the remainder is added to the 3 litre sea-water culture medium in the flasks, which have been prepared as follows:

Three-litre borosilicate glass flasks with cotton wool plugs are filled with sea water. The contents are either autoclaved at 1.06kg per square centimeter (15 psi) for 20 minutes, boiled for 30-45 minutes, or pasteurized. Whichever method is used, the sea water in the flasks should be allowed to cool before adding nutrient salts, Alternatively, sea water that has been filtered through a half micron filter may be used. To the 3 litres of sea water in the flask, 6 ml solution A, 0.6 ml of solution C and 6 ml of solution D are added.

A fresh 3 litre culture is started daily from a 3-day-old stock culture and aerated with a mixture of air and CO_2 at about 2 to 3 litres per minute. The gas mixture is filtered through an in-line catridge unit containing a 0.3-0.45 micron filter to reduce the risk of airborne contamination. When grown at about 21°C next to a continually lit, double flurescent lamp unit, a density of 45000 to 60000 cells per microlitre is reached in 3 to 4 days in culture medium prepared from heat treated sea water. In medium prepared from filtered sea water, growth of *Chaetoceros* is not as rapid and the density will only reach 20000 to 30000 cells per microlitre in this time. The culture should immediately be used for feeding, as if kept it will enter a declining phase, collapse, and become unsuitable.

Algae other than *Chaetoceros* usually take longer to grow under similar culture conditions. For these algae, stock cultures should be routinely sub-cultured every 6 to 7 days. The batch cultures, which are started from 6 or 7 day old stock cultures, will take 7 to 8 days to grow to a density suitable for feeding. Larger containers, of up to 10 litres, may be used for this method of culture. Nutrient salt solutions are used a s follows:

Solution A- 1ml per litre
Solution C- 0.1 ml per litre; and

Solution D (diatoms only) – 2ml per litre.

The batch cultures may be used directly as food or as inocula to start larger volume batch, semi-continuous or continuous food cultures.

Semi-continuous culture

Two-hundred-litre vessels

A method for large scale production in 200 litre, internally illuminated, glass reinforced plastic (grp) vessels, using semi-continuous culture is described below.

The vessels are 150 cm high, 40-45 cm in diameter and each has a central lighting unit into which are fitted six fluorescent lamps. A glass- fibre cooling pipe is moulded onto the outer jacket. These vessels are most useful for growing diatoms, but they may also be used for flagellates. The vessels are sterilized by filling with a solution of sodium hypochlorite (50 parts per million (ppm) free-chlorine concentrations). Note that domestic bleach contains about 100000 to 150000 ppm chlorine, so a dilution of 1 ml per 2-3 litres would give the required concentration. They are allowed to stand for 2-4 hours and the drained, and flushed with filtered air for 24 hours to drive off residual chlorine.

The vessels are filled (200 litres come to about 15 cm from the top) with filtered sea water at 20 psu to 25 psu salinity for diatiom cultures or 25 psu to 30 psu for flagellate cultures. For diatom cultures, filtration to 2 microns is usually sufficient, while for culture of flagellates, filtration to half a micron is preferable. Two hundred milliliters of solution A 20 ml of Solution C and, for diatom cultures, 1200 ml of Solution D are added to the vessels. The culture is inoculated with 2 to 5 litres of a 4 to 8 day-old batch culture, grown as described in the previous section and aerated with a filtered air/CO_2 supply at about 15 litres per minute.

Cultures should reach densities suitable for harvesting after 4 to 7 days. The cultures should be subsequently be diluted for the maximum yield. The amount of harvest which achieves this yield can be calculated from the following equation:

$$\text{Volume to harvest in liters} = \frac{\text{200 x densities to which culture needs to be diluted}}{\text{Actual culture density of algae harvested}}$$

After harvesting, the vessels are topped-up to 200 litres with filtered sea water of the correct salinity. For each litre harvested, 1 ml of solution A, 0.1 ml of solution C and, for diatom cultures, 6 ml of solution D are added. It is usually more convenient to harvest the culture every 2 to 3 days (e.g Mondays, Wednesdays and Fridays). That part of the harvest which is required for feeding on the intermediate days can be aerated in a plastic container away from bright light and in a cool place.

The length of time during which the culture is able to produce food will vary with the type of algae. Production of algae from 200 litre vessels should average the equivalent of 60-80 litres per day at the cell densities. When the culture is no longer required, or it has come to the end of its production period, the vessel can be drained and cleaned with a stiff brush, to remove any algae adhering to the sides. The vessel can now be sterilized for preparation for a new culture.

Continuous culture

This method is suitable for the culture of flagellates. The internally-illuminated, continuous culture vessels are made from polyethylene tubing supported by a metal framework. They consist of 160 cm lengths cut from 71 cm wide polyethylene, 'layflat' tubing. The tubing is free of potential contaminants due to the heat used in the manufacturing process and no further sterilization is necessary. The cut length is heat sealed across the width of one end and positioned around the acrylic cylinder containing the lamps. The six nuts and bolts securing the outer supporting mesh jacket are fastened and the outer reflective sheet of white, corrugated plastic is held in place by 12.7mm nylon power belting, which also supports the sensor housing unit against the outer surface of the culture.

The polyethylene tubing is filled with sea water at 25 psu to 30 psu salinity that has been filtered through a sterile, 0.45 micron, particle retention catridge filter. If the water has a high silt load, it should first be passed through a 2 micron filter. Solution A (100ml) and Solution C (10ml) are added to the sea water in the vessel. This is 2.5 times the usual amount, and is added to ensure that nutrient levels do not become limiting at the high cell densities at which the cultures are maintained. A 2.5 cm diameter circle is cut from the tubing, with its centre about 7 cm above the water level. Into this is fitted a 1.9 cm rigid, PVC tank connector, from which a 150 cm length of 1.5 cm bore flexible PVC tubing is run into a 125 litre collecting vessel. The overflow allows for automatic harvesting of the culture into the reservoir.

A supply of filtered air, enriched with sufficient carbon dioxide to maintain culture pH at 7.6-7.8 is introduced through a 0.4 cm bore, 150 cm long, acrylic tube inserted into the top of the culture. A flow rate of about 15 litres per minute ensures efficient mixing of the culture.

Cooling water, at a flow rate of about 0.35 litre per minute, is allowed to run down over the outer culture surface in order to maintain the culture temperature at about 21°C. The 40 litre culture should be inoculated with a 2 litre batch culture that has grown for 7 to 8 days.

Automatic harvesting of the culture is controlled by the following method. A cadmium sulphide photo-conductive cell is enclosed in a light-proof housing against the outer surface of the culture. The housing is placed about 50 cm from the base of the vessel and positioned so that the stream of air bubbles rising through the culture does not interfere with its operation. The resistance of the photo-conductive cell will increase as the light intensity reaching it from the lamps falls, when density of the culture increases, due to growth and division of the algal cells. A circuit switching the peristaltic pump will be energized when the resistance of the cell becomes greater than a present value on a relay sensitive to input resistance in the range 50-5000 ohm. Sea water, at 25 psu to 30 psu and enriched with 2.5 ml of solution A per litre and 0.25 ml of solution C per litre, is then pumped from the culture medium reservoir through the filter into the vessel and the volume is maintained by an overflow. The outflow of algae culture from the vessel is collected in an aerated container. As the culture is diluted, the decrease in resistance of the photo-conductive cell, caused by the higher light intensity now reaching it, is sensed by the relay and the pump circuit is switched off.

The relay should be set so that automatic harvesting of the culture occurs at the density that gives the most yield. When the yield begins to fall appreciably, all of the culture should be harvested for feeding and the bag discarded. A new, clean bag should be fitted to the vessel and the above operating procedure repeated.

Photobioreactors

Design Considerations

Many configurations of photobioreactors have been devised and built. These range from tubular and cylindrical systems to conical systems (Watanabe and Hall 1996, Morita *et al.*, 2000) to flat-sided vessels (Delente *et al.*, 1992, Iqbal *et al.*, 1993, Hu *et al.*, 1998), and these systems employ a wide variety of light sources (Takano *et al.*, 1992, Lee and Palsson 1994, An and Kim 2000). As such, each is usually a highly customized system and the availability of commercial photobioreactors is limited.

Despite various configurations, several basic design features must be considered when building a photobioreactor: how to provide light, how to circulate the algae, which materials to use for construction, how to provide CO_2 and remove O_2, and how to control pH and temperature. Sophistication is driven by purpose, and if whole algal biomass is the desired final product, a relatively unsophisticated system will suffice. Glass and acrylic are widely used in the construction of photobioreactors, and ultraviolet (UV)-stabilized acrylic is superior because it is lighter, more flexible, stronger, and easier to machine, cut, bond, and so on. Construction requires some minimal construction skills, but certainly not professional skills. Assembly of the photobioreactor system is merely the integration of various monitor and control subsystems (e.g., pH control and temperature control).

Light

Light is the most important parameter in the design and construction of a photobioreactor. Despite its importance, light can be a very difficult input to measure for efficient use (Pirt *et al.,* 1983, Kirk 1994, Ogbonna *et al.,* 1995, Janssen *et al.,* 2002). Light can be supplied continually or in light-dark cycles. As cell concentration changes, the light requirements change. Algal growth is limited by too little light, but too much light can be as deleterious. Phototrophs must receive sufficient light to exceed their light compensation point for their net growth; insufficient growth detracts from the net growth of the culture because of respiratory loss (Radmer *et al.,* 1987). Increasing light beyond the compensation point results in an increase in the growth rate until the culture becomes light saturated, and higher light intensities can lead to photoinhibition (AcienFernandez *et al.* 1998, Csögör *et al.,* 2001, Yun and Park 2001, Wu and Merchuk 2002, Barbosa *et al.,* 2003, Suh and Lee 2003). Incandescent lamps are inferior to the other lamps and are seldom used for photobioreactors (Table 13.1). Both fluorescent and high-intensity discharge lamps have very good electrical efficacy and substantial lifetimes. Fluorescent lamps distribute light more or less uniformly along the length of the lamp; light emanates from a point source in high-intensity discharge lamps, requiring distance between the lamp and algae for proper light dispersion. Although high-intensity discharge lamps are slightly more efficient than fluorescent lamps, however, fluorescent lamps offer the best all-around choice (Radmer *et al.,* 1987, Radmer 1990, Delente *et al.,* 1992).

Circulation

Circulation is important to ensure optimum illumination of the algae, adequate gas exchange, and temperature and pH control within the culture. The "airlift" principle in which circulation is accomplished by creating differences in water density in different regions of the photobioreactor is the one in commonly using (Manfredini and Molina Grima *et al.,* 1995, Blanch and Clark 1997). This principle is common in fermentors (see later discussion) and has been adapted for use in photobioreactors.

Photobioreactors can be bubbled with air, but the low CO_2 concentration in air (0.033%) will often limit phototrophic growth. With an airflow of 1 L min^{-1}, assuming all carbon dioxide is used and the biomass is 50% carbon, there is enough carbon to support 3.54 $*10^{-4}$ grams biomass · min^{-1}; this is a very low productivity. The simplest approach is to blend CO_2 with air, for example, 0.2 to 5.0% of the total gas flow (Lee and Pirt 1984, Merchuk *et al.,* 2000, Morita *et al.,* 2001, Babcock *et al.,* 2002). Care must be taken to ensure that the CO_2 input does not adversely lower the pH level of the culture. Also, with an open system, most of the CO_2 will exit the vessel unused. Small bubble size helps facilitate diffusion.

Temperature and pH

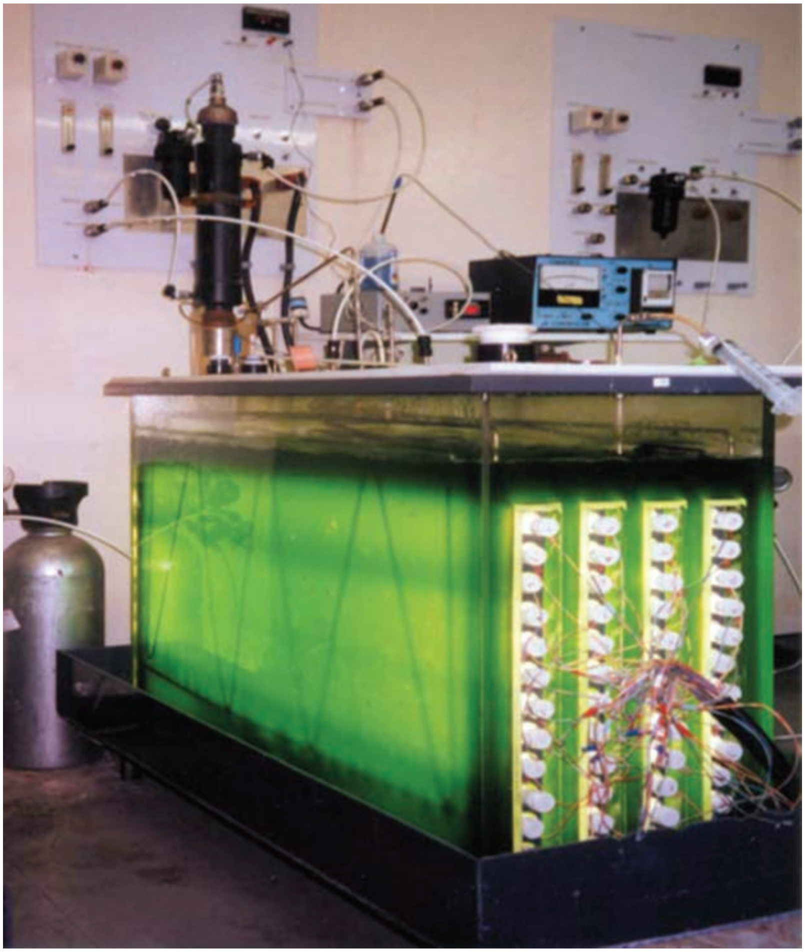
After light, CO_2, and O_2, pH and temperature are the next most important parameters to measure and control. Fortunately, these are very simple parameters to control using existing off-the-shelf technology (Sonnleitner 1999). Commercially available pH controllers (Omega Engineering) are recommended. Photosynthetic systems will always generate heat because of the inefficiency of photosynthesis in converting light energy into chemical energy (Pirt, 1983, Morita *et al.,* 2001). The theoretical conversion of red light into chemical energy (NADPH) is only 31%; 69% is lost as heat. The amount of cooling depends on the incident light intensity and the cell concentration (*i.e.*, how much light is absorbed), but regardless, cooling will be necessary. In principal, it is quite easy to control the temperature using commercially available temperature controllers (Omega Engineering). Cooling is achieved with a heat exchange system; external cool water is circulated through a good heat conducting material, which then draws heat from the photobioreactor. The more significant challenge is how to install a cooling system on a photobioreactor. The most preferred system is the one uses stainless steel cooling coils submerged in the culture medium. There is excellent contact between the cooling coil and water, which provides good cooling, but the cooling coil sometimes interferes with the circulation within the vessel. A refrigerated water source (or tap water, depending on the cooling demands of the culture) is used, and a temperature probe, connected to a controller, operates a solenoid to regulate cooling water flow. The best strategy is to use a "normally open" solenoid so that if there is a failure of the controller, the photobioreactor will overcool, which is preferred to overheating.

Sterilization

For many phototrophs, gross contamination by bacteria and fungi is not a significant problem because there is generally very little free organic carbon to support their growth (see Chapter 5 on sterility). A higher concern is to prevent contamination of the photobioreactor by other phototrophs. Photobioreactors are made of optically clear materials (e.g., glass or acrylic) which do not lend themselves to steam sterilization. Furthermore, the size of most photobioreactors exceeds what can be accommodated in an autoclave. Systems exist for sterilization with ozone (Quesnel 1987), but these systems are expensive and difficult to use. A more practical solution is sanitization rather than sterilization. Photobioreactor sanitization can be easily accomplished with bleach. Air pumps, analyzers, and other equipment can be kept free of algae and other microorganisms by the use of the appropriate prefilters.

Operational Strategies

With adequate measurement and control of the basic culture parameters of light, CO_2, O_2, pH, and temperature, it is possible to optimize these parameters to achieve the desired



Martek 120-liter photobioreactor

end product from the photobioreactor. The end product dictates the alga, which in turn dictates the general growth conditions. *Yield* and *productivity* are terms that require careful definition. Yield is the production of mass per unit volume, and it is often expressed in terms of g L^{-1}. Productivity is yield per unit time and is often expressed in terms of g L^{-1} $hour^{-1}$ or g L^{-1} day^{-1}. The growth conditions that produce maximal yield are rarely the same conditions that produce maximal productivity. For a given alga and/or a given product, it is possible to methodically test and optimize each culture parameter to determine the best value for maximizing either yield or productivity.

Although this is certainly a straight forward approach, a more efficient means to optimizing culture parameters is to employ a statistically based factorial or fractional factorial approach to experimental design (Anderson and Whitcomb 2000).This method uses statistics to identify the culture parameters and the interactions between culture parameters that are most important for achieving maximal yield and/or productivity. Perhaps more importantly, this approach identifies those parameters that are not important for maximum yield and/or productivity and thus eliminates the need for much unnecessary experimentation.

Harvesting Methods

The algal culture is still relatively dilute in a fully optimized photobioreactor. A dry weight concentration of even 5 to 10 g L^{-1} is far below that of a fermentor system (>50 g L^{-1}). The two most common harvesting approaches for photobioreactors are flocculation and centrifugation (Sukenik and Shelef 1984, Becker 1994). Although flocculents enable a concentration of the algal biomass, centrifugation is usually still necessary to achieve a suitable volume reduction. Small-scale recovery can be easily done in large centrifuge bottles, but larger scale cultures are best done with a continuous flow centrifuge such as a Sharples (Sharples Penwalt).

Other methods

There are other, similar, methods for growing marine algae that may be more appropriate in certain circumstances. For example, externally-illuminated 20 litre glass jars can be operated as batch cultures or semi-continuous cultures for a variety of algae. Another, widely used, type of culture container includes a mesh framework to support a 200-400 litre externally-illuminated polyethylene bag. Both of these methods have the disadvantage of being less efficient, as the light energy cannot penetrate the culture as well as the internally- illuminated unit, but they do have the advantage of being easier and cheaper to construct. Polyethylene bag cultures may also be operated as continuous, chemostat, cultures by using small pumps to introduce fresh filtered medium to the culture at a pre-determined rate.

Extensive methods may be employed to culture marine algae. Outdoor tanks are nutrient-enriched with agricultural fertilizers. Adding 1.5 g of urea, 1.6 g of triple superphosphate and 10.6 g of sodium metasilicate will provide the required amounts of nitrogen, phosphorous and silica to stimulate growth and division of algal cells and, depending on the temperature of the sea water and the amount of sunshine on the tanks, blooms of algae will develop. This system can be operated as a batch culture or managed as a semi-continuous or continuous culture with an in-flow of nutrient-enriched sea water to provide fresh medium as an impetus to further algal growth. The method is especially suitable for providing algae for feeding to bivalave mollusk spat held in nursery systems, or for mass ‘grow-out’ of brine shrimps (*Artemia*).

Conclusions

Whatever method of large-scale algae culture is adopted, it is liable to be expensive and technically difficult to operate. For this reason, a great deal of research is now being directed towards a suitable algae replacement diet for use in commercial aquaculture. Successful development of such a diet will perhaps eventually remove the need for large-scale production of algae for food.

CHAPTER

08

REGIONAL AND SEASONAL VARIATIONS IN PHYTOPLANKTON

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The phytoplankton are the main energy source for marine ecosystems. They are the main producers of oxygen and form the basis of marine food web. The distribution of phytoplankton is not unique all over the world. Some regions are more productive while others are not. The map (Figure 1) shows the phytoplankton production on a global scale.

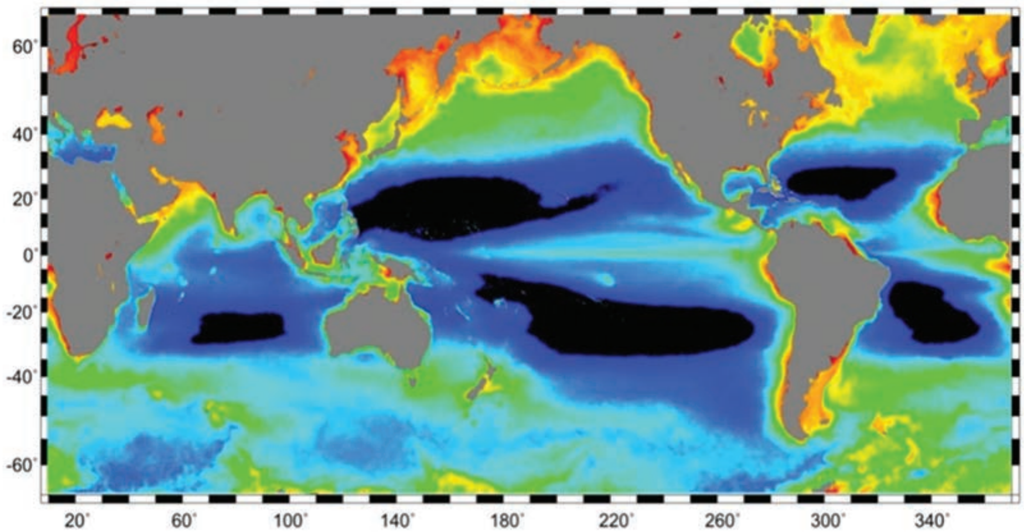

Fig. 1. Map showing the phytoplankton productivity in the Oceans, Red and yellow are most productive, followed by green and blue. Black is least productive.

Vertical variation in phytoplankton production

Vertical variation in production is also observed in oceans. The deep layers of ocean are light limited and hence photosynthesis, a process associated with sunlight cannot proceed leading low phytoplankton production. Another requirement for photosynthesis are sufficient concentration of nutrients (nitrates, phosphates, silicates, iron, *etc.*). In stratified waters, growth of phytoplankton is "nutrient limited". The nutrients in the upper mixed layer are consumed by phytoplankton. The growth of phytoplankton occurs in the layer where both light and nutrient concentration are sufficient. The depth at which maximum phytoplankton growth occurs is known as deep chlorophyll maxima (Figure 2).

During upwelling, the bottom nutrients are brought to the surface and hence the conditions of phytoplankton become better and the maximum of its vertical distribution moves to more shallow layer.

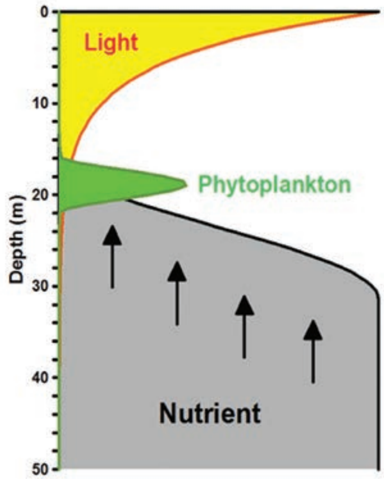

Fig. 2. Vertical variation of phytoplankton production in stratified waters

When intensive nutrient flux occurs, phytoplankton biomass proliferates and the maximum of vertical distribution of phytoplankton is located at the surface. This results in a direct correlation between total phytoplankton (or chlorophyll) concentration in water column (or within the euphotic layer) and in the thin surface layer (Figure 3). Hence, both the surface chlorophyll concentration and the chlorophyll concentration above the penetration depth can be used as a measure of water productivity, *i.e.*, phytoplankton biomass. Vertical distribution of ecosystem characteristics at a typical station in the oligotrophic waters shows deep phytoplankton maximum and nutricline. Deeper from the surface less light is reflected or scattered by phytoplankton cells and contributes to the colour of ocean surface.

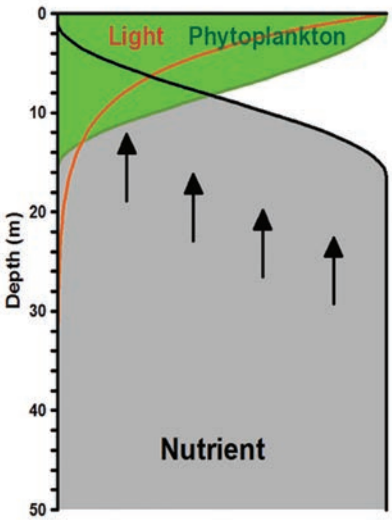

Fig. 3. Vertical variation of phytoplankton production in well mixed waters

Regional distribution of Phytoplankton

The distribution of phytoplankton varies spatially and temporally. Nearshore waters are rich in phytoplankton. River runoff and upwelling are considered as the events for higher production in coastal waters. In tropical regions, the production is comparatively low because of the limited availability of trapped nutrients below the thermocline. In polar regions, insufficient light acts as the limiting source for phytoplankton production. Highest production occurs in the temperate regions. Sufficient light and nutrients acts as the driving forces for increased production in these areas. The production pattern follows a two peak cycle in the regions. Spring peak is attributed with increased sunlight while fall peak is associated with increased mixing of nutrients.

Satellites equipped with colour scanners measure the concentration of chlorophyll in the ocean. Chlorophyll is an indicator of plankton and can be used to study plankton populations.

Seasonal cycles of phytoplankton biomass

One of the main goals of remote-sensing observations is the study of seasonal cycles of phytoplankton biomass in different regions of the World Ocean. In many regions these cycles repeat every year including minor details. This pattern is a result of seasonal oscillations of physical environment. In high latitudes these oscillations are more pronounced, and the response of phytoplankton is more evident.

Typical pattern of seasonal variations of phytoplankton in temperate latitudes is known since the beginning of 20th century. The main feature is a short-period (1-2 weeks) "vernal bloom" called in parallel with seasonal cycle of terrestrial plants. The cycle contains the period of exponential growth and then abrupt decrease resulting from grazing of phytoplankton by zooplankton (Figure 4). The hydrological conditions of start of the spring bloom of phytoplankton were described and explained by Harold Sverdrup in 1953. He attributed the beginning of spring bloom to the formation of seasonal thermocline, when the upper mixed layer is separated from deeper water column and phytoplankton is retained in illuminated (euphotic) layer. The strengthening of seasonal thermocline in summer results in nutrient limitation of phytoplankton growth. Stratification within the euphotic layer is a primary factor controlling phytoplankton growth. We consider two main factors limiting phytoplankton growth: illumination and nutrients. Light limitation is crucial under low stratification (eg., winter convection), because algal cells are dispersed by turbulent mixing within deep dark layers.

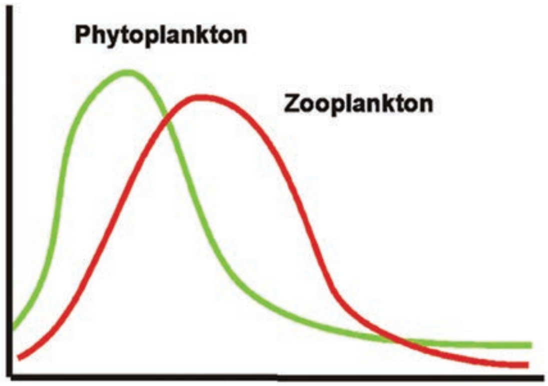

Fig. 4. Typical pattern of seasonal variations of Phytoplankton in temperate waters

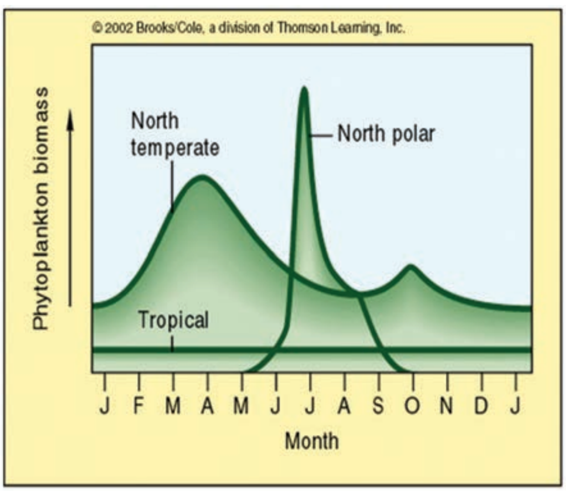

Fig. 5. Seasonal distribution of Phytoplankton in tropical, temperate and polar regions.

Nutrient limitation is crucial under enhanced stratification (eg., seasonal thermocline in summer), because nutrients do not penetrate into the euphotic (*i.e.*, well illuminated) upper mixed layer. The hydro-meteorological factors (heat flux, wind, freshwater load with precipitation and river discharge) either increase or decrease the stratification within the euphotic layer. Typical seasonal cycles of phytoplankton result from the combined effect of seasonal cycles of hydro-meteorological factors influencing water stratification within the euphotic layer. The most illustrative is the phytoplankton seasonal cycle in mid-latitudes with two maxima in spring and autumn:

In high latitudes (cold and windy) winter minimum is more pronounced and summer minimum is less pronounced. In low latitudes (warm and less windy) winter minimum is less pronounced or absent and summer minimum is more pronounced (Figure 5). Deviations from typical seasonal pattern of hydro-meteorological factors result in local peculiarities of phytoplankton cycle. Typical seasonal cycles of phytoplankton described by Alan Longharst are given below Table 1.

Table 1. Typical seasonal cycles of phytoplankton in high latitudes

Season	Hydro-meteorological factors	Stratification	Phytoplankton growth
Winter	Maximum wind mixing; Maximum cooling of upper layer	Deep convection	Winter minimum resulting from light limitation
Spring	Wind mixing weakens; Heating of upper layer increases	Formation of seasonal thermocline	Spring bloom
Summer	Maximum heating of upper layer; Minimum wind mixing	Maximum stratification	Summer minimum resulting from nutrient limitation
Fall	Cooling of upper layer increases; Wind mixing increases	Erosion of seasonal thermocline	Autumn bloom

The winter will be dark and summer with sunlight. Phytoplankton (diatoms) bloom occurs at this period and Zooplankton (mainly small crustaceans) productivity follows. Example: Arctic Ocean's Barents Sea.

Regional variation in phytoplankton size

In upwelling regions, rich in macronutrients, larger phytoplankton dominate and recycling of nutrient is inefficient (Dugdale and Goering, 1967). In weakly productive Subtropical Gyres, where macronutrients are at low levels, small picoplankton have been recorded to account for most of the primary productivity. picophytoplankton, owing to their high surface-area-to-volume ratio, can absorb nutrients with high efficiency under nutrient-limited conditions, and therefore dominate oligotrophic waters. They sink more slowly than larger cells. Microphytoplankton, represented chiefly by diatoms and dinoflagellates, dominate nutrient-rich waters and are the principal agents of the export of carbon to deeper waters. The contribution of smaller (eg., <2 μm) phytoplankton to total phytoplankton biomass decreases in the colder, high-latitude waters and as temperature rises a shift to smaller species within a diatom community was reported.

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CHAPTER 09

SPATIAL AND TEMPORAL VARIABILITY OF CHLOROPHYLL-A CONCENTRATION IN THE SOUTH EASTERN ARABIAN SEA (SEAS)

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1. Introduction

Satellite remote sensing is being effectively used in monitoring the ocean surface. Among the ocean observing satellite sensors, ocean colour sensors make use of visible band of electromagnetic spectrum (shorter wavelength). The use of shorter wavelength ensures fine spatial resolution of these parameters to depict oceanographic characteristics of any region having significant spatio-temporal variability. The Southeastern Arabian Sea (SEAS; encompassing between 70.5-77.5°E longitude and 8-15°N latitude) is such an area showing very significant spatio-temporal oceanographic and atmospheric variability due to the seasonally reversing surface winds and currents (Shankar *et al.*, 2002; Shetye *et al.*, 1990) (Figure 1). Consequently, the region is enriched with features like upwelling, sinking, eddies, fronts, *etc*. Among them, upwelling brings nutrient-rich waters from subsurface layers to surface layers. During this process primary production enhances, which is measured in ocean colour sensors as high values of chlorophyll a (Chl a) (Banse, 1959, Johannessen *et al.*, 1987, Shetye *et al.*, 1990), satellite observations (Jayaram, 2011) and model studies (Shankar *et al.*, 2002, Haugen *et al.*, 2002; Shaji and Gangopadhyay, 2007). The present work analyses the spatial and temporal variability in Chl a provided by satellite ocean colour sensors to understand oceanographic variability in the SEAS.

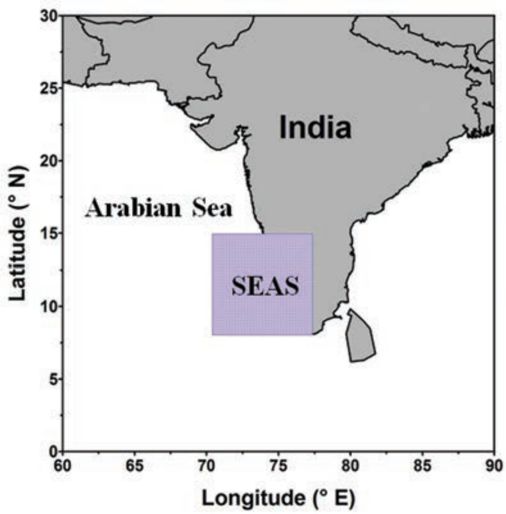

Fig. 1. Study area (SEAS) is demarcated using the violet shaded box in the Arabian Sea

2. Data

a. Chl a

Global Area Coverage on monthly Chl a at 9x9 km^2 of SeaWiFS sensor during the period September 1997- December 2010 were extracted from the NASA website (http://oceandata.sci.gsfc.nasa.gov/).

b. Wind

Daily averaged wind data on zonal and meridional scale were extracted from QuikSCAT for the period 19 July 1999 – 19 November 2009 (ftp://www.ssmi.com). Monthly wind was generated from the above dataset using ferret software. The alongshore component was calculated for each area using the monthly averaged dataset.

c. SST

SST from MODIS / AQUA sensor at 9 km spatial resolutions were downloaded from ocean colour website (http://oceandata.sci.gsfc.nasa.gov) on monthly scale.

d. Sea Surface Height Anomaly (SSHA)

Monthly SSHA data during January 1992 - February 2010 were downloaded from AVISO (www.aviso.soest.hawaii.edu). The SSHA data obtained from AVISO is the merged product of TOPEX, ERS and Jason-1 altimetry. The data has a spatial resolution of 0.33^{o}.

e. Rain data

Weekly rainfall data from TMI sensor (December 1997 – February 2011) at 0.25^{o} x 0.25^{o} spatial resolution was downloaded to generate monthly rainfall rate.

3. Results

3.1. Spatial variability - Climatology of Chl a in the study area

Distribution of Chl a is examined to understand the climatology of these parameters in the study area. In this regard, the monthly averages generated from the data provided by the sensors SeaWiFS is used. The spatial distribution of Chl a brought out seasonal as well as regional scale variability along the SEAS with maximum ranges of the variability during the southwest monsoon period (Figure 2).

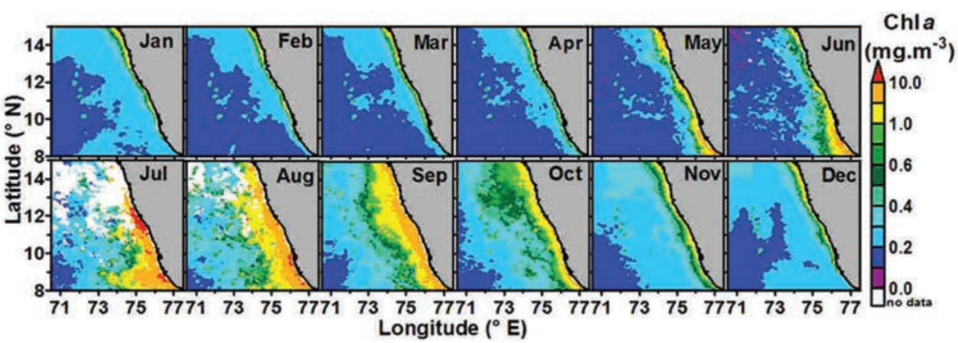

Fig. 2. Monthly climatology of Chl a in the SEAS. The upper panels represent the distribution pattern during January to June and the lower panel during July to December.

In general, the values of Chl a are high near the coast during all the months, which decreased towards offshore. During May, a marginal increase in Chl a sets in and this trend continues up to August. In addition, a significant cross-shore gradient is established in the southern area by June, which moves northward to encompass the entire study area by August and undergoes gradual decay during subsequent months. Similar to its intensification, the decay also starts from the south and moves northward. The gradient starts weakening from September and disappears from the southern area by October. By November, it fades off the northern area too. Thereafter, low Chl a values continue up to April all through the area.

3.2. Temporal variability

Most of the oceanographic and atmospheric parameters exhibit temporal variability. The time series observations on Chl a as obtained from SeaWiFS images during September 1997 – December 2010 is analysed to understand the temporal variability on Chl a. Spatial distribution has established the existence of large spatio-temporal variability in the study area especially during the southwest monsoon. Monthly Chl a were averaged for the selected area to explain their temporal variability. The influence of local environmental conditions (wind, ocean current, SSH and SST) on these parameters were also examined.

In general, Chl a in SEAS showed high values (> 1.20 mg m^{-3}) during June – September and very low values (~0.25 mg m^{-3}) during December – April. May and October / November can be considered as transition periods (Figure 3). The above three phases complete an annual cycle that recurs, while peak values occur during one of the months and found to vary each years between July and September (Table 1). In the following section, the corresponding supporting parameters representing oceanographic and atmospheric conditions were examined, to understand their influence on Chl a distribution.

The supporting parameters showed that in general, low SST/ SSHA and high equatorward components of currents and winds existed during the southwest monsoon. SST was found to follow a bi-annual oscillation, with lowest value in one of the months during the southwest monsoon, whereas, SSHA showed an annual cycle again with minima in one of the months during the southwest monsoon. The surface alongshore currents change its direction poleward during the northeast monsoon, but the alongshore winds has equatorward components irrespective of the season (0 to -5 ms^{-1}). The equatorward winds intensified during the southwest monsoon, except during 2006 and 2007. Thus, in general, the supporting parameters showed maximum equatorward current / wind and low SST / SSHA during the southwest monsoon, with their peak in one of the months similar to Chl a. In this context, it is to be noted that this low SST / SSHA and strong equatorward current / wind

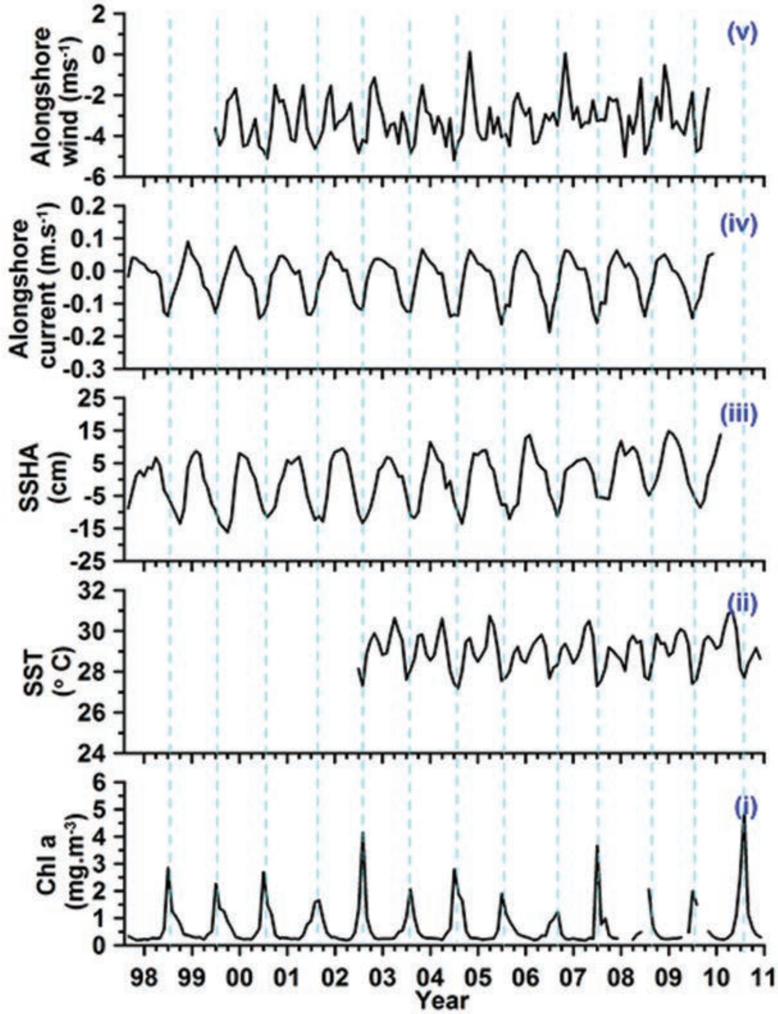

Fig. 3. Temporal variability in (i) Chl a, (ii) SST, (iii) SSH, (iv) alongshore surface current and (v) alongshore surface wind averaged for SEAS. The dotted vertical lines denote peak values of Chl a. The gap indicates non-availability of data. (Figure is redrawn from Shalin and Sanilkumar, 2014).

are associated features of upwelling (Bruce *et al.*, 1998; Shankar and Shetye, 1997; Shankar *et al.*, 2002). Therefore, the co-occurrence of high Chl a along with the above maxima/ minima of the supporting parameters during the southwest monsoon period suggests close linkage to them with upwelling. Further, the low SST and highest Chl a values co-occurred with the highest southward current/ wind in the same month or within the differences of one month during most of the years. This observation showed the increase in Chl a would have induced by upwelling as these factors are favorable for upwelling.

Table 1. Months during which maxima/ minima occurred in Chl a, SST, SSHA, current and winds in SEAS

Year	Maximum Chl *a*	Minimum SST	Lowest SSHA	Maximum southerly current	Maximum southward wind
1998	Jul	-	Oct	Jul	-
1999	Jul	-	Oct	Jul	Aug
2000	Jul	-	Aug	Jun	Aug
2001	Sep	-	Oct	Jul	Aug
2002	Aug	Aug	Aug	Aug	Jul
2003	Aug	Jul	Sep	Aug	Aug
2004	Jul	Aug	Sep	Jun	Jul
2005	Jul	Jul	Sep	Jul	Sep
2006	Sep	Jul	Sep	Jul	Mar
2007	Jul	Jul	Oct	Jul	Mar
2008	Aug	Aug	Aug	Jul	Feb
2009	Jul	Jul	Sep	Jul	Aug
2010	Aug	Aug	-	-	-

Conclusion

In general, Chl a in the SEAS (70.5-77.5°E, 8.0-15.0°N) follows an annual cycle with their maxima during the southwest monsoon period. Moreover, significant cross-shore gradient is observed on Chl a during the period, with high values (>1.0 $mg.m^{-3}$) near the coast. This gradient develops in the south by June and propagated north such that it encompasses the entire study area by August. Similarly, the decay of the gradient starts during September from south and moves north and completes the process by November. The spatial distribution on the three parameters showed large regional variability.

The supporting parameters showed low values of SST and faster southward current/ wind during the southwest monsoon period. These are the indicative features of intense upwelling. In most of the cases, the month of lowest SSTs and faster southward currents coincided with the month of peak Chl a. Therefore, the increase in Chl a were attributed to enhanced upwelling as evident from the supporting parameters. The present work brings out the utility of ocean colour data to study the oceanographic features in the SEAS, especially the upwelling phenomenon and its spatio-temporal variability.

Influence of upwelling in controlling surface chlorophyll was corroborated by time series analysis of monthly data on chla, SST, SSHA, winds, and currents. Peak values of chl-a were always concomitant with the highest equator-wards surface currents and lowest SST/SSHA.

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CHAPTER

10

STATISTICAL METHODS

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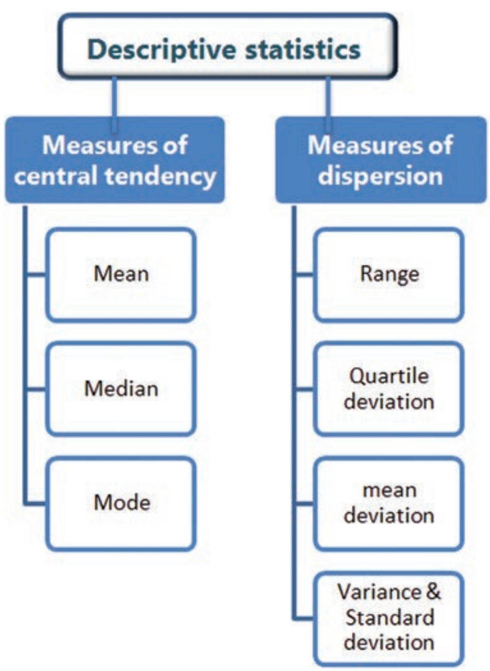
Statistics plays a central role in research, planning and decision-making in almost all natural and social sciences. It is the Science of collecting, organizing, analyzing, interpreting and presenting data. It deals with all aspects of this, including not only the collection, analysis and interpretation of such data, but also the planning the collection of data, in terms of the design of surveys and experiments. Two types of statistical methods are used in analysing data: descriptive statistics and inferential statistics. **Inferential statistics** makes inferences and predictions about a population based on a sample of data taken from the population in question. **Descriptive statistics** uses the data to provide descriptions of the population, either through numerical calculations or graphs or tables. Descriptive statistics therefore enables us to present the data in a more meaningful way, which allows simpler interpretation of the data.



Measures of central tendency

Description of a variable usually begins with the specification of its single most representative value, often called the measure of central tendency. The best way to reduce a set of data and still retain part of the information is to summarize the set with a single value. A measure of central tendency is a single value that attempts to describe a set of data by identifying the central position within that set of data. Measures of central tendency are sometimes called measures of central location or summary statistics. Measures of central tendency are measures of the location of the middle or the center of a distribution. There are several measures for this statistic.

Measures of central tendency

Arithmetic mean

The arithmetic mean of a set of values is the quantity commonly called the mean or the average. For a data set, the mean is the sum of the values divided by the number of values. The mean of a set of numbers $x_1, x_2, \ldots, x_n$ is typically denoted by $\bar{x}$ pronounced "*x* bar".

Arithmetic Mean = $\bar{x} = \dfrac{x_1 + x_2 + \ldots\ldots + x_n}{n}$ Or $\bar{x} = \dfrac{\sum_{i=1}^{n} x_i}{n}$

Arithmetic Mean from a grouped data

i) Discrete frequency distribution

Data arising from organising 'n' observed values into a smaller number of disjoint groups of values, and counting the frequency of each group; often presented as a frequency table. In this case the values of the variable are multiplied by their respective frequencies and this total is then divided by the total number of frequencies.

Arithmetic mean, $\bar{x} = \dfrac{f_1 x_1 + f_2 x_2 + \ldots\ldots + f_n x_n}{f_1 + f_2 + \ldots\ldots + f_n}$ $\bar{x} = \dfrac{\sum_{i=1}^{n} f_i x_i}{\sum_{i=1}^{n} f_i}$

where $x_1, x_2, \ldots x_n$ are values of the variable x and $f_1, f_2, \ldots f_n$ are their corresponding frequencies.

ii) Continuous frequency distribution

We take mid values of each class as representative of that class, multiply this mid values by their corresponding frequencies, total these products and divide by the total number of items. If $x_1, x_2, \ldots x_n$ represent the mid values of classes and $f_1, f_2, \ldots f_n$ the frequencies, then

$$\text{Arithmetic Mean} = \frac{f_1 x_1 + f_2 x_2 + \dots\dots\dots + f_n x_n}{f_1 + f_2 + \dots\dots\dots + f_n} = \frac{\sum_{i=1}^{n} f_i x_i}{N}$$

$$\text{Where } N = \sum_{i=1}^{i=n} f_i$$

The mean is valid only for interval data or ratio data. Since it uses the values of all of the data points in the population or sample, the mean is influenced by outliers that may be at the extremes of the data set. The mean uses all the observations and each observation affects the mean. Even though the mean is sensitive to extreme values (*i.e.*, extremely large or small data can cause the mean to be pulled toward the extreme data) it is still the most widely used measure of location. This is due to the fact that the mean has valuable mathematical properties that make it convenient for use with inferential statistics analysis. For example, the sum of the deviations of the numbers in a set of data from the mean is zero, and the sum of the squared deviations of the numbers in a set of data from the mean is minimum value. The following are the merits and demerits of arithmetic mean.

Merits and Demerits of Arithmetic Mean

Merits

- It is rigidly defined.
- It is easy to calculate and simple to follow.
- It is based on all the observations.
- It is determined for almost every kind of data.
- It is finite and not indefinite.
- It is readily put to algebraic treatment.
- It is least affected by fluctuations of sampling.
- It is easy to calculate

Demerits

- The arithmetic mean is highly affected by extreme values.
- It is not an approprite average for highly skewed distributions.
- It cannot be computed accurately if any item is missing.

Median

Median is the value in the middle of the data set, when the data points are arranged from smallest to largest. If there are an odd number of data points, then just arrange them in ascending or descending order and take the middle value. If there is an even number of data points, you will need to take the average of the two middle values. Hence median is determined by sorting the data set from lowest to highest values and taking the data point in the middle of the sequence. There is an equal number of points above and below the median.

Calculation of median in a grouped data

i) Discrete series

In this case also, data should be arranged in ascending or descending order of magnitude and find out the cumulative frequencies. Now find out the value of $(n+1/2)^{th}$ item. It can be found by first locating the cumulative frequency which is equal to (n+1/2) and then determine the value corresponding to it. This will be the value of median.

ii) Continuous series

For computing the value of the median in a continuous series, first determine the particular class in which the value of the median lies. Use N/2 as the rank of Median where N= total frequency. Hence it is N/2 which will divide the area of the curve into two parts. The following formula is used for determining the exact value of the median.

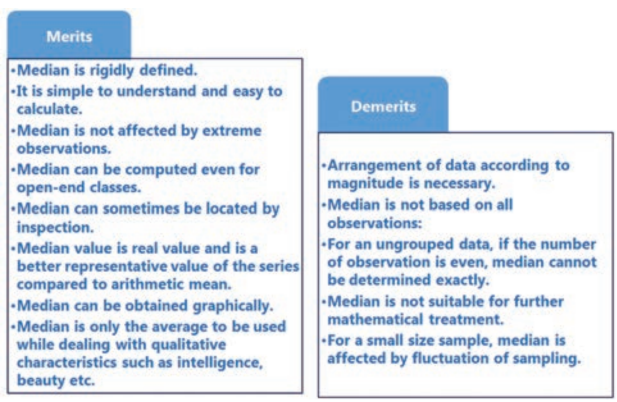
$$\text{Median} = l + \frac{(\frac{N}{2} - m) * c}{f}$$

where N= $\sum fi$ = Total frequency, l- the lower limit of the median class, m -cumulative frequency up to the median class, f- frequency of the median class and c- class width.

Median

The median can be determined for ordinal data as well as interval and ratio data. Unlike the mean, the median is not influenced by outliers at the extremes of the data set. Generally, the median provides a better measure of location than the mean when there are some extremely large or small observations (*i.e.,* when the data are skewed to the right or to the left). For this reason, the median is often used when there are a few extreme values that could greatly influence the mean and distort what might be considered typical. Note that if the median is less than the mean, the data set is skewed to the right. If the median is greater than the mean, the data set is skewed to the left. Median does not have important mathematical properties for use in future calculations.

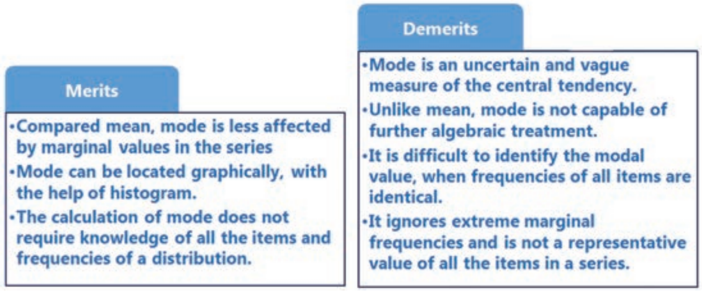
Merits and Demerits of Median



Mode

Mode is the most common value or most frequently occurring value in the data set. For finding the mode, just look at the data, count how many of each value you have, and select the data point that shows up the most frequently. If no value occurs more than once, then there is no mode. If two values occur as frequently as each other and more frequently than any other, then there are two modes. In the same way, there could also be more than two modes.

Merits and Demerits of Mode



Mode is very simple measure of central tendency. Because of its simplicity, it is a very popular measure of the central tendency. The mode can be very useful for dealing with categorical data. The mode also can be used with ordinal, interval, and ratio data. However, in interval and ratio scales, the data may be spread thinly with no data points having the same value. In such cases, the mode may not exist or may not be very meaningful. Following are the various merits and demerits of mode:

Weighted Mean

When two or more means are combined to develop an aggregate mean, the influence of each mean must be weighted by the number of cases in its subgroup.

$$\overline{X}_w = \frac{n_1\overline{X}_1 + n_2\overline{X}_2 + n_3\overline{X}_3}{n_1 + n_2 + n_3}$$

Geometric mean (GM)

The geometric mean is an average that is useful for sets of positive numbers that are interpreted according to their product and not their sum (as is the case with the arithmetic mean) e.g. rates of growth.

$$\bar{x} = \left(\prod_{i=1}^{n} x_i\right)^{1/n}$$

Harmonic mean (HM)

The harmonic mean is an average which is useful for sets of numbers which are defined in relation to some unit, for example speed (distance per unit of time).

$$\bar{x} = n \cdot \left(\sum_{i=1}^{n} \frac{1}{x_i}\right)^{-1}$$

Relationship between AM, GM, and HM

AM, GM, and HM satisfy these inequalities:

$$AM > GM > HM$$

Equality holds only when all the elements of the given sample are equal.

The mean (often called the average) is most common measure of central tendency, but there are others, such as, the median and the mode. The mean, median and mode are all valid measures of central tendency but, under different conditions, some measures of central tendency become more appropriate to use than others.

Measures of Dispersion

Measure of variation describes how spread out or scattered a set of data. It is also known as measures of dispersion or measures of spread. Measures of variation determine the range of the distribution, relative to the measures of central tendency. Measures of average such as the mean and median represent the typical value for a dataset. Within the dataset the actual values usually differ from one another and from the average value itself. The extent to which the mean and median are good representatives of the values in the original dataset depends upon the variability or dispersion in the original data. The measures of central tendency are specific data points, measures of variation are lengths between various points within the distribution. It provide us with a summary of how much the points in our data set vary, e.g. how spread out they are or how volatile they are. Measures of variation together with measures of central tendency are important for identifying key features of a sample to better understand the population from which the sample comes from. Datasets are said to have high dispersion when they contain values considerably higher and lower than the mean value. The most common measures of variation are Range, Quartile déviation or semi Interquartile Range, Mean deviation, Variance, Standard deviation and Coefficient of Variation.

Range

The range is the distance between the lowest data point and the highest data point. In other words, it is difference between the highest value and the lowest value.

Range = Highest value–lowest value

The range is the simplest measure of variation to find. Since the range only uses the largest and smallest values, it is greatly affected by extreme values, that is - it is not resistant to change.

The range is simple to compute and is useful when you wish to evaluate the whole of a dataset. It is useful for showing the spread within a dataset and for comparing the spread between similar datasets.

Since the range is based solely on the two most extreme values within the dataset, if one of these is either exceptionally high or low (sometimes referred to as outlier) it will result in a range that is not typical of the variability within the dataset. The range does not really indicate how the scores are concentrated along the distribution. The range only involves the smallest and largest numbers, and is affected by extreme data values or outliers. In order to reduce the problems caused by outliers in a dataset, the inter-quartile range is often calculated instead of the range.

Quartile Deviation or The semi inter-quartile Range

The inter-quartile range is a measure that indicates the extent to which the central 50% of values within the dataset are dispersed. If the sample is ranked in ascending order of magnitude two values of *x* may be found, the first of which is exceeded by 75% of the sample, the second by 25%; their difference is the interquartile range. It is based upon and related to the median. In the same way that the median divides a dataset into two halves, it can be further divided into quarters by identifying the upper and lower quartiles. The lower quartile, Q1 is found one quarter of the way along a dataset when the values have been arranged in order of magnitude; the upper quartile Q3 is found three quarters along the dataset. Therefore, the upper quartile lies half way between the median and the highest value in the dataset whilst the lower quartile lies halfway between the median and the lowest value in the dataset. Between Q1 and Q3 there is half the total number of items. Q3-Q1 affords a convenient and often a good indicator of the absolute variability. Usually one half of the Q3-Q1 is used and given the name semi-interquartile range or quartile deviation.

$$Quartile\ deviation = \frac{Q3 - Q1}{2}$$

The relative measure of quartile deviation is known as the coefficient of Q.D.

$$Coefficient\ of\ Q.D. = \frac{\frac{Q3 - Q1}{2}}{\frac{Q3 + Q1}{2}} = \frac{Q3 - Q1}{Q3 + Q1}$$

The larger the semi – interquartile range, the larger the spread of the central half of the data. Thus the semi –interquartile rang provides a measure of spread. Thus it indicate how closely the data are clustered around the median.

Mean deviation

Mean deviation is the average of the absolute values of the deviation scores; that is, mean deviation is the average distance between the mean and the data points. It is calculated as

$$\sum \frac{|\overline{X} - X_i|}{n}$$

Closely related to the measure of mean deviation is the measure of *variance*.

Variance

The variance is the most commonly accepted measure of variation. It represents the average of the squared deviations about the mean. Variance also indicates a relationship between the mean of a distribution and the data points; it is determined by averaging the sum of the squared deviations. Squaring the differences instead of taking the absolute values allows for greater flexibility in calculating further algebraic manipulations of the data. It is the average of the squared deviations between the individual scores and the mean. The larger the variance the more variability there is among the scores. When comparing two samples with the same unit of measurement (age), the variances are comparable even though the sample sizes may be different. Generally, however, smaller samples have greater variability among the scores than larger samples.

The average deviation from the mean is:

$$Ave.\ Dev = \frac{\sum(x - \mu)}{N}$$

The problem is that this summation is always zero. So, the average deviation will always be zero. That is why the average deviation is never used. So, to keep it from being zero, the deviation from the mean is squared and called the “squared deviation from the mean”. This “average squared deviation from the mean” is called the variance. The formula for variance depends on whether you are working with a population or sample:

The formula for the variance in a population is where $\sigma^2 = \frac{\sum(X-\mu)^2}{N}$ where μ is the mean and N is the number of scores.

When the variance is computed in a sample, the statistic $s^2 = \frac{\sum(X-M)^2}{N-1}$

where M is the mean of the sample and gives an unbiased estimate of σ^2.

Standard deviation

Standard deviation is the most familiar, important and widely used measure of variation. It is a significant measure for making comparison of variability between two or more sets of data in terms of their distance from the mean.

The standard deviation is the square root of the variance. It is denoted by σ and is computed as

$$\sigma = \sqrt{\frac{\Sigma (x_i - \bar{x})^2}{n}}$$

The standard deviation has proven to be an extremely useful measure of spread in part because it is mathematically tractable. Many formulas in inferential statistics use the standard deviation. It possess the majority of the properties which are desirable in a measure of dispersion and is based on all observations. Because of these merits SD should always be used as the measure of dispersion unless there is some definite reason for selecting any other measure of dispersion.

Coefficient of Variation

The coefficient of variation is the ratio of the sample standard deviation to the sample mean. It is calculated as

$$Coefficient\ of\ variation\ (C.V.) = \frac{\sigma}{\bar{x}} * 100$$

It expresses the standard deviation as a percentage of the mean, so it can be used to compare the variability of two or more distributions even when the observations are expressed in different units of measurement. The coefficient of variation is a dimensionless number. So when comparing between data sets with different units or widely different means, one should use the coefficient of variation for comparison instead of the standard deviation. A standard application of the Coefficient of Variation is to characterize the variability of geographic variables over space or time. Coefficient of Variation is particularly applied to characterize the interannual variability of climate variables or biophysical variables. When coefficient of variable is lesser in the data, it is said to be more consistent or have less variability. On the other hand, the series having higher coefficient of variable has higher degree of variability or lesser consistency. When the mean value is close to zero, the coefficient of variation will approach infinity and is hence sensitive to small changes in the mean. Unlike the standard deviation, it cannot be used to construct confidence intervals for the mean.

Correlation

Correlation is a statistical technique that can show whether and how strongly pairs of variables are related. The correlation analysis enables us to have an idea about the degree & direction of the relationship between the two variables under study. It is used to assess the possible linear association between two variables. If there is any relation between two variables *i.e.,* when one variable changes the other also changes in the same or in the opposite direction, we say that the two variables are correlated. Thus correlation is the study of existence, magnitude and direction of the relation between two or more variables. The measure of correlation called the correlation coefficient. If the ratio of change between two variables is uniform, then the correlation is said to be linear. If the amount of change in one variable does not bear a constant ratio to the amount of change in the other variable, then the correlation is said to be non-linear or curvilinear. The nature of the graph gives us the idea of the linear type of correlation between two variables. If the graph is in a straight line, the correlation is called a "linear correlation" and if the graph is not in a straight line, the correlation is non-linear or curvi-linear.

Positive and negative correlation

If two variables change in the same direction *i.e.*, if one increases the other also increases, or if one decreases, the other also decreases), then this is called a positive correlation. If two variables change in the opposite direction *i.e.,* if one increases, the other decreases and vice versa), then the correlation is called a negative correlation. Through the coefficient of correlation, we can measure the degree or extent of the correlation between two variables. On the basis of the coefficient of correlation we can also determine whether the correlation is positive or negative and also its degree or extent.

If two variables changes in the same direction and in the same proportion, the correlation between the two is **perfect positive**. According to Karl Pearson the coefficient of correlation in this case is +1. On the other hand if the variables change in the opposite direction and in the same proportion, the correlation is **perfect negative** and its coefficient of correlation is -1. In practice we rarely come across these types of correlations.

If two variables exhibit no relations between them or change in variable does not lead to a change in the other variable, then we can say that there is **no correlation** between the two variables. In such a case the coefficient of correlation is 0.

Methods of Determining Correlation

The following are the most commonly used methods of determining correlation..

(1) Scatter Plot

(2) Karl Pearson's coefficient of correlation

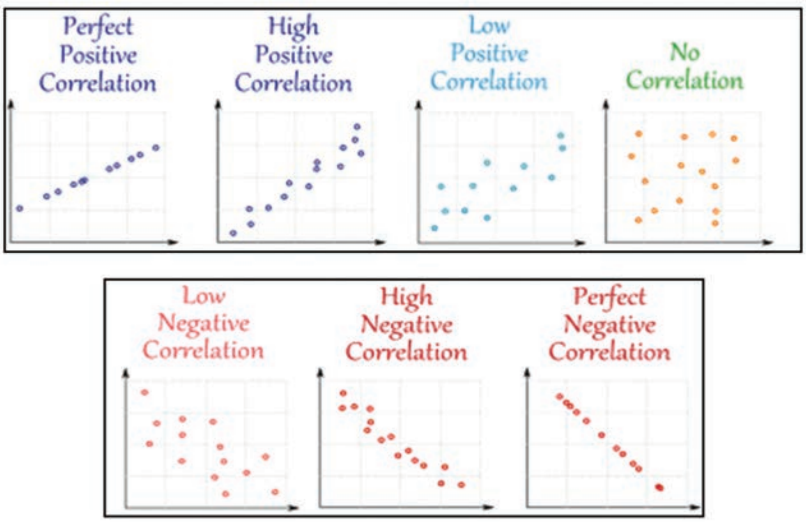
Scatter Plot (Scatter diagram or dot diagram)

The scatter diagram may be described as the diagram which helps us to visualize the relationship between two phenomena. This is the simplest method for finding out whether there is any relationship present between two variables. In this method the values of the two variables are plotted on a graph paper. One is taken along the x-axis and the other along the y-axis. By plotting the data, we get points on the graph which are generally scattered and hence the name 'Scatter Plot'. The manner in which these points are scattered, suggest the degree and the direction of correlation. The grater the scatter of the points on the chart, the lesser is the relationship between the two variables. The more closely the points come to a straight line, the higher the degree of relationship. The degree of correlation is denoted by 'r' and its direction is given by the signs positive and negative. Scatter diagrams will generally show one of five possible correlations between the variables:

- *Strong Positive Correlation* :The value of Y clearly increases as the value of X increases.
- *Strong Negative Correlation:* The value of Y clearly decreases as the value of X increases.
- *Weak Positive Correlation* : The value of Y increases slightly as the value of X increases.
- *Weak Negative Correlation:* The value of Y decreases slightly as the value of X increases.
- *No Correlation:* There is no demonstrated connection between the two variables.

Though this method is simple and provide a rough idea about the existence and the degree of correlation, it is not reliable. As it is not a mathematical method, it cannot measure the degree of correlation.

Illustrations



Karl Pearson's coefficient of correlation:

The most widely-used type of correlation coefficient is *Pearson r*, also called *linear* or *product- moment* correlation. It gives the numerical expression for the measure of correlation. The value of ' r ' gives the magnitude of correlation and sign denotes its direction. It is defined as

$$r = \frac{\sum XY}{n\sigma_x\sigma_y}$$

Where $X = (X_i - \overline{X})$, $Y = (Y_i - \overline{Y})$, $\sigma_x = s.d.of\ X$, $\sigma_y = s.d.of\ Y$ and n is the number of pairs of observations

Properties of Correlation coefficient

- The value of correlation does not depend on the specific measurement units used; for example, the correlation between height and weight will be identical regardless of whether *inches* and *pounds*, or *centimeters* and *kilograms* are used as measurement units.
- The value of correlation coefficient lies between -1 and +1, -1 means perfect negative linear correlation and +1 means perfect positive linear correlation.
- The correlation coefficient r only measures the strength of a linear relationship. There are other kinds of relationships besides linear.
- If the two variables are independent, then the value of the correlation coefficient is zero. If the value of the correlation coefficient is zero, it does not mean that there is no correlation, but there may be non-linear correlation.
- The value of r does not change if the independent (x) and dependent (y) variables are interchanged.
- The correlation coefficient r does not change if the scale on either variable is changed. You may multiply, divide, add, or subtract a value to/from all the x-values or y-values without changing the value of r.
- The correlation coefficient r has a Student's t distribution.

Assumptions to use the Pearson product-moment correlation

- The measures are approximately normally distributed
- The variance of the two measures is similar (homoscedasticity)

- The relationship is linear
- The sample represents the population
- The variables are measured on a interval or ratio scale

Testing the Significance of the Correlation Coefficient

The correlation coefficient, *r*, tells us about the strength and direction of the linear relationship between *x* and *y*. However, the reliability of the linear model also depends on how many observed data points are in the sample. We need to look at both the value of the correlation coefficient *r* and the sample size *n*, together.

We perform a hypothesis test of the "significance of the correlation coefficient" to decide whether the linear relationship in the sample data is strong enough to use to model the relationship in the population. The sample data are used to compute *r*, the correlation coefficient for the sample. If we had data for the entire population, we could find the population correlation coefficient. But because we have only have sample data, we cannot calculate the population correlation coefficient. The sample correlation coefficient, *r*, is our estimate of the unknown population correlation coefficient. The hypothesis test lets us decide whether the value of the population correlation coefficient σ is "close to zero" or "significantly different from zero". We decide this based on the sample correlation coefficient *r* and the sample size *n*.

The correlation coefficient r has a t distribution with n-2 degrees of freedom. The test statistic used is

$$t = r\sqrt{\frac{n-2}{1-r^2}}$$

If the test concludes that the correlation coefficient is significantly different from zero, we say that the correlation coefficient is significant and there exists a linear relationship between the two variables. If the test concludes that the correlation coefficient is not significantly different from zero (it is close to zero), we say that correlation coefficient is not significant and there is insufficient evidence to conclude that there is a significant linear relationship between the two variables.

Regression analysis

Regression analysis is a statistical tool used for the investigation of relationships between variables. It is the study of *linear*, *additive* relationships between variables. Correlation gives us a measure of the magnitude and direction between variables. It is a technique used for predicting the unknown value of a variable from the known value of another variable. When there is only one independent variable then the relationship is expressed by a straight line. This procedure is called simple linear regression or bivariate regression. More precisely, if X and Y are two related variables, then linear regression analysis helps us to predict the value of Y for a given value of X. Multiple regression is an extension of bivariate regression in which several independent variables are combined to predict the dependent variable. In multiple regression analysis, the value of Y is predicted for given values of $X_1, X_2, \ldots, X_k$. This technique is used for forecasting, time series modelling and finding the causal effect relationship between the variables.

Dependent and Independent Variables

By simple linear regression, we mean models with just one independent and one dependent variable. The variable whose value is to be predicted is known as the dependent variable and the one whose known value is used for prediction is known as the independent variable. Similarly for Multiple Regression the variable whose value is to be predicted is known as the dependent variable and the ones whose known values are used for prediction are known independent variables.

The Regression Model

The line of regression of Y on X is given by Y = a + bX where a and b are unknown constants known as intercept and slope of the equation. This is used to predict the unknown value of variable Y when value of variable X is known.

The Simple Linear Regression model is

$$Y = a + bX$$

The **Regression Coefficient** is the constant 'b' in the regression equation that tells about the change in the value of dependent variable X corresponding to the unit change in the independent variable Y and can be represented as:

$$b = r\frac{\sigma_x}{\sigma_y}$$

Where r is the correlation coefficient σ_x is the standard deviation of x, σ_y is the standard deviation of y.

In general, the multiple regression equation of Y on $X_1, X_2, \ldots, X_k$ is given by:

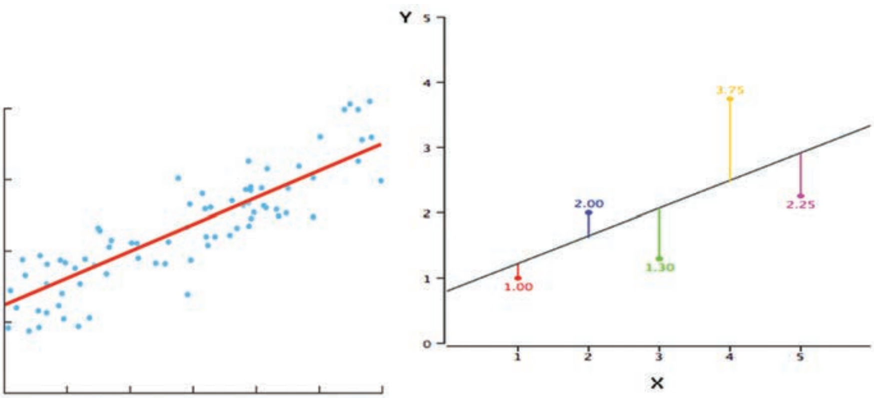
$$Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + b_k X_k$$

Here b_0 is the intercept and $b_1, b_2, b_3, \ldots, b_k$ are analogous to the slope in linear regression equation and are also called regression coefficients. They can be interpreted as the change in the value of dependent variable (Y) corresponding to unit change in the value of independent variable X_i.

Fitting of regression line

In scatter plot, we have seen that if the variables are highly correlated then the points (dots) lie in a narrow strip. If the strip is nearly straight, we can draw a straight line, such that all points are close to it from both sides. Such a line can be taken as an ideal representation of variation. This line is called the line of best fit if it minimizes the distances of all data points from it and also called as the line of regression. Now prediction is easy because all we need to do is to extend the line and read the value. Thus to obtain a line of regression, we need to have a line of best fit.

The problem of choosing the best straight line then comes down to finding the best values of a and b. By 'best' we mean the values of a and b that produce a line closest to all n observations. This means that we find the line that minimizes the distances of each observation to the line. Choose the values of a and b that give the line such that the sum of squared deviations from the line is minimized. This method of estimation of parameters is called least square method. The best line is called the regression line, and the equation describing it is called the regression equation. The deviations from the line are also called residuals.



R^2 - coefficient of determination

Once a line of regression has been constructed, one can check how good it is (in terms of predictive ability) by examining the coefficient of determination (R^2), which is defined as the proportion of variance of the dependent variable that can be explained by the independent variables. The coefficient of determination is a measure of how well the regression equation y = a + bX performs as a predictor of y. Its value represents the percentage of variation that can be explained by the regression equation. R^2 always lies between 0 and 1. Higher values of this are generally taken to indicate a better model. A value of 1 means every point on the regression line fits the data; a value of 0.5 means only half of the variation is explained by the regression. The coefficient of determination is also commonly used to show how accurately a regression model can predict future outcomes.

CHAPTER 11

DATA DIAGNOSTICS AND REMEDIAL MEASURES

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The raw data consist of measurements of some attribute on a collection of individuals. The measurement would have been made in one of the following scales *viz*., nominal, ordinal, interval or ratio scale.

Levels of Measurement

- **Nominal scale** refers to measurement at its weakest level when number or other symbols are used simply to classify an object, person or characteristic, *e.g.*, state of health (healthy, diseased).
- **Ordinal scale** is one wherein given a group of equivalence classes, the relation greater than holds for all pairs of classes so that a complete rank ordering of classes is possible, *e.g*., socio-economic status.
- When a scale has all the characteristics of an ordinal scale, and when in addition, the distances between any two numbers on the scale are of known size, **interval scale** is achieved, e.*g*., temperature scales like centigrade or Fahrenheit.
- An interval scale with a true zero point as its origin forms a ratio scale. In a **ratio scale**, the ratio of any two scale points is independent of the unit of measurement, e.g., height of trees.

The data can be classified as qualitative/quantitative depending on the levels based on which the observations are collected. There are several statistical procedures available in literature for the analysis of data which are broadly classified in to two categories *viz*., parametric tests and non-parametric tests. A parametric test specifies certain conditions about the distribution of responses in the population from which the research sample was drawn. The meaningfulness of the results of a parametric test depends on the validity of these assumptions. A nonparametric test is based on a model that specifies very general conditions and none regarding the specific form of the distribution from which the sample was drawn. Hence nonparametric tests are also known as distribution free tests. Certain assumptions are associated with most nonparametric statistical tests, but these are fewer and weaker than those of parametric tests.

Nonparametric test statistics utilize some simple aspects of sample data such as the signs of measurements, order relationships or category frequencies. Therefore, stretching or compressing the scale does not alter them. As a consequence, the null distribution of the nonparametric test statistic can be determined without regard to the shape of the parent population distribution. These tests have the obvious advantage of not requiring the assumption of normality or the assumption of homogeneity of variance. They compare medians rather than means and, as a result, if the data have one or two outliers, their influence is negated.

Besides, the interpretation of data based on analysis of variance (ANOVA)/Regression is valid only when the following assumptions are satisfied:

1. The regression function is linear
2. The error terms do have constant variance
3. The error terms are independent
4. No outlying observations
5. The error terms are normally distributed
6. Predictor variables are uncorrelated.

Also the statistical tests t, F, z, *etc*. are valid under the assumption of independence of errors and normality of errors. The departures from these assumptions make the interpretation based on these statistical techniques invalid. Therefore, it is necessary to detect the deviations and apply the appropriate remedial measures.

The assumption of independence of errors, *i.e*., error of an observation is not related to or depends upon that of another. This assumption is usually assured with the use of proper randomization procedure. However, if there is any systematic pattern in the arrangement of treatments from one replication to another, errors may be non-independent. This may be handled by using nearest neighbour methods in the analysis of experimental data.

Normality of Errors

The assumptions of homogeneity of variances and normality are generally violated together. To test the validity of normality of errors for the character under study, one can take help of Normal Probability Plot, Anderson-Darling Test, D'Augstino's Test, Shapiro - Wilk's Test, Ryan-Joiner test, Kolmogrov-Smirnov test, *etc*. In general moderate departures from normality are of little concern in the fixed effects ANOVA as F - test is slightly affected but in case of random effects, it is more severely impacted by non-normality. The significant deviations of errors from normality, makes the inferences invalid. So before analyzing the data, it is necessary to convert the data to a scale that it follows a normal distribution. In the data from designed field experiments, we do not directly use the original data for testing of normality or homogeneity of observations because this is embedded with the treatment effects and some of other effects like block, row, column, *etc*. So there is need to eliminate these effects from the data before testing the assumptions of normality and homogeneity of variances. For eliminating the treatment effects and other effects we fit the model corresponding to the design adopted and estimate the residuals. These residuals are then used for testing the normality of the observations. In other words, we want to test the null hypothesis H_0: errors are normally distributed against alternative hypothesis H_1: errors are not normally distributed. For details on these tests one may refer to D'Agostino and Stephens (1986). Most of the standard statistical packages available in the market are capable of testing the normality of the data. In SAS and SPSS commonly used tests are Shapiro-Wilk test and Kolmogrov-Smirnov test. MINITAB uses three tests *viz*. Anderson-Darling, Ryan-Joiner, Kolmogrov-Smirnov for testing the normality of data.

Homogeneity of Error Variances

A crude method for detecting the heterogeneity of variances is based on scatter plots of means and variance or range of observations or errors, residual vs fitted values, *etc*. To be clearer, let Y_{ij} be the observation pertaining to i^{th} treatment (i=1(1)v) in the j^{th} replication (j = 1(1)r_i). Compute the mean and variance for each treatment across the replications (the range can be used in place of variance) as

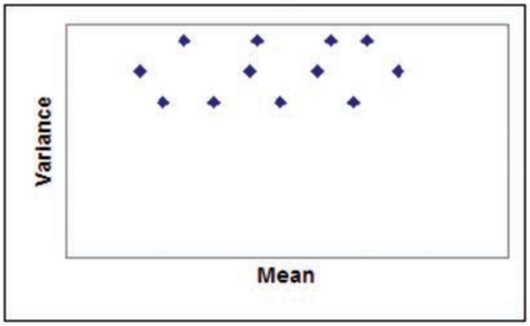
Mean = $\bar{Y}_{i.} = \frac{1}{r_i}\sum_{j=1}^{r_i} Y_{ij}$; Variance = $S_i^2 = \frac{1}{r_i - 1}\sum_{j=1}^{r_i}\left(Y_{ij} - \bar{Y}_{i.}\right)^2$

Draw the scatter plot of mean vs variance (or range). If $S_{i.}^2$'s $\left(i = 1(1)v\right)$ are equal (constant) or nearly equal, then the variances are homogeneous. Based on these scatter plots, the heterogeneity of variances can be classified into two types:

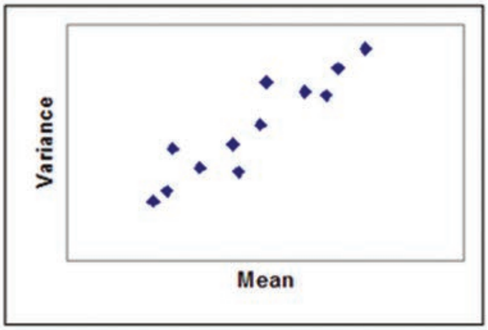
1. Where the variance is functionally related to mean.
2. Where there is no functional relationship between the variance and the mean.

For illustration some scatter - diagrams of mean and variances (or range) are given in below:

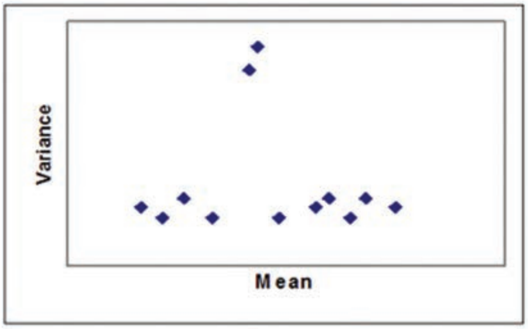
The first kind of variance heterogeneity (figure b) is usually associated with the data whose distribution is non-normal *viz.*, negative binomial, Poisson, binomial, *etc*. The second kind of variance heterogeneity usually occurs in experiments, where, due to the nature of treatments tested, some treatments have errors that are substantially higher (lower) than others. For example, in varietal trials, where various types of breeding material are being compared, the size of variance between plots of a particular variety will depend on the degree of genetic homogeneity of material being tested. The variance of F_2 generation, for example, can be expected to be higher than that of F_1 generation because genetic variability in F_2 is much higher than that in F_1. The variances of varieties that are highly tolerant of or



(a) Homogeneous variance



(b) Heterogeneous variance where variance is proportional to mean



(c) Heterogeneous variance without any functional relationship between variance and mean

highly susceptible to, the stress being tested are expected to be smaller than those of having moderate degree of tolerance. Also in testing yield response to a chemical treatment, such as, fertilizer, insecticide or herbicide, the non-uniform application of chemical treatments may result in a higher variability in the treated plots than that in the untreated plots.

The scatter-diagram of means and variances of observations for each treatment across the replications gives only a preliminary idea about homogeneity of error variances. Statistically the homogeneity of error variances is tested using Bartlett's test for normally distributed errors and Levene test for non-normal errors. These tests are described in the sequel.

Bartlett's Test for Homogeneity of Variances

Let there are v- independent samples drawn from same population and i^{th} sample is of size r_i and $(r_1 + r_2 + ... + r_v) = N$. In the present case, the independent samples are the residuals of the observations pertaining to v treatments and i^{th} sample size is the number of replications of the treatment *i*. One wants to test the null hypothesis H_0: $\sigma_1^2 = \sigma_2^2 = ... = \sigma_v^2$ against the alternative hypothesis H_1 : at least two of the σ_1^2's are not equal, where σ_1^2 is the error variance for treatment *i*.

Let e_{ij} denotes the residual pertaining to the observation of treatment *i* from replication *j*, then it can easily be shown that the sum of residuals pertaining to a given treatment is zero. In this test $S_i^2 = \frac{1}{r_i - 1}\sum_{j=1}^{r_i}(e_{ij} - \bar{e}_{i.})^2 = \frac{1}{r_i - 1}\sum_{j=1}^{r_i} e_{ij}^2$ is taken as unbiased estimate of σ_i^2. The procedure involves computing a statistic whose sampling distribution is closely approximated by the χ^2 distribution with *v - 1* degrees of freedom. The test statistic is

$$\chi_0^2 = 2.3026\frac{q}{c}$$

and null hypothesis is rejected when $\chi_0^2 > \chi^2_{\alpha,v-1}$, where $\chi^2_{\alpha,v-1}$ is the upper α percentage point of χ^2 distribution with *v - 1* degrees of freedom.

To compute χ_0^2, follow the steps:

Step 1: Compute mean and variance of all *v*-samples.

Step 2: Obtain pooled variance $S_p^2 = \frac{\sum_{i=1}^{v}(r_i - 1)S_i^2}{N - v}$

Step 3: Compute $(N - v)\log_{10} S_p^2 - \sum_{i=1}^{v}(r_i - 1)\log_{10} S_i^2$

Step 4: Compute $1 + \frac{1}{3(v-1)}\left(\sum_{i=1}^{v}(r_i - 1)^{-1} - (N - v)^{-1}\right)$

Step 5: Compute χ_0^2.

Bartlett's χ^2 test for homogeneity of variances is a modification of the normal-theory likelihood ratio test. While Bartlett's test has accurate Type I error rates and optimal power when the underlying distribution of the data is normal, it can be very inaccurate if that distribution is even slightly non-normal (Box 1953). Therefore, Bartlett's test is not recommended for routine use.

An approach that leads to tests that are much more robust to the underlying distribution is to transform the original values of the dependent variable to derive a *dispersion variable* and then to perform analysis of variance on this variable. The significance level for the test of homogeneity of variance is the *p*-value for the ANOVA *F*-test on the dispersion variable. Commonly used test for testing the homogeneity of variance using a dispersion variable is Levene Test given by Levene (1960). The procedure is described in the sequel.

Levene Test for homogeneity of Variances

The test is based on the variability of the residuals. The larger the error variance, the larger the variability of the residuals will tend to be. To conduct the Levene test, we divide the data into different groups based on the number of treatments if the error variance is either increasing or decreasing with the treatments, the residuals in the one treatment will tend to be more variable than those in others treatments. The Levene test than consists simply F – statistic based on one way ANOVA used to determine whether the mean of absolute/ Square root deviation from mean are significantly different or not. The residuals are obtained from the usual analysis of variance. The test statistic is given as

$$F = \frac{\left\{\sum_{i=1}^{v}(r_i - 1)\right\}}{v-1} \frac{\left\{\sum_{i=1}^{v} r_i(\bar{d}_{i.} - \bar{d}_{..})^2\right\}}{\sum_{i=1}^{v}\sum_{j=1}^{r_i}(d_{ij} - \bar{d}_{i.})^2} \sim F\left((v-1), \sum_{i=1}^{v}(r_i - 1)\right)$$

where $d_{ij} = \left|e_{ij} - \bar{e}_i\right|;\ \bar{d}_{i.} = \frac{\sum_{j=1}^{r_i} d_{ij}}{r_i};\ \bar{d}_{..} = \frac{\sum_{i=1}^{v}\sum_{j=1}^{r_i} d_{ij}}{\sum_{j=1}^{r_i} r_i}$ and d_{ij} is the j^{th} residual for the i^{th} plot, e_i is the mean of the residuals of the i^{th} treatment.

This test was modified by Brown and Forsythe (1974). In the modified test, the absolute deviation is taken from the median instead of mean in order to make the test more robust.

In the present investigation, the Bartlett's χ^2 – test has been used for testing the homogeneity of error variances when the distribution of errors is normal and Levene test for non-normal errors.

Remark 1: In a block design**,** it can easily be shown that the sum of residuals within a given block is zero. Therefore, the residuals in a block of size 2 will be same with their sign reverse in order. As a consequence, *q* in Bartlett's test and numerator in Levene test statistic becomes zero for the data generated from experiments conducted to compare only two treatments in a RCB design. Hence, the tests for homogeneity of error variances cannot be used for the experiments conducted to compare only two treatments in a RCB design. Inferences from such experiments may be drawn using Fisher-Behren t-test. Further, Bartlett's test cannot be used for the experimental situations where some of the treatments are singly replicated.

Remark 2: In a RCB design, it can easily be shown that the sum of residuals from a particular treatment is zero. As a consequence, the denominator of Levene test statistic is zero for the data generated from RCB designs with two replications. Therefore, Levene test cannot be used for testing the homogeneity of error variances for the data generated from RCB designs with two replications.

Presence of Outliers

Outliers are extreme observations. Residual outliers can be identified from residual plots against *X or Y*. Outliers can create great difficulty. When we encounter one, our first suspicion is that the observation resulted from a mistake or other extraneous effect. On the other hand, outliers may convey significant information, as when an outlier occurs because of an interaction with another predictor omitted from the model. A safe rule frequently suggested is to discard an outlier only if there is direct evidence that it represents in error in recording, a miscalculation, a malfunctioning of equipment, or a similar type of circumstances.

Omission of Important Predictor Variables

Residuals should also be plotted against variables omitted from the model that might have important effects on the response. The purpose of this additional analysis is to determine whether there are any key variables that could provide important additional descriptive and predictive power to the model. The residuals are plotted against the additional predictor variable to see whether or not the residuals tend to vary systematically with the level of the additional predictor variable.

Overview of Tests

Graphical analysis of residuals is inherently subjective. Nevertheless, subjective analysis of a variety of interrelated residuals plots will frequently reveal difficulties with the model more clearly than particular formal tests.

Tests for Randomness

A run test is frequently used to test for lack of randomness in the residuals arranged in time order. Another test, specially designed for lack of randomness in least squares residuals.

Durbin-Watson test:

The Durbin-Watson test assumes the first order autoregressive error models. The test consists of determining whether or not the autocorrelation coefficient (p, say) is zero. The usual test alternatives considered are:

$H_0: p = 0$

$H_0: p > 0$

The Durbin-Watson test statistic D is obtained by using ordinary least squares to fit the regression function, calculating the ordinary residuals: $e_t = Y_t - Y_{t'}$ and then calculating the statistic:

$$D = \frac{\sum_{t=2}^{n}(e_t - e_{t-1})^2}{n\sum_{t=1} e_t^2}$$

Exact critical values are difficult to obtain, but Durbin-Watson have obtained lower and upper bound and such that a value of D outside these bounds leads to a definite decision. The decision rule for testing between the alternatives is:

if $D > d_U$, conclude H_0

if $D < d_L$, conclude H_1

if $dL < D < d_U$, test is inconclusive.

Small value of D lead to the conclusion that $p>0$.

Multi-collinearity

The use and interpretation of a multiple regression model depends implicitly on the assumption that the explanatory variables are not strongly interrelated. In most regression applications the explanatory variables are not orthogonal. Usually the lack of orthogonality is not serious enough to affect the analysis. However, in some situations the explanatory variables are so strongly interrelated that the regression results are ambiguous. Typically, it is impossible to estimate the unique effects of individual variables in the regression equation. The estimated values of the coefficients are very sensitive to slight changes in the data and to the addition or deletion of variables in the equation. The regression coefficients have large sampling errors which affect both inference and forecasting that is based on the regression model. The condition of severe non-orthogonality is also referred to as the problem of multicollinearity.

Data transformation

In this section, we shall discuss the remedial measures for non-normal and/or heterogeneous data in greater details.

Data transformation is the most appropriate remedial measure, in the situation where the variances are heterogeneous and are some functions of means. With this technique, the original data are converted to a new scale resulting into a new data set that is expected to satisfy the homogeneity of variances. Because a common transformation scale is applied to all observations, the comparative values between treatments are not altered and comparison between them remains valid.

Error partitioning is the remedial measure of heterogeneity that usually occurs in experiments, where, due to the nature of treatments tested some treatments have errors that are substantially higher (lower) than others.

Here, we shall concentrate on those situations where character under study is non-normal and variances are heterogeneous. Depending upon the functional relationship between variances and means, suitable transformation is adopted. The transformed variate should satisfy the following:

1. The variances of the transformed variate should be unaffected by changes in the means. This is also called the variance stabilizing transformation.
2. It should be normally distributed.
3. It should be one for which effects are linear and additive.
4. The transformed scale should be such for which an arithmetic average from the sample is an efficient estimate of true mean.

The following are the three transformations, which are being used most commonly, in biological research.

a) Logarithmic Transformation

b) Square root Transformation

c) Arc Sine or Angular Transformation

a) Logarithmic Transformation

This transformation is suitable for the data where the variance is proportional to square of the mean or the coefficient of variation (S.D./mean) is constant or where effects are multiplicative. These conditions are generally found in the data that are whole numbers and cover a wide range of values. This is usually the case when analyzing growth measurements such as trunk girth, length of extension growth, weight of tree or number of insects per plot, number of eggmass per plant or per unit area *etc*.

For such situations, it is appropriate to analyze $\log X$ instead of actual data, X. When data set involves small values or zeros, $\log (X+1)$, $\log (2X + 1)$ or $\log \left(X+\frac{3}{8}\right)$ should be used instead of $\log X$. This transformation would make errors normal, when observations follow negative binomial distribution like in the case of insect counts.

b) Square-Root Transformation

This transformation is appropriate for the data sets where the variance is proportional to the mean. Here, the data consists of small whole numbers, for example, data obtained in counting rare events, such as the number of infested plants in a plot, the number of insects caught in traps, number of weeds per plot, parthenocarpy in some varieties of mango. This data set generally follows the Poisson distribution and square root transformation approximates Poisson to normal distribution.

For these situations, it is better to analyze $\sqrt{X}$ than that of *X*, the actual data. If X is confirmed to small whole numbers then, $\sqrt{X+\frac{1}{2}}$ or $\sqrt{X+\frac{3}{8}}$ should be used instead of $\sqrt{X}$.

This transformation is also appropriate for the percentage data, where, the range is between 0 to 30% or between 70 and 100%.

c) Arc Sine Transformation

This transformation is appropriate for the data on proportions, *i.e.,* data obtained from a count and the data expressed as decimal fractions and percentages. The distribution of percentages is binomial and this transformation makes the distribution normal. Since the role of this transformation is not properly understood, there is a tendency to transform any percentage using arc sine transformation. But only that percentage data that are derived from count data, such as % barren tillers (which is derived from the ratio of the number of non-bearing tillers to the total number of tillers) should be transformed and not the percentage data such as % protein or % carbohydrates, %nitrogen, *etc.* which are not derived from count data. For these situations, it is better to analyze $\sin^{-1}(\sqrt{X})$ than that of *X*, the actual data. If the value of X is 0%, it should be substituted by $\left(\frac{1}{4n}\right)$ and the value of 100% by $\left(100-\frac{1}{4n}\right)$, where *n* is the number of units upon which the percentage data is based.

It is interesting to note here that not all percentage data need to be transformed and even if they do, arc sine transformation is not the only transformation possible. The following rules may be useful in choosing the proper transformation scale for percentage data derived from count data.

Rule 1: The percentage data lying within the range 30 to 70% is homogeneous and no transformation is needed.

Rule 2: For percentage data lying within the range of either 0 to 30% or 70 to 100%, but not both, the square root transformation should be used.

Rule 3: For percentage that do not follow the ranges specified in Rule 1 or Rule 2, the Arc Sine transformation should be used.

The other transformations used are reciprocal square root [$\frac{1}{\sqrt{X}}$, when variance is proportional to cube of mean], reciprocal [$\frac{1}{X}$, when variance is proportional to fourth power of mean] and tangent hyperbolic transformation.

The transformation discussed above are a particular case of the general family of transformations known as Box-Cox transformation.

d) Box-Cox Transformation

By now we know that if the relation between the variance of observations and the mean is known then this information can be utilized in selecting the form of the transformation. We now elaborate on this point and show how it is possible to estimate the form of the required transformation from the data. The transformation suggested by Box and Cox (1964) is a power transformation of the original data. Let y_{ut} be the observation pertaining to the u^{th} plot; then the power transformation implies that we use y_{ut}'s as

$$y^{*}_{ut} = y^{\lambda}_{ut}.$$

The transformation parameter λ in $y^{*}_{ut} = y^{\lambda}_{ut}$ may be estimated simultaneously with the other model parameters (overall mean and treatment effects) using the method of maximum likelihood. The procedure consists of performing, for the various values of λ, a standard analysis of variance on

$$y_{ut}^{(\lambda)} = \begin{cases} \dfrac{y_{ut}^{\lambda} - 1}{\lambda \dot{y}_{ut}^{\lambda-1}} & \lambda \neq 0 \\ \dot{y}_{ut} \ln y_{ut} & \lambda = 0 \end{cases} \qquad \text{(A)}$$

$$\text{where } \dot{y}_{ut} = \ln^{-1}\left[(1/n)\sum_{u=1}^{N}\sum_{t=1}^{n_u} \ln y_{ut}\right].$$

y^{*}_{ut} is the geometric mean of the observations. The maximum likelihood estimate of λ is the value for which the error sum of squares, say SSE (λ), is minimum. Notice that we cannot select the value of λ by directly comparing the error sum of squares from analysis of variance on y^{λ} because for each value of l the error sum of squares is measured on a different scale. Equation (A) rescales the responses so that the error sums of squares are directly comparable. This is a very general transformation and the commonly used transformations follow as particular cases. The particular cases for different values of are given below.

λ	Transformation
1	No Transformation
½	Square Root
0	Log
-1/2	Reciprocal Square Root
-1	Reciprocal

Remark 3: If any one of the observations is zero then the geometric mean is undefined. In the expression (A), geometric mean is in denominator so it is not possible to compute that expression. For solving this problem, we add a small quantity to each of the observations.

Note: It should be emphasized that transformation, if needed, must take place right at the beginning of the analysis, all fitting of missing plot values, all adjustments by covariance *etc.* being done with the transformed variate and not with the original data. At the end, when the conclusions have been reached, it is permissible to 're-transform' the results so as to present them in the original units of measurement, but this is done only to render them more intelligible.

As a result of this transformation followed by back transformation, the means will rather be different from those that would have been obtained from the original data. A simple example is that without transformation, the mean of the numbers 1, 4, 9, 16 and 25 is 11. Suppose a square root transformation is used to give 1, 2, 3, 4 and 5, the mean is now 3, which after back- transformation gives 9. Usually the difference will not be so great because data do not usually vary as much as those given, but logarithmic and square root transformation always lead to a reduction of the mean, just as angles of equal formation usually lead to its moving away from the central value of 50%.

However, in practice, computing treatment means from original data is more frequently used because of its simplicity, but this may change the order of ranking of converted means for comparison. Although transformations make possible a valid analysis, they can be very awkward. For example, although a significant difference can be worked out in the usual way for means of the transformed data, none can be worked out for the treatment means after back transformation.

Non-parametric tests in the Analysis of Experimental Data

When the data remains non-normal and/or heterogeneous even after transformation, a recourse is made to non-parametric test procedures. A lot of attention is being paid to develop non-parametric tests for analysis of experimental data. Most of these non-parametric test procedures are based on rank statistic. The rank statistic has been used in development of these tests as the statistic based on ranks is

1. distribution free
2. easy to calculate and
3. simple to explain and understand.

Another reason for use of rank statistic is due to the well known result that the average rank approaches normality quickly as n (number of observations) increases, under the rather general conditions, while the same might not be true for the original data {see e.g. Conover and Iman (1976, 1981)}. The non-parametric test procedures available in literature cover completely randomized designs, randomized complete block designs, balanced incomplete block designs, design for bioassays, split plot designs, cross-over designs and so on. For an excellent and elaborate discussions on non-parametric tests in the analysis of experimental data, one may refer to Siegel and Castellan Jr. (1988), Deshpande, Gore and Shanubhogue (1995), Sen (1996), and Hollander and Wolfe (1999).

Kruskal-Wallis Test can be used for the analysis of data from completely randomized designs. Skillings and Mack Test helps in analyzing the data from a general block design. Friedman Test and Durbin Test are particular cases of this test. Friedman Test is used for the analysis of data from randomized complete block designs and Durbin test for the analysis of data from balanced incomplete block designs.

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CHAPTER 12

STATISTICAL METHODS IN ECOLOGICAL DATA ANALYSIS

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Introduction

Although analytical methods in statistics have all along been generic and evolutionary in the first half of past century, the developments happening in the field of computational statistics in the past couple of decades are more need based and custom tuned. A lot of effort is being put in by researchers in bundling methods, theory and procedures in classical statistical literature on their common applicability to a targeted exploration. It is common place to collate various univariate, multivariate, parametric, non-parametric, frequentist and non-frequentist methods, which have applications in different domains like ecology, clinical trials, bioinformatics *etc.* and tag them as per the domain subject matter. Thus the generic and specific procedures which are of relevance in exploratory and confirmatory analyses in the field of ecological studies of communities have been grouped under a common pivot. During the course of this discussion a couple of such statistical methods used in community structure studies would be dwelled upon.

On the ecological datasets

The typical community structure dataset would have either or both the tags, *viz.* temporal and spatial. The data could have been collated over multiple sampling spots in a region and also over a period of time. This makes these data to be looked upon from the time series as well as space- series points of view. And another ubiquitous feature of such datasets are their being multivariate. Communities, comprising many species at various levels of abundance, are always recorded as n-tuples at each sampling session and hence are multivariate at core. Although there are possibilities of isolating responses and causes from the bunch and possible univariate procedures could be applied upon, thereafter.

Multivariate tools

Analysis of ecological data involves almost the entire gamut of multivariate data analytical tools. The pivot based (could be labelled region or cluster) comparison of the community abundance has its roots in Hotelling's T square(d) thereafter raising to the multiple comparisons using MANOVA using Wilk's Lambda, Pillai's trace *etc.* Needless to add, a set of single response multiple regression analysis and univariate ANOVA get subsumed in the multivariate projection and analysis. The common thread in most of these analyses is the polarization of near independent components which have a telling impact on the response variables or the system tracking as a whole.

Another important area in multivariate analysis is the clustering and discrimination domain. The basic thrust in this sector is about measuring the closeness or remoteness of the multiple streaks of expressions of communities, which then gets utilized in grouping or clustering the similarly placed or paced dynamics or also for contrasting the most orthogonal or independent of bunches of variables which could sufficiently project the overall variability in the system. In a way these types of procedures aim at reducing the dimensionality of the bouquet of variables in such a way that inferences and depictions of scenario can be made with two or three dimensional projections. The community datasets often indicate similarity in pattern amongst their subsets, which when zoomed in would yield more interesting bio-climatic cause- effect mechanisms. Tools like Principal Component Analysis (PCA), ordinations by Principal Coordinate Analysis (PCoA) and Redundancy Analysis (RDA) fall broadly under this conceptualization. Of this the RDA can be viewed as the multivariate extrapolation of univariate multiple regression analysis and it yields the proportion of variance of a set of variables that could be explained by a set of causative factors. PCoA has its action rooting on the distances (preferably Euclidean) between the multi-dimensional points and routing a starting point with its nearest neighbor in as much less a dimension possible so that the resultant scatter of these points clearly shows clusters based on which further PCA type recasting can be done. This is otherwise referred to as Multi Dimensional Scaling (MDS), the metric variant of it. Also in the context of abundance of communities datasets, the dissimilarities (distances) between the observations can be estimated more nonparametrically (with less leanings on the traditional orthodox assumptions on the values thrown out by the study variables, aka distribution) by using a “Stress” reducing monotonic transformation which simultaneously takes care of point-point contrast as well as distances between the realized observations.

The major bottleneck or invisible opportunity with ecological datasets is that they are predominantly counts based with a large possibility of null entries. Also at times the community sampling boils down to presence or absence type of information. Hence under these circumstances parametric exploration and testing on orthodox moulds would be highly inefficient and error prone. Hence a whole lot of quasi parametric or non-parametric tools have been conceptualized by resonating or tweaking the existing parametric options. One such set of tools is available in the Plymouth Routine In Multivariate Ecological Research (PRIMER). The following routines enshrined in the software are quite useful in numerically testing and robustly inferring and graphically assimilating large sets of community sample sets.

(i) CLUSTER (grouping) (ii) MDS (Ordination) (iii) PCA (recast visualisation) (iv) ANOSIM (hypothesis testing) (v) SIMPER (sample discrimination) (vi) BEST (trend correlations) (vii) BIOENV (paired group comparison) and (viii) PERMANOVA (permutational multivariate analysis of variance) among others. PRIMER also has extensive routines for estimating various beta, alpha and gamma diversity measuring indices. All these routines are built on a near total non-parametric platform thereby warding off the presumption and assumption blues. A classic routine worth focusing on is ANOSIM. Smartly worded to sound akin ANOVA this routine has a refreshingly different set of approach rooted deeply on all generated by the data alone. Under this procedure the samples are treated as arrays whose rows are samples and columns are the component resources like planktons *etc*. Based on the intensity of the resources available in each location, a rank based similarity matrix is generated equivalent to the sample dimension. This index popularly known as Bray- Curtis similarity is then subjected to the inter and intra factor comparison yielding a functional known as R statistic. The value falling between 0 to 1 practically with lower limit indicating perfect similarity in divergence within factor groups and between them and the upper limit indicating near perfect similarity between pairs within groups as compared to those between them, thereby indicating significant inter group heterogeneity. The measure of the R value's robustness is also arrived at by estimating the R estimate on prior number of large recombinations of the sample data and noting down the values of R falling above the one realized from the original sample. Thus the non-parametric conceptualization right from estimating the group similarity to studying its distributional aspect is complete in this approach.

Modeling options with Ecological data sets

To start with even the simple multiple regression itself is a model in the strict statistical sense which depicts the role and measure of causal factor upon explaining the variability of the response variables. These regression models fall under the category of linear models with normality assumptions. However with the responses being binary at times and highly skewed and noisy counts on the other end of the spectrum, the classical assumptions of normality which validates the tests of significance are most inapplicable in these datasets. Hence the more liberated and broader versions of the linear model called Generalised Additive Models (GAM) are the most aptly poised set of paradigms to fit into such situations. With a wide range of link functions, smooth functions and a range of distributions including non Gaussian like Poisson *etc*. GAMs can practically link any type of causative variable with any type of response sets which can be foreseen in ecological studies. With many measures for their rates of success based on Information criterion, the best of such group of models can always be zeroed in on.

The developments made in the time series modeling area including the methods to split the time spanned datasets into components of trend, cyclicity *etc*. have come in handy while dealing with the biotic and temporal factors and their influence on the community structures. The direction oriented process based decomposition of time series like Asymmetric Eigenvector Mapping and the direction free mapping like Morgan/s Eigenvector Mapping have given a specific thrust towards modeling the data with a view to focus on temporal and spatial angles.

Tools like Local contributions to beta diversity (LCBD) help in arriving at comparative measures of ecological uniqueness of samples which would go a long way in studying and inferring about the community structures.

To conclude, it can be safely assumed that the rate of development of computational statistics has lead a sort of newer opportunities and horizons in locating and studying the hitherto unknown camouflaged patterns and undercurrents existing in community structure datasets. With the rate of innovation higher on the computational front the treading of hitherto unheralded territory is becoming all the more in vogue thing for researchers.

Referred literature

(i) Legendre P, Gauthier O. 2014 Statistical methods for temporal and space–time analysis of community composition data. Proc. R. Soc. B

(ii) Clarke, KR, Warwick RM (2001). Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E

(iii) Other classical statistical text books

Annexure:

Certain computational tools that can be put to use in Ecological data analysis

In R language

(1) Vegan- A contributed package totally dedicated to the procedures and methods discussed by Clarke and Warwick (2001), whose software version is Primer-E. This contains most of the common tools like dissimilarity measures, Anosim, BioEnv *etc.*

(2) CatDyn: Fishery Stock Assessment by Generalised Depletion Models

As a recourse to viewing the stock dynamics through catch rather than the population, which is of course used as an index for the latter, routines have been developed to assess, model and predict stock health using Generalised Depletion models. The entire gamut of parametrisation, modelling and forecasting has been made handy by the R library CatDyn. As per the introduction given by the author(s) of CatDyn, the library is capable of the following:

Based on fishery Catch Dynamics instead of fish Population Dynamics (hence CatDyn) and using high-frequency or medium-frequency catch in biomass or numbers, fishing nominal effort, and mean fish body weight by time step, from one or two fishing fleets, estimate stock abundance, natural mortality rate, and fishing operational parameters. It includes methods for data organization, plotting standard exploratory and analytical plots, predictions, for 77 types of models of increasing complexity, and 56 likelihood models for the data.

The concept of depletion modelling is set into motion using the following parametrization. The process equations in the Catch Dynamics Models in this package are of the form

$$C_t = ke^{-\frac{M}{2}} E_t^a N_t^b$$

$$N_t = N_0 e^{-Mt} - e^{\frac{M}{2}} \sum_{i<t} C_{t-1} e^{-M(t-i-1)} + \sum_{j} P_j e^{-M(t-j)}$$

where C is catch in numbers, t, i are time step indicators, j is perturbation index (j=1,2,...,100), k is a scaling constant, E is nominal fishing effort, an observed predictor of catch, a is a parameter of effort synergy or saturability, N is abundance, a latent predictor of catch, b is a parameter of hyperstability or hyperdepletion, and M is natural mortality rate per time step. The second summand of the expanded latent predictor is a discount applied to the earlier catches in order to avoid an M-biased estimate of initial abundance. Perturbations to depletion represent fish migrations into the fishing grounds or expansions of the fishing grounds by the fleet(s) resulting in point pulses of abundance. In transit models (limited to one fleet) there are also emigration events happening at specific time steps for each perturbation. In 2 fleet cases the fleets contribute complementary information about stock abundance, and thus operate additively; any interaction between the fleets is latent and affects the estimated values of fleet dependent parameters, such as k, a, and b.

The observation model can take any of the following forms: a Poisson counts process or a negative binomial counts process for catch recorded in numbers, an additive random normal term added to the continuous catch (in weight) predicted by the process (normal and adjusted profile normal), a multiplicative exponential term acting on the process-predicted catch such as the logarithm of this multiplier distributes normally (lognormal and adjusted profile lognormal), and Gamma (shape and scale parameterization).

The library CatDyn takes care of almost all the parameterisation issues and dishes out the type of output which would magnify the status of fisheries as seen from the macro dynamic level in such a way to aid the policy makers.

(3) mefa- Yet another package in R which specializes in data analysis using ecological information. This apart from dealing with community structure information, progresses to the extent of generating analysis based report in popular formats like LaTeX and html *etc*.

Other sources

(1) XLSTAT- is an MS Excel friendly data analysis package which performs canonical correspondence analysis in tandem with Excel spreadsheet and finds EC50 values *etc*. and omics data analysis.

(2) FLORA- is another software scripted for Windows environment, which handles the multivariate routines as applied to community structure data.

Summarizing, it can be recorded that the tools mostly applied for dealing with eco-biological data sets based on communities of flora and fauna stem from multivariate analysis tools and the software variants focus mostly on the customized output and report generation.

CHAPTER 13

SAMPLING METHODOLOGY EMPLOYED BY CMFRI FOR COLLECTION AND ESTIMATION OF MARINE FISH LANDINGS IN INDIA

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Fisheries sector plays a key role in Indian economy. The sector supports livelihood, nutritional security, and subsistence to large number of people as well as foreign exchange earnings. India's coast line stretches about 8129 km. There are 1511 landing centres scattered along the coastline of the main land as per the records from National Marine Fisheries Data Centre at Central Marine Fisheries Research Institute (CMFRI). Marine fish landings take place almost all along the coast line throughout the day and sometimes during night. Under these circumstances, collection of statistics by complete enumeration would involve a very large number of enumerators and a huge amount of money apart from the time involved in collection of data. Therefore, a possible solution for quantifying marine fish landings is adoption of a suitable sampling technique. As, monitoring and assessment of the exploited marine fishery resources of India is one of the important mandates of the CMFRI, institute made attempts to evolve the scientific methods for collection of data on catch and effort, since its inception in 1947. Pilot surveys were conducted along the coastline of India and different sampling designs were tested.

CMFRI introduced collection of marine fish statistics through a stratified sampling design along the west coast of India in the year 1959 and extended to other states over the years. Keeping in pace with the changing marine fisheries scenario, the sampling design has been modified over the periods. Presently, CMFRI estimate marine fish landings based on a multi-stage stratified random sampling technique, stratification is done over space and time. Each maritime state is divided into suitable, non-overlapping zones on the basis of fishing intensity and geographical considerations (Fig. 1). The number of landing centres varies from zone to zone.

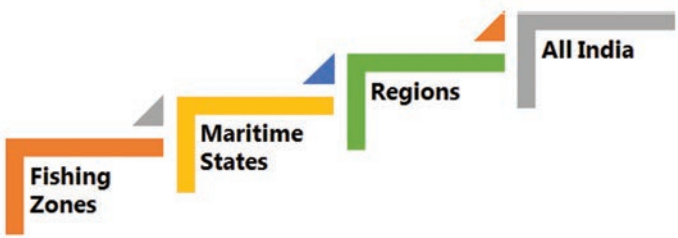

Fig. 1. Stratification over Space

Over space, each zone is regarded as a stratum and over time, a calendar month is considered as a stratum. Consequently, a zone and a calendar month constitute a space-

*Reprinted from Course Manual of Summer School on Advanced Methods for Fish Stock Assessment and Fisheries Management. Lecture Note Series No. 2/2017. CMFRI, Kochi, pp. 109-112 time stratum. Suppose, in a zone, if there are 5 landing centres and 30 fishing days in the month; then 5 x 30 = 150 landing centre days, combination of centre and day constitute the primary stage units (PSU). The fishing craft that land on a landing centre day forms the second stage units (SSU). Furthermore, the fish landings vary considerably among the landing centres in a multi-centre zone, mainly in different seasons and hence a zone is further stratified into substrata *viz.*, major, minor and very minor. The centres in which either mechanised crafts or 100 or more non-mechanised/motorised crafts are operating are considered as major centres. Likewise, other strata are defined based on the number and type of fishing crafts operating.

Further, a month is divided into three groups each with ten days. A day is selected at random from the first five days of a month and 5 successive days are selected automatically. Three clusters of two successive days are made from the above selected days. To illustrate the selection of landing centres and days, let us consider a fishing zone in a month. Initially, select a date at random from the first five days, let it be 3. Then from the first 10 day group, three clusters of 2 days (3,4) (5,6) and (7,8) can be formed. From the second group of 10 days, the clusters are systematically selected with an interval of 10 days. The clusters of days formed are (13,14) (15,16) and (17,18). Similar selection can be done for the next group of ten days. Accordingly, 9 clusters of two days can be formed in a month. Afterwards, 9 centres are selected with replacement from the total number of landing centres in a zone and allotted to the 9 cluster days as explained before. Thus, a combination of a landing centre and a day (landing centre day) forms the Primary Stage Units. A landing centre day has been divided into 3 periods as given in the infographic. That means a landing centre day is 24 hour duration which starts at noon of the first day and ends at noon of the following day.

Period 1	• 1200-1800 hours on 1st day
Period 2	• 0600-1200 hours on 2nd day
Period 3	• 1800 hours to next morning 0600 hours

The marine fish landings data collection is done by the technical staff of CMFRI. Usually, one staff is identified to collect data from each zone. Data collection starts from period 1 on each selected landing centre day. The staff will be present throughout the periods 1 and 2 at the centres. The data on landings during period 3 (night landings) is usually collected from the landing centre by enquiry on the following day morning. The observations on the 3 periods contribute the data for one landing centre day (24hrs). So, in a 10 day period, data from 3 centre-days are sampled and thus in a month 9 landing centre days are sampled.

After reaching the landing centre, if the landed number of crafts is large, it may not be practical to record the catches of all crafts landed during an observation period. In that situation, sampling of crafts become essential. When the total number of crafts landed is 15 or less, the total landings from all the crafts are enumerated for catch composition and other particulars. When the total number of crafts exceeds 15, the following procedure is followed to sample the number of crafts.

Less than or equal to 15	16 -19	20 - 29	30 - 39	40 - 49	50 - 59
100%	First 10 and the balance 50 %	1 in 2	1 in 3	1 in 4	1 in 5 and so on

The catches are normally removed in baskets of standard volume from the crafts. The weight of fish contained in these baskets being known, the total weight of the fish in each boat under observation has been obtained. The procedures of selection of the landing centre days and the crafts landed on the selected day for single centre zones are the same as in the case of a stratum in a multi-centre zone. From the landings of the observed fishing units, the landings for all the units landed during the observation period are estimated. By adding the quantities landed during the two 6- hour's periods and during the night (12-hours) the quantity landed for a day (24-hours) at a centre that is the landings for each centre day included in the sample is estimated. From these, the monthly zonal landings are obtained. From the zonal estimates, district-wise, state-wise and all India landings are arrived. The corresponding sampling errors are also estimated. The estimation procedure is detailed in Srinath *et. al.,* (2005).

Administration of the Survey

The survey staff is given 10-12 weeks training course immediately after recruitment and is posted to the survey centres. Each survey centre each centre is provided with literature connected with the identification of fish, a reference collection of local fish species, crustaceans and molluscs, field notebooks and registers. The programme of work for the following month is carefully designed by the staff of Fishery Resources Assessment Division at the CMFRI headquarters. Generally one field staff is allotted to each zone to collect the fish landings data. At the end of every month, the survey staff receives the programme of work for the next month by post, that includes the names of landing centres to be observed and details such as dates and time for observations at each landing centre. The field staff are instructed to send the data collected during every month to reach the Institute's headquarters at least by the end of first week of the subsequent month.

Surprise inspections are carried out by the supervisory staff of the Institute and the enumerators are inspected while at work in the field and their field notebooks and diaries are scrutinised. The estimated zonal landings are always compared with the previous year's survey figures, and if any variation which cannot be explained is observed, the technique of interpenetrating sub-samples is adopted to detect observational errors. Zonal workshops are held periodically to review the progress of work and update the sampling frame and to impart refresher courses to the field staff. Non-response occurs when the regular field staff is not available to observe the centre-day included in the sample. Usually, arrangements are made at the Headquarters/Research/Regional Centre to minimise the non-response.

In the existing sampling methodology, the interest is to estimate gear-wise, species-wise landings for the state in a month, fishing effort according to different types of fishing crafts and also in terms of man hours. The analysis is carried out at CMFRI headquarters. Before the data is processed for analysis it will be ensured that the data collection is made as per the approved schedule, by checking the appropriate proforma. The responsibilities and functions of staff at the headquarters are data coding, estimation and database management. The data analysis is computerised and estimates are made using the software developed by the Fishery Resources Assessment Division of the Institute. The processed data are again counter- checked for errors. When discrepancies are detected, the estimation procedure is scrutinised in detail.

References

M. Srinath, Somy Kuriakose and K.G. Mini, 2005. Methodology for the Estimation of Marine Fish Landings in India, CMFRI Special Publication No. 86, p.57.

CHAPTER 14

AN INTRODUCTION TO R PROGRAMMING

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Introduction

R language is the GNU arm of S language, which has taken the computational world by storm in the last decade. Starting as a compendium of statistical tools, this language has grown up into a canopy lording over a research analysis environment thereby subsuming many hitherto complicated manoeuvres onto the realms of syntactical simplicity. As this an exponentially expanding field of development with ever exploding information downpour, it would be a near impossible task to frame it onto a short simple foundational discourse. However in the subsequent sections we would try to view the potential and the extent of practicality we would unravel the hidden features of the software through a GUI envelop also apart from the regular console and syntax based one. To get its power more understandable we would visualize its forays into the field of analytics using medium scale examples from marine fisheries data.

- R is "GNU S" — A language and environment for data manipulation, calculation and graphical display.
  - R is similar to the award-winning S system, which was developed at Bell Laboratories by John Chambers *et al.*,
  - a suite of operators for calculations on arrays, in particular matrices,
  - a large, coherent, integrated collection of intermediate tools for interactive data analysis,
  - graphical facilities for data analysis and display either directly at the computer or on hardcopy
  - a well developed programming language which includes conditionals, loops, user defined recursive functions and input and output facilities.
- The core of R is an interpreted computer language.
  - It allows branching and looping as well as modular programming using functions.
  - Most of the user-visible functions in R are written in R, calling upon a smaller set of internal primitives.

It is possible for the user to interface to procedures written in C, C++ or FORTRAN languages for efficiency, and also to write additional primitives.

R, S and S-plus- a brief time line

- S: an interactive environment for data analysis developed at Bell Laboratories since 1976
  - 1988 - S2: RA Becker, JM Chambers, A Wilks
  - 1992 - S3: JM Chambers, TJ Hastie
  - 1998 - S4: JM Chambers
- Exclusively licensed by *AT&T/Lucent* to *Insightful Corporation*, Seattle WA. Product name: "S-plus".
- Implementation languages C, Fortran.
- See: *http://cm.bell-labs.com/cm/ms/departments/sia/S/history.html*
- R: initially written by Ross Ihaka and Robert Gentleman at Dep. of Statistics of University of Auckland, New Zealand during 1990s.
- Since 1997: international "R-core" team of ca. 15 people with access to common CVS archive.

What R does and does not

o data handling and storage: numeric, textualo matrix algebrao	o is not a database, but connects to DBMSs
o hash tables and regular expressions	o has no graphical user interfaces, but connects to Java, TclTko
o high-level data analytic and statistical functions	o language interpreter can be very slow, but allows to call own C/C++ code
o classes (Object Oriented "OO")	o no spreadsheet view of data, but connects to Excel/MsOffice
o graphics	o no professional / commercial support
o programming language: loops, branching, subroutines	

R and statistics

- Packaging: a crucial infrastructure to efficiently produce, load and keep consistent software libraries from (many) different sources / authors, which are updated at a best possible refresh rate

- o Statistics: most packages deal with statistics and data analysis and there are many conduit and value addition libraries which augment the statistical inference
- o State of the art: many statistical researchers provide their methods as R packages

Statistical Analysis

Data Analysis and Presentation happen to be the core strength of R software environment and the ease with which this is performed makes the environment as the ultimate winner. Faster computational routines and amenability of access and modification to interim steps and results makes the programming environment a winner.

- The R distribution contains functionality for large number of statistical procedures.
  - linear and generalized linear models
  - nonlinear regression models
  - time series analysis
  - classical parametric and nonparametric tests
  - clustering
  - smoothing
- R also has a large set of functions which provide a flexible graphical environment for creating various kinds of data presentations.

References For R

- The basic reference is The New S Language: A Programming Environment for Data Analysis and Graphics by Richard A. Becker, John M. Chambers and Allan R. Wilks (the "Blue Book") .
- The new features of the 1991 release of S (S version 3) are covered in Statistical Models in S edited by John M. Chambers and Trevor J. Hastie (the "White Book").
- Classical and modern statistical techniques have been implemented.
  - Some of these are built into the base R environment.
  - Many are supplied as packages. There are about 8 packages supplied

with R (called "standard" packages) and many more are available through the cran family of Internet sites (via http://cran.r-project.org).

- All the R functions have been documented in the form of help pages in an "output independent" form which can be used to create versions for HTML, LATEX, text *etc*.

– The document "An Introduction to R" provides a more user-friendly starting point.

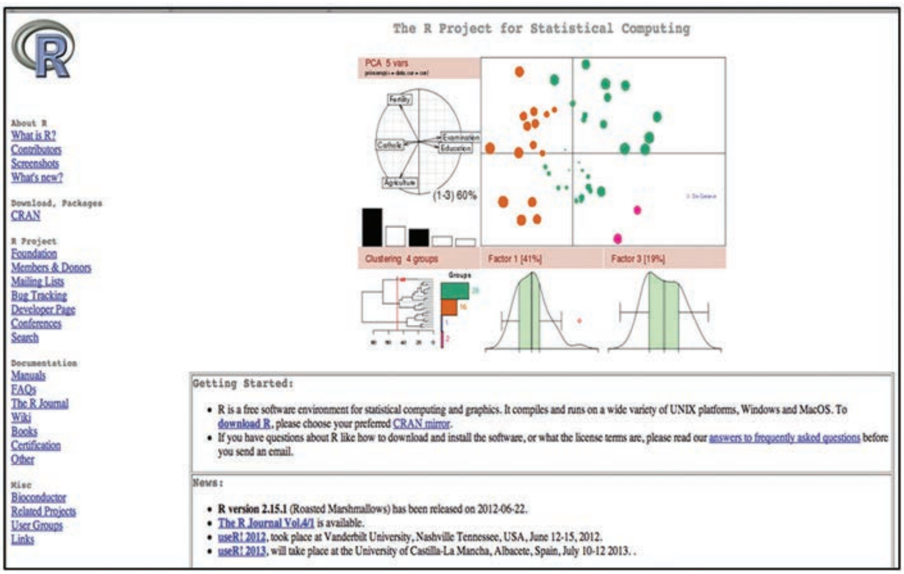
– An "R Language Definition" manual

– More specialized manuals on data import/export and extending R.

R installations

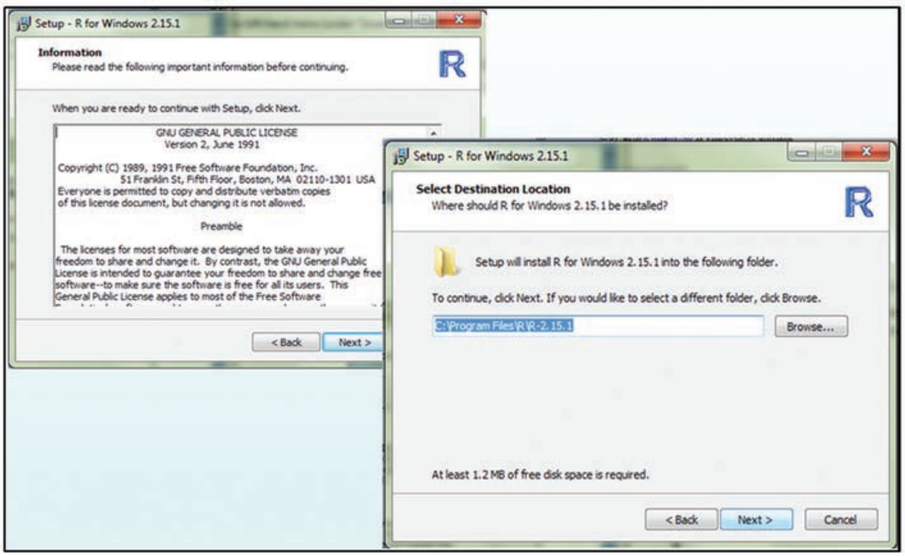
Getting Started

To install R on your MAC or PC the starting point has to be *http://www.r-project.org/*.

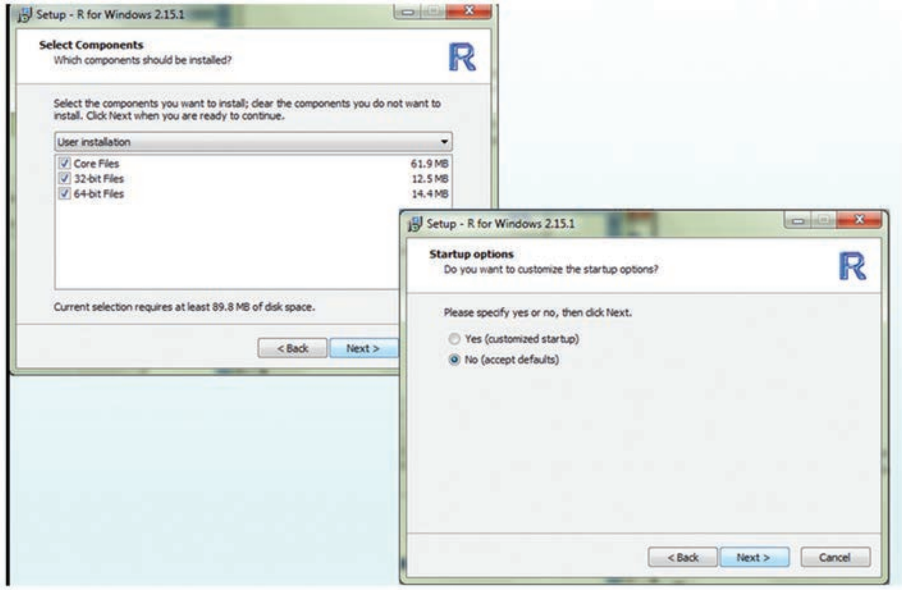


Depending on the choice of operating system the installer/ zip file with checksum may be downloaded and verified.

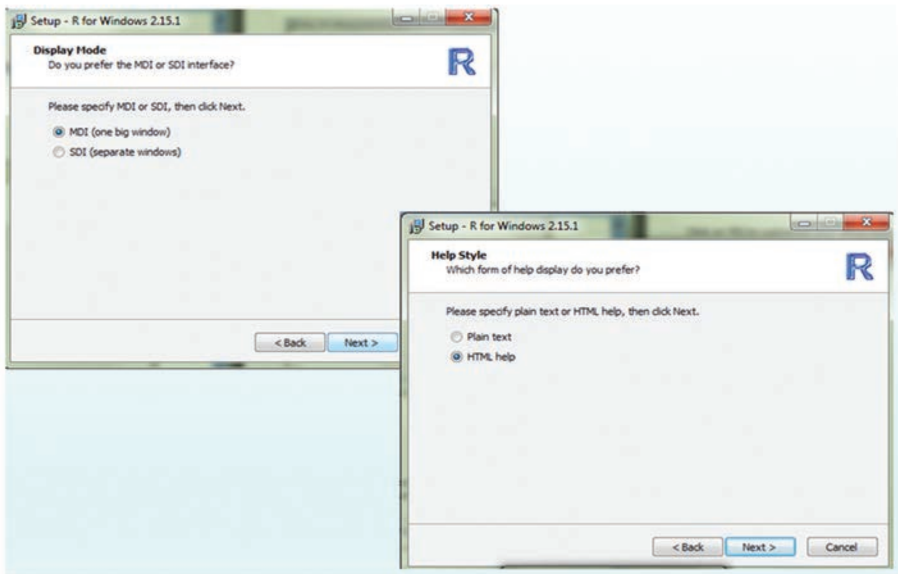
An effort to download R for Windows would have the following sequence of interactions with the portal, whose snapshots are given below:



Its always a good idea to download all the files.



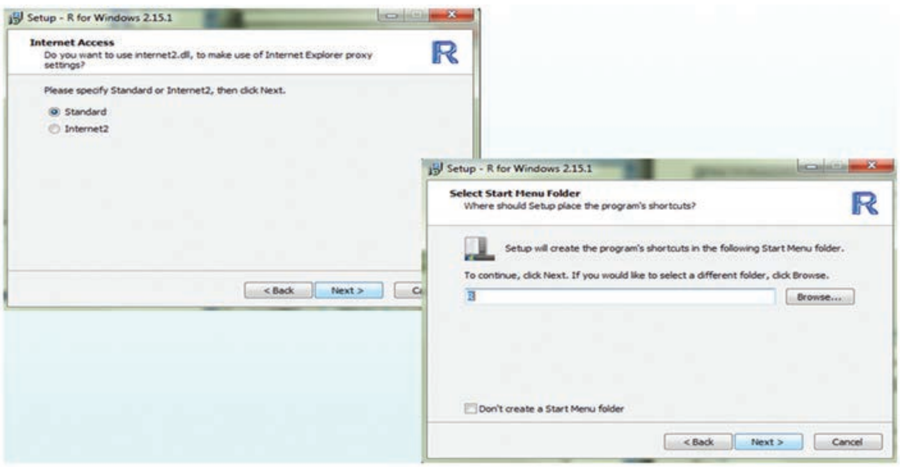
MDI is when the windows will be contained within one large window.

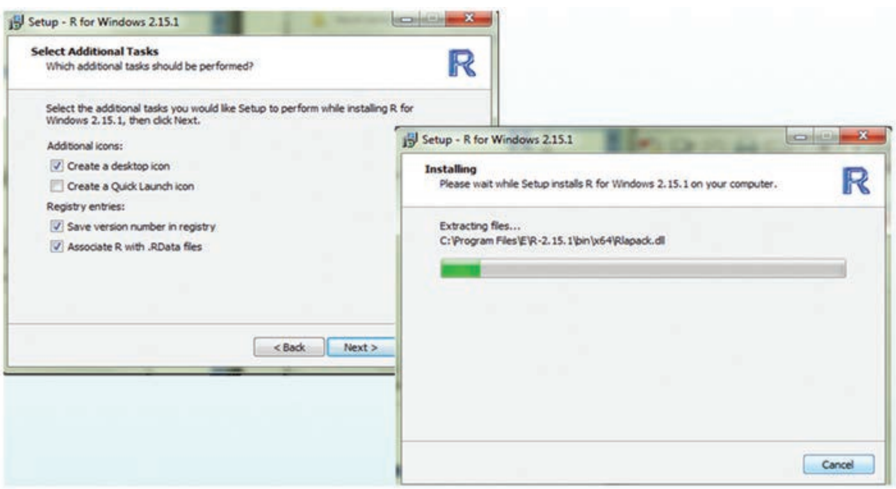


This is similar to how Excel is setup. SDI is a single document interface where every item will get its own window. This is similar to how SPSS is set up where it has separate data editor, viewer, and syntax windows. Once you choose which your prefer, click next.

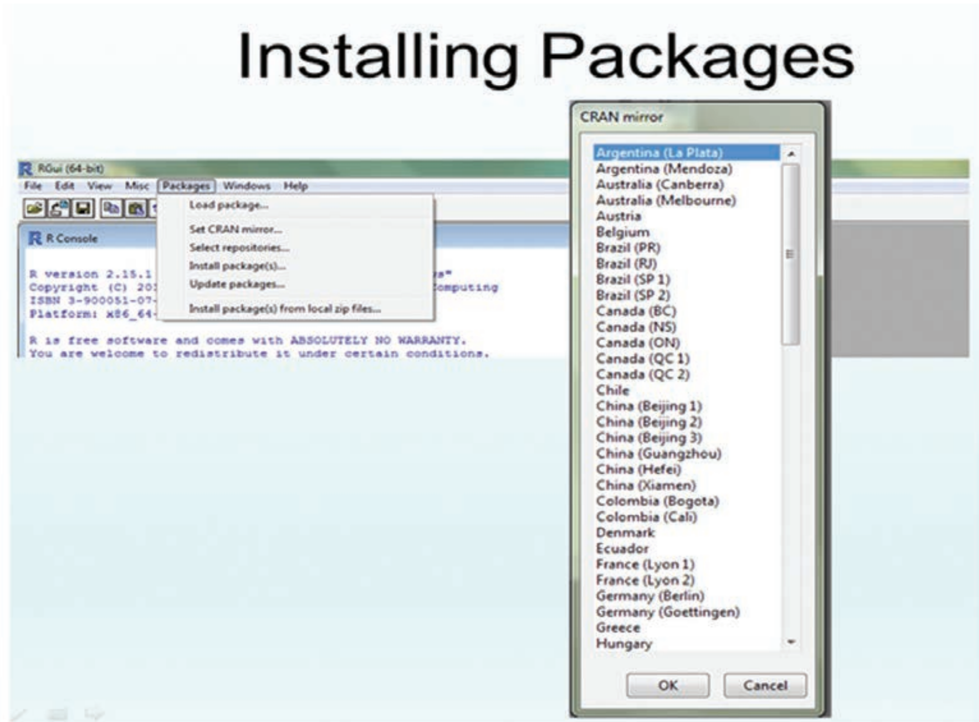
Choosing either html or plain text and clicking is the next step.

The installation may take awhile





To install packages on Windows, clicking on packages and install packages will be the next step.



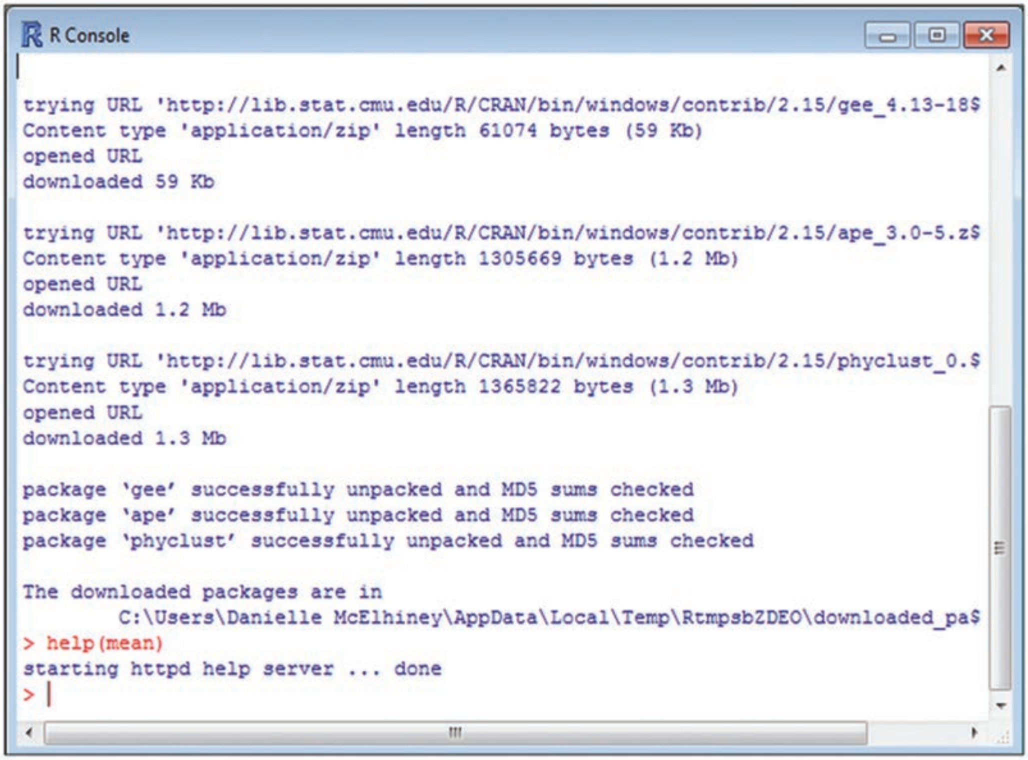
Scrolling down to country nearest and choosing a "mirror" that is close is the next step.

Scrolling down list until the requisite package is the next step, keeping in mind that R lists things in alphabetical order and by uppercase than lowercase. Once a package is clicked to load, R will install not only the package but all of the packages needed to run the package, including the dependencies.

To actually use the package, one has to go back to the package tab and click on load package.

Using Help Command

?solve translates on to giving details of help information about “solve” function whilst help.search or ?? allows searching for help in various ways.

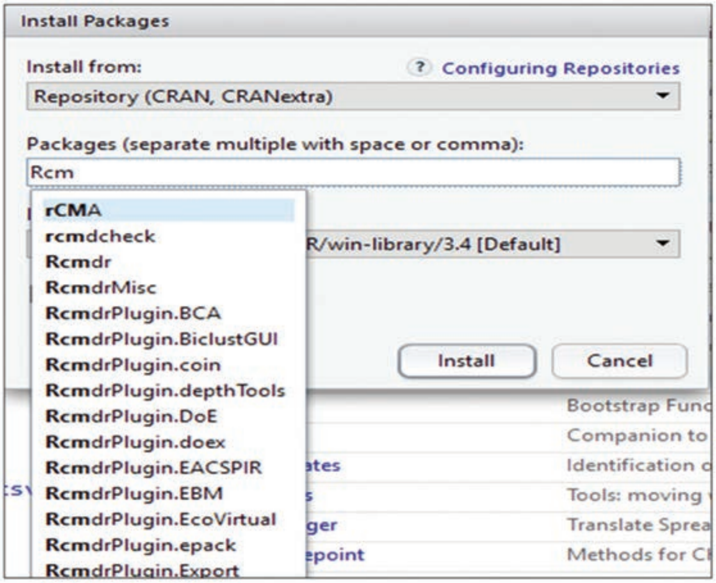


R Commander – A graphical interaction "skin" for R

R provides a powerful and comprehensive system for analysing data and when used in conjunction with the R-commander (a graphical user interface, commonly known as Rcmdr) it also provides one that is easy and intuitive to use. Basically, R provides the engine that carries out the analyses and Rcmdr provides a convenient way for users to input commands. The Rcmdr program enables analysts to access a selection of commonly-used R commands using a simple interface that should be familiar to most computer users. It also serves the important role of helping users to implement R commands and develop their knowledge and expertise in using the command line — an important skill for those wishing to exploit the full power of the program.(*http://www.rcommander.com/*)

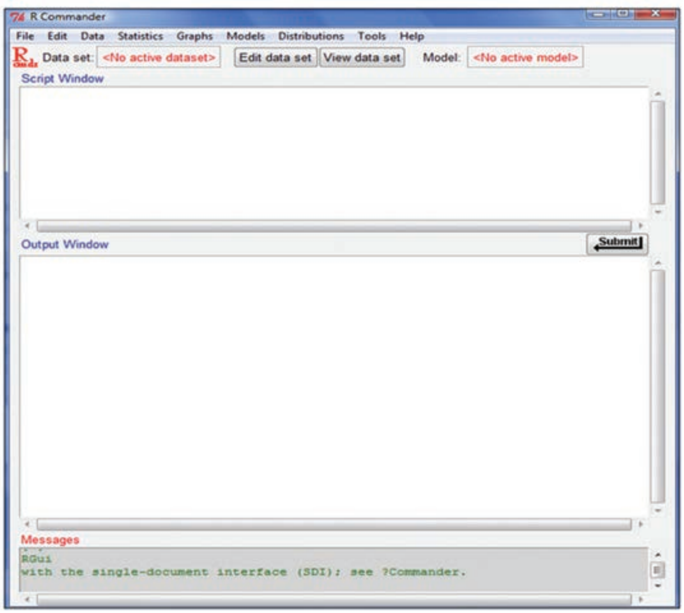
a) Loading R Commander

– Packages -> Install Packages -> Cran Mirror Selection -> Rcmdr



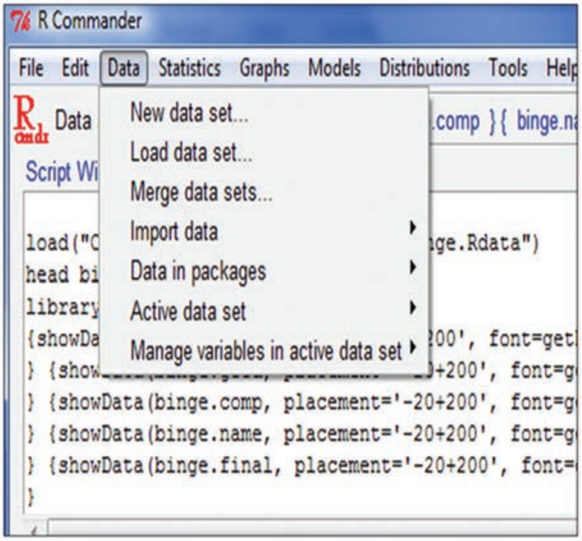
b) Opening R Commander

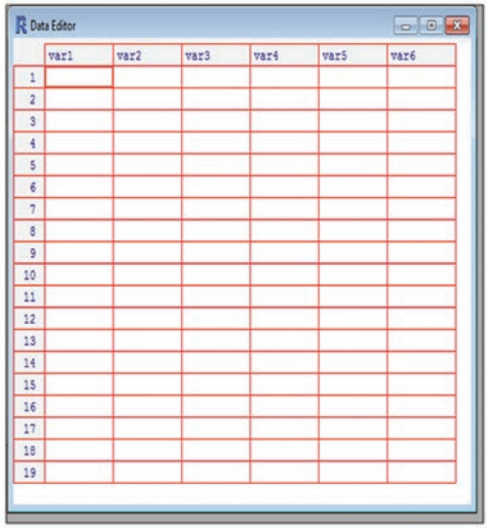
Open R -> Packages -> Load Packages -> Rcmdr



c) Loading Data

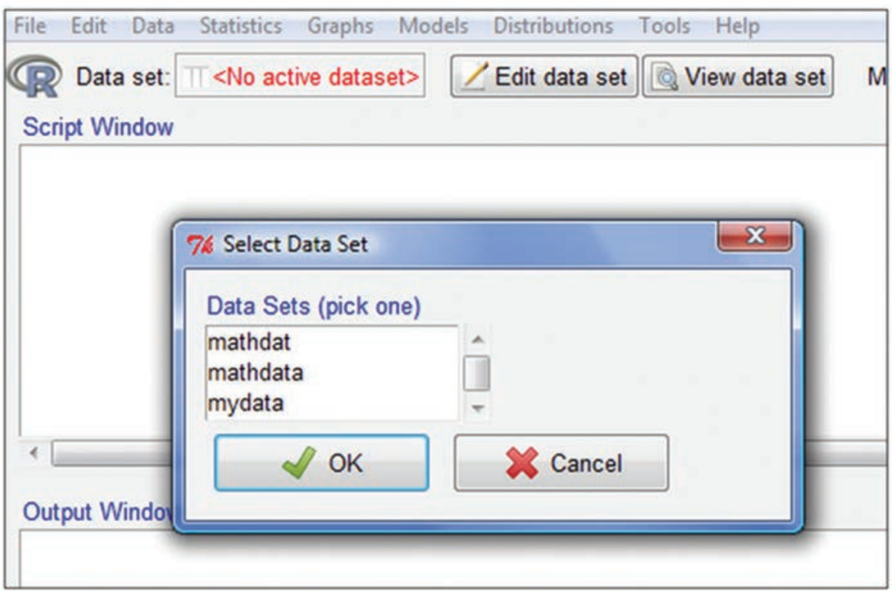
Data->Load data





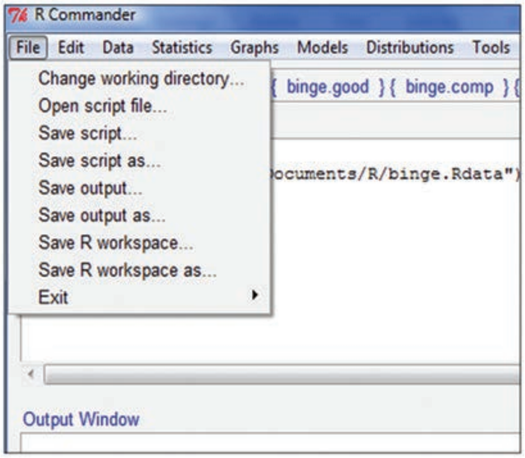
d) Active Data selection

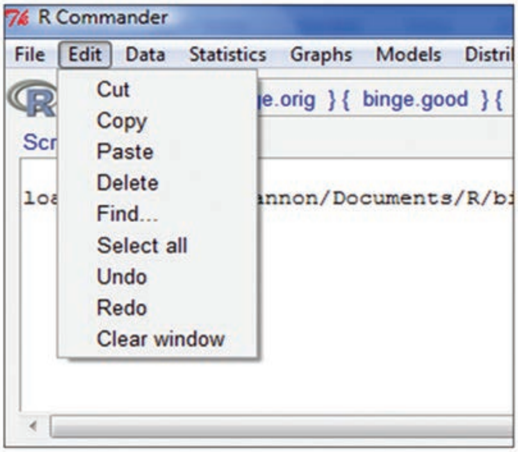
Data ->Active data set -> Select active data set



e) Menu driven File edit options

Script will save it as an R file .R and Output will save it as a text file. .txt

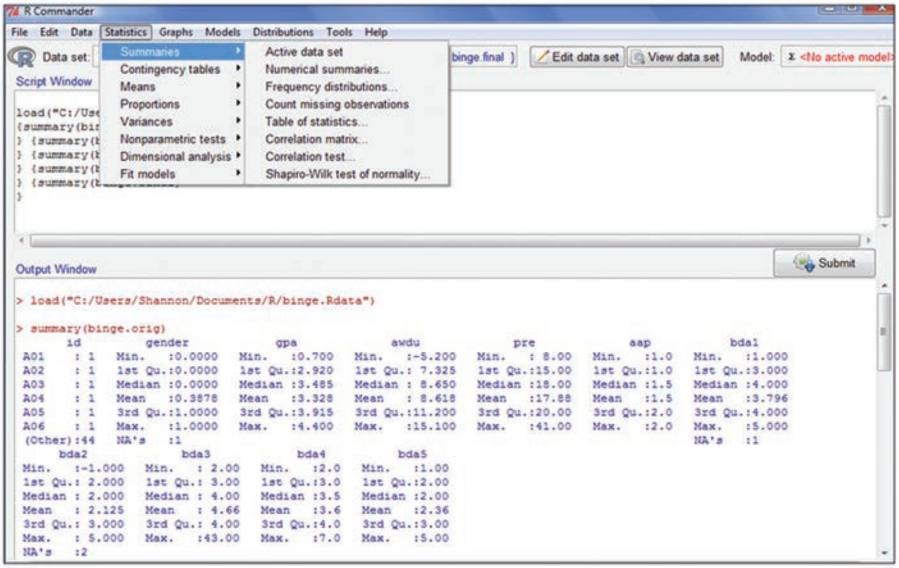




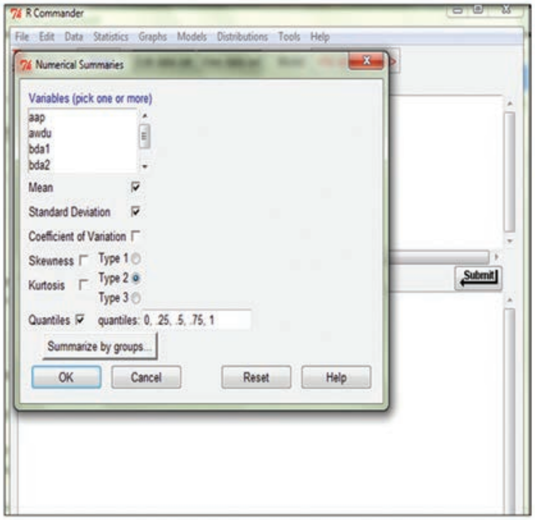
f) Summary of the data

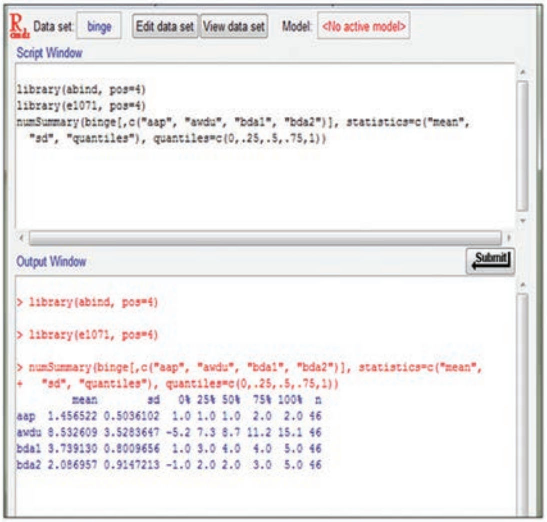
Statistics -> Summaries

Numerical Summeries – can also provide mean, standard deviation, skewness, kurtosis *etc.*

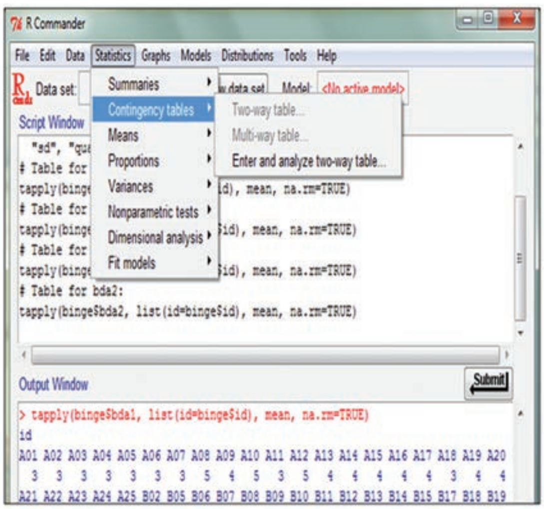


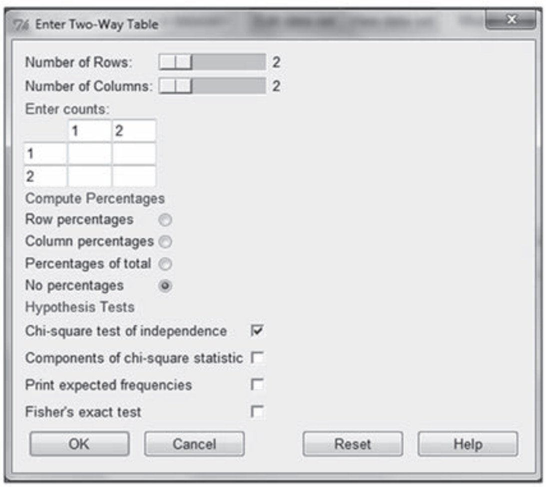
g) Mean, Standard Deviation, Skewness, Kurtosis





h) Contingency Tables

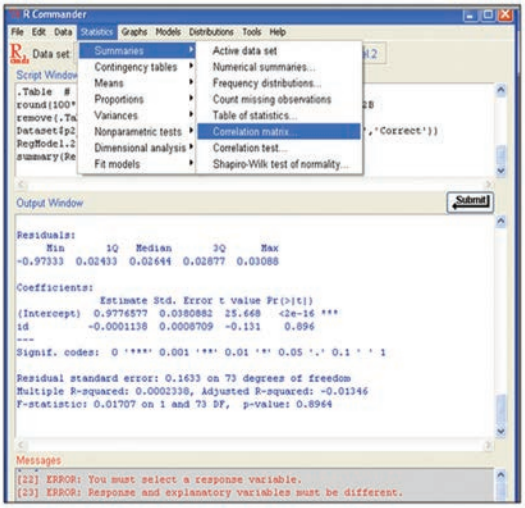


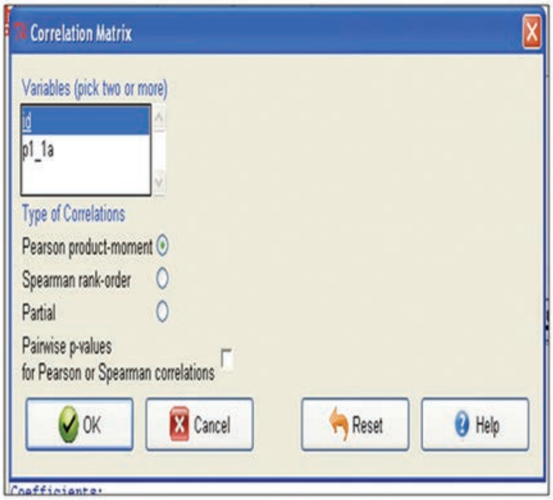


i) Correlations in R Commander

Correlation analysis can be done with R as follows.

Correlation is a bivariate analysis that measures the strengths of association between two variables and the direction of the relationship. In terms of the strength of relationship, the value of the correlation coefficient varies between +1 and -1. When the value of the correlation coefficient lies around ± 1, then it is said to be a perfect degree of association between the two variables. As the correlation coefficient value goes towards 0, the relationship between the two variables will be weaker. the direction of the relationship is simply the + (indicating a positive relationship between the variables) or - (indicating a negative relationship between the variables) sign of the correlation. Usually, in statistics, we measure four types of correlations: Pearson Correlation, Kendall rank correlation, Spearman correlation, and the Point-Biserial correlation. The software below allows you to very easily conduct a correlation.

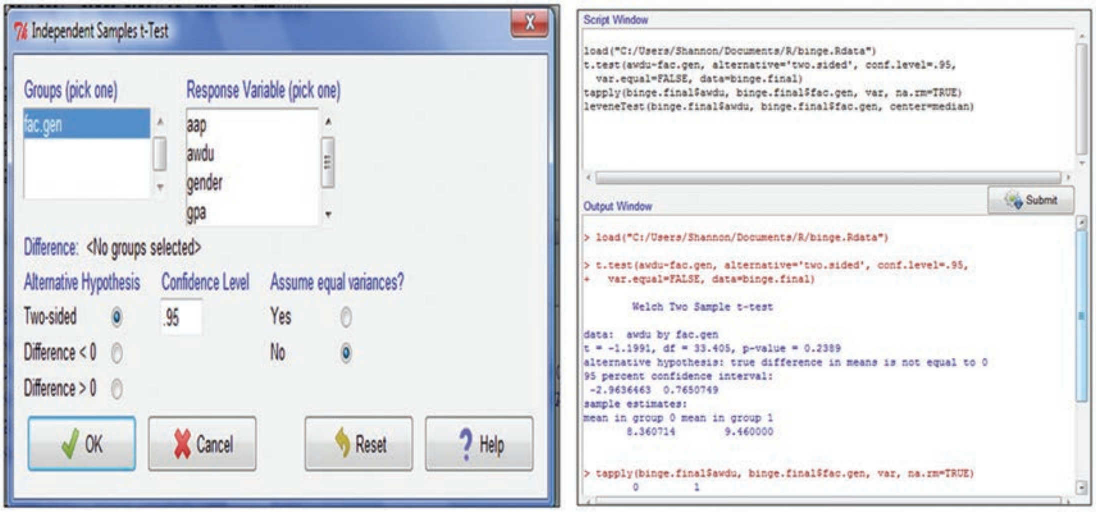




j) Independent T-Test

The independent t-test, also referred to as an independent-samples t-test, independent measures t-test or unpaired t-test, is used to determine whether the mean of a dependent variable (e.g., weight, anxiety level, salary, reaction time, *etc.*) is the same in two unrelated, independent groups (e.g., males vs females, employed vs unemployed, under 21 year olds vs those 21 years and older, *etc.*). Specifically, you use an independent t-test to determine whether the mean difference between two groups is statistically significantly different to zero.

Statistics->Independent T Test



k) One Way ANOVA

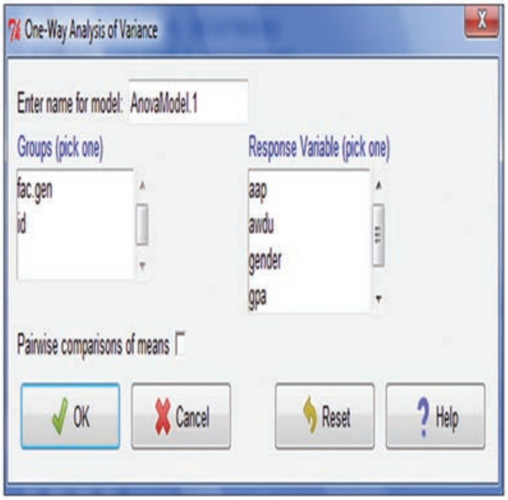
ANOVA(Analysis of Variance) is a statistical technique that assesses potential differences in a scale-level dependent variable by a nominal-level variable having 2 or more categories. For example, an ANOVA can examine potential differences in IQ scores by Country (US vs. Canada vs. Italy vs. Spain). The ANOVA, developed by Ronald Fisher in 1918, extends the *t* and the *z* test which have the problem of only allowing the nominal level variable to have just two categories. This test is also called the Fisher analysis of variance. ANOVAs are used in three ways: one –way Anova, two-way ANOVA, and N-way Multivariate ANOVA.

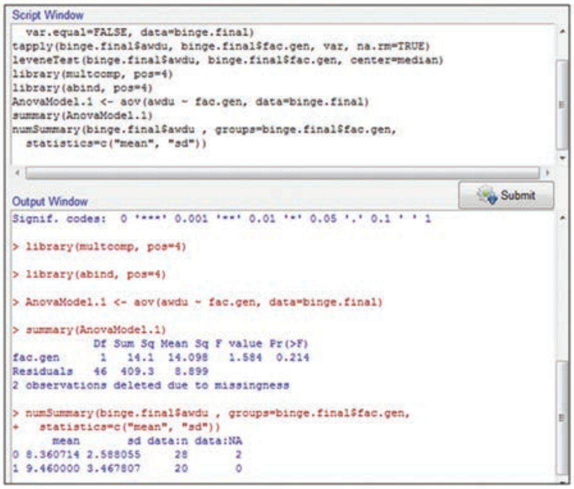
One-Way ANOVA

A one-way ANOVA refers to the number of independent variables—not the number of categories in each variables. A one-way ANOVA has just one independent variable. For example, difference in IQ can be assessed by Country, and County can have 2, 20, or more different Countries in that variable.

The software below allows you to easily conduct an ANOVA.

Statistics->One Way ANOVA





l) Factor Analysis

Factor analysis is a technique that is used to reduce a large number of variables into fewer numbers of factors. This technique extracts maximum common variance from all variables and puts them into a common score. As an index of all variables, we can use this score for further analysis. Factor analysis is part of general linear model(GLM) and this method also assumes several assumptions: there is linear relationship, there is no multicollinearity, it includes relevant variables into analysis, and there is true correlation between variables and factors. Several methods are available, but principal component analysis is used most commonly.

Types of factoring:

There are different types of methods used to extract the factor from the data set:

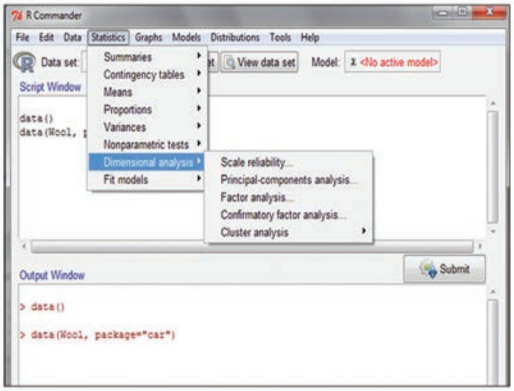
1. **Principal component analysis**: This is the most common method used by researchers. PCA starts extracting the maximum variance and puts them into the first factor. After that, it removes that variance explained by the first factors and then starts extracting maximum variance for the second factor. This process goes to the last factor.

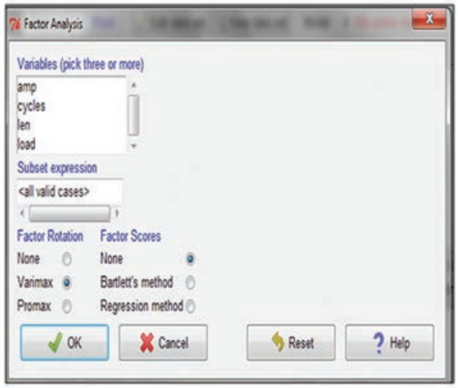
2. **Common factor analysis:** The second most preferred method by researchers, it extracts the common variance and puts them into factors. This method does not include the unique variance of all variables. This method is used in SEM.

3. **Image factoring:** This method is based on correlation matrix. OLS Regression method is used to predict the factor in image factoring.

4. **Maximum likelihood method:** This method also works on correlation metrix but it uses maximum likelihood method to factor.

5. **Other methods of factor analysis:** Alfa factoring outweighs least squares. Weight square is another regression based method which is used for factoring.





Result are shown as follows

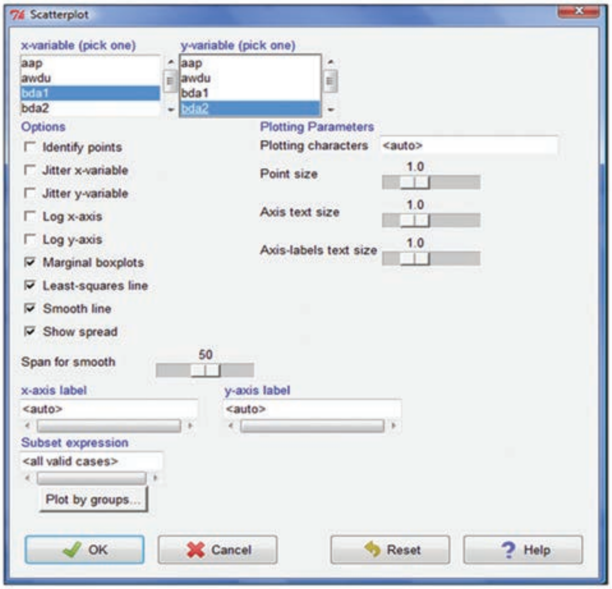
```
Script Window
.FA <- factanal(~aap+awdu+bdal, factors=1, rotation="varimax",
  scores="none", data=binge.orig)
.FA
remove(.FA)
library(sem, pos=4)
```

```
> .FA <- factanal(~aap+awdu+bdal, factors=1, rotation="varimax",
+   scores="none", data=binge.orig)

> .FA

Call:
factanal(x = ~aap + awdu + bdal, factors = 1, data = binge.orig,     scores = "none", rotation = "varimax")

Uniquenesses:
  aap  awdu  bdal
0.849 0.324 0.596

Loadings:
     Factor1
aap  0.388
awdu 0.822
bdal 0.636
```

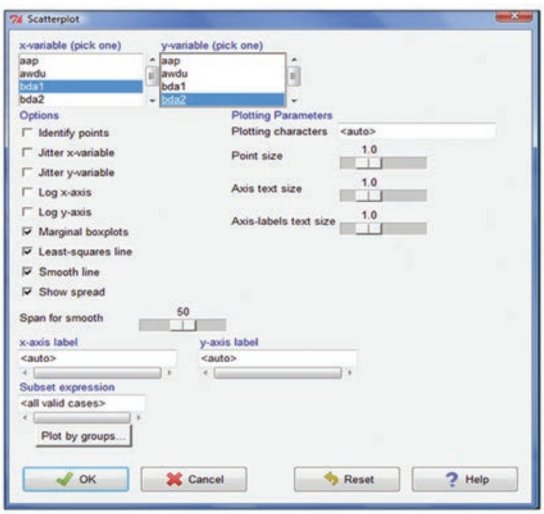
```
               Factor1
SS loadings      1.231
Proportion Var   0.410

The degrees of freedom for the model is 0 and the fit was 0

> remove(.FA)

> library(sem, pos=4)
```

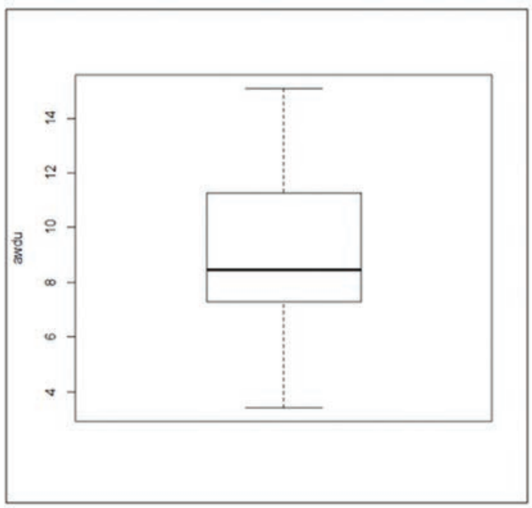
J) Graphs

Gparhs->Scatter plot



Gparhs->Box plot





R Basics

R is object base

Types of objects (scalar, vector, matrices and arrays Assignment of objects)

Building a data frame

Operation Symbols

Symbol	Meaning
+	Addition
-	Subtraction
*	Multiplication
/	Division
%%	**Modulo (estimates remainder in a division)**
^	Exponential

R as a Calculator

```
1550+2000
## [1] 3550
```

or various calculations in the same row

```
2+3; 5*9; 6-6
## [1] 5
## [1] 45
## [1] 0
```

As Mathematics

```
1+1
## [1] 2
2+2*7
## [1] 16
(2+2)*7
## [1] 28
```

As Variables

```
x<-2
x
## [1] 2
```

```
y<-3
y
## [1] 3
5->z
(x*y)+z
## [1] 11
```

Numbers in R: NAN and NA

NAN (not a number) NA (missing value) -Basic handling of missing values

Missing values are noise to statistical estimations. We are going to learn a basic command for handling missing values.

```
x<-c(1,2,3,4,5,6,NA)
mean(x)
## [1] NA
mean(x,na.rm=TRUE)
## [1] 3.5
```

Objects in R

Objects in R obtain values by assignment.

This is achieved by the gets arrow, <-, and not the equal sign, =.

Objects can be of different kinds.

Built in Functions

R has many built in functions that compute different statistical procedures.

Functions in R are followed by ( ). Inside the parenthesis we write the object (vector, matrix, array, dataframe) to which we want to apply the function.

```
# Create a sequence of numbers from 32 to 44.
print(seq(32,44))
##  [1] 32 33 34 35 36 37 38 39 40 41 42 43 44
# Find mean of numbers from 25 to 82.
print(mean(25:82))
## [1] 53.5
# Find sum of numbers frm 41 to 68.
```

```
print(sum(41:68))
## [1] 1526
```

Vectors

Vectors are variables with one or more values of the same type.

A variable with a single value is known as scalar. In R a scalar is a vector of length 1. There are at least three ways to create vectors in R: (a) sequence, (b) concatenation function, and (c) scan function.

Create two vectors of different lengths.

```
vector1 <- c(5,9,3)
vector2 <- c(10,11,12,13,14,15)
vector1
## [1] 5 9 3
vector2
## [1] 10 11 12 13 14 15
```

Arrays

Arrays are numeric objects with dimension attributes. The difference between a matrix and an array is that arrays have more than two dimensions.

```
# Take the above  vectors as input to the array.
result <- array(c(vector1,vector2),dim = c(3,3,2))
print(result)
## , , 1
##
##      [,1] [,2] [,3]
## [1,]    5   10   13
## [2,]    9   11   14
## [3,]    3   12   15
##
```

```
## , , 2
##
##        [,1]   [,2]   [,3]
##  [1,]    5     10     13
##  [2,]    9     11     14
##  [3,]    3     12     15
```

Matrices

A matrix is a two dimensional array. The command colnames

```
# Elements are arranged sequentially by row.
M <- matrix(c(3:14), nrow = 4, byrow = TRUE)
print(M)
##        [,1]   [,2]   [,3]
##  [1,]    3      4      5
##  [2,]    6      7      8
##  [3,]    9     10     11
##  [4,]   12     13     14
```

String Characters

In R, string variables are defined by double quotation marks.

```
letters<-c("a","b","c")
letters
## [1] "a" "b" "c"
```

Subscripts and Indices

Select only one or some of the elements in a vector, a matrix or an array. We can do this by using subscripts in square brackets [ ].

In matrices or dataframes the first subscript refers to the row and the second to the column.

Dataframe

Researchers work mostly with dataframes. With previous knowledge you can built dataframes in R. Also, import dataframes into R.

```
# Create the data frame.
emp.data <- data.frame (
emp_id = c (1:5),
emp_name = c("Rick","Dan","Michelle","Ryan","Gary"),
salary = c(623.3,515.2,611.0,729.0,843.25),
 start_date = as.Date(c("2012-01-01", "2013-09-23", "2014-11-15", "2014-05-11",
"2015-03-27")),
stringsAsFactors = FALSE
)
# Print the data frame.
print(emp.data)
##   emp_id   emp_name   salary   start_date
## 1   1      Rick       623.30   2012-01-01
## 2   2      Dan        515.20   2013-09-23
## 3   3      Michelle   611.00   2014-11-15
## 4   4      Ryan       729.00   2014-05-11
## 5   5      Gary       843.25   2015-03-27
```

A journey wading through the amazing summarizing and analytical capabilities of R- a case study

Let the presumed data pertain to landings and standardized effort of a maritime state estimated by ICAR-CMFRI during the interregnum 1997 to 2013

calling file in R

```
klm<-read.csv("C:/Users/cmfri/Desktop/cpue_spcode_kldata.csv",header=TRUE)
```

To know header portion of the data set

```
head(klm)
##      year   month   species   raised     nomeff     stdcpue
## 1    1997   1       40        20595.35   122.0811   3.634042
## 2    1997   2       40        24201.10   114.3719   4.532246
## 3    1997   3       40        23497.64   255.0315   3.926130
```

```
## 4      1997   4    40     50176.75   154.7663   6.762821
## 5      1997   5    40     137626.24  314.6413   13.805531
## 6      1997   6    40     38149.38   649.1328   16.071358
```

To check the last few rows of the dataset

tail (klm)

```
##          year  month  species  raised  nomeff    stdcpue
## 245815   2013  7      4580     0       0.000000  0.000000
## 245816   2013  8      4580     1674    2.059835  1.667304
## 245817   2013  9      4580     0       0.000000  0.000000
## 245818   2013  10     4580     0       0.000000  0.000000
## 245819   2013  11     4580     0       0.000000  0.000000
## 245820   2013  12     4580     0       0.000000  0.000000
```

to know the observations in the data

length(klm)

```
## [1] 6
```

to know the structure of the dataframe

str(klm)

```
## 'data.frame':   245820 obs. of  6 variables:
##  $ year   : int  1997 1997 1997 1997 1997 1997 1997 1997 1997 1997 ...
##  $ month  : int  1 2 3 4 5 6 7 8 9 10 ...
##  $ species: int  40 40 40 40 40 40 40 40 40 40 ...
##  $ raised : num  20595 24201 23498 50177 137626 ...
##  $ nomeff : num  122 114 255 155 315 ...
##  $ stdcpue: num  3.63 4.53 3.93 6.76 13.81 ...
```

Descriptive statistics analysis

summary(klm)

```
##      year         month         species       raised
##  Min.   :1997   Min.   : 1.00   Min.   :   0   Min.   :      0
##  1st Qu.:2001   1st Qu.: 3.75   1st Qu.: 867   1st Qu.:  0
##  Median :2005   Median : 6.50   Median :1513   Median :  0
```

```
## Mean   :2005   Mean   : 6.50   Mean   :2201   Mean   :   42699
## 3rd Qu.:2009   3rd Qu.: 9.25   3rd Qu.:4016   3rd Qu.:       0
## Max.   :2013   Max.   :12.00   Max.   :9999   Max.   :71536031
##                                               NA's   :30
##     nomeff           stdcpue
## Min.   :     0.0   Min.   :   0.000
## 1st Qu.:     0.0   1st Qu.:   0.000
## Median :     0.0   Median :   0.000
## Mean   :   154.2   Mean   :   7.112
## 3rd Qu.:     0.0   3rd Qu.:   0.000
## Max.   :119100.1   Max.   :5600.000
##
```

If further enhanced list of summary statistics information about the data like third and fourth order moments, then the describe function of psych or summary function would come in handy.

```
library(psych)
describe(klm[,3:6])
##         vars      n     mean        sd median trimmed     mad min
## species    1 245820  2201.15   1951.83   1513 1941.16 1257.24   0
## raised     2 245790 42699.02 719150.48      0   62.52    0.00   0
## nomeff     3 245820   154.25   1543.66      0    0.16    0.00   0
## stdcpue    4 245820     7.11     52.38      0    0.11    0.00   0
##                max      range  skew kurtosis      se
## species     9999.0     9999.0  1.40     1.91    3.94
## raised  71536030.7 71536030.7 44.70  2681.18 1450.57
## nomeff    119100.1   119100.1 22.83   770.70    3.11
## stdcpue     5600.0     5600.0 21.65   971.06    0.11
```

If one wants to study monthly catch grouped information so that an idea about issues like which month (used as a group) would have etched up maximum landings/ catch, then simple literally rooted commands like describeBy (psych) or aggregate would come in handy.

```
library(psych)
describeBy(klm$raised,klm$month)
##
##  Descriptive statistics by group
## group: 1
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 41379.48 784622.6      0  146.65   0   0 51193526 51193526
##     skew kurtosis      se
## X1 46.55  2497.42 5482.05
## ------------------------------------------------------------------
## group: 2
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 32904.06 535506.3      0  113.45   0   0 45468199 45468199
##     skew kurtosis      se
## X1 49.62  3259.68 3741.51
## ------------------------------------------------------------------
## group: 3
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 39087.37 569052.1      0  162.51   0   0 31762665 31762665
##    skew kurtosis      se
## X1 38.4  1796.15 3975.89
## ------------------------------------------------------------------
## group: 4
##    vars     n     mean     sd median trimmed mad min      max    range
## X1    1 20471 33795.18 477389      0   64.13   0   0 31931384 31931384
##     skew kurtosis      se
## X1 42.59  2353.01 3336.59
## ------------------------------------------------------------------
```

```
## group: 5
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 37566.67 469275.5      0    96.2   0   0 30492626 30492626
##     skew kurtosis      se
## X1 33.18  1478.99 3278.76
## --------------------------------------------------------
## group: 6
##    vars     n    mean       sd median trimmed mad min      max    range
## X1    1 20485 34552.2 655525.6      0   30.67   0   0 65432961 65432961
##     skew kurtosis      se
## X1 61.23  5239.89 4580.07
## --------------------------------------------------------
## group: 7
##    vars     n    mean       sd median trimmed mad min      max    range
## X1    1 20485 32621.2 643003.1      0       0   0   0 49428947 49428947
##     skew kurtosis      se
## X1 42.19  2362.03 4492.57
## --------------------------------------------------------
## group: 8
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20484 57397.86 713381.8      0   31.03   0   0 38795185 38795185
##     skew kurtosis      se
## X1 26.21   920.16 4984.42
## --------------------------------------------------------
## group: 9
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20485 55833.65 901880.9      0    34.3   0   0 71536031 71536031
##     skew kurtosis      se
## X1 41.11  2415.63 6301.32
## --------------------------------------------------------
```

```
## group: 10
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20484 57071.88 915432.9      0   89.05   0   0 55973676 55973676
##    skew kurtosis      se
## X1 34.05  1453.38 6396.16
## ------------------------------------------------------------
## group: 11
##    vars     n     mean     sd median trimmed mad min      max    range
## X1    1 20485 51210.52 915220      0  133.56   0   0 49127745 49127745
##    skew kurtosis      se
## X1 36.33  1488.92 6394.51
## ------------------------------------------------------------
## group: 12
##    vars     n     mean       sd median trimmed mad min      max    range
## X1    1 20471 38960.92 830555.4      0  134.37   0   0 66844967 66844967
##   skew kurtosis      se
## X1   56  3639.25 5804.96
```

Selecting subsets of data:

```
#to know the whole species entries
t<-klm$species
length(t)
## [1] 245820
# to know the june species entries
d<-klm$species[klm$month=="6"]
length(d)
## [1] 20485
```

to exclude some data

```
#exclude june catch and know the entries
e<-klm$species[klm$month!="6"]
```

length(e)

[1] 225335

correlation of the data

correlation between catch and effort for the whole period

attach(klm)

cor.test(raised,nomeff,method="pearson")

```
##
##  Pearson's product-moment correlation
##
## data:  raised and nomeff
## t = 434.94, df = 245790, p-value < 2.2e-16
## alternative hypothesis: true correlation is not equal to 0
## 95 percent confidence interval:
##  0.6572472 0.6617152
## sample estimates:
##      cor
## 0.659487
##multiple correlation
```

##Here we select the oilsardine catch.The oilsardine species code as 362

##we pick all the years monthly oil sardine

sp362<-klm[(klm$species=="362"),]

cordat<-sp362[,4:6]

cor(cordat)

```
 raised     nomeff    stdcpue
raised  1.0000000 0.45713639 0.61135090
nomeff  0.4571364 1.00000000 0.06860281
stdcpue 0.6113509 0.06860281 1.00000000
```

Linear regression & ANOVA

fit <- **lm**(raised~ year + month + nomeff, data=sp362)

show results

```
summary(fit)
##
## Call:
## lm(formula = raised ~ year + month + nomeff, data = sp362)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -24406856  -5945766   -838374   4725596  40857882
##
## Coefficients:
## Estimate Std. Error t value Pr(>|t|)
## (Intercept) -2.148e+09  2.787e+08  -7.706 5.93e-13 ***
## year         1.072e+06  1.389e+05   7.716 5.59e-13 ***
## month        7.997e+05  1.969e+05   4.062 6.97e-05 ***
## nomeff       3.997e+02  4.493e+01   8.897 3.44e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 9689000 on 200 degrees of freedom
## Multiple R-squared:  0.4275, Adjusted R-squared:  0.4189
## F-statistic: 49.78 on 3 and 200 DF,  p-value: < 2.2e-16
# model coefficients
coefficients(fit)
##   (Intercept)          year         month        nomeff
## -2.147604e+09  1.072090e+06  7.997178e+05  3.997276e+02
# CIs for model parameters
confint(fit, level=0.95)
##                     2.5 %        97.5 %
## (Intercept) -2.697162e+09 -1.598046e+09
## year         7.980987e+05  1.346082e+06
## month        4.115344e+05  1.187901e+06
```

```
## nomeff      3.111348e+02  4.883205e+02

# predicted values

fitted(fit)

##          10609        10610        10611        10612        10613        10614
##    -3789651.96    -75345.54  15111313.36  13412874.31  17168949.26    120681.70
##          10615        10616        10617        10618        10619        10620
##    11475956.42   2176177.37   4491241.24  20281254.70  10248865.43   6278101.08
##          10621        10622        10623        10624        10625        10626
##     1848628.97   -945019.58  10648970.16  18599757.89   1915100.95   4945529.10
##          10627        10628        10629        10630        10631        10632
##     1844457.32   4524979.63   8480021.57  27270345.64  26410785.24   7449598.25
##          10633        10634        10635        10636        10637        10638
##     8195286.59  18056830.84  12504031.29   4797286.88    690139.61   7333241.94
##          10639        10640        10641        10642        10643        10644
##     9086615.20  12777192.22  16114211.77  21825496.12  23957847.88  30125417.82
##          10645        10646        10647        10648        10649        10650
##    16794955.21   8159428.15  18423291.70  38539644.49  22526843.37  15428828.71
##          10651        10652        10653        10654        10655        10656
##    19942372.43   8463199.11  16820433.97  16852255.88  19772511.73  16832240.83
##          10657        10658        10659        10660        10661        10662
##     6812947.52   2187489.33   3280344.12  24388104.43  18000977.41  15107404.98
##          10663        10664        10665        10666        10667        10668
##    11071325.90   8804492.99  11659447.99  15882452.30  13614255.15  14360781.30
##          10669        10670        10671        10672        10673        10674
##     4963345.25   3874425.71   8638896.83  15820079.63   9947652.94  10608928.30
##          10675        10676        10677        10678        10679        10680
##    11831223.68  10715678.08  18370843.69  18033007.59  24787443.71  20792659.27
##          10681        10682        10683        10684        10685        10686
##    10734553.89  14786524.50  23586068.72  15174415.81  14696669.45  21641645.35.88
##    26747332.20  27817053.16  27904369.27

# residuals
```

```
residuals(fit)
##        10609       10610       10611       10612       10613
##   5952459.84 12255563.09 -3371411.14 -4445741.27 -8889076.47
##        10614       10615       10616       10617       10618
##    986134.71 -5748266.48  -336390.21  2807133.26  1645172.74
##        10619       10620       10621       10622       10623
##  -3629105.70 -4577842.81  3072907.21  3243308.73 -5672890.07
##        10624       10625       10626       10627       10628
## -15696727.40   289232.12  2042122.32  1117366.99  2926082.40
##        10629       10630       10631       10632       10633
##   5230228.43 -20382271.56 -5264124.44 -5075967.51  1491577.71
##        10634       10635       10636       10637       10638
##  -9837151.49 -6712232.19  -764792.30  -437886.38  2231690.27
##        10639       10640       10641       10642       10643
##  -1443831.23 -2440345.04 14926587.99 -6794617.92  2635516.43
##        10644       10645       10646       10647       10648
## -17311907.92 -5709093.26  4952910.28 -6048902.56 -6642668.40
##        10649       10650       10651       10652       10653
##  -9406029.73 11491464.13 29486574.30  2963737.40  3482526.36
##        10654       10655       10656       10657       10658
##    764926.90  5721591.58 -8014761.85  -334238.52  5160023.79
##        10659       10660       10661       10662       10663
##   3802703.26 -10108379.25 -2107670.27 -3238790.51  6520269.00
##        10664       10665       10666       10667       10668
##   6117951.47  3707721.08  4118584.97   744008.66 -2535146.08
##        10669       10670       10671       10672       10673
##   5587891.61   247621.47 -2882708.00   800991.54  -911955.00
# anova table
anova(fit)
## Analysis of Variance Table
##
## Response: raised
```

```
##  Df  Sum SqMean Sq F valuePr(>F)
## year        1 4.6080e+15 4.6080e+15  49.083 3.663e-11 ***
## month       1 1.9813e+15 1.9813e+15  21.104 7.689e-06 ***
## nomeff      1 7.4316e+15 7.4316e+15  79.159 3.445e-16 ***
## Residuals 200 1.8776e+16 9.3882e+13
## —-
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
# covariance matrix for model parameters
vcov(fit)
##                (Intercept)          year         month        nomeff
##   (Intercept)  7.767104e+16 -3.872335e+13 28849322448.9 -1.085409e+09
##          year -3.872335e+13  1.930661e+10  -132736938.4  5.147853e+05
##         month  2.884932e+10 -1.327369e+08 38753042588.4 -5.204691e+05
##        nomeff -1.085409e+09  5.147853e+05     -520469.1  2.018502e+03
# regression diagnostics
influence(fit)
## $hat
##       10609       10610       10611       10612       10613       10614
## 0.042348953 0.032174152 0.030947216 0.024014063 0.027363125 0.031587019
##       10615       10616       10617       10618       10619       10620
## 0.018101845 0.031744185 0.029944584 0.028749417 0.028915850 0.042004060
##       10621       10622       10623       10624       10625       10626
## 0.036951680 0.032836278 0.020628210 0.029105061 0.025090117 0.020127986
##       10627       10628       10629       10630       10631       10632
## 0.028928511 0.025311220 0.021317185 0.041136744 0.038894083 0.038442958
##       10633       10634       10635       10636       10637       10638
## 0.024751425 0.032951924 0.018613317 0.018864207 0.027982400 0.015391058
##       10639       10640       10641       10642       10643       10644
## 0.014401572 0.013346093 0.015061997 0.022355644 0.027879390 0.046154691
##       10645       10646       10647       10648       10649       10650
## 0.031627027 0.018558780 0.023833019 0.112821017 0.025427226 0.010871644
##       10651       10652       10653       10654       10655       10656
```

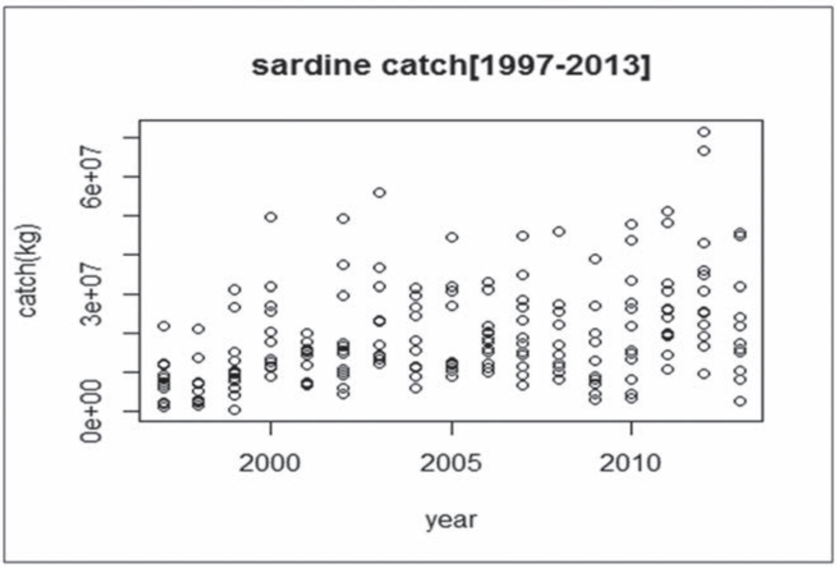
```
##  0.014936315  0.016434376  0.012730547  0.015052097  0.018993675  0.022811653
##        10657        10658        10659        10660        10661        10662
##  0.021590355  0.025598024  0.021891454  0.030677847  0.012303026  0.008431467
##        10663        10664        10665        10666        10667        10668
##  0.010270283  0.015731396  0.014200211  0.013621161  0.019758522  0.024082289
##        10669        10670        10671        10672        10673        10674
## $coefficients
##               (Intercept)          year         month       nomeff
##      10609   2.217824e+07 -1.095925e+04 -1.325088e+04 -3.148198546
##      10610   4.411931e+07 -2.183848e+04 -2.228032e+04 -4.498752468
##      10611  -1.067489e+07  5.318300e+03  5.379473e+03 -1.436946526
##      10612  -1.430707e+07  7.125744e+03  5.005198e+03 -1.244058740
##      10613  -2.792623e+07 1.393898e+046   .644383e+03 -3.898604484
##      10614   3.637567e+06 -1.803856e+03 -6.792737e+01 -0.548821439
##      10615  -1.912700e+07  9.531031e+03 -1.168978e+03 -0.136134257
##      10616  -1.236679e+06  6.142401e+02 -2.614444e+02  0.182574103
##      10617   1.017484e+07 -5.060185e+03  3.311361e+03 -1.300911103
##      10618   5.221933e+06 -2.616049e+03  2.285340e+03  0.594874799
##      10619  -1.269309e+07  6.332354e+03 -7.146199e+03  0.885644012
##      10620  -1.689093e+07  8.416379e+03 -1.142621e+04  2.385068449
##      10621   9.988869e+06 -4.931698e+03 -6.845283e+03 -1.449495213
##      10622   1.048887e+07 -5.182988e+03 -5.814728e+03 -1.523215775
##      10623  -1.631084e+07  8.103095e+03  8.519957e+03 -0.699865368
##      10624  -4.218674e+07  2.105372e+04  1.871018e+04 -8.082331986
##      10625   9.242638e+05 -4.579190e+02 -1.489350e+02 -0.132336511
##      10626   6.358893e+06 -3.155937e+03 -2.504379e+02 -0.691128004
##      10627   3.641035e+06 -1.805648e+03  3.989493e+02 -0.629386219
##      10628   9.337116e+06 -4.637748e+03  2.201757e+03 -1.355018464
## $sigma
##       10609   10610   10611   10612   10613   10614   10615   10616   10617
##     9704033 9673382 9710573 9708368 9692571 9713348 9704899 9713577 9711506
##       10618   10619   10620   10621   10622   10623   10624   10625   10626
```

```
##        9712887  9710099  9707947  9711071  9710794  9705104  9647742  9713585  9712507
##          10627    10628    10629    10630    10631    10632    10633    10634    10635
##        9713275  9711335  9706375  9600885  9706147  9706674  9713017  9687689  9701725
##          10636    10637    10638    10639    10640    10641    10642    10643    10644
##        9713453  9713556  9712299  9713060  9712046  9654918  9701385  9711759  9631991
##          10645    10646    10647    10648    10649    10650    10651    10652    10653
##        9704897 9707140  9703907  9700734  9690097  9679013  9482552 9711297 9710429
##          10654    10655    10656    10657    10658    10659    10660    10661    10662
##        9713454 9704972  9696589  9713578  9706537  9709783  9686303 9712444 9710871
##          10663    10664    10665    10666    10667    10668    10669    10670    10671
##        9702490 9703766  9710000  9709158  9713461  9711904  9705335 9713591 9711428
##          10672    10673    10674    10675    10676    106771    0678    10679    10680
##        9713440 9713390  9713495  9706020  9709067  9620081  9679152 9556146 9705788
##          10681    10682    10683    10684    10685    10686    10687    10688    10689
##        9703041 9712489  9696177  9713305  9713033  9713274  9711229 9713210 9707532
##          10690    10691    10692    10693    10694    10695    10696    10697    10698
##        9484558 9670016  9694154  9710393  9710677  9712970  9696964 9665645 9703363
##          10699    10700    10701    10702    10703    10704    10705    10706    10707
##        9699470 9711903  9695548  9685330  9698839  9696413  9712539 9713605 9645521
##          10708    10709    10710    10711    10712    10713    10714    10715    10716
##        9692194 9657695  9711752  9708527  9712793  9693026  9705844 9708928 9616936
##          10717    10718    10719    10720    10721    10722    10723    10724    10725
##        9700975 9709924  9687368  9702069  9706975  9713608  9712002 9705092 9711736
##
## $wt.res
##          10609          10610          10611          10612          10613
##     5952459.84    12255563.09    -3371411.14    -4445741.27    -8889076.47
##          10614          10615          10616          10617          10618
##      986134.71    -5748266.48     -336390.21     2807133.26     1645172.74
##          10619          10620          10621          10622          10623
##    -3629105.70    -4577842.81     3072907.21     3243308.73    -5672890.07
##          10624          10625          10626          10627          10628
```

```
##    -15696727.40     289232.12    2042122.32    1117366.99    2926082.40
##           10629         10630         10631         10632         10633
##      5230228.43  -20382271.56   -5264124.44   -5075967.51    1491577.71
##           10634         10635         10636         10637         10638
##     -9837151.49   -6712232.19    -764792.30    -437886.38    2231690.27
##           10639         10640         10641         10642         10643
##     -1443831.23   -2440345.04   14926587.99   -6794617.92    2635516.43
##           10644         10645         10646         10647         10648
##    -17311907.92   -5709093.26    4952910.28   -6048902.56   -6642668.40
```

Plots in R

```
##scatter plot
sp3621<-sp362[c(1:2,4)]
attach(sp3621)
## The following objects are masked from klm:
##
##     month, raised, year
plot(year,raised,main="sardine catch[1997-2013]",xlab="year",ylab="catch(kg))
```



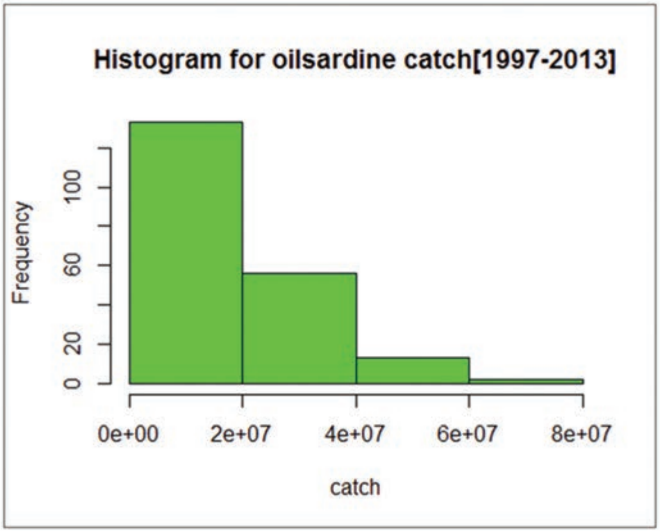
##Histogram

hist(raised,main="Histogram for oilsardine catch[1997-2013]",

lab="catch",

col="green",

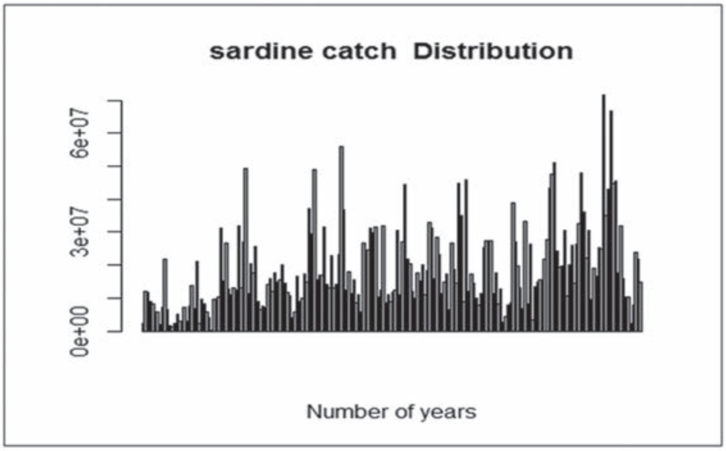
breaks=5)



##Bar plot

barplot(raised, main="sardine catch Distribution",

xlab="Number of years")

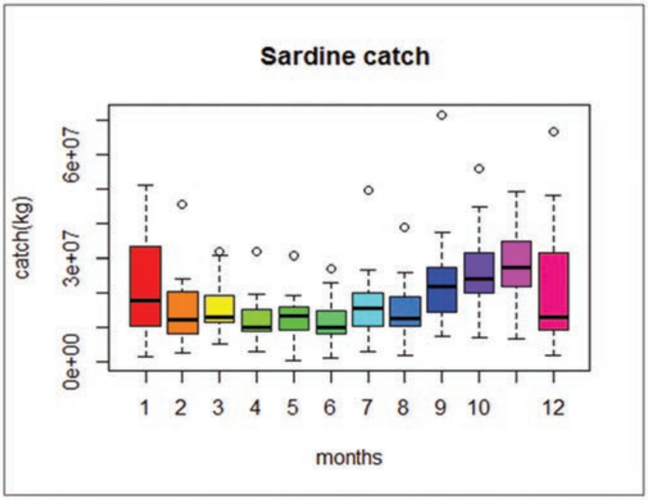


Boxplot in r

Boxplot of catch vs month

boxplot(raised~month,data=sp3621, main="Sardine catch ",

lab="months", ylab="catch(kg)",col=**rainbow**(**length**(**unique**(month))))



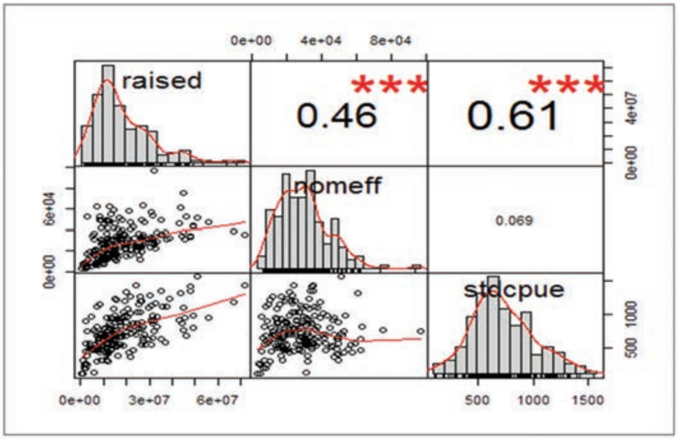
to plot a correlation in r

##we select sardine correlations

cordat<-sp362[,4:6]

library(PerformanceAnalytics)

chart.Correlation(cordat,method="pearson")



R for reading NetCDF data

NetCDF files contain one or more variables, which are usually structured as regular N-dimensional arrays. For example, you might have a variable named “Temperature” that is a function of longitude, latitude, and height. NetCDF files also contain dimensions, which describe the extent of the variables’ arrays. In our Temperature example, the dimensions are “longitude”, “latitude”, and “height”. Data can be read from or written to variables in arbitrary hyperslabs (for example, you can read or write all the Temperature values at a given height, or at a given latitude).

The R package ‘ncdf4’ allows reading from, writing to, and creation of netCDF files, either netCDF version 3 or (optionally) netCDF version 4. If you choose to create version 4 output files, be aware that older netcdf software might only be able to read version 3 files.

In fact this package can help extracting details from HDF5 format files too. This package can create NetCDF files from data.frames also. Nc_open() is the function to be used for opening a NetCDF fils and for creating a NetCDF file the function is nc_creat(). Once opened the attributes and variable names of the data can be got by using the generic print() command. To get specific variables the function is ncvar_get()

An example:

```
library(ncdf4)

ncold <- nc_open(“states_population.nc”)

data <- ncvar_get(ncold)

print(“here is the data in the file:”)

print(data)

nc_close( ncold )
```

The output is given below:

```
> ncold <- nc_open(“states_population.nc”)

> print(ncold)

File states_population.nc (NC_FORMAT_CLASSIC):

1 variables (excluding dimension variables):

int Pop[StateNo]

units: count

_FillValue: -1
```

long_name: Population

1 dimensions:

StateNo Size:50

units: count

long_name: StateNo

1 global attributes:

source: Census 2000 from census bureau web site

>

R in numerical methods

Taking cue from the fact that integration is infinitesimal addition, brutal algorithmic power of R has been put to use to find solutions of definite integrals. The most common function used for this purpose is integrate().

An example:

For the double integral given below

$$\int_0^1 \int_x^1 x\sin(y^2)dydx$$

A couple of lines as given below would do the job in R environment

```
integrate(function(x) {
sapply(x, function(x) {
integrate(function(y) x*sin(y^2),x,1)$value
})
},0,1)
```

The output is given below (with error measure)

```
> integrate(function(x) {
+  sapply(x, function(x) {
+  integrate(function(y) x*sin(y^2),x,1)$value
+     })
+ },0,1)
0.09105548 with absolute error < 1e-15
>
```

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CHAPTER

15

PYTHON: A TOOL FOR ANALYSIS AND VISUALIZATION OF REMOTELY SENSED DATASETS

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What is Python?

Python is a programming language which helps you to tell the computer what you want to do with the data that you have.

Why should I bother to learn Python?

- **It is extremely user-friendly**

Whether you are a beginner in using programming languages or have solid experience in programming, Python is a tool that is going to be an asset in your repository. It provides you with the basic building-blocks that you need in order to develop a solution to almost any problem that the data analysis/ visualization can throw at you.

- **A complete solution**

It has built-in packages/libraries that allow you to deal with data files with different types of files (example .csv, .txt, .xlsx, .netcdf, .grib, *etc*). So you don't have to worry about finding another software/tool in order to process a data set whose format is not very popular.

- **Automation**

If you have come across situations where you want to automate the mundane tasks such as data download, iterate a specific data analysis procedure (that you have done for one month/year) across multiple months/years, *etc.* Python can help you do so and in turn save you a lot of time that you could invest in more demanding tasks.

Ok, now where do I get Python from and how do I install it?

For Python installation there are three key aspects that a beginner should be aware of:

An Editor named Spyder

As a beginner in programming, it is recommended to have an editor that helps you to monitor the syntax and changes in variables as and when you type or run the code.

Python programming language

For you to have the full benefit of Python, it is recommended to have the Python compiler installed which will help to convert the script you write into machine-readable code which the computer can understand and execute.

Installation of additional libraries/packages

Although Python comes with a pre-installed set of libraries/packages, at times you might want to perform a particular task using Python that requires the installation of additional packages. Therefore, it is essential for the beginner to know how to install additional libraries as and when required.

All three elements come together in a distribution named Anaconda which is freely available for download and use from the following link:

https://www.anaconda.com/download/#download

The link is directed for Windows installation whose steps can be followed using this link: https://conda.io/docs/user-guide/install/windows.html. Please remember the location in which you have installed your Anaconda distribution (preferably in C drive itself)

So I got Python installed. What now? (For Windows users)

For you to start writing your first script, you need an interactive development environment (IDE) named Spyder.

To launch the Spyder editor, follow the steps mentioned below:

Step 1) Search for Terminal window by typing the keyword "cmd" in the Search window

Step 2) Select the command prompt icon (it appears as a small rectangular black icon)

Step 3) Your command prompt may look like this:

C:/Windows**>blank space**

You need to relocate the command prompt ">" to the folder where Anaconda distribution is installed. Let's say the Anaconda distribution is installed in C drive. If so, there will be a folder named Anaconda2. If that's the case type the following in the terminal window after the ">" symbol and press "Enter".

C:/Windows>cd Anaconda2

Then the command prompt will appear like this:

C:/Windows/Anaconda2>blank space

Type the following command after the ">" symbol and press "Enter"

C:/Windows/Anaconda2>cd Scripts

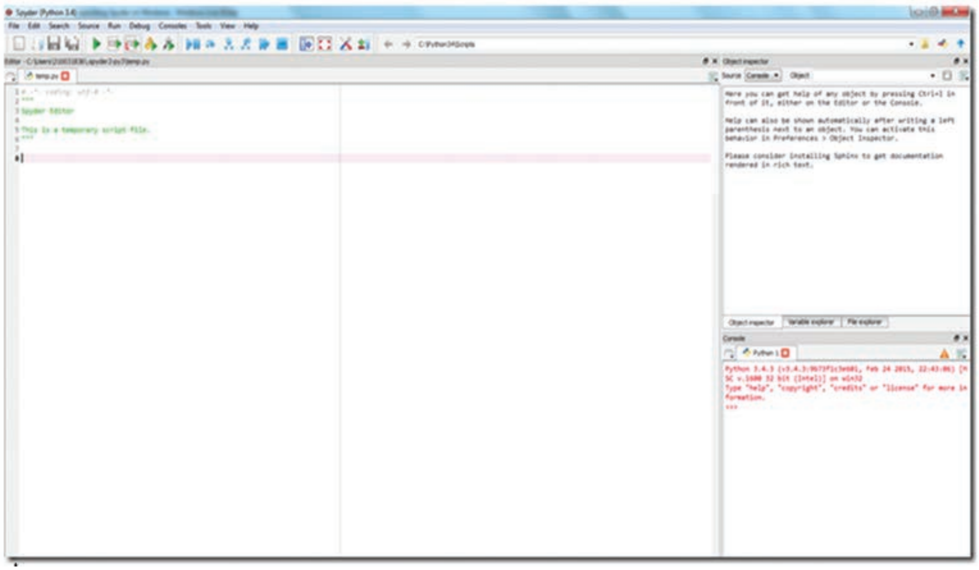
The command prompt will again change its appearance and might look like this:

C:/Windows/Anaconda2/Scripts>blank space

Type "Spyder" after the ">" symbol and press "Enter" to launch the Python editor

C:/Windows/Anaconda2/Scripts>Spyder

If you have installed your Pythonic enviroment correctly, then Spyder environment should get launched automatically and you'll see the IDE displayed on your screen (Refer Fig. 1).



Now that we have Python up and running, let's begin with the programming.

For running the case studies, we require an additional libraries namely netCDF4, matplotlib and Basemap. For installation of libraries, following steps will help.

Step 1) Search for Terminal window by typing the keyword "cmd" in the Search window

Step 2) Select the command prompt icon (it appears as a small rectangular black icon)

Step 3) your command prompt may look like this:

C:/Windows**>blank space**

You need to relocate the command prompt ">" to the folder where Anaconda distribution is installed. Let's say the Anaconda distribution is installed in C drive. If so, there will be a folder named Anaconda2. If that's the case type the following in the terminal window after the ">" symbol and press "Enter".

C:/Windows>cd Anaconda2

Then the command prompt will appear like this:

C:/Windows/Anaconda2>blank space

Type the following command after the ">" symbol and press "Enter"

C:/Windows/Anaconda2>cd Scripts

The command prompt will again change its appearance and might look like this:

C:/Windows/Anaconda2/Scripts>blank space

Type "conda install netcdf4"after the ">" symbol and press "Enter" to install the netcdf4 library

C:/Windows/Anaconda2/Scripts> conda install netcdf4

The screen prompt will ask your permission to proceed once it is able to find the package required. Type "y" and press the "Enter" key.

The installation might take a while.

Similarly, you can install other libraries such as matplotlib and Basemap using the command "conda install matplotlib" and "conda install basemap" respectively.

Upon getting the required libraries installed, launch the Spyder Editor. Click on File -> Open file and find the python_data_read_visualize.py file that you have been given for this session. Click on "Open". Once it the code opens in Spyder, you can inspect it line by line and read the comments written along-side to better understand the code.

Things you should be aware of before running the script

Before you run the script, make sure you change the path of the input file in line 11 of the code and the path where the plot needs to be saved (line 57). The code is separated into smaller chunks using "#————————————————————" symbol.

Make sure you understand each chunk individually with the help of comments, before attempting to run the code as a whole.

In order to run the statements in the code individually, select the statement and click the symbol on the top left corner of the IDE interface. Note the changes that occur simultaneously in the Ipython console. After the script gets run, if variables get created, you can monitor them in the variable explorer space.

It is a good practice to always comment using "#" symbol your code so that when you revisit your script after a few days, just by having a look at the code, you'll be able to understand the purpose of each statement in the script.

Test run

Case study 1: Read data from a NetCDF file

For this exercise, we will use a Python code named python_data_read_visualize.py. This code will read a data file and display its attributes. Additionally, it will extract the data from the file and store it in variables which can be easily visualized. Please take note of the comments which will help you to better understand what exactly the python script is doing.

Case study 2: Visualization of data

Once you know how to extract the data and store them into variables, we'll learn how to create a spatial plot and save it as per the desired resolution. The script imports the required libraries at the beginning, creates a grid using latitude and longitude values provided in the file, creates a spatial plot along with the grids (parallels and meridians), provides the title, displays the plot and saves the file in the desired format.

CHAPTER 16

INTRODUCTION TO GEOSTATISTICS

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Geographical Information System (GIS) is a technological tool used to describe and characterize spatially referenced geographical information for the purpose of visualizing, querying and analyzing. The tool enables capturing, storing, analyzing, sharing, displaying and modelling of spatial data maintained with in single database. Making decision based on geography is basics to human thinking and spatial analysis using GIS enable people to combine information from many independent sources and derive entirely new layers of information that are more accurate and reliable in decision making. Spatial analysis involves study of phenomenon that varies with time and space. Geostatistics is a branch of statistics used for analysis of spatial or spatiotemporal data set by applying sophisticated set of various statistical and probabilistic models. Here, we estimate the value of phenomenon from unknown location where no measurements are available with the help of direct measurements derived from known locations. GIS has emerged as powerful tool in the recent years by providing various geospatial solutions in urban planning, mining, natural resource evaluation and management, pollution estimation, risk assessment and large scale mapping thus becoming integral tool in our day today life.

1. Data for GIS

Data for GIS are obtained from various sources like aerial & satellite imageries, digital data, conventional maps, census, meteorological department, field data (surveys/GPS) *etc.* The information obtained can be classified into types of database: spatial data which describe the location (where the object is?) and attribute data which characterize the location (what the object is? or how much the object is?)

1.1. Spatial Database

Spatial data is representation of complex real world in a simplified manner. Here the geographical features are represented by three basic types- points, lines and area. *Points* represent dimensionless features such as wells, post box, tube well *etc.* that are very small and their location can be explained by only coordinate's values. Lines depict features with length, such as roads, railways stations, administrative and international boundaries *etc.* and are two-dimensional. Area or polygons are used to represent three-dimensional objects that have height, width and length such as agriculture lands, water bodies, forest areas and administrative areas.

1.2. Attribute database

Attribute data depicts various characteristics of different object/ features on earth surface. This can of qualitative types like land use type, soil type, name of the city/ river *etc.*) or of quantitative types (like elevation, temperature, pressure of a particular place, crop yield per acre *etc.*). Thus, attribute data can be both numeric and textual.

2. Representation of Database

The way that location is represented in a geodatabase can be either a raster or a vector position.

2.1. Raster data

A raster based format uses imaginary grid of cells or matrix to displays, locates and stores graphical data. The fundamental unit of raster system is pixel. Here, the whole study area is divided into uniform rows and columns and each cell or pixel is used for storing point, line or area entities. Here, points are represented by individual column/ row entities, lines are depicted by connecting the adjacent cells or pixels and areas are stored as set of contiguous cells defining the interior. The accuracy of raster data formats depends on pixel or grid size and may vary from submeter to kilometres. Layers are functionally related map features that are used to represent different two-dimensional features on map. Different layers are used to in GIS for storing various unique information such as forest cover, soil types, land use pattern and wetlands. Satellite images, Digital terrain models (DTM) and digital elevation models (DEM) are examples of raster data (Koeln *et al.,* 1994 and Huxhold 1991). Raster data formats require less processing over vector formats but they consumes more computer space for storing of data.

2.2. Vector data

In vector maps, world is represented by points, lines and polygons. The fundamental unit of vector system is point. Lines are set of mathematically connected points and area are represented by set of mathematically connected coordinates or lines joined together to form polygons which define the boundary of area. Unlike raster images, vector images can be of high resolution. Vector data requires less computer storage space and maintaining topological relationships is easier in this system (Koeln *et al.,* 1994; and Huxhold 1991).

3. Projections

Once the spatial data have been collected, the data needs to be in same coordinate system for display and analysis. As earth surface is ellipsoidal therefore set of set of systematic mathematical transformation is needed to display earth's latitude and longitude onto a plane.

Projection is a method by which curved surface of the earth is portrayed on a flat surface. Initially the earth was thought to be flat surface but later on it was proven that earth is an ellipsoidal/spheroid, the circumference of the earth is about 1/300th smaller around the poles *vs* equator. This difference in distance around the poles and equator use to cause error in the readings and to rectify the errors different projection systems were created. These are just different measurements of the "flattening" at the poles. The different projection systems are helpful in measuring and preserving one or more properties such as area, shape, direction or distance over commonly used latitude longitude (x, y, which measures in degree and not in distance) coordinate system.

3.1 Different types of projections

Azimuthal or planner projection: Projection surface laid flat against the earth.

Conic- Cone is placed on or through the surface of earth.

Cylindrical- projection surface wrapped around the earth.

Coordinate system: A reference framework consisting of set of points that are used to define its position in space either in two or three dimensions.

Cartesian Coordinate system: Two dimensional, planner coordinates system in which the horizontal distance is measures along the x axis and vertical distance is measures along the y axis. Each point ids are defined by x, y coordinate.

Datum: Set of coordinates that measures the position on a surface using x,y coordinates (horizontal) and height above or below the surface (vertical datum).

Geocentric datum: A horizontal geodetic datum based on a ellipsoidal that has its origin at the earth centre's mass and measures coordinate of every point on Earth using latitude longitude and height above its surface. Ex. World Geodetic system of 1984. (WSG84).

3.2 Common GIS projections

Mercator : It is cylindrical projection tangent to the equator of earth. Preserves the local shapes and display accurate compass bearing for sea travel.

Transverse Mercator: It is also a type of cylindrical projection similar to Mercator except the cylinder is tangent along a meridian instead of the equator. It minimizes the distortion along north-south line, but does not maintain true direction.

Universal Transverse Mercator (UTM): *UTM is* based on transverse Mercator projection and divides the whole world in 60 north south zones, each zone having a width of 6^o longitude. Each zone is numbered consecutively beginning with zone one covering longitude 180^o to 174^o West and progressing east word to zone 60, between 174^o to 180^o East longitude.

Lambert Conformal Conic – A conic, conformal projection typically intersecting parallels of latitude, standard parallels, in the northern hemisphere. This projection is one of the best for middle latitudes because distortion is lowest in the band between the standard parallels. It portrays shape more accurately than area.

Most commonly used projection in GIS is UTM or the preference may change depending on the area of interest.

4. Interpolation

Spatial data is important in making important decisions in natural resource management. Collection of spatially continuous data is often difficult and expensive. Most of the data collected by field surveys will be typically from point sources. But scientists and managers requires accurate spatial continuous data to make justified interpretations.

Spatial continuous data of environmental variables are in demand in the geographic information systems (GIS) and modelling techniques for studying the ecology and biological conservation (Collins and Bolstad, 1996; Hartkamp *et al.*, 1999). Thus, spatial interpolation methods have overarching importance in converting point data in to spatially continuous data. Interpolation methods can fall under two categories 1. Global methods and 2. Local methods. Global methods use all available data of the region of interest to derive the estimation and capture the general trend. Local methods operate within a small area around the point being estimated (*i.e.*, use samples within a search window) and capture the local or short-range variation (Burrough and McDonnell, 1998).

4.1 Global interpolators

4.1.1 Regression Models

Regression interpolation is using a linear regression model (LM) as interpolator and assumes that the data are independent of each other, normally distributed and homogeneous in variance. Regression methods explore a possible functional relationship between the primary variable and explanatory variables that are easy to measure (Burrough and McDonnell, 1998). The final model can be selected by a thorough understanding of the relationships between the primary variable and secondary variables and/or by Akaike information criteria (AIC) or Bayesian information criteria (BIC) methods.

4.1.2 Trend surface models

An inexact method, trend surface analysis approximates points with known values with a polynomial equation. This is similar to the regression model but uses only geographic coordinates as indirect variables for prediction of the primary response variable (Collins and Bolstead, 1996).

4.2 Local interpolators

4.2.1 Nearest Neighbours (NN)

The nearest neighbours (NN) method draws perpendicular bisectors between sample points (n), predicting the values at the unsampled regions. The resultant polygons are called as Thiessen or Voronoi polygons. All the area inside each polygon will have same value, which is the value of the midpoint of the polygon.

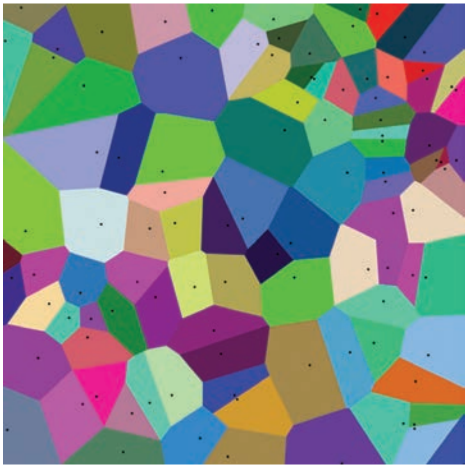

Fig. A Voronoi Polygon map

4.2.2 Triangular Irregular Network

In the triangular irregular network (TIN), all sampled points are joined into a series of triangles based on a Delauney's triangulation. It forms a different basis for making estimates in comparison with those used in NN. The value of the regions falling in a triangle is estimated by linear or cubic polynomial interpolation. Peuker *et al.,* (1978) developed the method for digital elevation modelling (DEM) that avoids repetitions of the altitude matrix in the grid system.

4.2.3 Natural Neighbours

The natural neighbours (NaN) method combines many characters of NN and TIN. The method was developed by Sibson (1981). The first step is a triangulation of the data by Delauney's method, in which the apices of the triangles are the sample points in adjacent Thiessen polygons. This triangulation is unique Spatial Interpolation Methods 7 except where the data are on a regular rectangular grid. To estimate the value of a point, it is inserted into the tessellation and then its value is determined by sample points within its bounding polygons. For each neighbour, the area of the portion of its original polygon that became incorporated in the tile of the new point is calculated. These areas are scaled to sum to 1 and are used as weights for the corresponding samples (Webster and Oliver, 2001).

4.2.4 Inverse Distance Weighting

The inverse distance weighting (IDW) method estimates the values of the unsampled points using a linear combination of values of the sampled points weighted by an inverse function of the distance from the said point to the sampled points. The weight diminishes by an inverse factor and sampled points will have more influence on nearby points. The rate of diminishing value depends on the factor (Isaaks and Srivastava, 1989).

The weights can be expressed as:

$$\lambda_i = \frac{1/d_i^p}{\sum_{i=1}^{n} 1/d_i^p}$$

where d_i is the distance between point of interest x_0 and sampled point x_i, p is a power parameter, and n stands for the number of sampled points used for the estimation. The power parameter is arbitrary decided by the validation at field. Most popular value for p is 2 and then the IDW is called as Inverse square or inverse distance squared (IDS) method.

4.2.5 Splines

This is an inexact, gradual interpolation which uses piecewise polynomial equation as interpolator. The polynomials describe pieces of a line or surface (*i.e.*, they are fitted to a small number of data points exactly) and are fitted together so that they join smoothly (Burrough and McDonnell, 1998; Webster and Oliver, 2001). For degree p = 1, 2, or 3, a spline is called linear, quadratic or cubic respectively. Typically, the splines are of degree 3 and they are cubic splines (Webster and Oliver, 2001).

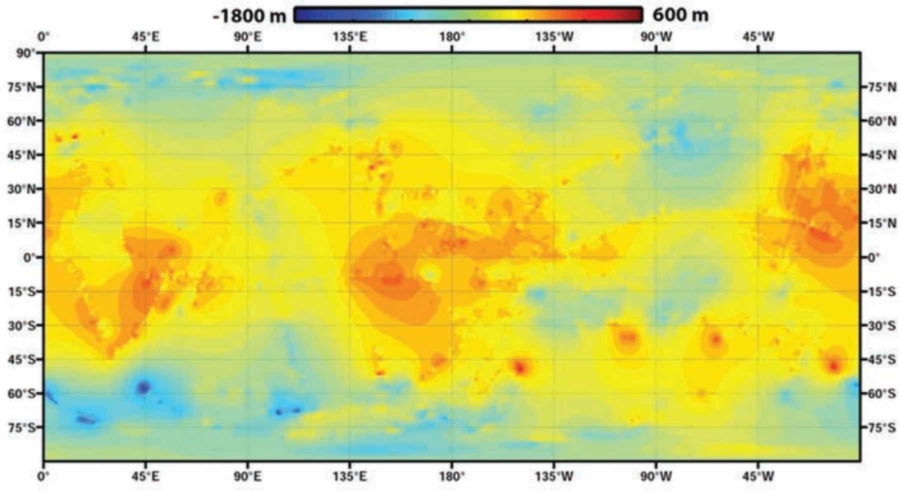

Fig. NASA's Cassini spacecraft gridded elevation data has been splined create the first global topographic map of Saturn's moon Titan [Image credit: NASA/JPL-Caltech/ASI/JHUAPL/Cornell/Weizmann]

4.2.6 Krigging

Basic concept of Geostatistics is that variables of a specific geographic region tend to have a particular structure. Though this particular domain of spatial interpolation has its origin in 1910s in agronomy (Webster and Oliver, 2001), this is mostly developed in the works of geology and mining by Krige (1951). Geostatistics includes several methods that use kriging algorithms for estimating continuous attributes. Kriging is a generic name for a family of generalised least-squares regression algorithms, used in recognition of the pioneering work of Danie Krige (1951). Li and Heap (2008) gives a good review of all the available interpolation methods. In Krigging interpolation is performed by modelling a Gaussian process which considers method of interpolation for which the interpolated values are modeled by a Gaussian process governed by prior assumptions and gives the best unbiased estimate of the unsampled values.

CHAPTER 17

UTILIZING GIS TOOLS FOR ECOSYSTEM RELATED MAPPING

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Geographic information system (GIS) is a tool for making and using spatial information and it is mainly concerned with location of the features as well as properties/attributes of those features. It helps us gather, analyse and visualize spatial data for different purposes. A GIS quantifies the locations of features by recording their coordinates which are the numbers that describe the position of these features on Earth. The uniqueness of GIS is its ability to do spatial analysis. GIS helps us analyse the spatial relationships and interactions. Sometimes, GIS proves to be the only way to solve spatially-related problems and it is one of the most important tools that aid in decision making process. GIS basically helps to answer three questions; How much of what is where? What is the shape and extent of it? Has it changed over time?

Globally, on an average, GIS tools save billions of dollars annually in the delivery of goods and services through proper route planning. GIS regularly help in the day-to-day management of many natural and man-made resources, including sewer, water, power, and transportation networks. GIS help us identify and address environmental problems by providing crucial information on where problems occur and who are affected by them. It also helps us identify the source, location and extent of adverse environmental impacts. GIS enable us to devise practical plans for monitoring, managing, and mitigating environmental damage. Human impacts on the environment, conflicts in resource use, concerns about pollution, and precautions to protect public health have spurred a strong societal push for the adoption of GIS.

GIS is composed of hardware, software, data, humans and a set of organizational protocols. The selection and purchase of hardware and software is often the easiest and quickest step in the development of a GIS. Data collection and organization, personnel development and the establishment of protocols for GIS use are often more difficult and time consuming endeavours. A fast computer, large data storage capacities and a high quality, large display form the hardware foundation of most GIS. GIS software provides the tools to manage, analyse, and effectively display and disseminate spatial information. GIS as a technology is based on geographic information science and is supported by the disciplines like geography, surveying, engineering, space science, computer science, cartography, statistics *etc.*

In GIS, we handle the spatial and attribute data sets. Spatial data describes the absolute and relative location of geographic features while the attribute data describes characteristics of the spatial features. These characteristics can be quantitative and/or qualitative in nature. Attribute data is also referred to as tabular data. Vector and raster are two different ways of representing spatial data. Raster data is made up of pixels (or cells), and each pixel has an associated value. A digital photograph is a simple example of a raster dataset where each pixel value corresponds to a particular colour. In GIS, the pixel values may represent elevation above/below sea level, or chemical concentrations, or rainfall *etc.* The key point is that all of this data is represented as a grid of (usually square) cells. Vector data consists of points, lines, and polygons. The individual points are stored as pairs of (x, y) co-ordinates. The points may be joined in a particular order to create lines, or joined into closed rings to create polygons, but all vector data fundamentally consists of lists of co-ordinates that define vertices, together with rules to determine whether and how those vertices are joined.

As with many other systems, GIS basically works on the principle of '*GIGO*' that is *garbage in garbage out*. Hence the quality of data that you feed into GIS is very important and it determines the quality of the end products. But, when used wisely, GIS can help us live healthier, wealthier, and safer lives.

Hands on: Mapping the Progress of El Nino/La Nina using ONI

El Niño and La Niña are the two phases of the El Niño-Southern Oscillation (ENSO) cycle. The ENSO cycle describes the fluctuations in temperature between the ocean and atmosphere in the east-central Equatorial Pacific. La Niña is referred to as the cold phase of ENSO and El Niño as the warm phase of ENSO. These deviations from normal sea surface temperatures can have large-scale impacts not only on ocean processes, but also on global weather and climate. El Niño and La Niña episodes typically last nine to 12 months, but some prolonged events may last for years. The frequency of El Niño and La Niña episodes can be quite irregular, but El Niño and La Niña events occur on average every two to seven years. Typically, El Niño occurs more frequently than La Niña.

El Niño

El Niño means The Little Boy, or Christ Child in Spanish. El Niño was originally recognized by fishermen off the coast of South America in the 1600s, with the appearance of unusually warm water in the Pacific Ocean around December. The term El Niño refers to the large-scale ocean-atmosphere climate interaction linked to a periodic warming in sea surface temperatures across the central and east-central Equatorial Pacific. Typical El Niño effects are likely to develop over North America during the upcoming winter season. Those include warmer-than-average temperatures over western and central Canada and over the western and northern United States. Wetter-than-average conditions are likely over portions of the U.S. Gulf Coast and Florida, while drier-than-average conditions can be expected in the Ohio Valley and the Pacific Northwest. The presence of El Niño can significantly influence weather patterns, ocean conditions and marine fisheries across large portions of the globe for an extended period of time.

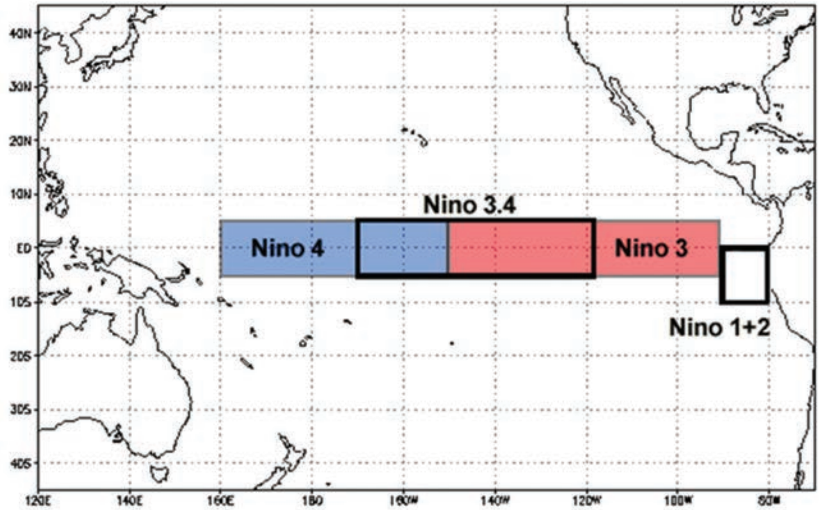
La Niña

La Niña means The Little Girl in Spanish. La Niña is also sometimes called El Viejo, anti-El Niño, or simply "a cold event." La Niña episodes represent periods of below-average sea surface temperatures across the east-central Equatorial Pacific. Global climate La Niña impacts tend to be opposite those of El Niño impacts. In the tropics, ocean temperature variations in La Niña also tend to be opposite those of El Niño.

ENSO events are thought to have been occurring for thousands of years. Modern day research and reanalysis techniques have find that at least 26 El Niño events since 1900 with the 1982-83, 1997–98 and 2015–16 events among the strongest on record.

Different countries have different criteria to determine what constitutes an El Niño/ La Niña event, which is tailored to their specific interests. For example, the Australian Bureau of Meteorology looks at the trade winds, Southern Oscillation Index (SOI), weather models and sea surface temperatures in the Nino 3 and 3.4 regions, before declaring an El Niño. However, the Japan Meteorological Agency declares that an El Niño event has started when the average five-month sea surface temperature deviation for the NINO 3 region, is over 0.5 °C (0.90 °F) warmer for 6 consecutive months or longer. The Peruvian government declares that an El Nino is under way, if the sea surface temperatures in the Nino 1 and 2 regions, equal or exceed +0.4 °C for at least 3 months.

The Oceanic Niño Index (ONI) is the standard used by NOAA for identifying El Niño (warm) and La Niña (cool) events in the tropical Pacific. It is the running 3-month mean SST anomaly for the Niño 3.4 region (*i.e.*, 5^oN-5^oS, 120^o-170^oW). The events are defined as 5 consecutive overlapping 3-month periods at or above the +0.5^oC anomaly for warm (El Niño) events and at or below the -0.5 ^oC anomaly for cold (La Niña) events. The threshold is further categorized as Weak (with a 0.5 to 0.9 SST anomaly), Moderate (1.0 to 1.4), Strong (1.5 to 1.9) and Very Strong (> 2.0) events.



Spatial Extent of Nino regions

It has been found that necessary condition for the development and persistence of deep convection (enhanced cloudiness and precipitation) in the Tropics develops when the local SST is 28°C or greater. Once the pattern of deep convection has been altered due to anomalous SSTs, the tropical and subtropical atmospheric circulation adjusts to the new pattern of tropical heating, resulting in anomalous patterns of precipitation and temperature that extend well beyond the region of the equatorial Pacific. An SST anomaly of +0.5°C in the Niño 3.4 region is sufficient to reach this threshold from late March to mid-June. During the remainder of the year a larger SST anomaly, up to +1.5°C in November-December-January, is required in order to reach the threshold to support persistent deep convection in that region.

Task: Categorize the years into El Nino/ La Nina or normal year based on ONI.

Software Required: QGIS 2.18.14 and Microsoft Excel

Data sets required:

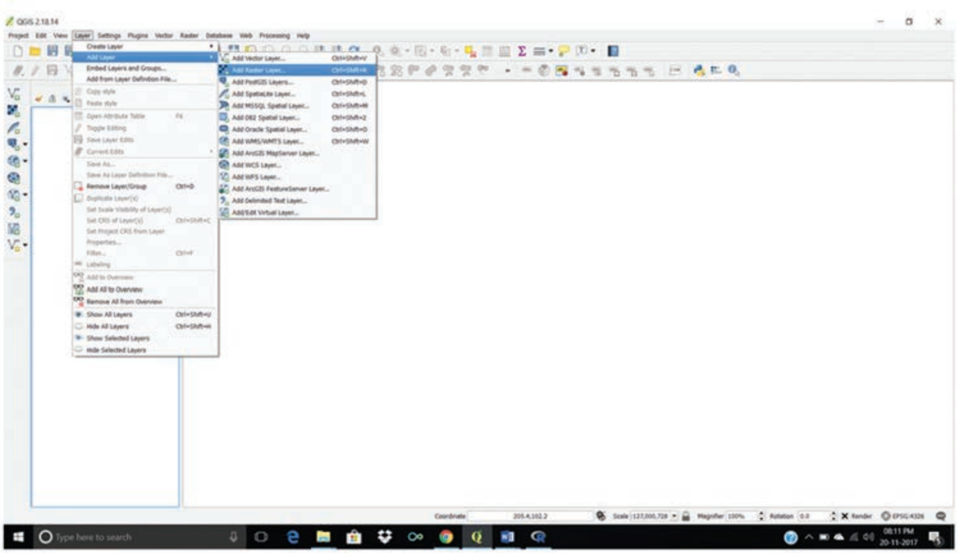
Climatic (1981-2010) monthly mean SST (1_JAN.tif, 2_FEB.tif, 3_MAR.tif, 4_APR.tif, ... 12_DEC.tif)

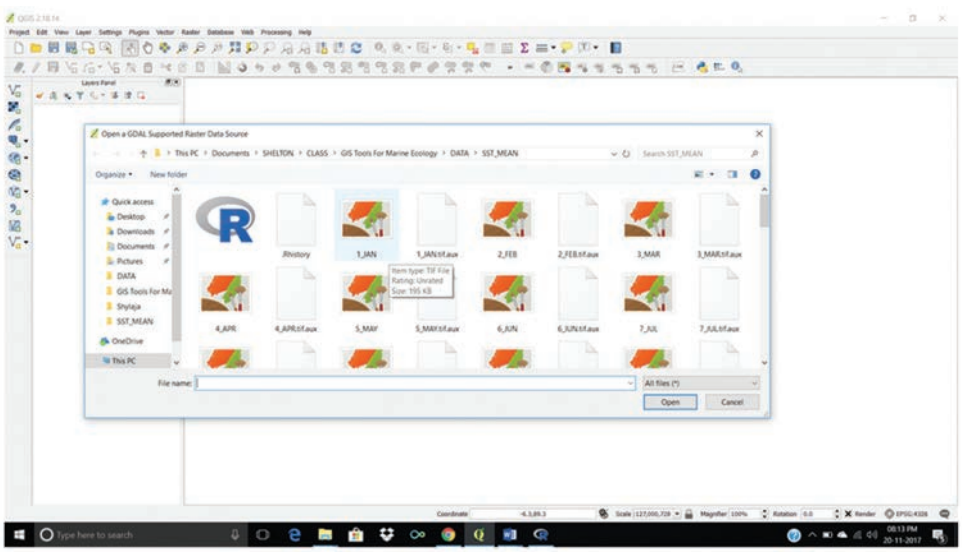
Actual monthly mean SST (2015_JUN.tif, 2015_JUL.tif, 2015_AUG.tif, ... 2017_OCT.tif)

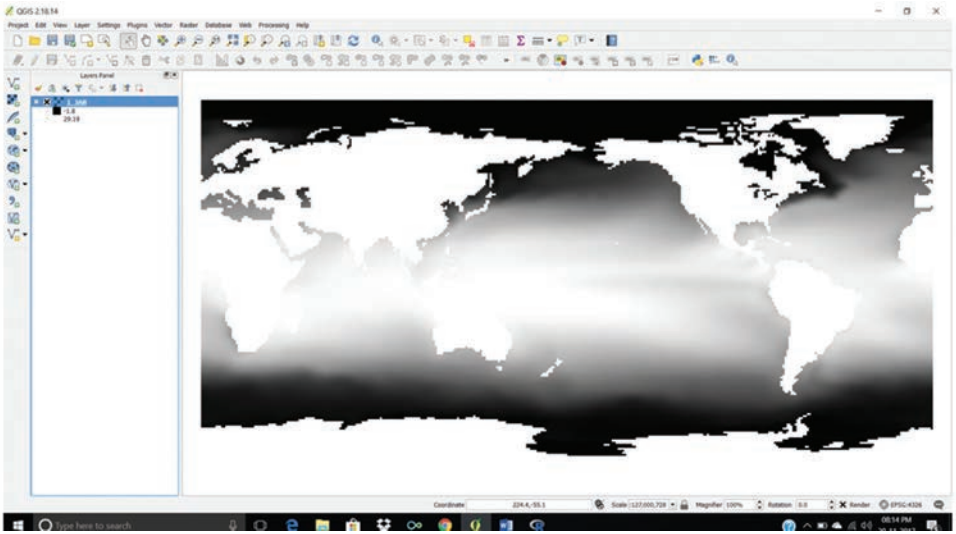
Shape file for Nino 3.4 region: NiNo_3.4_Poly.shp

Loading SST data into QGIS:

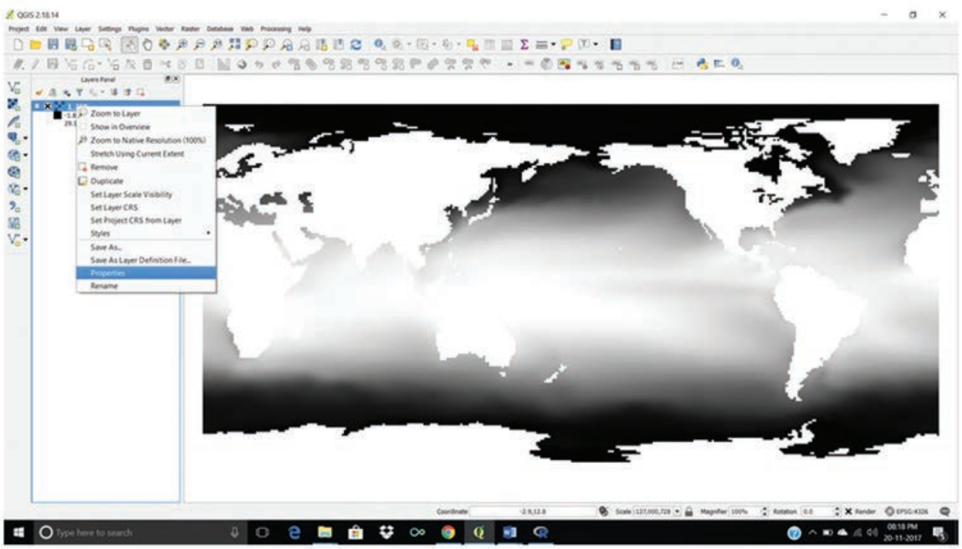
Open QGIS -> Go to Layer menu -> Add raster layer -> Browse to the folder location -> Select the file -> 1_JAN.tif and load the file into the map view.



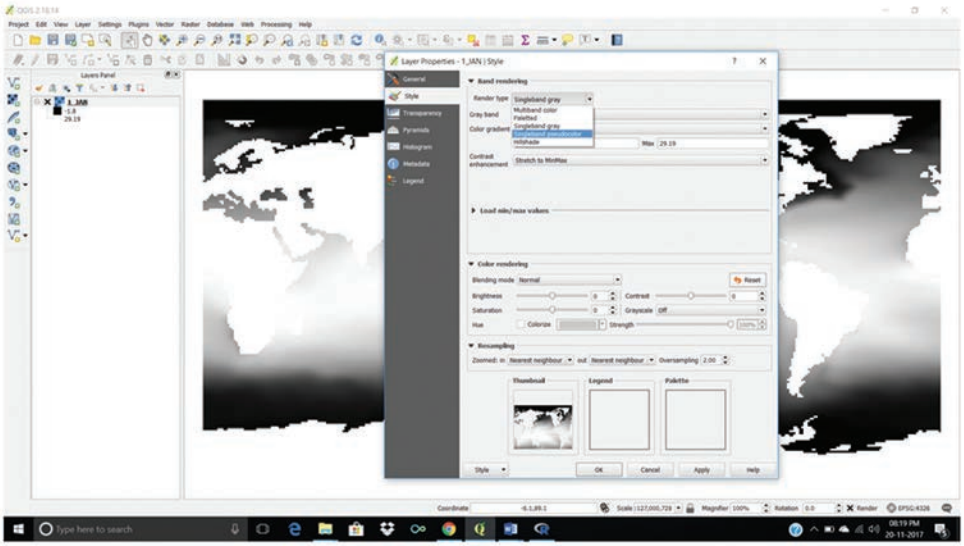




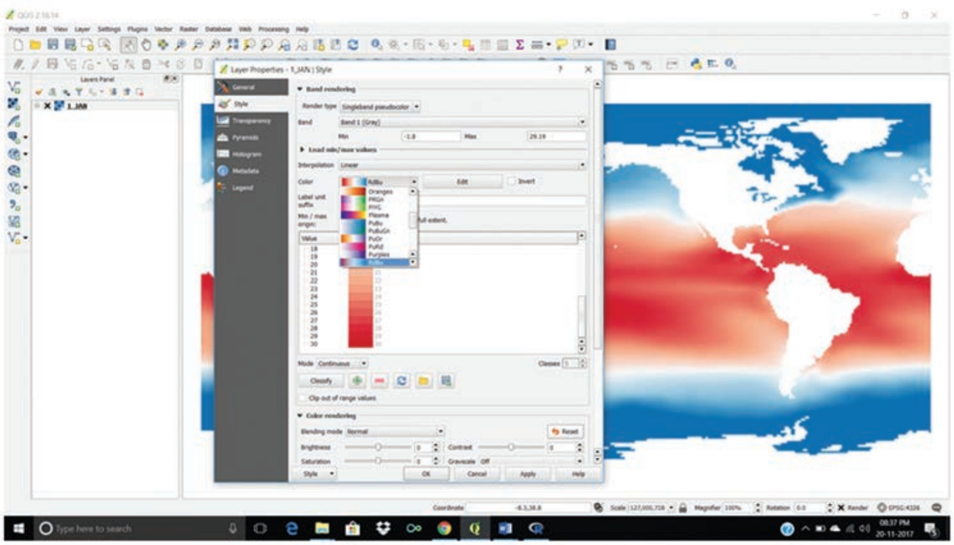
Now, to get a clear visual effect of the temperature variation, change the grey scale of the map to pseudo colour rendering. For that, right click the file name on the Layers panel (left side of the main view panel) and select the properties.



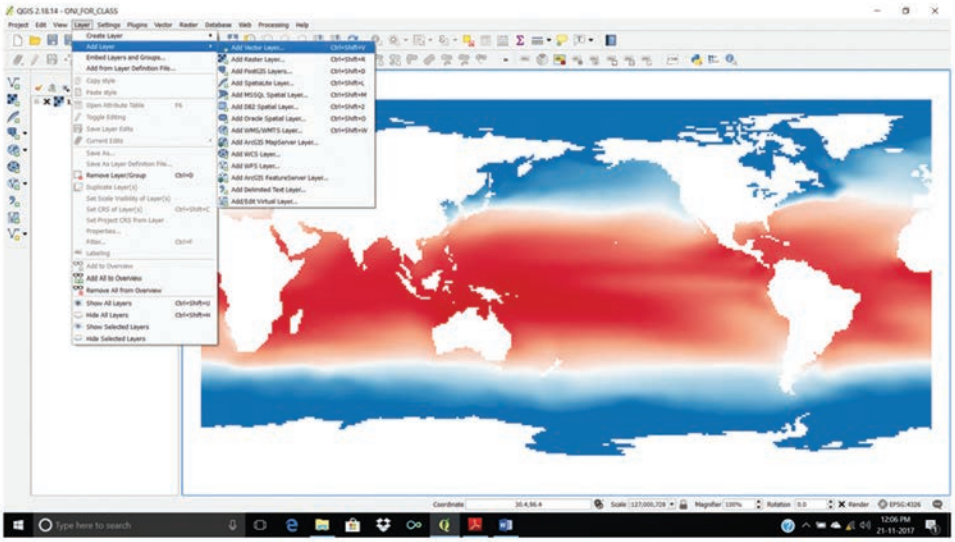
From the Layer Properties pane, go to style tab and change the band render type to 'Single band pseudo colour'.



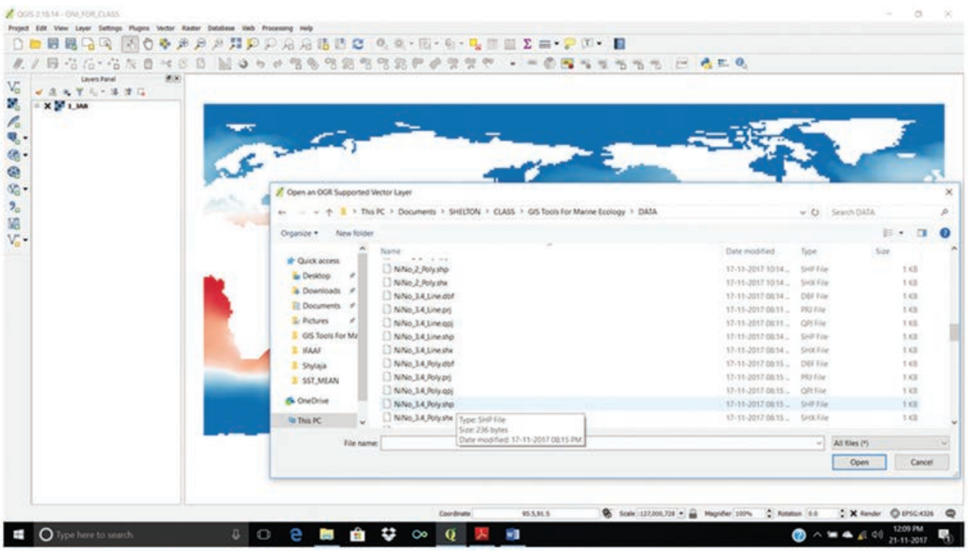
Then choose a 'Colour' band. Change the 'Mode' to 'Equal interval', set 'Classes' to '30' and press the 'Classify' button. The display will change to pseudo colour gradient as per the SST variations. Likewise, load all the SST layers.



Now, we have to load the shape file for Nino 3.4 region. Go to Layers menu -> Add Layers -> Add Vector Layer.

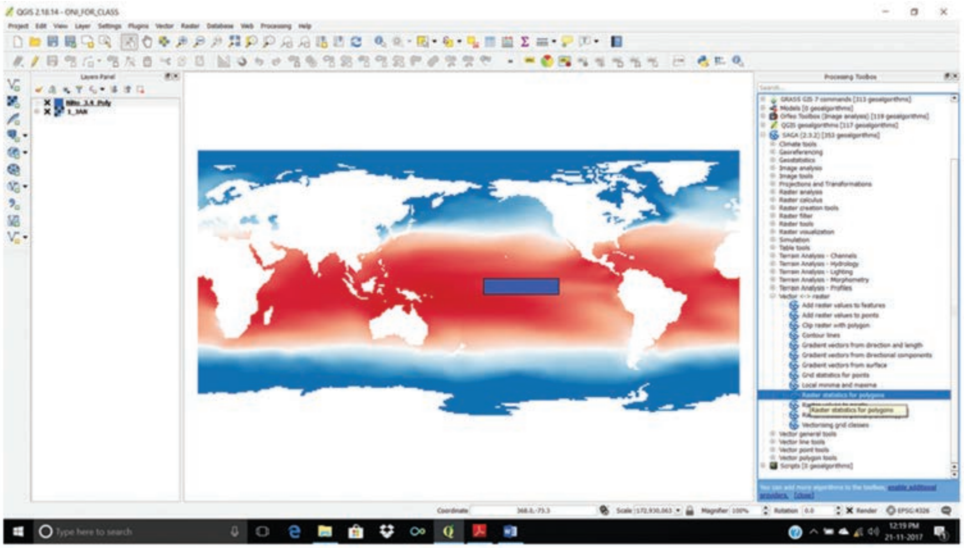


Browse to the file 'NiNo_3.4_Poly.shp' and open it.

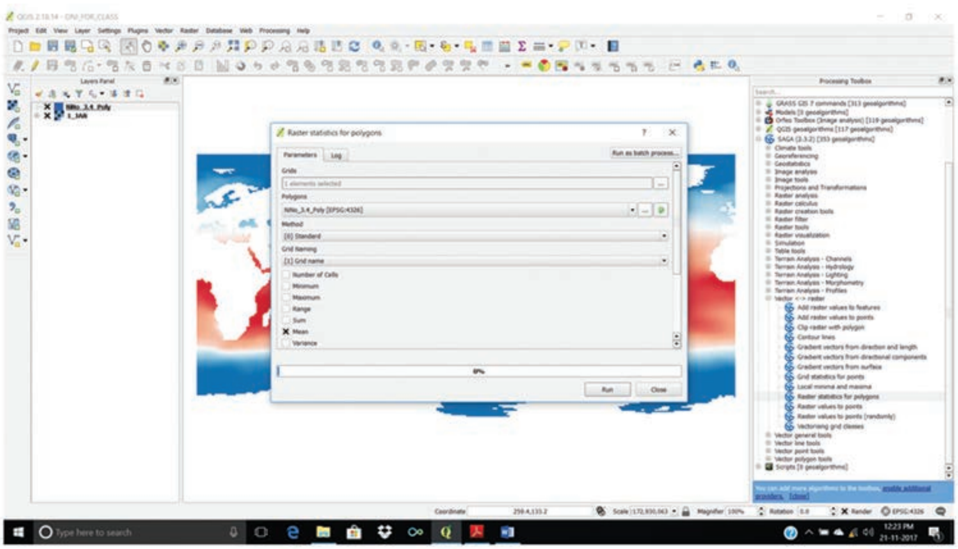


Now, we have to extract the mean value of SST from the Nino 3.4 region. For that we have to use the 'SAGA' tool 'Raster Statistics for Polygons'.

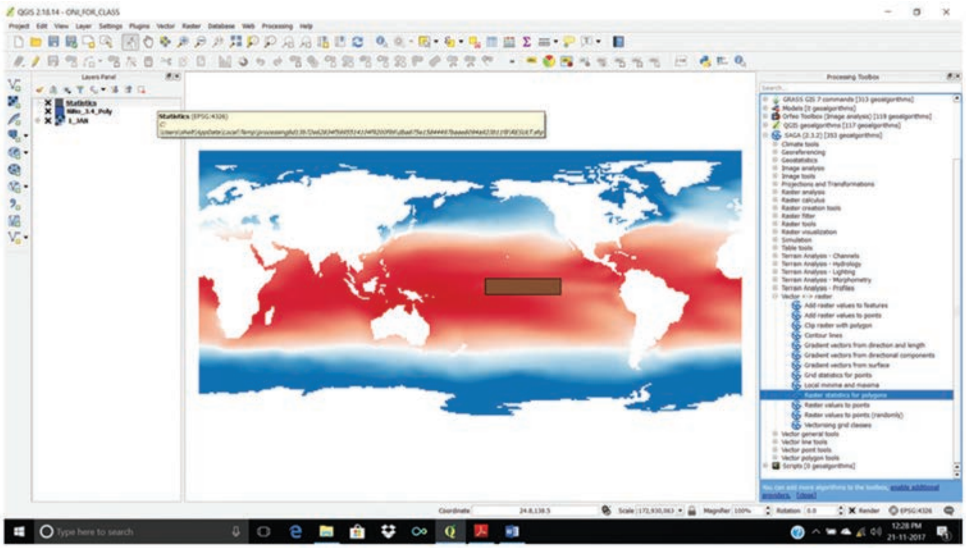
Go to 'Processing' menu -> select 'Toolbox'. On right side of the Main window, tools panel will get displayed. In the tool box, under SAGA tools, go to Vector<->Raster sub group and select the tool 'Raster Statistics for Polygons'.



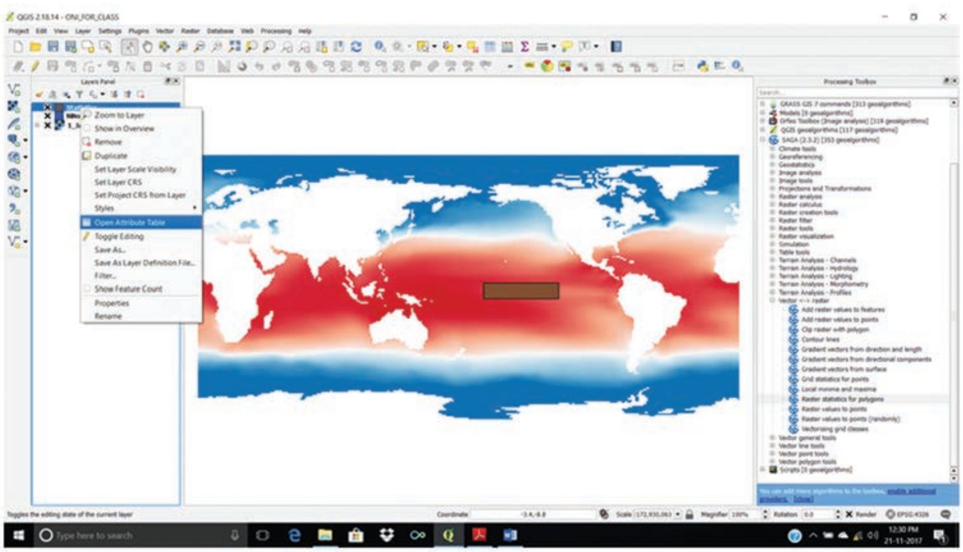
In the 'Raster Statistics for Polygons' tool panel, in the Grids option, select the SST datasets. For 'Polygons' select NiNo_3.4_Poly.shp', Method-> Standard, Grid Naming -> Grid Name, tick mark 'Mean' and press 'Run'.



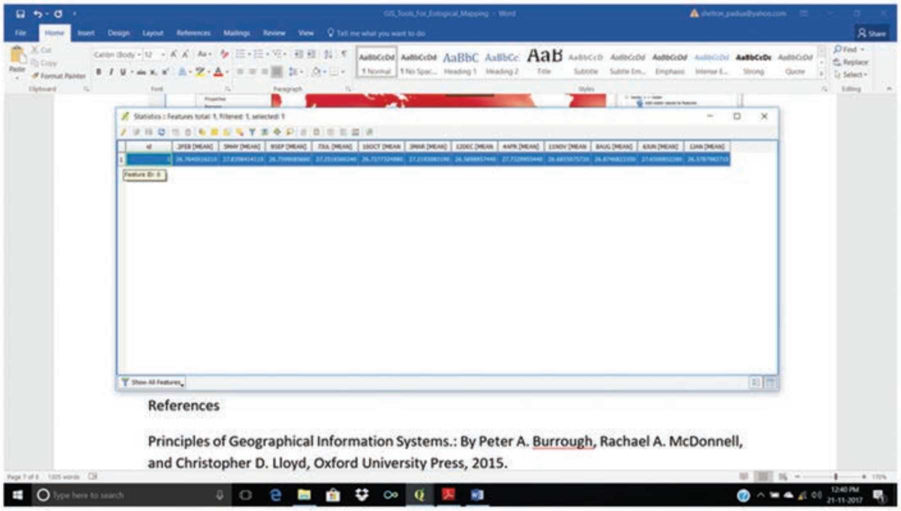
Now, you will get a 'Statistics' vector layer in the 'Layers Panel'.



Right click on the layers panel and open the 'Open Attribute Table' button. This will open up the attribute table.

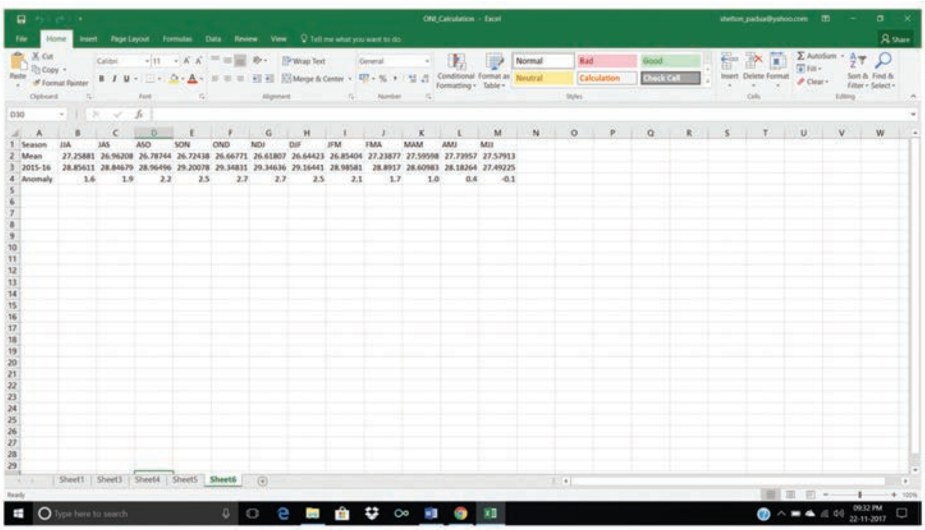


From the attribute table, select the row of attributes by 'left clicking' the corresponding row number.



Once the row is highlighted, copy the records to clipboard by clicking the 'Copy' button or using the keys 'ctrl+c'. Now open a Microsoft Excel sheet and paste the copied values. Do the procedure for both climatic monthly mean SST data (1_JAN to 12_DEC) and actual monthly mean SST data (2015_JUN to 2017_OCT).

Calculate the three months running mean from 2015_JUN to 2017_OCT and three months climatic running means. Now, find the SST anomaly (difference between these two sets of running means).



Now, see if the SST anomaly qualifies for El Nino/ La Nina or normal year as per the criteria and report accordingly.

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CHAPTER 18

ROLE OF CALCULUS IN MARINE SCIENCES

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1. Introduction

Calculus has two parts: differential and integral calculus. Historically, differential calculus was concerned with finding lines tangent to curves and with calculating extrema (*i.e.*, maxima and minima) of curves. Integral calculus has its roots in attempting to determine the areas of regions bounded by curves or in finding the volumes of solids. The two parts of calculus are closely related: The basic operation of one can be considered the inverse of the other. This result is known as the fundamental theorem of calculus and goes back to Newton and Leibniz, who were the first to understand its meaning and to put it to use in solving difficult problems (Reference 3).

2. Worked out Examples

2.1) Differentiation

Differentiation is an aspect of calculus that enables us to determine how one quantity changes with regard to another. It tells you how quickly (or slowly) a function changes at a given point. Finding tangents, locating extrema, and calculating areas are basic geometric problems, and it may be somewhat surprising that their solution led to the development of methods that are useful in a wide range of scientific fields. The main reason for this historical development is that the slope of a tangent line at a given point is related to how quickly the function changes at that point. Knowing how quickly a function changes at a point opens up the possibility of a dynamic description of biology, such as a description of population growth, the speed at which a chemical reaction proceeds, the firing rate of neurons, and the speed at which an invasive species invades a new habitat. For this reason, calculus has been one of the most powerful tools in the mathematical formulation of scientific concepts (Reference 3).

By working out the following examples, you will be able to develop an appreciation of the usefulness of calculus across multiple fields.

Example 1: Application of Differentiation (References 1.a and 1.b)

Carlos has taken an initial dose of a prescription medication. The amount of medication, in milligrams, in Carlos's bloodstream after t hours is given by the following function:

$$M(t) = 20 * e^{(-0.8*t)}$$

What is the instantaneous rate of change of the remaining amount of medication after 1 hour? In what units is this rate of change measured?

Solution to Example 1

The instantaneous rate of change of M(t) is given by its derivative, M′(t). Therefore, the instantaneous rate of change of the remaining amount of medication after 1 hour is simply M′(1).

Therefore, we need to find the value of M′(t) at t=1 or

$M'(1)\ M'(t) = -16 * e^{(-0.8*t)}$

$M'(1) = -16* e^{(-0.8*1)}$

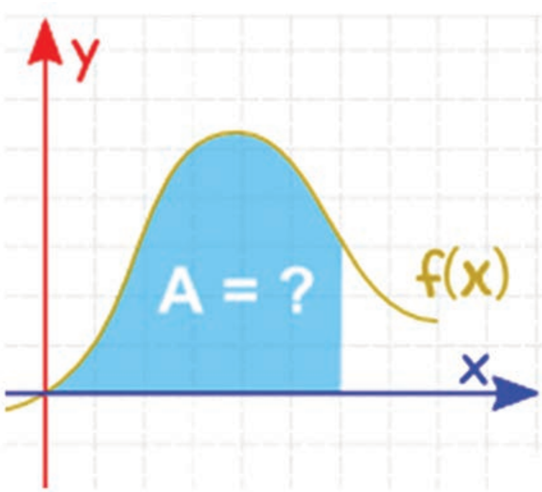
$M'(1) \sim 7.2$

M(t) is the amount of medication that remains in Carlos's blood stream after 't' hours. Therefore, the rate of change is measured in milligrams per hour.

In conclusion, the instantaneous rate of change of the remaining amount of medication after 1 hour is -7.2 milligrams per hour. The rate of change is negative because the amount of medication is decreasing.

2.2) Integration (References 1.a and 1.b)

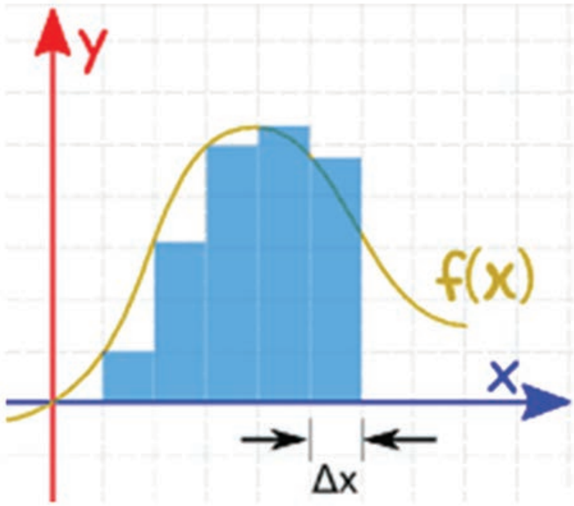
Integration is a way of adding slices, summing them to find the whole area of a curve. Integration can be used to find areas, volumes, central points and many useful things. But it is easier to start with finding the **area under the curve of a function** like this:



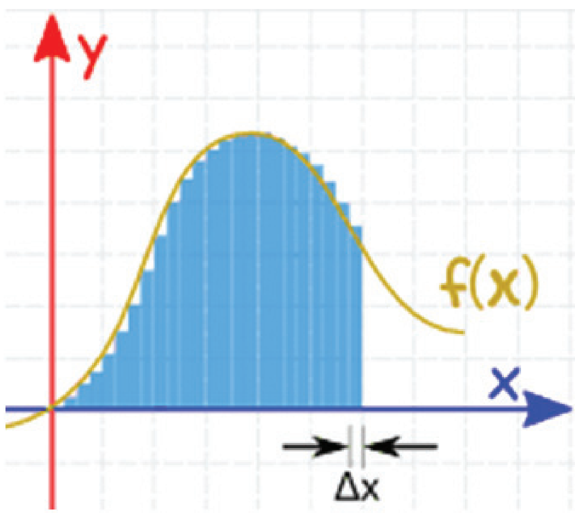
What is the area under **y = f(x)** ?

Slices

We could calculate the function at a few points and **add up slices of width Δx** like this (but the answer won't be very accurate):

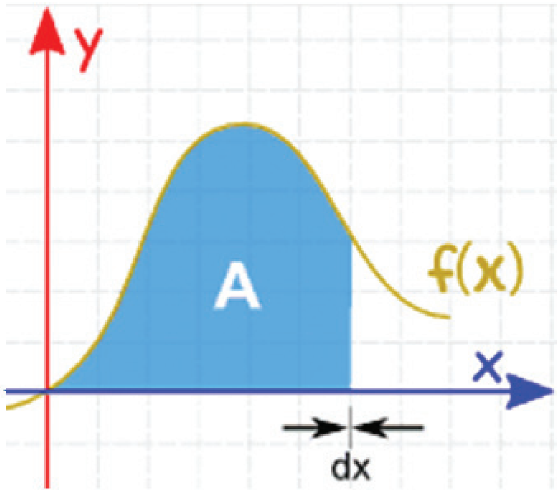


We can make **Δx** a lot smaller and **add up many small slices** (answer is getting better):

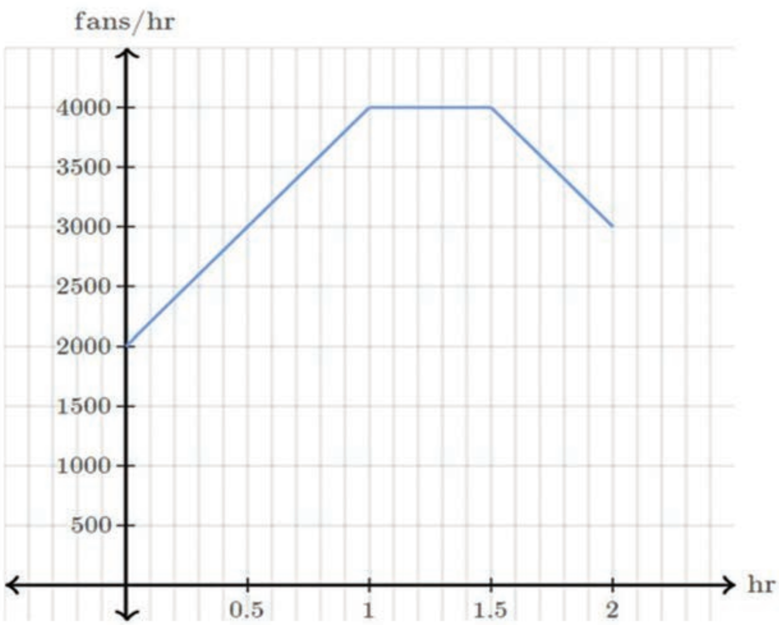


And as the slices **approach zero in width**, the answer approaches the **true answer**.

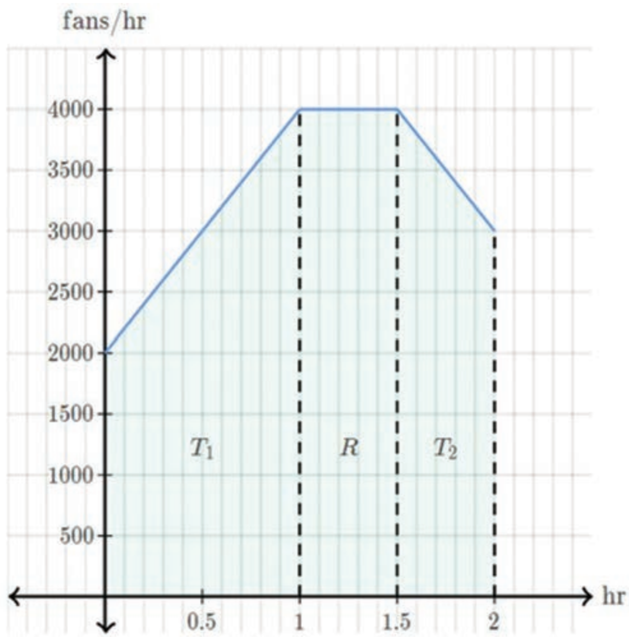
We now write **dx** to mean the **Δx** slices are approaching zero in width.



Example 2: Application of Integration (References 1.a and 1.b)



Solution to example 2:



2.3) Application of Differential Equations (Reference 2) Example 3: Given:

State variables : N - Amount of nutrient available

P - Phytoplankton

Process of interest - Photosynthetic production of organic matter

$$\frac{d}{dt} P = v_{max} f(N) P$$

where

$$f(N) = \frac{N}{kN+N}$$

When N is large

f(N) =1

When N is small

f(N)= N/k_n

Case 1

What would be the growth profile of Phytoplankton in presence of ample nutrients (*i.e.*, when N is large)? In such a scenario, keeping the plankton concentration a constant, how would Nutrient concentration vary with time?

Case 2

Keeping the plankton concentration a constant in presence of limited nutrients (*i.e.* when N is small), how will Nutrients change with respect to time?

Solution to Example 3

The nitrogen consumed by the phytoplankton for growth must be lost from the *Nutrients* state variable. Therefore,

$$\frac{d}{dt} P = v_{max} f(N)P$$

$$\frac{vd}{dt} N = v_{max} f(N)P$$

and

$$\frac{d}{dt} (P+N) = 0$$

Because the total *inventory* of nitrogen is conserved.

Case 1

When nutrient availability is ample, f(N) = 1

$$\frac{dP}{dt} v_{max}P \text{———————————}(1)$$ After integrating with respect to time, we get

$$P = A\, e^{v_{max}t} \text{———————————}(2)$$ **Growth of P will be exponential**

When plankton concentration is kept under ample nutrient conditions, we have

$$\frac{dN}{dt} P = v_{max}P \text{———————————}(3)$$ After integration, we get

$N(t) = -v_{max}{*}P{*}t$ ——————————(4)

N will decrease linearly with time as it is consumed to grow P

Case 2

When nutrient availability is scarce, $f(N) = N/K_n$

Therefore,

$$\frac{dN}{dt} = \frac{v_{max}P}{kn}N \qquad (5)$$

On integrating (5) with respect to time, we get

$$N = Ae \, \frac{v_{max}P}{kn} \qquad (6)$$

N will exponentially decay to zero until it is exhausted

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CHAPTER 19

APPLICATIONS OF GEOPHYSICAL DATA SETS TO RESOLVE ECOSYSTEM CHALLENGES

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Introduction

Satellite Remote Sensing (SRS) datasets are often used in empirical or semi-analytical validated models, either to extrapolate regional datasets in space or to generate derived geo-physical products. A simple example for this can be the summation of thermal signals from different wavelengths for generation of SST. In a similar way, some of the most useful and relevant environmental properties in fisheries research such as sea surface salinity (SSS), Wind Speed (WS) and Wind Direction (WD), sea surface height (SSH), chlorophyll-a (Chl-a) and Chl-a derived primary production (PP) are available online as processed and unprocessed geo-physical datasets. These datasets can be used to advantage in various fisheries research and management programmes. A few such case studies are illustrated in this section:

SRS chlorophyll data providing cues on fish stock variability

Variations between years in the seasonal cycle of SRS Chl-a have been implicated in fluctuations in fish stock variability (Platt *et al.,* 2003). In this section, we describe the results of an analysis of Chl-a with Indian oil sardine in the coastal waters of India. Fishing effort in the coastal waters of India changed little in the period 1998-2006, with 238,772 fishing craft in 2005 (CMFRI 2005) in comparison with 239,000 craft in 1997 (Sathiadhas, 2006). Thus, the variability in sardine landings during the study period, despite steady fishing effort, indicates that other factors such as environment or food to the sardines are involved. A correlation analysis between available environmental factors (SST, sea bottom temperature, surface salinity, surface dissolved oxygen, bottom dissolved oxygen, pH, nutrients, chlorophyll, zooplankton, rainfall, multivariate El Niño Southern Oscillation index, coastal upwelling index, and derived SST) and sardine catch from the study area emphasised the high significance of chlorophyll compared with other environmental factors in explaining the variability in sardine catch (Krishnakumar and Bhat, 2008). Using their fine branchial apparatus, sardines feed predominantly on phytoplankton and zooplankton. In a given area, Chl-a is a good index of the food availability to sardines. Summer surface Chl-a from the study area lies in the range 0.1 to 5 mg/m^3, and can be very high, from 5 to 10 mg/m^3, during bloom periods. Given the wide dynamic range of chlorophyll concentration in the coastal waters of southwest India and the dominant role of chlorophyll as a determinant of variability in sardine stocks, it seems likely that much will be gained in studying this link in detail.

Algal bloom in the study area often occurs during upwelling. Upwelling in the waters of the southwest coast of India (5 to 15^0 N latitude) and the variability in local physical parameters drives changes in the chlorophyll concentration (Smitha *et al.,* 2008). Physical processes affect not only the magnitude of the plankton biomass, but also its species composition (Huntsman *et al.,* 1981), which may in turn affect larval fish feeding and survival (Lasker 1975; Simpson 1987). According to the Hjort-Cushing match-mismatch hypothesis (Hjort 1914; Cushing 1974; 1990), the survival rate of fish larvae is a function of the match between timing of hatching of eggs and initiation of spring phytoplankton bloom. The advent of SRS provides information at the appropriate temporal and spatial scales for testing this hypothesis (Platt *et al.,* 2007). With SRS, it is possible to characterize the spring bloom objectively based on the timing of initiation, amplitude and duration. The statistical moments of all of these properties, and their inter-annual variation, can be calculated and the results used to analyze the effect of ecosystem fluctuations on exploited fish stocks (Platt *et al.,* 2003).

The case study presented below deals with the interannual variability of Indian oil sardine (*Sardinella longiceps*) stock in the southwest coastal waters of India and its relationship with the phytoplankton bloom characteristics computed from SRS, with a view to explain larval survival and interannual variability at the synoptic scale (Grinson *et al.,* 2012). The life cycle of sardines includes an active breeding season from May to September. This coincides with the high chlorophyll concentration seen during May to September every year.Thus, we find a probable connection between the life history of sardines and phytoplankton bloom dynamics. This supports the finding that the fish itself times its breeding and adjusts its migration to exploit the productive southwest monsoon period. In this study, magnitude of the bloom during initiation month is selected for characterization of bloom, which naturally falls in the month of May every year. May is the most critical month for sardines because both bloom initiation and the beginning of sardines' active breeding phase occur during this month. A delay in the initiation of bloom in the area results in a delay in the onset of suitable conditions for survival of sardine larvae (Grinson *et al.,* 2012).

Reef Health Advisories Using SRS Derived SST

Globally, there are several instances of mass coral bleaching incidents leading to heavy reef mortality (Krishnan *et al.,* 2011). The application of SRS provides synoptic views of the global oceans in near-real-time for monitoring the reef areas (Liu *et al.,* 2003; Bahuguna *et al.,* 2008; Mahendra *et al.,* 2010). SST during night time is an important parameter for assessment of the thermal conditions inducing the bleaching. SRS provides SST information during day and night routinely, facilitating the development of a coral reef bleaching warning system to generate early warning advisories/ bulletins in near realtime. The estimation of monthly maximum mean using night time SST climatology retrieved using NOAA, AVHRR is used for generating reef health advisories to eliminate the effect of solar glare and reduce the variation in SST caused by the heating during day time. Threshold hotspot (HS) and daily heating week (DHW) values for a region are calculated the advisory (Mohanty *et al.*, 2013). Depending on the intensity of HS and DHW there can be advisories such as 'no stress'; 'watch'; 'warning' and 'alert levels-I & II' which progressively indicate the severity of a potential bleaching event. Based on this study INCOIS offers reef stress advisories to alert the reef managers to take appropriate measures to reduce the damage caused to reefs during bleaching events.

SRS Data for Cyclone Tracks Creating Productive Fishing Grounds

Even though cyclones are devastating, there are some positive effects of cyclones on the fishery. Study of the effect of tropical cyclones on biological processes has gained momentum in the recent past. In thermally-stratified coastal waters, cyclones trigger the breaking up of nutrient-depleted surface waters and bring in nutrient-rich sub-surface waters inducing sudden algal blooms and enhancing the regional scale PP. The effect of physical forcings on PP, its variation and associated hydrography in the southwestern Bay of Bengal during the southwest monsoon (July) and post-cyclone period (November) of 1999 was studied by Madhu *et al.,* (2002). In the post cyclone period, the combined effects of well-mixed coastal waters and freshwater injection from the land runoff associated with the cyclone brought nutrients to the mixed layer, which enhanced PP. Potentially, such enhancement of PP results in improving the regional fishery. But cyclone tracks alone will not provide the information on enhanced PP. SRS is able to detect the environmental changes caused by tropical cyclones. Geo-physical data sets from SRS are useful in such studies for indicating possible productive fishing grounds after a lag following the cyclone (Rao *et al.*, 2006).

Demarcation of Ecological Provinces in Support of an Ecosystem Approach to Fisheries Management

Globally, the ecosystem approach to fisheries management (EAFM) is preferred as a basis for sustainable management of fish stock (Garcia *et al.*, 2003). In this context, it is useful to have a spatial structure for global oceans defined on the basis of ecological provinces rather than geo-political considerations. There are various approaches for classifying the global oceans into ecological provinces (Ekman 1953; Margelef 1961; Yentsch and Garside 1986; Cushing 1989; Fanning 1992; Sathyendranath *et al.*, 1995). The classification by Longhurst *et al.*, (1995) is the most comprehensive, identifying some 50 biogeochemical provinces globally (Longhurst *et al.*, 1995). Some other methodologies require huge data sets for demarcating ecological provinces (Hooker *et al.*, 2000; Li *et al.*, 2004; Alvain *et al.*, 2005; Sherman *et al.*, 2011). But there is lack of *in situ* data to suppport these approaches. As oceanic realms are dynamic, there are logistic issues in sampling. Consequently, SRS data are very useful to clasification protocols. PP derived from SRS can be a very useful input as PP provinces subsume many oceanographic forcing mechanisms on synoptic scales (Platt and Sathyendranath 2008). These ecological provinces are useful in fisheries management as the physical processes and the ecosystems in each province support characteristic fisheries different from those in nearby provinces (Stuart *et al.,* 2011). Beyond static partitioning, there is a further goal for dynamic bio-geography at regional scales that would incorporate complexities of a dynamic marine environment and their effect on the phytoplankton. SRS will be an invaluable source of inputs in case of such partitioning. Changes in spatial extent of the ecological provinces arising from temporal variations in physical forcing can be captured in a SRS climatology of ocean colour.

Coupling Modelled and SRS Data for Effective Fishery Management

So far in this chapter, we have discussed the usage of environmental data sets from models and SRS for various aspects in fisheries research and management. But lack of environmental time series data sets pointed to the need for more data. Coupled with SRS, numerical modelling is an alternative tool to generate environmental and biological datasets, which can help to mitigate problems arising from data gaps.

Trophic Modelling Using SRS Data as an Ecosystem Approach To Fisheries Management

Trophic levels in the marine ecosystem are similar to those in terrestrial systems starting with primary producers and ending in scavengers. But, the trophic structure in marine systems is web like, rather than a linear food chain. Fishing often alters the ecosystem structure. Trophic webs will respond differently to fishing depending on whether the target species is a predator or prey species. Single-species fish stock-assessment models ignore food web interactions. Ecosystem based fish stock assesement is offered as another option. EAFM models often resort to SRS-based PP as an input for forcing at the base of the food web to investigate energy transfers and biomass in an ecosystem without fishing, from lower to upper trophic levels (Chassot *et al.,* 2011).

Generating Potential Fishing Zones (PFZ) and Their Dissemination along With Ocean State Forecasts (OSF)

Identification of PFZ involves an understanding of oceanic processes and interaction of hydro-biological parameters (Desai *et al.,* 2000). The forage base and the physical gradients of temperature and Chl-a help the predatory fish to locate their prey and the same cues are used by fishermen. A number of studies have examined the use of SRS as an aid to locate more productive fishing areas (Waluda *et al.,* 2001). Indian Remote Sensing Satellite P4 Ocean Colour Monitor (IRS P4 OCM) derived chlorophyll concentration and National Oceanographic Aerospace Administration Advanced Very High Resolution Radiometer

(NOAA AVHRR) derived SST images have been used to characterise the relationship between the biological and physical variables in coastal waters and it was observed that chlorophyll concentration and SST were inversely correlated with each other (Solanki *et al.,* 1998). The relationship between these two parameters was estimated by a clustering technique called ARNONE (NCAER, 2010) and the matching features were selected for generating integrated PFZ forecasts from the composite images on the basis of latitude and longitude (Solanki *et al.*, 2005; NCAER 2010).

Validation of studies of PFZ forecasts have shown that the forecast may lead to substantial increase in fish catch (Solanki *et al.,* 2001; 2003; Nayak *et al.,* 2003). PFZ forecasts in near-real time indicating the likely availability of fish stocks for the next 2 days are disseminated in the Indian EEZ by INCOIS to about 225 nodes for operational use (Nayak *et al.,* 2003). A significant increase in total catch by following PFZ forecasts has been documented from ANI (Grinson-George *et al.,* 2011, 2013).

Detection of Meso-Scale Features Such as Eddies and Fronts that may Indicate Productive Fishing Grounds

Oceanographic features such as eddies, currents and meanders are pervasive features in the world's oceans. These conspicuous hydrographic features influence the horizontal and vertical distributions of the chemical (e.g. nutrients), physical (e.g. SST) and biological (e.g. Chl-a) propertiesin pelagic systems (Yoder *et al.,* 1981, Seki *et al.,* 2001). Eddies have been found to be localized regions of higher PP leading to aggregation and development of forage species base communities. The presence of mesoscale eddies and their detection by the fishing fleet is an important factor in fishery performance, leading to increased catch per effort for most pelagic species (Laurs *et al.,* 1984). The influence of mesoscale processes at fronts, such as the formation of rings, meanders and streamers arising or breaking off from these dynamic current systems, has also been shown to be important in shaping the distribution of pelagic fish and shellfish (Waluda *et al.,* 2001). Studies linking the physical oceanographic processes with fish have been carried out around the major boundary currents and related mesoscale processes, such as in the fishing grounds associated with Kuroshio frontal regions (Yokouchi *et al.*, 2000), mesoscale eddies and pelagic fisheries off Hawaiian waters (Seki *et al.,* 2001), upwelling and longline fishery of Portuguese waters (Santos *et al.,* 2006), Atlantic tuna and Gulf of Mexico circulation (Block *et al.,* 2005), oceanographic conditions of spawning grounds of bluefin tuna in the NE Indian ocean (Matsuura *et al.,* 1997), bluefin and frigate tunaspawning along the Balaeric archipelago (Garcia *et al.,* 2003) and tuna exploitation near the mesoscale processes near the Sechelles (Fonteneau *et al.,* 2006).

The chlorophyll-SST based advisories depend on the surface manifestation by algal blooms and thermal fronts which result from eddies and upwelling. Using altimetry data however, one would be able to follow the evolution of feature from inception to maturation and dissipation with time. There is a time lag between physical upwelling of nutrients to the ocean surface and development of phytoplankton blooms, and subsequently the aggregation of planktivorous and piscivorous fish. Altimetry data helps to identify the fish-aggregating meso-scale features from the outset giving valuable time to forecast and exploit the consequences. Difficulties in getting cloud free imageries sometimes limits the scope of this approach. Altimetry data, especially the SSH have been useful to study the physical oceanography and mesoscale circulation. Advances in SRS altimetry are making it possible to extend the information to the coastal areas where the fishermen are most active. Inputs from the altimetry data on the mesoscale features can be used to augment the PFZ advisories and also provide data during cloud cover.

Forecasting Cyclones and Ocean State to Reduce Impacts on Coastal Fisher Folk and Resources

Apart from elucidating the areas of likelihood of fish/ shellfish distributions during the Planktonic Larval Duration (PLD) phase, the wind models used for generating wind inputs in simulation of physical process can be utilized for studying cyclone tracks. Fisheries is one of the sectors with high occupational hazard. The extent of direct mortality caused by storms at local or regional scales is severe (Gardner *et al.,* 2005; Done 1992). OSF derived as products of numerical models are provided as input to fishermen to mitigate this risk. OSF provides wave and swell height as well as period, WS as well as wind direction (WD), Tsunami and rough sea warnings and coastal current details. To ensure safe navigation and operations at sea, and to forewarn the fishermen community, INCOIS started the OSF service in 2005 by issuing forecasts seven days in advance and at three hourly intervals, with daily updates. Fishermen utilize these forecasts to guide their daily operational activities and to ensure safe navigation. Though international agencies such as National Centres for Environmental Prediction (NCEP), USA and European Centre for Medium-Range Weather Forecasts (ECMWF) and UK issue sea state forecasts based on models such as WAVEWATCH III and WAM, these forecasts are for the open ocean. The INCOIS model provide accurate location-specific forecast in the coastal waters using high resolution local bathymetry, and tuning them using observed wave measurements. Real-time and on-line validation of the forecast products is disseminated through various means by INCOIS (Nair *et al.,* 2013).

Cyclones also render coastal resources vulnerable. The ecological effects of cyclones on coral reefs have been reviewed by Harmelin-Vivien (1994). Tropical storms cause severe damage to the reefs; their impacts include the removal of reef matrix, scouring and fragmentation (Rogers *et al.,* 1991; Done 1992), deposition of loosened material onto beaches above sea level or transporting it into deeper sub-reef environments (Done 1992). The reefs in Andaman and Nicobar Islands (ANI) suffered severe damage following a tropical cyclone in the Bay of Bengal off Myanmar coast during13–17 March 2011 (Krishnan *et. al.,* 2012). The investigation exposed the vulnerability of the reefs to oceanographic features which generally remain unnoticed unless they directly affect the life or the property of coastal inhabitants. The wind tracks of cyclone were generated using weather research and forecasting (WRF) models which clearly indicated the passage of cyclone where reefs suffered damage.

Estimation of Potential Fishery Resources of an Exclusive Economic Zone (EEZ) for Fishing Fleet Management

Global marine fish production increased from less than 20 million tons per year in early 1950's to average around 90 million tons per year during the last decade. If the unreported and discarded catches are also taken into account, the global catches will be around 120 million tons per year (Zeller *et al.,* 2005). The general trend in shortfall from traditional fishing grounds in the EEZ's of developed countries is compensated by the increasing exploitation of resources in developing countries. The United Nations Convention on the Law of the Sea (UNCLOS) bestows the coastal states with the right to exploitation and responsibility for management of fishery resources of their EEZs. Observations are of paramount importance for managing the resources, and there is a need to establish acccurate catch data collection systems. Fish captured are considered to reflect fish abundance in coastal waters. From marine fish catch data, we can estimate the potential harvestable fish by plotting the catch effort curve, and estimate the maximum sustainable yield (MSY). But, mere post-mortem analysis of landed fish may lead to imperfect estimates as fish catch data without geotags of catching locations may not provide samples representative of the stock in the sea. Therefore, an estimate of harvestable fish based on *in situ* water productivity, taking into account the tropho-dynamics in the EEZ may afford very useful complimentary information.

Chlorophyll, which is an index of algal biomass (ML^{-3}) present in a water column (L) is a prerequisite for primary production and subsequent fish production ($ML^{-2}T^{-1}$) which is the annual rate of production of fish biomass per unit area of sea bed. The importance of the potential link between PP and fish was understood decades ago (Ryther 1969), but the advent of SRS Chl-a and modelled PP data sets now available on global and meso-scale prompted policy planners to utilize this for estimation of fishery potential in the EEZ. Past studies relied on *in situ* datasets resulting from different sampling and processing methods and were generally characterized by low spatio temporal sampling coverage. SRS Chl-a data are now basic to cross-trophic-level analyses of ecosystem production, structure, and function because of the easy and free availability of a wide-ranging, high resolution, and consistent sampling framework (Platt *et al.,* 2007) at a reliable accuracy.

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CHAPTER

20

INTRODUCTION TO SATELLITE REMOTE SENSING BASED MARINE PRIMARY PRODUCTIVITY

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1. Primary productivity and Photosynthesis

Primary Productivity is the rate at which light energy or inorganic chemical energy is converted to the chemical energy of organic compounds by autotrophs in an ecosystem. To adequately define primary production it is require having basic understanding of the food chain. All organisms feed off from the organisms below them on the food chain. These organisms create their food through the process of photosynthesis. In the ocean, photosynthesis is performed by phytoplankton in the sunlit or euphotic zone. This process takes carbon dioxide and water and combines them with the help of the energy contained in sunlight creates a monosaccharide and oxygen (Fig. 1).

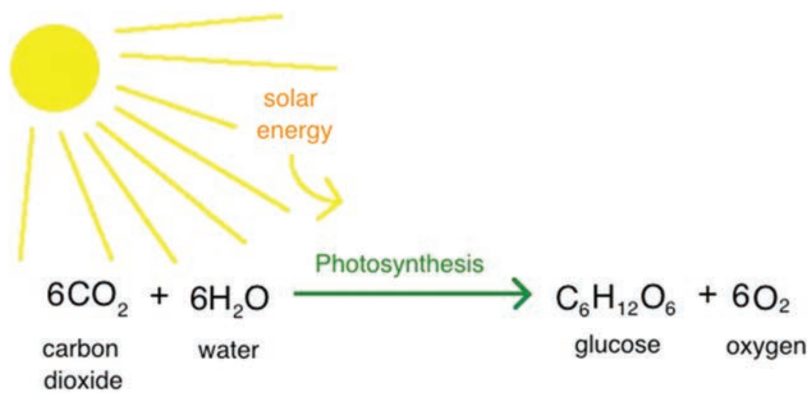

Fig. 1. Schematic indicating process of photosynthesis

2. Productivity in the surface ocean

The many nested cycles of carbon are associated with ocean productivity. “Gross primary production” (GPP) refers to the total rate of organic carbon production by autotrophs, while “respiration” refers to the energy-yielding oxidation of organic car-bon back to carbon dioxide. “Net primary production” (NPP) is GPP minus the autotrophs’ own rate of res-piration;

it is thus the rate at which the full metabo-lism of phytoplankton produces biomass. "Secondary production" (SP) typically refers to the growth rate of heterotrophic biomass. Only a small fraction of the or-ganic matter ingested by heterotrophic organisms is used to grow, the majority being respired back to dis-solved inorganic carbon and nutrients that can be re-used by autotrophs. Therefore, SP in the ocean is small in comparison to NPP. Fisheries rely on SP; thus they depend on both NPP and the efficiency with which or-ganic matter is transferred up the foodweb (*i.e.*, the SP/NPP ratio). "Net ecosystem production" (NEP) is GPP minus the respiration by all organisms in the ecosystem. The value of NEP depends on the boundaries defined for the ecosystem. If one considers the sunlit surface ocean down to the 1% light level (the "euphotic zone") over the course of an entire year, then NEP is equivalent to the particulate organic carbon sinking into the dark ocean interior plus the dissolved organic carbon being circulated out of the euphotic zone. In this case, NEP is also often referred to as "export production" (or "new production").

Ocean biology is responsible for the storage of more carbon away from the atmosphere than is the terrestrial biosphere which is achieved by the sinking of organic matter out of the surface ocean and into the ocean interior before it is returned to dissolved inorganic carbon and dissolved nutrients by bacterial decomposition. This process as the "biological pump," as it pumps carbon dioxide (CO_2) out of the surface ocean and atmosphere and into the voluminous deep ocean.

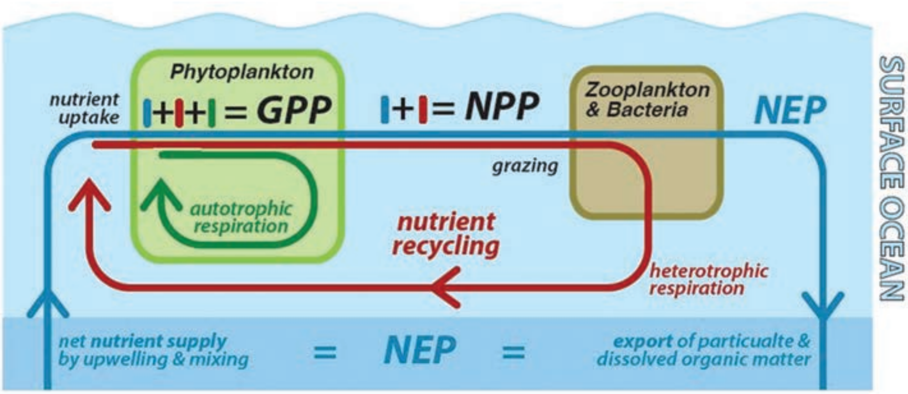

Fig. 2. Productivity in the surface ocean and its connections to nutrient cycling. The blue cycle for "net ecosystem production" (NEP). The red cycle illustrates the fate of the majority of organic matter produced in the surface ocean. The green cycle represents the internal respiration of phytoplankton themselves
Source: Sigman and Hain 2012

Only a fraction of the organic matter produced in the surface ocean has the fate of being exported to the deep ocean. Of the organic matter produced by phytoplankton (NPP), most is respired back to dissolved inorganic forms within the surface ocean and thus recycled for use by phytoplankton.

3. Pre-requisite for Ocean Productivity and limitations

The ocean primary production largely depends upon three factors: Sunlight, dissolved oxygen and nutrients.

Sunlight is the ultimate energy source — directly or indirectly — for almost all life on Earth, including in the deep ocean. However, light is absorbed and scattered such that very little of it penetrates below a depth of ~80 m (as deep as 150 m in the least productive subtropical regions, but as shallow as 10 m in highly productive and coastal regions). Thus, photosynthesis is largely restricted to the upper light-penetrated skin of the ocean.

The availability of dissolved oxygen is also critical for the process of photosynthesis which depends upon the rate of oxygen utilization. However as the productivity is limited to euphotic zone the concentration of DO is not limiting in this zone.

Phytoplankton requires a suite of chemicals, and those with the potential to be scarce in surface waters are typically identified as "nutrients." Broadly important nutrients include nitrogen (N), phosphorus (P), iron (Fe), and silicon (Si). There appear to be relatively uniform requirements for N and P among phytoplankton. The export of organic matter to depth depletes the surface ocean of nutrients, causing the nutrients to accumulate in deep waters where there is no light available for photosynthesis. Because of the density difference between surface water and the deep sea across most of the ocean, ocean circulation can only very slowly reintroduce dissolved nutrients to the euphotic zone. By driving nutrients out of the sunlit, buoyant surface waters, ocean productivity effectively limits itself.

Phytoplankton growth limitation has traditionally been interpreted in the context of Liebig's Law of the Minimum, which states that plant growth will be as great as allowed by the least available resource, the "limiting nutrient" that sets the productivity of the system (de Baar 1994).

4. The measurement

Primary productivity can be measured in three ways: 1) The amount of carbon dioxide used, 2) The rate of sugar formation and 3) The rate of oxygen production. The first being the most accurate.

4.1. Oxygen measurement

Primary productivity can be measured from the amount of oxygen consumed by a volume of water in a fixed period of time; water for which productivity is to be determined is enclosed in sealed white and dark bottles (bottle painted dark so light would not enter). DO (dissolved oxygen) measurement of water is made at the beginning of the immersion period. The two bottles are then immersed in the water body concerned at the level from which the water is taken. The phytoplankton and other elements in the water produce oxygen in the water bottle, but some oxygen disappears due to respiration. The latter is measured from the readings of dark bottle, where only respiration takes place. Thus from the oxygen produced by photosynthesis of enclosed organism (representing a sample of the water body) can be known. However this oxygen production indicates net primary productivity only. From the DO difference in dark bottle oxygen consumed by the enclosed organisms can be obtained and when this respiration value is added to the oxygen production in the white bottle, a value for gross primary productivity is obtained.

4.2. Carbon measurement

The most accurate method for determining productivity is the method of using carbon tracer. In this method, a known quantity of carbon tracer is added into a bottle containing water with the phytoplankton and other organisms and after a short period of incubation, carbon fixed can be measured. The productivity measured thus is net primary productivity as the carbon fixed in the tissues only are measured here.

5. Primary productivity from satellite

By virtue of the broad synoptic coverage of remotely sensed images of ocean color are seen as important tools for the spatial extrapolation of local data collected from ships in ocean biogeochemical studies. One of the principal applications of the imageries the estimation of ocean primary production at large geographical scale. Various methods have been proposed to convert pigment fields derived from ocean color images in to maps of primary production. These models differ in complexity and therefore in the computing time and the amount of information required to implement them. Satellite based primary productivity models computed daily water column primary production as a function of available light and biomass.

The simplest productivity models estimate time and depth integrated primary production as a function of sea surface chlorophyll. The next step in algorithm complexity introduces surface irradiance as a second factor controlling productivity, where depth-integrated production is the product of depth-integrated chlorophyll, daily surface irradiance, and a constant, water- column averaged quantum yield for photosynthesis.

At any depth z (positive downwards) and time t, the dependence of biomass-specific primary production $P^B(z)$ on photon flux or irradiance (I) can be written as

$$P^B(z,t) = P[I(z,t)]$$

Where the superscript indicates normalization to the pigment biomass B, and the function represents family of curves whose general shape is known from experiments.

6. Photosynthesis – Irradiance parameters

In the absence of photo inhibition it is a function that requires no more than two parameters, conventionally chosen to be the slope σ^B of p(I) near the origin (the initial slope) and the height P_m^B of the plateau (the assimilation number).

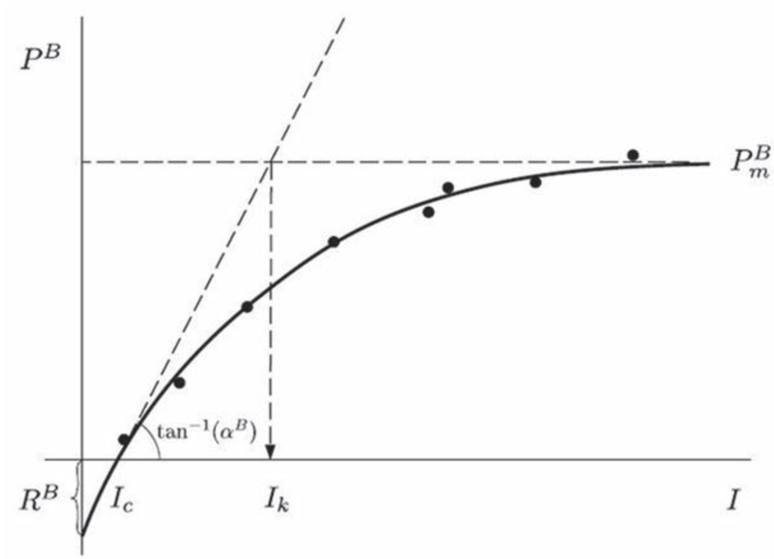

Fig. 3. The photosynthesis – irradiance curve (solid line) as fitted to imaginary experimental data

The PI parameters can be retrieved through a controlled experiment. In these experiments, samples of water containing phytoplankton are inoculated with a tracer for either oxygen or carbon and incubated in a light gradient for a certain time period. The addition of the tracer allows the average rate of photosynthesis to be determined for the duration of the incubation. The range of light intensities covered will be from near zero to near surface-light intensities. The results from idealized P^B v/s I experiment are shown in Fig. 3. The filled circles represent the experimental data points and the heavy line is a smooth curve that fits the data. It is called the light-saturation curve, or the P^B vs I curve. Observe that the curve does not necessarily pass through the origin. The intercept R^B on the ordinate can be interpreted as a measure of the dark respiration of phytoplankton (loss of carbon at zero light, when photosynthesis is zero by the definition). The point where the curve cuts the abscissa defines the irradiance value Ic, called the compensation point, interpreted as the irradiance for which photosynthesis just balances the dark respiration. Close to the abscissa, the curve is quasi-linear with slope denoted as σ^B, called the initial slope. At higher irradiances, the slope of the curve decreases progressively until the curve reaches a plateau of amplitude P^Bm, called the assimilation number. The projection of the intersection of the initial slope with the plateau onto the abscissa defines the irradiance I_k, called the photo-adaptation parameters.

7. Operational estimation of primary production

The protocol developed for calculation of phytoplankton production from remotely-sensed data in the operational mode include the key element as an objective assignment, on a pixel-by-pixel basis, of the parameters required to implement a primary production model (parameters of the photosynthesis-response function and of the vertical distribution of pigment biomass). In a regional context, the assignment is made by searching the archived data on these parameters according to the (remotely-sensed) chlorophyll concentration and surface temperature. This approach is referred as the Nearest-Neighbour Method. The procedure is justified on the basis of the known variation of bio-optical properties of phytoplankton with chlorophyll and temperature as well as through consideration of the seasonal variation of water column stratification and its effect on the vertical pigment profile. The method is well illustrated using the data from the Northwest Atlantic Ocean.

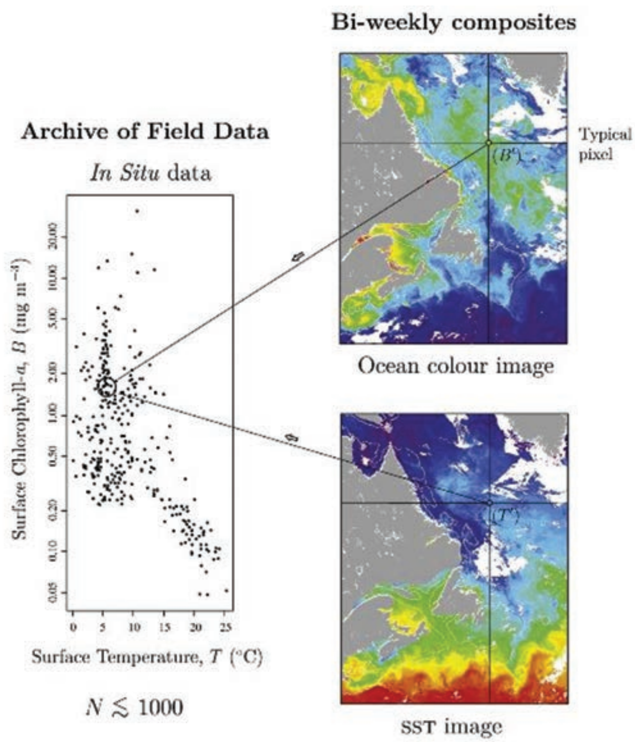

Figure 4. The protocol used for parameter assignment in calculation of primary production. For every pixel in the remotely-sensed images, the chlorophyll and the sea-surface temperature were determined, then enter the archive of in situ data with these values of chlorophyll and temperature. For the station that most closely matches these coordinates, we select the parameters we need as the ones that were measured on that station.
Source: Platt et al., 2008

CHAPTER 21

ESTIMATION OF PRIMARY PRODUCTION BY REMOTE SENSING

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I. Introduction

Global concern over the atmospheric increase in carbon dioxide have lead to the study of the sources and sinks responsible for regulating the increase, and to the conclusion that the oceans are the major sinks for atmospheric CO_2. The uptake of atmospheric CO_2 by the oceans is the flux of carbon through the surface mixed layer into the deep ocean controlled by the fixation of carbon by marine phytoplankton through photosynthetic processes of primary production. Primary production is defined as the amount of organic material (Biomass) present per unit space per unit time. Photosynthetic processes occur in both oceanic and terrestrial ecosystems. About 50 % of total primary production in the biosphere occurs in the sea, through phytoplankton ranging from chains of diatoms to 1 μm-sized photosynthetic bacteria. Oceanic photosynthetic organisms turn over much more rapidly than terrestrial counterparts. Oceanic photosynthetic organisms are extremely efficient in fixing carbon compared to terrestrial plants and mediate a large flux of organic carbon into the ocean, often referred as the biological pump. In addition to sustaining the marine food chain, phytoplankton strongly influence ocean chemistry. During photosynthesis, they remove carbon dioxide dissolved in seawater to produce sugars and other simple organic molecules, and release oxygen as a by-product. Phytoplankton also require inorganic nutrients (e.g., nitrogen, phosphorus, silicon) as well as trace elements (e.g., iron) to synthesize complex molecules, such as proteins. Ocean productivity thus plays a key role in the global biogeochemical cycles of carbon, oxygen, and other elements critical to both marine and terrestrial life. The magnitude and variability of primary production are poorly known on a global scale, largely because of the high spatial and temporal variability of marine phytoplankton concentrations. Study of large-scale variations in productivity; global coverage by ship borne instruments is impossible. Only ocean colour sensors provides the rapid, global coverage required for studies of ocean productivity at global over world ocean basins. The focus is on the estimation of oceanic phytoplankton biomass and primary production on regional and global scales using both in-situ and Remote Sensing techniques and the objective is to develop coupled climate and bio-geochemical models required for predicting climate forcing and responses.

II. Primary Productivity Measurements

Definition

Biomass is defined as the total weight (total number X average weight) of all the organisms in a given area or volume. It is the mass of the organism/ unit volume or unit area.

Measurements & Units

Since the process of photosynthesis involves the conversion of inorganic carbon into organic carbon (sugar), the rate of this conversion (or carbon fixation) is called photosynthetic rate. The ecological term for photosynthetic rate is the rate of primary production denoted by the symbol P. It is expressed in terms of mass of carbon converted per unit volume of water per unit time and units are mg C/m^3/day or per time. The biomass engaged in primary production is denoted as B, and units are mg/m^3. The biomass can be chlorophyll-a or chlorophyll like pigments or simply pigment biomass. Chlorophyll concentration has been the most preferred one because of its central role plays in the photosynthetic process and also the relative ease measurements in the field. It also happens to be the biological variable that is easily monitored from space as a mass of carbon per unit volume or unit area.

In-situ measurements are using microscopic and flow cytometry techniques. Both methods require conversion factors for cell numbers to cell volume and cell volume to mass of carbon. Typical oceanic range of photosynthetic pigment per unit volume is 0.01-2.0 ug Chl_a l^{-1} (mg chl/m^3) or unit area is 10-70 mg Chl_a/ m^2 and typical range of oceanic productivity is per unit volume 10-60 ug C l^{-1} and per unit area is 1-2 g C/ m^2 per unit time.

There are several methods for measuring Primary Production by different authors summarized by Platt & Sathyendranath, 1995. These include a) in vitro methods like ^{14}C assimilation, O_2 evolution, $^{15}NO_3$ assimilation, $^{15}NH_4$ assimilation, b) bulk property methods like NO_3flux to photic zone, O_2 utilization rate below the photic zone, c) ^{238}Uranium/ ^{234}Thorium method *etc*. The routine way to assess primary production in the filed is through *in-situ* incubations using the ^{14}C method. Also preferred techniques are optical methods like double flash fluorescence. (Falkowski and Kobler (1990). Other technique are fluorescence and remote sensing technique suggested by Kieffer(1983) and Subha & Platt(1988, 1990).This method gives a vertical profile of primary production through the photic zone. The profile can be integrated over depth and perhaps adjusted for incubation time, to give an estimate of daily water column production.

C14 technique for Primary Production

The 14C-radiotracer method is used to measure the assimilation of dissolved inorganic carbon (DIC) by phytoplankton as an estimate of the rate of photosynthetic production of organic matter in the euphotic zone.

The 14C method, originally proposed by Steeman - Nielsen (1952), is used to estimate the uptake of dissolved inorganic carbon (DIC) by planktonic algae in the water column. The method is based on biological uptake of 14C-labeled DIC is proportional to the biological uptake of 12C-DIC. If one knows the initial concentration of DIC in a water sample, the amount of 14C-DIC added, the 14C retained in particulate organic matter (14C-POC) at the end of the incubation and the metabolic discrimination between the two isotopes of carbon (*i.e.*, 5% discrimination against the heavier 14C isotope), then it is possible to estimate the total uptake of carbon from the following relationship:

$$\text{C uptake} = \frac{\text{DIC} * \text{14C-POC} * 1.05}{\text{14C-DIC added}}$$

III. Productivity modeling & variables

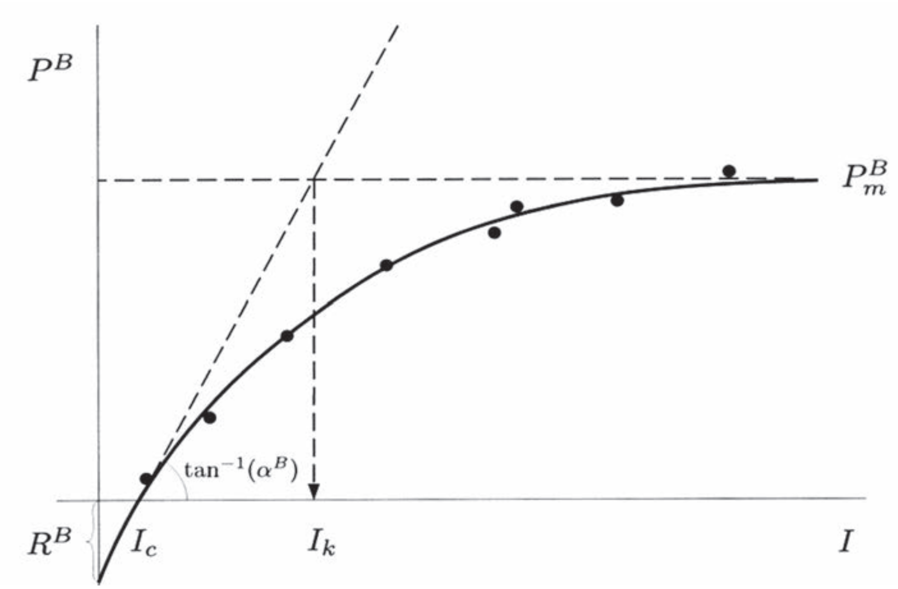
Light intensity and photosynthesis relation

Light intensity is used as a forcing function both for the physical and the biological model. In the physical model, light intensity influences water temperature and therefore water density. The basic aspects of irradiance or light having biological importance are quantity and quality. Light is qualitatively described by its spectral distribution depending on difference in wavelengths. Total radiation at these wavelength is called as Photosynthetic active radiation (PAR). PAR is for all practical purposes considered between 400-700 nm since total energy shorter than 400 is lee than 10%. Thus light is the most important variable expressed as flux of energy per unit area per unit time. In the biological model, the photosynthetically active radiation (PAR) forces primary productivity. Properties of irradiance field are ë, angular distribution of wavelength (zenith and azimuth angles). Estimation of light intensity and radiation fluxes between the sea and the atmosphere was based on standard formulations described in literature.

Photosynthesis and Irradiance (PI) curve

Since photosynthesis is a photochemical process, the functional response of phytoplankton photosynthesis to available light is studied through the use of photosynthesis light experiments or PI experiments. The relationship between light and photosynthesis is called light saturation curve or PI curve. The curve is a reflection of environmental effects on photosynthesis and can be used to diagnose certain properties of algal species, or natural samples of phytoplankton. Photosynthesis increases with increasing light intensity up to some asymptotic value where the system becomes light saturated. The curve does not necessarily pass through the origin. The intercept R on the ordinate can be interpreted as a measure of dark respiration of phytoplankton (loss of carbon at zero light when photosynthesis is zero by definition). The point where the curve cuts the abscissa defines the irradiance value I_c called the compensation point, interpreted as the irradiance for which the photosynthesis just balances the dark respiration. Close to abscissa the curve is quasi linear with **slope ($\Delta P/\Delta I$)** denoted **as α or initial slope**. The initial slope is a function of light reaction and is not usually affected by other factors. It depends on the angular distribution and wavelength of irradiance field. The units are [mgC[mgChl a]$^{-1}$ hour^{-1}] Wm^{-2}. In plant physiology the initial slope of P vs. I curve has been defined as **'the quantum yield, φ'** in which the light intensity is expressed in the quantum unit. The quantum yield can then be expressed as the number of moles of oxygen evolved (or of carbon incorporated) per unit light intensity(in Einsteins). At higher irradiances, the slope of the curve decreases progressively until the curve reaches a plateau of amplitude P_{max} or P_m, called the assimilation number or biomass specific primary production at saturating irradiance. The units are mgC[mgChl a]$^{-1}$ hour^{-1}. The projection of the intersection of the initial slope with the plateau onto the abscissa defines the irradiance called the photo adaptation parameter or in other words the ratio of P_m to α is I_k (μ Em^{-2}hour^{-1}). It has the same dimensions of irradiance and it is therefore used as a scale to normalize the irradiance and render it dimensionless. *i.e.,*

$$I^* = I / I_k = \alpha / P_m$$



A typical photosynthesis-light (P I) curve for the experimental data

When the value $I^* = 1$, corresponding to $I = Ik$, the curves are divided into two regimes. For I less than or equal to 1, photosynthesis depends strongly on irradiance. For I greater than 1, photosynthesis depends less strongly on irradiance, eventually becoming independent of it. If one assumes that the curve passes through the origin, then the curve can be represented by two parameters á and Pm and can be written as

$$P(I) = p\,(I; \alpha, Pm) \qquad (1)$$

Thus it can be seen that the functional response of phytoplankton photosynthesis to the available light is parameterized by two quantities, α and P_m or in other words photosynthesis light curve is a function of one variable, irradiance and two parameters. This function p defines a family of curves, the individual members identified by the value or magnitude of parameters α and P_m. Since α and P_m varies for different areas and seasons, it is necessary to know the magnitude of α and Pm to compute primary production instead of taking a single value. The slope α is also depth dependent. In deeper depths due to its exponential decay nature, magnitude of light will be less. Therefore at less light intensity á will be sharper since it indicates the efficiency of phytoplankton to perform photosynthesis at available light conditions. Slope of the P vs. I curve is also spectral in nature. As seen from equation (1) photosynthesis is dependent on the available irradiance and therefore photosynthesis at depth is also dependent upon the irradiance available at that depth. In order to estimate the light reaching at a particular depth, a parameter known as diffuse attenuation coefficient or K is used. This K describes the behavior of light at a given depth.

Daily Water Column production – General equation

To estimate primary production P given information on biomass B and irradiance I, it is useful to have an index of production from which the effects of variations in B have been removed. This is because both P and B are local variables since their magnitude can vary over short scales of time and space. Since variations in biomass are the principal biogenic cause of variation in the rate of primary production it is necessary to normalize the production to biomass. This gives a quantity known as normalized production, P^B which is of more significance than P because its variation between regions and seasons can be analysed without the complications that might arise from chance fluctuations in the local biomass.

$$P^B = P / B \qquad (2)$$

When required the absolute production P can be recovered by inversion of (2)

$$P = B \times P^B \qquad (3)$$

The pigment biomass usually depends on depth, z, so that eq^n. (3) can be written as

$$P(z) = B(z) \times P^B(z) \qquad (4)$$

From eq^n. (1) it is evident that production is dependent on available irradiance and in aquatic systems, irradiance is always a function of depth. Therefore the dependence of $P^B(z)$ on photon flux may be stated as

$$P^B(z) = p^B(I(z)) \qquad (5)$$

From eq^n. (4) and (5)

$$P(z) = B(z) \times p^B(I(z)) \qquad (6)$$

I(z) in the above eq^n. is a time dependent variable. Therefore eq^n. (6) can be rewritten as

$$P(z,t) = B(z,t) \times p^B(I(z,t)) \qquad (7)$$

The above equation computes production at discrete depths. To compute production of a layer (mixed layer, euphotic layer) of water column the above eq^n. has to be integrated over depth. Thus water column production P_z can be computed as

$$P_Z = \int_z P(z)dz = \int_0^\infty B(z)\, p^B(I(z,t))\, dz \qquad (8)$$

It is also necessary to integrate the above eq^n. which gives the instantaneous, water column rates through time to compute primary production for the day. Thus

$$P_{Z,T} = \int_0^D \int_0^\infty B(z,t)\, p^B(I(z,t))\, dz\, dt \qquad (9)$$

Where time t is measured from sunrise and D is the day length. For integration through time, it is usual to consider that diurnal changes is sufficiently slow to be insignificant. *i.e.*, the time dependence of B in above equation is suppressed to give

$$P_{Z,T} = B(z,t)\, p^B(I(z,t))\, dz\, dt \qquad (10)$$

his is the basic formalism for computation of water column primary production and evaluation of equation (10) about B, p^B and I under various assumptions has resulted in empirical, semi-analytical, analytical algorithms.

IV. Estimation of Primary Productivity using Remote Sensing Techniques

Satellite measurements of ocean color have played a key role in understanding of oceanographic processes from local to regional to global scales. The measurement of ocean color from space has revealed for the first time, the global-scale variability in the distribution and concentration of phytoplankton, which provides the ultimate source of food for marine life. Since phytoplankton pigments absorb energy primarily in the red and blue regions of the spectrum and reflect green light, there is a relationship between the spectrum of sunlight backscattered by upper ocean layers and the distribution of phytoplankton pigments in these layers. Satellite measurements of ocean radiance at selected wavelengths can thus be used to estimate near-surface phytoplankton concentrations and the extent of primary productivity.

For the last 20 years ocean colour data became widely available and provided an opportunity to analyze the spatial and temporal variability in upper ocean chlorophyll distribution. The fundamental problem is regarding the utilization of ocean colour measurements for estimating the Primary production. This includes 1) algorithm development, classification and similarities and differences among the available productivity algorithms 2) algorithm parameterization 3) algorithm testing and validation. The problem in the development of PP models has been that the sea truth has changed with time. Within the past two decade estimates of global Oceanic primary production have been revised upward by about two fold, to about 50 Gt C/y. The increase in estimated global pp is based on the belief that the historical radiocarbon measurements were poisoned by metals. The second problem is the in consistency in model development and structure.

Empirical, semi-empirical and analytical methods are used to estimate the concentration of chlorophyll-a and its degradation products from satellite measurements of backscattered sunlight at three wavebands centered at 443, 520, and 550 nm, covering the blue and green regions of the spectrum. These radiances are not merely reflected from the sea surface, but are derived from sunlight that has entered the ocean, been selectively absorbed, scattered and reflected by phytoplankton and other suspended material in the upper layers, and then backscatter through the surface. This approach permits quantitative estimates of phytoplankton pigment concentrations within the upper tens of meters of the open ocean, and within somewhat lesser depths in coastal waters

For the non-specialist (and others) the ***Standard Products*** might be just what you need if you are looking for ocean productivity data. For more specialist applications where you want to compare or use productivity products from different models or sensors (OCM, SeaWiFS and MODIS), you should refer to the defined in ***Custom Products.***

Standard Products

Global PP products are derived using two operational semi-empirical and mixed layer model. NASA is providing the Global PP data at different time and space scales. Such algorithms are Vertical Generalized Production Model (VGPM). The VGPM algorithm integrates productivity over the euphotic depth and uses a seventh order polynomial to estimate the quantum efficiency for photosynthesis as a function of sea surface temperature. The Howard-Yoder-Ryan algorithm differs from the VGPM algorithm in that it calculates the average radiative energy over the mixed-layer, and the maximum photosynthetic yield, as an exponential function of temperature. The algorithm uses these to compute carbon fixation per volume over the depth of the mixed-layer, Pz, which is multiplied by the mixed-layer depth, Zml, to integrate productivity to that depth. The algorithm, as it was first presented in a master's thesis by Howard in 1995 and currently NASA is producing global PP products using parameters.

A standard productivity product initially has been developed using the Vertically Generalized Production Model (VGPM) (*Behrenfeld and Falkowski, 1997a*) as the standard algorithm. The VGPM is a "chlorophyll-based" model that estimate net primary production from chlorophyll using a temperature-dependent description of chlorophyll-specific photosynthetic efficiency. For the VGPM, net primary production is a function of chlorophyll, available light, and the photosynthetic efficiency.

VGPM Net Primary Production (NPP) calculations

The VGPM was first described by Behrenfeld and Falkowski (1997a) and is a commonly used algorithm for estimating regional to global ocean NPP. The foundation of the VGPM and other chlorophyll-based models is that NPP varies in a predictable manner with chlorophyll concentration (chl) that is a NPP = f(chl).

Because NPP is a rate and chlorophyll is a standing stock, derivation of the former from the later requires a "rate" term, specifically a chlorophyll-specific assimilation efficiency for carbon fixation. The description of this rate term is the single most important uncertainty in all chlorophyll based models.

The VGPM employs a variable termed **Pb_opt,** which is the maximum daily net primary production found within a given water column and expressed in units of mg carbon fixed per mg chlorophyll per hour. NPP at the depth of Pb_opt is thus:

NPP = chl * pb_opt * day length

where day length is the number of hours of day light at the location of interest and NPP is milligrams of carbon fixed per day per unit volume.

Water column NPP is generally regarded as the primary production taking place from the surface to the depth at which 1% of surface light is available, this light depth the "euphotic depth" or "z_eu". If you were to consider the hypothetical condition where photosynthetic rates were uniform from the surface to z_eu, then water column production could simply be calculated as:

NPP = chl * pb_opt * day length * z_eu

or, in words, surface production times the euphotic depth.

In the real world, however, photosynthesis through the water column is far from constant. The most important factor driving this vertical variability is light. As sunlight penetrates the water column, some of it is absorbed and scattered backward. Consequently, sunlight decreases rapidly with depth in a near exponential manner. If it is really bright at the surface, photosynthesis will be light saturated and relatively constant in the upper layer, but eventually it will begin to decrease with depth toward z_eu. If surface light levels are low (e.g., cloudy day or high latitude winter), photosynthetic rates will be maximal right at the surface and decrease rapidly throughout the euphotic zone. These effects of light on water column production are accounted for in the VGPM by including a light-dependent term, f(par), in the volume function:

volume function = f(par) * z_eu

The f(par) term can be thought of as the ratio of realized water column integrated NPP to the maximum potential NPP if photosynthetic rates were maintained at maximum levels (*i.e.*, Pb_opt) throughout the water column. The paramterization of this light-dependent term in the VGPM was determined empirically using thousands of field productivity measurements and is given by:

f(par) = 0.66125 * par / (par + 4.1)

Replacing the "volume function" with the above two equations, yields the basic VGPM relationship:

NPP = chl * pb_opt * day length * [0.66125 * par / (par + 4.1)] * z_eu

For more details on the volume function, the f(par) relationship, and differences between NPP algorithms, see Platt & Sathyendranath (1993) and Behrenfeld & Falkowski (1997b).

Pb_opt Parametrization

Chlorophyll-based NPP models take many forms. Some models are simple expressions relating surface properties to water column integrated products. At the end the two primary factors that control differences and similarities between chlorophyll-based NPP models are the choice of input chlorophyll data and the description of how light-saturated photosynthetic efficiencies vary in the environment. All NPP models require this description of physiological variability(whether it is based on daily integrated production measurements) (Pb_opt) or "instantaneous" photosynthesis-irradiance measurements (Pb_max)] and it is universally the "Achilles tendon" of each algorithm.

For the standard VGPM, physiological variability is linked to the Pb_opt variable and it is described as a function of sea surface temperature. The general shape of the VGPM Pb_opt function is one of rising values from -1 to 20 degrees Celsius and then decreasing values above 20 degrees C.

The function was derived by fitting a polynomial to a large number of field Pb_opt values:

pb_opt = sum(i=0,7) ai * (sst/10)i**

Parameter values and a description of the data can be found in Behrenfeld & Falkowski 1997b. From a physiological standpoint, the dependence of Pb_opt on temperature is not envisioned as reflecting a direct effect of temperature on carbon fixation efficiencies. Instead, Pb_opt initially rises with temperature because there is a general correspondence between increasing temperature and increasing surface light levels and photoacclimation to higher light yields higher chlorophyll-specific photosynthetic efficiencies (thus, Pb_opt). The decrease in Pb_opt above 20 degrees C is attributed to nutrient stress effects on light-saturated net primary production. Specifically, macronutrients become vanishingly scarce in warm surface ocean waters. The standard VGPM Pb-opt relationship emphasizes the nutrient-stress effect at high sea surface temperatures (SSTs), while the Eppley-VGPM Pb_opt relationship emphasizes the photoacclimation effect at high SSTs (see Website Home Page for more discussion.)

Euphotic depth (z_eu)

Euphotic depth (z_eu) in the VGPM is calculated using the Morel and Berthon (1989) Case I model. This model estimates z_eu from surface chlorophyll concentrations and is based on empirical equations to fit field data. In practice, total water column chlorophyll concentration is calculated from satellite surface chlorophyll using a formula that distinguishes between lower and higher chlorophyll waters. Then, given the amount of total chlorophyll, the euphotic depth is estimated, again using separate equations for lower and higher total chlorophyll conditions. In essence, light penetration is inversely related to chlorophyll: the more phytoplankton, the shallower the euphotic depth, and vice versa.

The standard VGPM equation is: NPP = chl * pb_opt * day length * f(par) * z_eu

Mixed layer primary production

Currently models which calculates Primary production ranges from empirical, semi empirical to highly parameterized analytical models of P-I relationships using derived in-situ spectral irradiance and chlorophyll distribution from ocean colour sensors. All these models have its own advantages and advantages, but these models use constants for parameters which in nature are inherently variable functions of space, time, species composition and spectral irradiance. Many of the current productivity algorithms calculate total light energy absorbed by chlorophyll and satellite chlorophyll concentration are computed from the ratios of water leaving radiances which leads maximum uncertainty. Satellite derived chlorophyll represents only the surface chlorophyll or to the first optical depth. Many of the times chlorophyll increases with depth and attains maximum and starts decreasing with depth with in the mixed layer. This shows that the seasonal changes PP is mainly depends upon the vertical profiles of the chlorophyll and its changes with in the mixed layer. For computing annual PP it requires seasonal PP, its variability and accounting the peaks of Primary production with in the water column (seasonal and spatial variability). The basic requirements are the structure of Vertical chlorophyll profile and Mixed layer variability and description of chlorophyll & MLD relation. High insolation and week winds results in thin Mixed layer representing oligotrophic conditions during inter monsoon period in Arabian sea. During May MLD is mostly less than 50 meters and pigment concentration is less than 0.1 mg/l. In contrast to this winter and summer season results in deepening of MLD and strong regional phytoplankton blooms observed in most part of the Arabian sea. (Banse and McClain1986, Bauer *et al.,* 1991, Brock *et al.,* 1991 and Brock & McClain 1992), Blooms are due to vertical mixing or due to convective overturn. These studies reveals that the column PP mainly depends upon the vertical structure of chlorophyll and MLD and its seasonal variability (Plat 1986).

Basic methodology

1. Compute light available at sea surface
2. Estimate biomass at surface
3. Define biomass profile
4. Estimate parameters of P-I model
5. Compute parameters of light transmission
6. Compute primary production

Required Parameters

Surface Irradiance (PAR)

Irradiance (PAR) Profile Or (K)

Surface Chlorophyll and Chlorophyll Profiles

P-I Parameters ($P^B m$, α^B)

Sea Surface Temperature (SST), Mixed Layer Depth (MLD)

and *in-situ* PP measurements at selected places and also to construct compute estimation P I parameters.

Conclusions

The entire marine food chain depends on the rate of primary production of organic matter. For most of the ocean, photosynthetic primary production dominates, and is carried out by the phytoplankton. To first order, the rate of primary production is proportional to the biomass, either measured in carbon or chlorophyll units. Photosynthesis consists of the photolysis of water, and the subsequent reduction of carbon dioxide to form organic matter. Oxygen is produced as a byproduct. Photosynthesis consists of light and dark reactions, and can be measured using the uptake of radioactive carbon dioxide, or the evolution of oxygen. The relationship between primary production and irradiance typically is linear at low light, then saturates, and may be inhibited at high light. The rate of primary production on a local and global scale can be estimated from the solar irradiance, the attenuation of light, the distribution of biomass, and the photosynthesis-irradiance curve, suitably integrated in time and space.

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CHAPTER 22

CHANGES IN PRIMARY PRODUCTIVITY AND IMPACTS IN FISHERIES

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Introduction

Fixation of inorganic carbon to organic carbon in the ocean is driven purely by phytoplankton. Phytoplankton carbon fixation plays an important role in maintaining the quasi-steady state level of atmospheric CO_2. Relative contribution of marine primary productivity to global photosynthetic production is between 10 and 50 percent. The magnitude ranges from 20 to 55 Gt of C/ year (Ryther, 1969; Walsh, 1984; Martin 1992). Ocean-atmospheric coupled climate models predict changes in the ocean circulation and hypothesize that changes in the ocean circulation will stimulate phytoplankton biomass production in the nutrient depleted areas in the open ocean (Roemmich and Wunsch, 1985). The effect on atmospheric CO_2 is uncertain because the relationship between the enhanced primary production and air-sea exchange of CO_2 is not understood. The challenge is to study the magnitude and variability of primary productivity, its time scales and changes in atmospheric forcing and upscale it into secondary and tertiary productivity.

Northern Indian Ocean (NIO)- atmospheric composition of productive zones

The Northern Indian Ocean (NIO) comprises a unique variety of biogeochemical provinces, including eutrophic, oligotrophic, upwelling, and oxygen-depleted zones, all within an area of relatively small geographic extent. This reflects the pronounced semi-annual reversals in regional winds (the seasonal monsoons) that make this region a focus for intense study. Previously published sea-air flux estimates indicate that the NIO could account for 12-52% and 0.1-133 % respectively of the known oceanic sources of N_2O and CH_4. Even though the uncertainties are large, particularly for CH_4, the Arabian Sea/NWIO could be an important contributor to the marine CH_4 source and a dominant global source of atmospheric N_2O. The atmospheric inventories of N_2O and CH_4 are currently both increasing by about 0.3% per year. Both gases are strongly active and together account for 18% of enhanced greenhouse forcing. N_2O is implicated in the generation of stratospheric NO_2, which influences stratospheric O_3 levels, and CH_4 participates in the photochemistry or tropospheric O_3 and OH and in the formation of stratospheric H_2O. Existing estimates of oceanic N_2O and CH_4 sources are dominated by disproportionately large contributions from biologically productive areas such as the NIO. However, because the spatial and temporal coverage of such regions remains limited, our global estimates remain unsatisfactory. Future climatically induced modifications to the upwelling and circulation characteristics of the NIO and other regions experiencing strong wind-driven upwelling may have profound effects on future biogas emissions from the oceans.

Computing and integrating column Primary Production using satellite remote sensing- A preliminary approach

Integrated *in-situ* column primary production (PP) can be estimated and computed at biome level using *in-situ* and satellite remote sensing (SRS) data by adopting suitable mixed layer PP model. SRS methods can be applied for computing primary productivity to integrate at biome level.

Chlorophyll is an important indicator of the quality of aquatic ecosystems that are amenable to *in situ* and space borne measurement. This property can be retrieved from ocean colour data after removal of the atmospheric signal from the detected radiance. Phytoplankton blooms (indicated by rapid increase in chlorophyll concentration) and spurts in primary productivity are important for maintaining the marine organisms at higher tropic levels, but when associated with eutrophication and harmful algal blooms, as noticed in the coastal waters of India, such events are directly linked (negatively) to the quality of water. Another important measure of water quality in the coastal environment is the suspended sediment load. Together with chlorophyll concentration they determine water light penetration, and light available for photosynthesis. Optical instruments such as spectral radiometers are able to monitor changes in chlorophyll and suspended sediment load in real time. Furthermore, such measurements can form the basis of local algorithms for application in remote sensing, allowing the results to be extrapolated to the entire study area through remote sensing. Optical methods for monitoring water quality and productivity have been established in other marine environments, for example in the USA. In India, a start in this direction has been established and operationalized by the SATCORE programme of ESSO-INCOIS.

Can we reach to fish biomass from primary production estimates?

Marine resources, especially fishery resources, have a strikingly important place of prominence in the biodiversity map of the earth. Their dynamics have very important influence; both direct as well as derived, on the wealth, health and eco-balance of many a maritime nations. Context to the afore mentioned issue in the region can never be overstated with a prominent chunk of future requirement of socio-economic and nutritional sustenance centered in the marine sector. Towards establishing a scientifically deduced relationship between the marine environment and the resource availability on a realistic basis, there is a need for a focused application of established easy-to-surveil oceanic, geophysical and physicochemical parameters and their direct or latent influence upon plankton, which happens to be the self-replenishing source of food and nutrition for fishery resources.

The spatio-temporal fluctuation of plankton richness, which can be remotely sensed, has long been established as a major factor in predicting resource richness in general and congregation and catchable availability in particular. Taking cue from these established models, paradigms can be designed to predict the resource availability from easy-to-observe parameters after a thorough validation of the prediction scenarios juxtaposed with the estimated catch attributable to various fishing grounds. The change in the pattern of fishing, period of absence and the composition of fish caught per haul, when analysed for a range of geo-spatial expanses would help refining and augmenting the existing paradigms resulting in a comprehensive prediction algorithm. Further, such models would come in handy in the assessment of marine resource potentials and their periodic revalidation on a homogenous platform with a proper measure of confidence interval.

A simple exercise to estimate biomass from primary productivity for conceptualizing the idea

Authors	**Estimated 1^0 productivity**	**Extrapolated fish production**	**Remarks**
Riley, 1945 in Rabinowitch, 1945	375 kg C/km^2 annually= 3.75 tonnes/ha	**15.5 million tonnes** (Indian Ocean)	8 times higher than terrestrial productivity
Steeman Nielsen and Jensen, 1957 Galathea expedition	40% for respiration from net productivity averages globally 1.2-1.5*10^6 tons	**2 million tonnes** (Indian Ocean)	Average annual production of hydrosphere similar to terrestrial productivity
Steeman Nielsen and Jensen, 1957	Eutrophic area productivity high	0.2-0.3% of fixed carbon as fish removed annually	High level of efforts in coastal waters with active fishery
Rhyther, 1959	Seasonal maxima also addressed	**3 million tonnes** (Indian Ocean)	Sea twice as productive as land
Schaefer, 1965	1.9*10^6 tons of organic carbon for all seas as average	200*10^6 tonnes for world oceans **40 million tonnes** (Indian Ocean)	Fish production 0.03% of potential
Raghuprasad *et al.*, 1969	Compilation of all the above	100 million tonnes (world oceans) **20 million tonnes** (Indian Ocean)	0.4% of potential harvested

(All the estimates were based on primary production – Organic carbon biomass generated by the producers)

Calculation of potential estimates of fishery from primary productivity estimates for Indian Ocean basin scale (Raghuprasad *et al.*, 1969)

Average annual productivity of Indian Ocean (Anton Brunn survey)	:	$3*10^9$ tonnes of Carbon = 0.35 hC/m^2
Respiration requirement	:	40% of organic production
Average net production	:	0.24 gC/m^2/day (Western Indian Ocean) 0.19 gC/m^2/day (Eastern Indian Ocean)
Area	:	$29*10^6$ km^2 (Western Indian Ocean)
	:	$22*10^6$ km^2 (Eastern Indian Ocean)
Net production of carbon	:	$2.3*10^9$ (Western Indian Ocean) $1.6*10^9$ km^2 (Eastern Indian Ocean)
Total fish yield (0.03% of net production)	:	12.6 million tons In 1967 the production was 2.1 million tons. A six fold increase in catch is possible as per the potential estimated

Estimates based on ecological efficiency

- Estimates of potential yield on annual basis is calculated and the potential biomass at the safest level (@10% ecological efficiency level)
- 23 million tons of fish from Western Indian Ocean and
- 15 million tons from Eastern Indian Ocean
- Total of 38 million tons possible from the entire Indian Ocean

Estimation of potential fish yield from zooplankton biomass

Zooplankton biomass estimated for Western Indian Ocean	=	$3.25*10^8$ tonnes
Zooplankton biomass estimated for Eastern Indian Ocean	=	$1.94*10^8$ tonnes
At 10 % ecological efficiency level		
Theoretical estimate from carbon production for Western Indian Ocean	=	$2.3*10^9$ tonnes
Theoretical estimate from carbon production for Eastern Indian Ocean	=	$1.6*10^9$ tonnes
Potential fish biomass estimated for Western Indian Ocean	=	18 million tonnes
Potential fish biomass estimated for Eastern Indian Ocean	=	11 million tonnes
Total fish biomass estimated for Indian Ocean	=	**29 million tonnes**

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CHAPTER 23

INDIAN OCEAN PHYSICS AND REGIONAL OCEANOGRAPHY OF THE NORTH INDIAN OCEAN

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Underlying physics

Currents and associated features in the oceans can be addressed by Newton's second law of motion as follows:

$$\text{acceleration} = \text{force/unit mass}$$

where force is the sum of pressure gradient, coriolis force, gravity and friction. Among them, the pressure gradient on the ocean surface is generated by the differential heating by the sun, unequal distribution of salinity and gravitational force. Coriolis force is an apparent force that deflects moving objects towards right in the northern hemisphere and towards left in the southern hemisphere due to earth's rotation. Gravity is the force that attracts all objects towards its centre, whereas friction is a retarding force.

Upwelling / downwelling

In some coastal areas of the ocean, the combination of persistent winds, Earth's rotation (the Coriolis effect) and restrictions on lateral movements of water caused by shorelines and shallow bottoms induces upward and downward water movements. Due to Coriolis effect, surface water moves at about 90 degrees to the right of the wind direction in the Northern Hemisphere and to the left of the wind direction in the Southern Hemisphere. Consequently, wherever coast is on the left side of the coast in northern hemisphere, surface water moves away from coast and subsequently, subsurface moves vertically upward to compensate the displaced water at the surface. This vertical movement is known as upwelling. Upwelling brings nutrient rich waters to the surfaces and thus induces high productivity. Contrary to this, when coast is on the right side to the wind direction in the northern hemisphere, reverse process of vertically downward movement occurs. This process is known as downwelling, which is counterproductive. Off the Somali coast, southwest coast of India and certain portions along the east coast of India are well known upwelling regions during the southwest monsoon period in the north Indian Ocean. Generally, downwelling happens during the northeast monsoon season. In addition, along the equator, when winds are easterly (going to west) due to the opposing directions of Coriolis force on either side of the equator, upwelling is induced along the equator, whereas downwelling occurs when the winds westerly (going to east). Due to the seasonality, wind regimes are becoming easterly (during Jan-Feb and Aug-Sep) and westerly (during Apr-May and Oct-Nov) alternatively twice in a year.

Kelvin waves

Due to the occurrences of alternate wind regimes along the equator as described above, both upwelling and downwelling Kelvin waves are generated and propagate eastward. Reaching at eastern boundary, these waves are bifurcated and one branch encircles the entire Bay of Bengal as coastally trapped wave with the coast on right side. Among the four waves mentioned above, the second downwelling Kelvin wave reaches even up to the South Eastern Arabian Sea (SEAS) and induces anticyclonic eddy. Similarly, during the initial phases of upwelling, the influence of upwelling Kelvin wave has also been observed in SEAS.

Indian Ocean Currents

The South Indian Ocean currents follow generally the pattern of the Atlantic and Pacific but with differences in the North Indian Ocean caused principally by the seasonal monsoons induced by the land masses that limit northward extent of the ocean in the Northern Hemisphere. Moreover, the Indian Ocean is connected to the Pacific Ocean through the Indonesian Sea, which is the only pathway that connects different ocean basins in the tropics, and therefore plays a pivotal role in the coupled ocean and climate system. During the northern hemisphere winter, the North Equatorial Current and South Equatorial Current flow toward the west, with the weaker, eastward Equatorial Countercurrent flowing between them, as in the Atlantic and Pacific (but somewhat south of the equator). But during the northern hemisphere summer, the North Equatorial Current and the Equatorial Countercurrent are replaced by the Southwest Monsoon Current, which flows eastward and southeastward across the Arabian Sea and the Bay of Bengal. Near Sumatra, this current curves in a clockwise direction and flows westward, augmenting the South Equatorial Current, and setting up a clockwise circulation in the northern part of the Indian Ocean. Off the coast of Somalia, the Somali Current reverses direction during the northern hemisphere summer with northward currents reaching speeds of 5 knots or more and with intense upwelling unlike in the other oeans. Twice a year, around May and November, westerly winds along the equator result in an eastward Equatorial Jet which feeds warm water towards Sumatra. As the South Equatorial Current approaches the coast of Africa, it curves toward the southwest, part of it flowing through the Mozambique Channel between Madagascar and the mainland, and part flowing along the east coast of Madagascar. At the southern end of this island the two join to form the strong Agulhas Current, which is analogous to the Gulf Stream. South of South Africa, the Agulhas Current retroflects, and most of the flow curves sharply southward and then eastward to join the West Wind Drift; this junction is often marked by a broken and confused sea, made much worse by westerly storms. A small part of the Agulhas Current rounds the southern end of Africa and helps form the Benguela Current; occasionally, strong eddies are formed in the retroflection region and these too move into the Southeastern Atlantic. The eastern boundary currents in the Indian Ocean are quite different from those found in the Atlantic and Pacific. The seasonally reversing South Java Current has strongest westward flow during August when monsoon winds are easterly and the Equatorial jet is inactive. Along the coast of Australia, a vigorous poleward flow, the Leeuwin Current, runs against the prevailing winds. West India Coastal Current (WICC) off the southwest coast of India is analogous to the above current during northeast monsoon. However, during southwest monsoon, WICC is southward and support significant upwelling as seen in the eastern boundary currents in the other ocean basins. Similarly, East India Coastal Current (EICC) off the east coast of India is analogous to the other ocean basin currents during pre-monsoon with the presence of a very significant northward boundary current. This current also is associated with upwelling at most of the regions. During the progress of the southwest monsoon, EICC reverses its direction to southward.

Ocean Eddies

Eddies with horizontal diameters varying from 50-150 km have their own pattern of surface currents with circulation around their axis at centre. These features may have either a warm or a cold core and currents flow around this core, either cyclonically for cold cores or anticyclonically for warm cores. Maximum speed associated with these features is about 2 knots. Rings have also been observed to pinch off from the Agulhas retroflexion in the south Indian Ocean. Similarly, strong anticyclonic eddies are occasionally spawned at many locations in the north Indian Ocean. These eddies induces vertical movement of waters causing upwelling/downwelling at the centre and periphery.

El Nino / La Nina (Tele connection to Indian Ocean)

El Niño and La Niña events are a natural part of the global climate system. They occur when the Pacific Ocean and the atmosphere above it change from their neutral ('normal') state. El Niño events are associated with a warming of the central and eastern tropical Pacific, while La Niña events are the reverse, with a sustained cooling of these same areas. These changes in the Pacific Ocean and its overlying atmosphere occur in a cycle known as the El Niño–Southern Oscillation (ENSO). The atmosphere and ocean interact, reinforcing each other and creating a 'feedback loop' which amplifies small changes in the state of the ocean into an ENSO event. Influence of these events on variability of the Indian Ocean surface layer characteristics and monsoon conditions is well established.

Indian Ocean Dipole

The Indian Ocean Dipole (IOD), also known as the Indian Niño, is an irregular oscillation of sea-surface temperatures in which the western Indian Ocean becomes alternately warmer and then colder than the eastern part of the ocean. Monsoons in India are generally affected by this phenomenon.

CHAPTER

24

UPWELLING OVER THE EASTERN ARABIAN SEA

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Introduction

Upwelling is a vital oceanographic phenomena determining the biological productivity of the coastal oceanic provinces in a greater extent. The annual pelagic fisheries of coastal rim countries, adjacent to the eastern boundary of the Ocean, over the trade wind zone are greatly dependent on upwelling. Over the North India Ocean (NIO), west coast of India, adjacent to the eastern Arabian Sea is well known for its seasonal occurrence of upwelling and downwelling annually. Over the past, several authors have studied upwelling along the west coast of India (Banse 1959, 1968; Sharma 1978; Johannessen *et al.*, 1987; Gopalakrishna *et al.*, 2008; Smitha *et al.*, 2008; Jayaram *et al.*, 2010: Shah *et al.,* 2015). Smith (1962) provided a generally accepted definition of upwelling in 1962 and as follows. "Upwelling is the ascending motion of some minimum duration and extent by which water from the subsurface layers is brought in to the surface layer and is removed from the area of upwelling by means of horizontal flow". Wherever they occur, upwelling was characterized by upward movement of Isotherms/Isopycnals, lowering of sea surface height, cooling of sea surface temperature than the surrounding areas and enhanced primary productivity.

According to the previous studies, upwelling sets in during April/May at deeper levels along the southern tip of India (8ºN) and progressively advances to the northern latitudes as the summer monsoon progresses. Surface manifestation of upwelling along the west coast of India is less conspicuous towards north above 15ºN latitude. Most intense upwelling was observed during July from 8ºN to 15ºN. Nevertheless summer monsoon winds are conducive for upwelling over the eastern Arabian Sea.

Rest of this tutorial will discusses the several proxies used in the study of vertical circulation and provided some insight on general phenomenon of upwelling and downwelling with a special emphasis to the eastern Arabian Sea.

Indices used for the study of upwelling

Several proxies are used in the study of upwelling and downwelling, some of them are based on the causative forces or the generation mechanisms, while the others are relies on the aftermath of these vertical motions.

Ekman mass transport due to the alongshore wind

Classical explanation of upwelling favors wind induced Ekman divergence as a fundamental forcing mechanism for the generation of upwelling. Along the west coast of India whenever the alongshore wind is parallel to the coast and is equatorward, it will leads to the offshore transport of surface water from the coast and consequently the surface water is replaced by subsurface water. This process is generally referred as upwelling. The offshore transport due to the alongshore wind is calculated as follows

Mass transport due to alongshore wind, $M_{ev} = \tau_y / f$

where τ_y is the alongshore wind stress and f is the Coriolis parameter ($2\Omega\sin\varphi$), Ω is the angular frequency of earth and φ is the latitude. The alongshore wind stress is calculated as follows

Alongshore wind stress, $\tau_y = \rho_a C_d \, w \, v$

where ρ_a is the air density, Cd is the nonlinear drag coefficient, w and v are the magnitude and alongshore component of the wind speed. Negative values of M_{ev} represents offshore transport and positive values indicates onshore transport. Along the west coast of India offshore Ekman transport was observed during the summer monsoon from May to

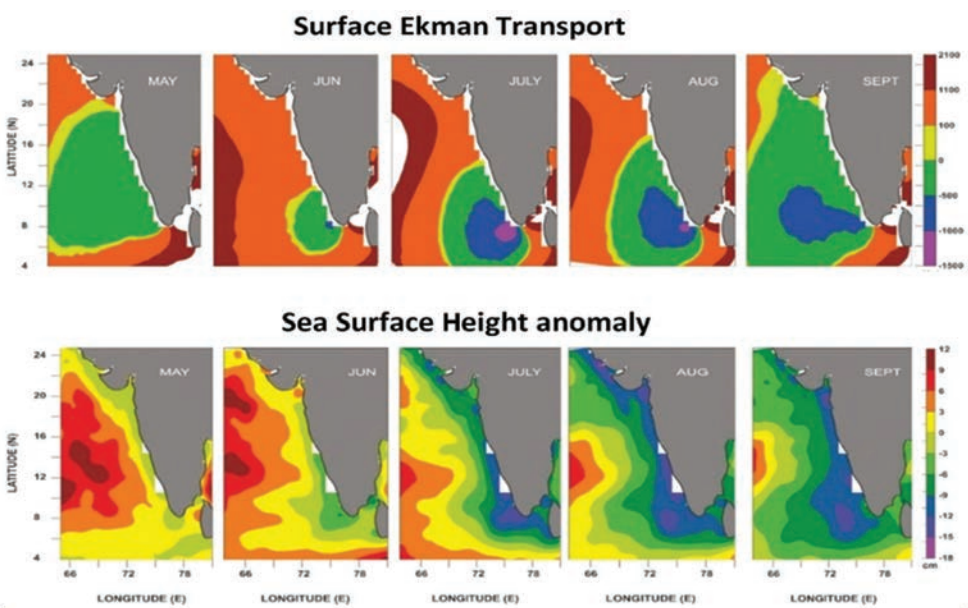

Fig. 1. Climatology of surface Ekman mass transport due to the alongshore wind (kg/m/s) [Upper panel] and Sea Surface Height Anomaly (cm) [Lower panel] along the west coast of India during the summer monsoon [Figure courtesy: Shah, 2016].

September and intense offshore transport and upwelling was noticed during the peak summer monsoon month July. Figure 1 (upper panel) represents the surface transport due to the alongshore wind.

Vertical movement of Isotherms

Since the upwelling areas are characterized by the replacement of the surface water by the subsurface water, upward movement of isotherms are used as a proxy for the study of upwelling. The analyses of figure 2 represents these upward movements are happened during May to September along the west coast of India. This is also substantiate the generation of upwelling during the summer monsoon months. Compared to the surrounding areas upwelling areas are cool because of the presence of subsurface water.

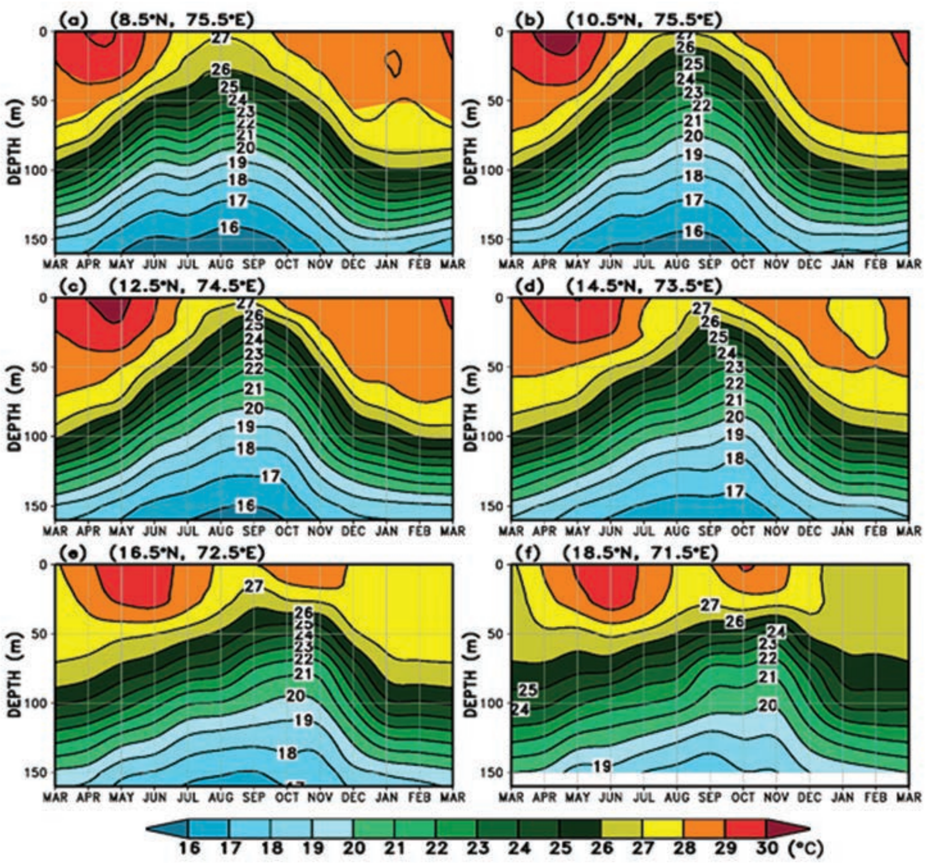

Fig. 2. Vertical oscillation of isotherms at particular latitudes along the west coast of India during a year (Climatology).

Sea Surface Height Anomaly

Because of the presence of subsurface water upwelling areas are characterized by sea surface cooling compared to the surrounding areas. Hence, inorder to maintain the isostatic balance upwelling areas are experienced by lowering of sea level than the surroundings. In tune with the observations on sea surface temperature, isotherms and Ekman mass transport, analysis on sea level anomaly along the west coast of India also shown a fall in Sea level anomaly during the summer monsoon and this fall is intensified during July (Fig.2, lower panel).

Chlorophyll-a

Along the west coast of India, upwelling enhances the nutrient concentration in the surface water during the summer monsoon from May to September. Consequently chlorophyll-a concentration along the coast increases compared to the surroundings (Fig. 3). Hence Chlorophyll-a concentration along coastal areas are used as a suggested proxy for the study of upwelling.

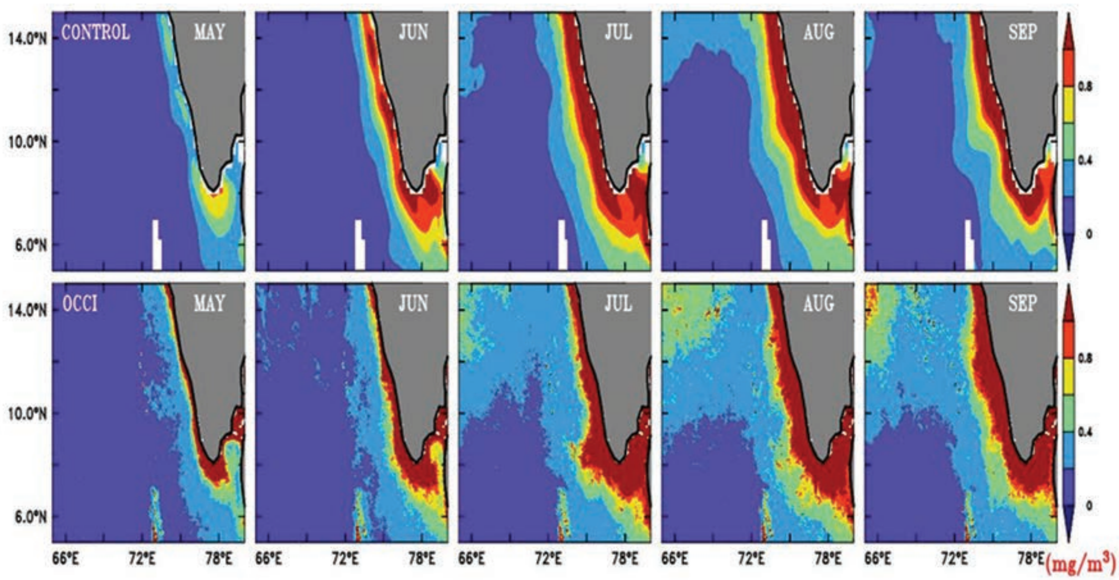

Fig 3. Chlorophyll -a concentration along the west coast of India during summer monsoon [climatology]

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CHAPTER 25

BIOGEOGRAPHY OF NORTHERN INDIAN OCEAN

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Biogeography is defined as the branch of science that deals with the large-scale distribution of flora and fauna in the context of environmental properties and topographic features. Studies on biogeography in Northern Indian Ocean have been relatively few. These lectures will survey the available literature, will mention as-yet unpublished work and will discuss possible future directions for biogeographical research in the Northern Indian Ocean.

General Characteristics of the Arabian Sea and Bay of Bengal

The Indian coastline is about 7517 km long, with 5423 km along the mainland and 2094 km in the Andaman and Nicobar, and Lakshadweep Islands (Table. 1). The Northern Indian Ocean includes the Arabian Sea to the west and the Bay of Bengal to the east of India. Arabian Sea is bounded by Pakistan and Iran in the north, Northeastern Somalia and the Arabian Peninsula in the west and by India in the east. Its total area is 3,862,000 sq.km and its maximum depth is 4,652 meters. Bay of Bengal is the largest one among the world bays. It forms the northeastern part of the Indian Ocean. It is bordered by India and Sri Lanka to the west, Bangladesh to the north and by Myanmar and the Andaman and Nicobar islands to the east. The Bay of Bengal occupies an area of 2,172,000 sq. km. A number of large rivers – the Ganges and its tributaries such as the Padma and Hooghly, the Brahmaputra and its tributaries such as the Jamuna and Meghna, and other rivers such as the Irrawaddy River, Godavari, Mahanadi, Krishna and Kaveri flow into the Bay of Bengal. Geographically, the Northern Indian Ocean is subdivided by several major islands – the Andaman and Nicobar Islands in the Bay of Bengal and the Lakshadweep in the Arabian Sea. The islands were formed as a result of various geological processes such as volcanism, seafloor spreading and continental drift. The Lakshadweep islands are a group of 36 low-lying coral islands, 10 of which are inhabited. The Andaman and Nicobar Archipelago in the Bay of Bengal, comprises 554 islands, some of which are merely large rocks. If these are excluded, the total number of islands is 294, of which 36 are inhabited.

The Arabian Sea covers the Gulf of Oman, the Persian Gulf and Red Sea, which is in total 1.8 times the area of the Bay of Bengal. The Carlsberg-Murray Ridge (Fig. 1) is one of the important features of the Arabian Sea. It plays a vital role in the process of upwelling (mixing up of nutrient rich dense cold water towards the ocean surface by wind driven motion). The continental shelf width is greater in the Arabian Sea compared with the Bay of Bengal (Table 1). Seven large rivers and several smaller ones discharge into the Bay of Bengal.

Riverine discharge is comparatively lower in the Arabian Sea. The difference in freshwater input between the two regions has led to decrease in surface salinity in BOB and higher salinity levels in the AS. The higher salinity and surface temperature in AS are also influenced by the influx of rich saline waters from the Persian Gulf and Red Sea and the intense thermal stratification in the northern Arabian Sea. Higher surface temperatures are observed in the Arabian Sea than the regions of Bay of Bengal. The thermocline is usually below 50-55m in the Bay of Bengal but occasionally it may lie between 100-125m. In the AS, in the cold months the thermocline descends to about 100-125m, then it moves up reaching in 20-30 m under the influence of wind. Surface currents show many differences between the regions. During the south-west monsoon, the surface currents in the equatorial regions of the north Indian Ocean are driven by the southwest monsoon winds and are therefore easterlies. Somalia current flows parallel to the coast of Somalia in the north-east direction, with a weak surface counter current on its right. The meridional components of the currents in the western half of the Arabian Sea are northerly while in the eastern half they are southerly. The surface currents in the BOB are easterly during the southwest monsoon period but they are very weak compared with the currents in the Arabian Sea. During the northeast monsoon,

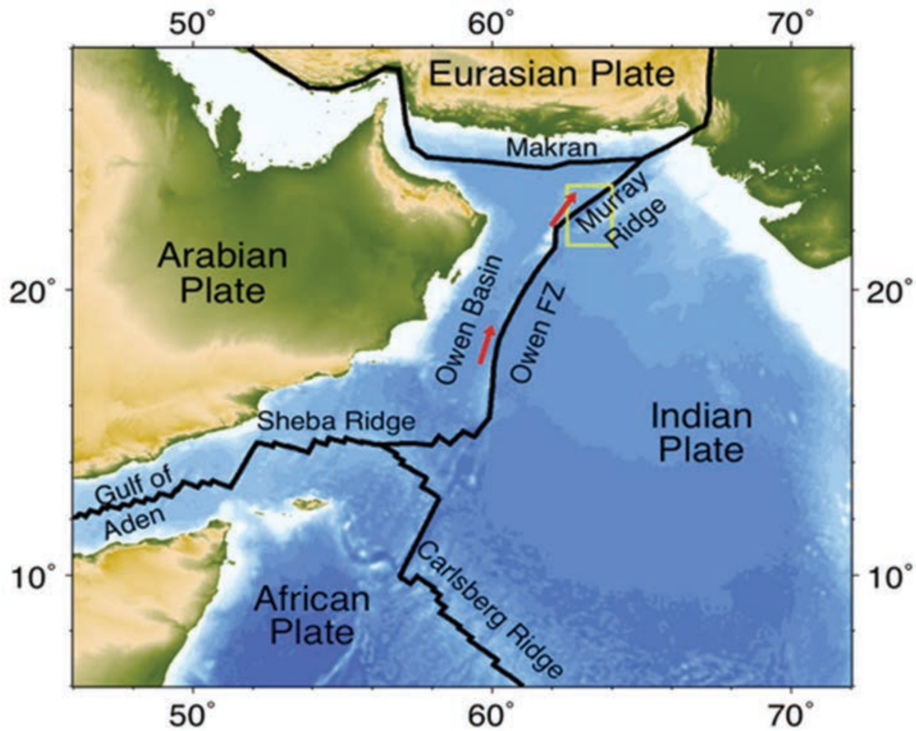

Fig. 1. Carlsberg - Murray Ridge in the west coast of India

the complete reversal of the surface currents takes place and the currents are westerlies in both Arabian Sea and the BOB. The seasonally reversing monsoon current is one of the important characteristic features of the Northern Indian Ocean.

Table 1. Coastal Resources of the Indian Ocean

Maritime states	Total length of coastline (sq. km)	Length of coast affected by erosion (km)	Continental shelf width ('000 km)
Gujarat	1214.7	36.4	184
Maharashtra	652.6	263	112
Goa	151	10.5	10
Karnataka	280	249.6	27
Kerala	569.7	480	40
Tamil Nadu	906.9	36.2	41
Andhra Pradesh	973.7	9.2	33
Orissa	476.6	107.6	26
West Bengal	157.5	49	17
Daman and Diu	9.5	0	-
Pondicherry	30.6	6.4	1
Total Mainland	5422.6	1247.9	-
Lakshadweep	132	132	4
Andaman and Nicobar	1962	0	35

(*Sanil Kumar *et al.*, 2006 obtained from Naval Hydrographic chart)

Biogeographic partitioning of an ocean or a region means finding the borders between biogeographical area based on the distribution of floral and faunal species (Golikov *et al.*, 1990). The Indian coast has important geological features and biologically productive areas such as sandy beaches, estuaries, sandy beaches, bays and creeks, lagoons, rocky shores, coral reefs, mangroves, marshes and mudflats. The East and west coast of India provide a wide range of habitats to plants and animals. The distributional patterns of floral and faunal species can be homogenous or heterogeneous, depending on both abiotic and biotic factors such as physical-chemical conditions and trophic structures. These factors shape the distribution of organisms, such that the biological communities are in harmony with their environment in space and time.

Phytoplankton

Phytoplanktons are a diverse group of unicellular microalgae metabolically and physiologically similar to higher plants. Phytoplankton play a major role in indicating the ecology of the region and it highly contributes as primary producer in the food web and are key partners in cycling of carbon and nutrients in the ocean. Diatoms, cyanobacteria, dinoflagellates and coccolithophores are the most dominant phytoplankton taxa in the Indian coastline. These groups are named as "phytoplankton functional types" because they play vital role in biogeochemical cycles of the marine ecosystem. Phytoplankton community structures vary from one place to another depending upon various environmental factors resulting in heterogeneous biogeographical patterns. The major factors that influence the biogeographical patterns of phytoplankton are (1) environmental conditions (e.g. temperature and nutrient concentrations), (2) interspecific relationships (*i.e.,* predation and competition), and (3) dispersal (Follows *et al.*, 2007). The distribution and species composition of phytoplankton determines the structure and functioning of the marine food web (Finkel *et al.*, 2007). Therefore, detailed investigations of the mechanisms that lead to certain phytoplankton biogeographical patterns can help us to understand better the processes involved in pelagic ecosystems and their response to a changing environment.

Early research in the phytoplankton of the Indian Ocean was conducted during the International Indian Ocean Expedition (1963). From the surveyed literature, approximately 600 species represent the phytoplankton community structure in the Northern Indian Ocean. Chrysophytes, cryptophytes, haptophytes, chlorophytes and prasinophytes are the diverse phytoplankton communities representing the Indian coastal waters. Dominant species reported in the Bay of Bengal region are *Proboscia alata, Climacodium frauenfeldianum* and *Thalassionema nitzchioides*. Associated species reported includes *Pseudo-nitzschia Pseudo delicatissima, Chaetoceros messanensis*, *Chaetoceros compressus, Thalassionema frauenfeldii, Thalassiothrix longissima, Leptocylinfrus minimus, Lauderia annulata, Guinardia striata, Thalassionema nitzchoides* and cyanobacterium *Trichodesmium* (D'Silva *et al.*, 2012; Paul *et al.*, 2007; Subrahmanyan *et al.*, 1971). Diatoms are the dominant groups found in the east and west coast of India. Proliferation of diatoms in these regions has been reported with sharp pycnocline, thermal stratification and deficiency of nutrients in the upper mixed layer (Sukhanova *et al.*, 2006; Tomas, 1997). There are reports of replacement of diatom dominance by the presence of *Trichodesmium* during the onset of monsoon in the Chennai, Port-Blair and Kolkata regions of the southeast coast and southwest coast of India (Mohanty *et al.*, 2010; Sahu *et al.*, 2014). *Noctiluca scintillans* and *Trichodesmium erythraeum* are the two common causative species of phytoplankton blooms in the Indian coast. Some species of diatoms and cyanobacteria (presence of cyanobionts) are capable of utilizing nitrogen and ammonium as a urea source. This indicates the symbiosis of nitrogen fixation by phytoplankton's in the nitrogen depleted environment of Bay of Bengal. Species such as *Chaetoceros coarctatum*, *Nitzschia sp*, *Dactyliosolen fragilissimus*, *Leptocylindrus danicus* and *Pseudo-nitzschia heimii*, *Oxytoxum nanum, Scrippsiella* sp. are the major dominant species occurred along the southwest coast and Gulf of Kutch and Khambhat (Ahmed *et al.*, 2016). Picoplankton such as *Synechococcus* and *Prochlorococcus* are reported from the tropical waters with influx of higher nutrients, representing the systems of regenerated production; which states that the north and southern eastern Arabian sea is one of the major region with higher nutrients reported during the upwelling in the summer monsoon season (Bhattathiri *et al.*, 1996; Madhupratap *et al.*, 1996; Ramaiah *et al.*, 1996; Roy *et al.*, 2006). There are two peaks of plankton distribution observed during March-April and October-November off the Mumbai (North West) coast of India. This peak coincides with the season of peak abundance of the commercial pelagic fishes *Bregmaceros mcclellandi* and *Harpodon neherus* in the North west coast of India (Gulf of Kutch and Khambhat) (Raghuprasad, 1968). These water masses are found throughout the stronger upwelling region, Somalia and Gulf of Aden with similar phytoplankton community structure.

Going by the literature, phytoplankton species in classified water masses undergo continuous changes over time in their dominance and diversity, a process that may be compared to terrestrial succession.

Zooplankton

Zooplankton plays an important role in the pelagic community structure as consumers of primary production. Literature on the plankton biomass and diversity of the Northern Indian Ocean covering all the seasons and regions is limited. The International Indian Ocean Expedition (IIOE) of 1960-1965 was the first attempt to describe the biogeography of zooplankton in the Arabian Sea based on quantitative data such as biomass and density (Currie, 1963). Based on the literature of Zooplankton diversity and distribution of the Northern Indian Ocean, approximately 7100 species of zooplankton were recorded from the Indian seas (Venkataraman and Wafar, 2005). The most common distribution of zooplankton includes copepods (Gajbhiye *et al.*, 1991; Haq *et al.*, 1973; Madhupratap *et al.*, 1990), ostracods (George and Nair, 1980; Stephen, 1996), euphausiid species (Mathew, 2000), amphipods (Nair and Jayalakshmi, 1992), total hydromedusae (Santhakumari, 1976, 1978, 1997), and chaetognatha (Nair *et al.*, 2002; Wishner *et al.*, 2001). The zooplankton biomass was reported to be highest in the northern and western Arabian Sea, the coasts of Somalia and Arabia (Somalia and Gulf of Aden and Persian Gulf), and also on the southwest coast of India (Southwest coast). Crustaceans followed by copepoda, rotifera, cirripede larvae, polycheates and cladocerans are the dominant groups found in these regions. Species reported are *Acartia* sp., *Acartia pacifica, Acartiella faoensis, Arctodiaptomus salinus, Oithona* sp., *Oncae* sp., *Alona affinis, Moina brachiate,* Mysid larvae and Zoea larvae of crabs (Ajeel, 2012). The southwest monsoon experiences two offshore current jets, one associated with the parting of the Somali Current from the coast. This jet brings up the upwelling of cooler rich water developing the blooms of diatoms *Nitzschia delicatissima* (Smith and Codispoti, 1980). Adult females and copepodites of *Calanoides carinatus* and *Eucalanus* spp., which can readily ingest the diatoms, were markedly more abundant only within upwelling areas along the Somalia coast during the southwest monsoon and not found elsewhere in the northern Arabian Sea.

The northwestern Arabian Sea *i.e.*, the Gulf of Kutch and Khambhat represents the higher density of Copepods. Some copepod species reported are *Gaussia princeps*, *Euchaeta* spp., *Haloptilus* spp., *Pontella* spp., and *Candacia* spp. Of the large calanoid copepods the family Eucalanidae dominates the Arabian Sea. During the summer monsoon, the peak and high densities of copepod abundances occur in the upwelling regions off Somalia and Gulf of Aden and far offshore regions of the Arabian Sea (Southwest and Gulf of Kutch and Khambhat). Copepods are the major dominant species reported in dominant during the southwest monsoon which is replaced by *Oithona* sp (Madhupratap *et al.*, 1990; Piontkovski *et al.*, 2013). The other dominant copepods, *Paracalanus*, *Clausocalanus*, *Acartia negligens*, and *Acrocalanus* sp., present in both the northeast and southwest monsoons are equally abundant within and outside the areas of upwelling. During the summer coastal upwelling, *Calanoides carinatus*, is an indicator species for upwelling in the tropical Indian and Atlantic Oceans. In offshore, non-upwelled waters, *Eucalanus attenuatus*, *Pleuromamma indica*, and *Pleuromamma abdominalis* were dominant (Smith, 1982, 1984, 1995). Some endemic species of the Arabain Sea and Bay of Bengal are copepod *Gaussia sewelli*, *hydromedusae Aglaura hemistoma* and *Solmundella bitentaculata*. Mysids belonging to the genera Paralophogaster are confined to the Red Sea and Arabian Sea, while the species *Siriella ionesi* is limited to the Arabian Sea. The Arabian Sea is stratified for several variables, with particular importance to zooplankton and fish associated to the intense oxygen minimum layer from about 150 to 1500 m, particularly on the east side.

The southeast coast of India was recorded with dominance of Ostracods, Salps, Chaetognaths and Decapods (Santhakumari and Saraswathy, 1981). Other taxa include Foraminifera, Calanoida, Cheatognatha, Appendicularia, Polychaeta, Hydrozoa and Echinodermata. Fish eggs and larvae occurrence was noted throughout the year and had peak abundance in summer (Soundarapandian and Varadharajan, 2013). The characterization of the zooplankton community structure is essential in detail to understand the life cycles, recruitment of the dominant species (zooplankton and fishes) of the physical domains of the coastal waters of the NIO.

Plankton Diversity and Pelagic fisheries

Plankton diversity is said to be an index of fertility not only in the water column but also at the sea bottom. Earlier attempts on studying the relationship between the plankton diversity and fisheries along the coasts of India were restricted mostly to specific areas either on the east or west coast of India. Studying the production of phytoplankton and zooplankton should give insight into the fishery potential of the study regions.

Indian Ocean is with rich plankton biomass, highly concentrated to the upwelling regions. There are several investigations on plankton biomass and relationship to potential fishery rich regions. From the surveyed literatures, it is seen that the seasonal rhythm in the organic production is well reflected in the fishery trends, *i.e.,* the peak of organic production corresponds with the low fishery periods and vice versa, suggesting an inverse relationship. Higher fishery yields were found after the peak organic production allowing some time for the conversion of the organic matter synthesized to form fish protein. Applying this concept, analyzing the trends of annual fish production in the recent years, the seasonal abundance of the pelagic fishes including Clupeidae, Scrombidae, Carangidae and Engraulidae are observed during October in the west coast of India. In the east coast, the seasonal abundance of pelagic resources is found during June-September. This abundance pattern in the west coast of India coincides with the post southwest monsoon with enrichment of nutrients by upwelling and plankton production. April to September remains calm and is favorable for fishing activities on the east coast.

Zooplankton distribution was 3.5 times higher in the southerly half of the west coast and 2.5 times more productive than the east coast. This is well reflected in the fish landings also, since the landings along the west coast are about three times those of the east coast. It is very evident that the zooplankton biomass is higher in the Arabian Sea than in the Bay of Bengal. If the abundance of zooplankton is an indication of the potential fishery resources of an area, there is possibility of substantial increase in the rate of exploitation particularly in areas such as the south-eastern coast of India, west Pakistan and Iran in the Arabian Sea region, Burma coasts, East Pakistan, West Bengal, Orissa and Sri Lankan coast, Andaman Sea in the Bay of Bengal. There are several reports on exploratory and commercial fishing activities in these areas of high plankton production and potentially rich fishing grounds. A good understanding of the biogeography of the region will support possible expansion of sustainable fisheries in Northern Indian Ocean.

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CHAPTER

26

FISHERIES OCEANOGRAPHY- ESTABLISHED LINKS IN EASTERN ARABIAN SEA

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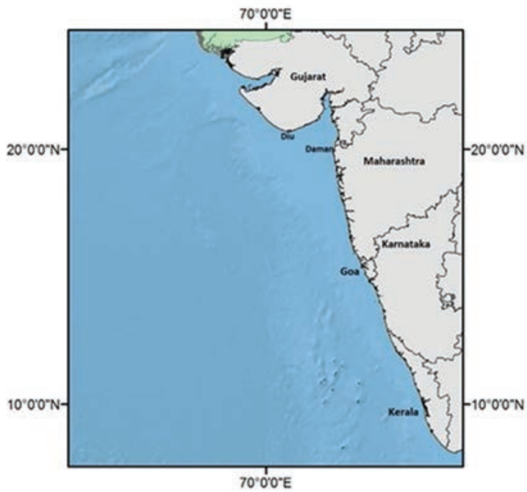
Introduction

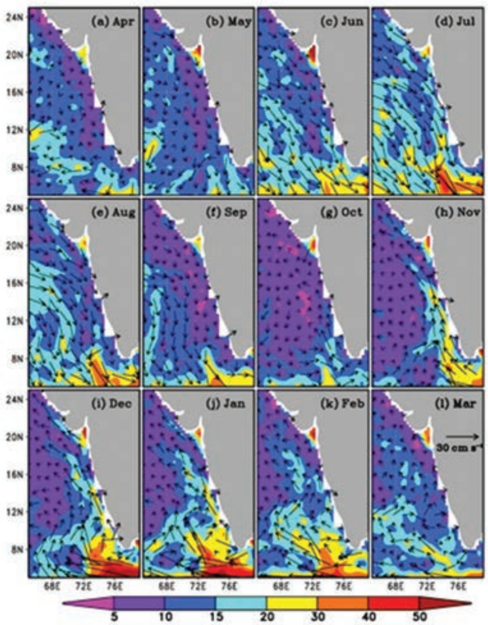
Fish distribution along the western Indian coastal waters indicates a bias for pelagic-planktivores to the southern coast and carnivores to the northern coast. Southwest coast of India is an upwelling zone rich in phytoplankton dominated by diatoms during summer monsoon. The landing centre observation data since 1985 clearly indicate a dominance of Indian oil sardine (*Sardinella longiceps*) in this upwelling zone. The physiological activity of the fish is also tuned to the arrival of summer monsoon. A resting season is expected with the retrieval of monsoon in this area. Further north of our coastal waters, we see that the dominant group of fishes includes the Sciaenids popularly known by the name 'Ghol' (*Protonibea diacanthus*), 'Koth' (*Otolithoides biauritus*) and 'Dhoma' (*Johnius dussumieri*). These fishes seem to flourish on the winter productivity in the northern coastal waters. The winter primary productivity in southern waters is not good enough to support carnivores with physiological active season during the winter. The productivity differences in the coastal waters in time and space and the oceanographic features supporting these could be studied from a synoptic scale with the help of satellite remote sensing and geographical information system. In this study, we have utilized the various open sources remote sensing data to identify the oceanographic responses and the physical forcing that govern the distributional preferences of some dominant marine fish species.



Variability in fish biodiversity – north and south of eastern Arabian Sea

The tropical waters are often characterized by high species diversity. Along the west coast of India, the number of species that contribute to the commercial fisheries is found to be higher in tropical waters than temperate regions. India, being one of the most prominent tropical fishing nations contribute about 3.5 million tons of fish annually. With a coastline of formidable (8129 km approximately) length, regional differences in catch composition have been observed consistently. Such differences may arise due to influence of multiple forcing factors of physical, chemical, geological and biological origin.

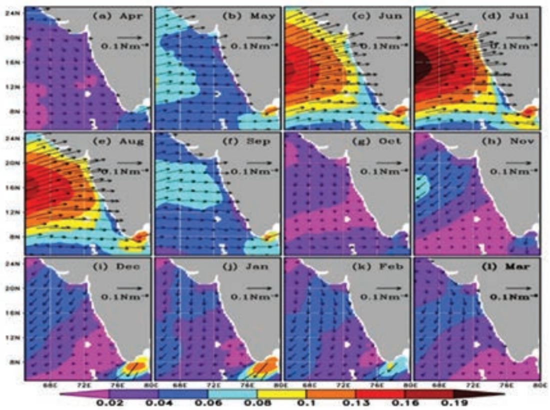
There exists a strong difference in catch composition along the west coast across the 15^0 N latitude with the planktivorous species dominating the South Eastern region and carnivorous species thriving in the North Eastern Arabian Sea (NEAS). However, the study was unable to explain this difference in catch composition and also highlights the due importance of the role played by feeding and breeding behaviour of fishes in order to adequately understand their response to oceanographic forcing. The relationship between oceanographic forcing (physical and chemical) upon fish response (spatial distribution) has remained largely elusive owing to the lack of synoptic-level datasets on the oceanographic variables which differentiates multiple ocean sites from each other.



Satellite remote sensing have played a pivotal role in addressing this data gap by offering the opportunity to systematically measure and monitor multiple oceanographic variables at desired resolutions. With the advent of remote sensing capabilities, optical responses of coastal waters can easily be monitored which makes ecological classification based on remote sensing reflectance possible. The South Eastern Arabian Sea (SEAS) exhibits a strong seasonality in remote sensing reflectance comparison to its north eastern counterpart. However, the general notion is that seasonal extremes in weather are more dominant in the temperate latitudes than in the tropics. Seasonal changes in the biological behaviour (breeding/ feeding) of fish have strong links with weather conditions. In order to ensure improved chances for survival of fish larvae, the physiological activity of adult fish should coincide with the onset of better food conditions in close proximity both temporally and spatially. Fish also exhibit a natural tendency to avoid predators and provide its larvae with best possible resources to ensure their survival to adulthood. In general, the most dominant commercial tropical fishes can be classified based on their feeding behaviour as planktivorous and carnivorous and their breeding responses exhibit a strong seasonality with the onset of summer and winter monsoon respectively.

There is a major role played by physical (winds, temperature, salinity, tidal amplitude and sea surface height), biological (surface chlorophyll, catch ratio, feeding and spawning behaviour of fishes) and geological (nature of shelf region) forcing in explaining the difference in catch composition.

Wind over the eastern Arabian Sea



Characteristic feature of the north Indian Ocean is the seasonal reversal of wind pattern and associated reversal of oceanic circulation. Being the part of north Indian Ocean eastern Arabian Sea also exhibits seasonal reversal of wind. During the summer monsoon season from May to September winds are south westerly (blowing from south-west) over the eastern Arabian sea. During the winter monsoon winds are north easterly (Blowing from north east). Principal eastern boundary of the Arabian Sea (west coast of India) is characterised by wind driven upwelling during summer monsoon. Compared to the winter monsoon, winds are stronger during summer monsoon.

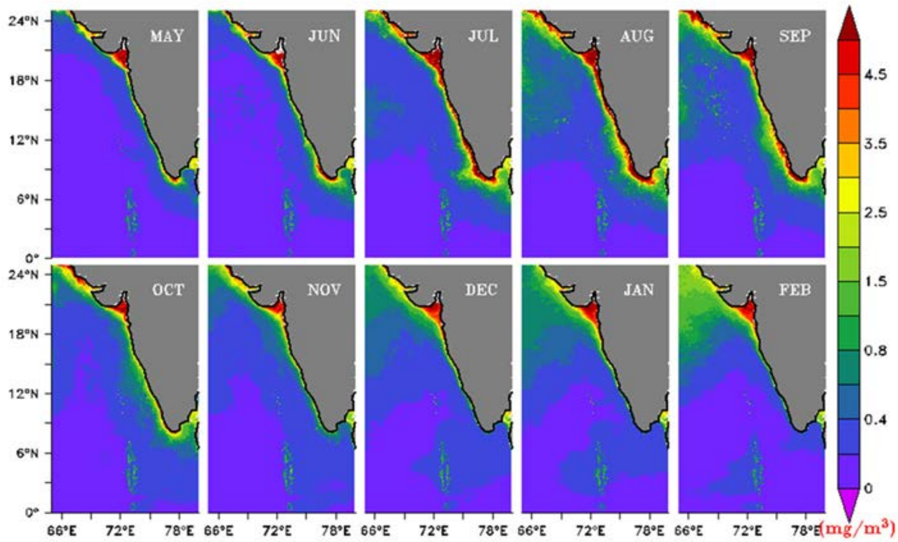
Currents over the eastern Arabian sea

In tune with the seasonal reversal of prevailing atmospheric circulation, current pattern over the Eastern Arabian Sea also exhibits a seasonal reversal. Principal eastern boundary current in the Arabian Sea is the west India coastal current and it reverses twice in a year. During the summer monsoon from May to September currents are equatorward along the west coast of India and during the winter monsoon from November to February it is poleward. Divergence of surface currents feeds the upwelling zones along the west coast of India during summer monsoon.

Chlorophyll - a concentration during Upwelling

Upwelling and downwelling are the two predominant mechanisms that determine the biological productivity over the eastern Arabian Sea. Productivity over the South eastern Arabian Sea mainly dependent on the upwelling during summer monsoon. Convective mixing and downwelling induced by coastally trapped waves during winter monsoon are the causative mechanism for the biological productivity over the north east Arabian Sea.

Chlorophyll concentration along the north-west coast of India maintains a threshold throughout the year, while south west coast of India is characterised by high biological productivity and Chlorophyll concentration during the period of upwelling from May to September. Cold coastal upwelling and subsequent phytoplankton growth are most evident along the eastern coasts of Seas.



CHAPTER 27

CLASSIFICATION TECHNIQUES FOR REMOTELY SENSED DATA

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1. Introduction

Hyperspectral imaging sensors measure the radiance of the materials within each pixel area at a very large number of contiguous spectral wavelength bands. So, they can generate hundreds of images of a scene on the real surface. The radiance is converted into hyperspectral data cube digital form. The spectral information available in a hyperspectral image (cube) may serve to classify the nature of the target object because every material had a unique fixed spectrum and could be used as a spectral signature of the material and perhaps provide additional information for further processing and exploitation. Hyperspectral data contain extremely rich spectral attributes, which offer the potential to discriminate more detailed classes with classification accuracy.

2. Cluster Analysis (Unsupervised learning)

Unsupervised learning is a type of machine learning algorithm used to draw inferences from datasets consisting of input data without labeled responses. The most common unsupervised learning method is cluster analysis, which is used for exploratory data analysis to find hidden patterns or grouping in data.

Cluster analysis is usually done in an attempt to combine cases into groups when the group membership is not known prior to the analysis. Cluster analysis is a technique for grouping individual or objects into unknown groups.

There are 4 basic steps to conduct cluster analysis for any data. Those are given below:

1. Select a suitable distance measure.
2. Select a clustering algorithm.
3. Determine the number of clusters.
4. Validate the analysis.

2.1 Clustering Methods (Johnson and Wichern, 2006)

The commonly used methods of clustering fall into two general categories.

(i) Hierarchical and

(ii) Non hierarchical.

2.1.1 Hierarchical cluster Analysis

Hierarchical clustering techniques proceed by either a series of mergers or a series of successive divisions. Agglomerative hierarchical method starts with the individual objects, thus there are as many clusters as objects. The most similar objects are first grouped and these initial groups are merged according to their similarities. Eventually, as the similarity decreases, all subgroups are fused into a single cluster.

Divisive hierarchical methods work in the opposite direction. An initial single group of objects is divided into two sub groups such that the objects in one sub group are far from the objects in the others. These subgroups are then further divided into dissimilar subgroups. The process continues until there are as many subgroups as objects *i.e.*, until each object form a group. The results of both agglomerative and divisive method may be displayed in the form of a two dimensional diagram known as Dendrogram. It can be seen that the Dendrogram illustrate the mergers or divisions that have been made at successive levels.

Linkage methods are suitable for clustering items, as well as variables. This is not true for all hierarchical agglomerative procedure. The following types of linkage are now discussed:

(i) Single linkage (minimum distance or nearest neighbour),

(ii) Complete linkage (maximum distance or farthest neighbour) and

(iii) Average linkage (average distances).

Also other methods of hierarchical clustering techniques like Ward's method and Centroid method are available in the literature.

Steps of Agglomeration in Hierarchical Cluster analysis

The following are the steps in the agglomerative hierarchical clustering algorithm for groups of N objects (items or variables).

i. Start with N clusters, each containing a single entity and an N×N symmetric matrix of distance (or similarities) $\mathbf{D} = \{d_{ik}\}$.

ii. Search the distance matrix for the nearest (most similar) pair of clusters. Let the distance between most similar clusters U and V be $d_{uv.}$

iii. Merge clusters U and V. Label the newly formed cluster (UV). Update the entries in the distance matrix by (a) deleting the rows and columns corresponding to clusters U and V and (b) adding a row and column giving the distances between cluster (UV) and the remaining clusters.

iv. Repeat steps (ii) and (iii) a total of N-1 times (All objects will be in a single cluster after the algorithm terminates). Record the identity of clusters that are merged and the levels (distances or similarities) at which the mergers take place.

2.1.2 Non Hierarchical Clustering Method

Non-hierarchical clustering techniques are designed to group items, rather than variables, into a collection of K clusters. The number of clusters, K, may either be specified in advance or determined as part of the clustering procedure. Because a matrix of distance does not have to be determined and the basic data do not have to be stored during the computer run. Non hierarchical methods can be applied to much larger data sets than can hierarchical techniques. Non hierarchical methods start from either (1) an initial partition of items into groups or (2) an initial set of seed points which will form nuclei of the cluster.

2.1.2.1 K means Clustering (Afifi, Clark and Marg, 2004)

The K means clustering is a popular non hierarchical clustering technique. For a specified number of clusters K the basic algorithm proceeds in the following steps:

- Divide the data into K initial cluster. The number of these clusters may be specified by the user or may be selected by the program according to an arbitrary procedure.
- Calculate the means or centroid of the K clusters.
- For a given case, calculate its distance to each centroid. If the case is closest to the centroid of its own cluster, leave it in that cluster; otherwise, reassign it to the cluster whose centroid is closest to it.
- Repeat step (iii) for each case.
- Repeat steps (ii), (iii), and (iv) until no cases are reassigned.

2.2. Dendrogram

Dendrogram is also called hierarchical tree diagram or plot, and shows the relative size of the proximity coefficients at which cases are combined. The bigger the distance coefficient or the smaller the similarity coefficient, the more clustering involved combining unlike entities, which may be undesirable. Cases showing low distance are close, with a line linking them a short distance from the left of the Dendrogram, indicating that they are agglomerated into a cluster at a low distance coefficient, indicating alikeness. When, on the other hand, the linking line is to the right of the Dendrogram the linkage occurs at a high distance coefficient, indicating the cases/clusters were agglomerated even though much less alike.

2.3. Distance Measures

Some distance measures commonly used for assessing spectral similarity/dissimilarity are as follows:

1) Spectral Similarity Index or Spectral Correlation or Spectral Angle Mapper (SAM)
2) Spectral Contrast Angle
3) Spectral Information Divergence (SID)
4) Spectral Absorption Index (SAI)
5) Euclidian Distance
6) Mahalanobis D^2
7) City-Block Distance

2.4. Validations

- **Relative clustering validation**, which evaluates the clustering structure by varying different parameter values for the same algorithm (e.g., varying the number of clusters k). It's generally used for determining the optimal number of clusters.
- **External clustering validation**, which consists in comparing the results of a cluster analysis to an externally known result, such as externally provided class labels. Since we know the "true" cluster number in advance, this approach is mainly used for selecting the right clustering algorithm for a specific dataset.
- **Internal clustering validation**, which use the internal information of the clustering process to evaluate the goodness of a clustering structure without reference to external information. It can be also used for estimating the number of clusters and the appropriate clustering algorithm without any external data.
- **Clustering stability validation**, which is a special version of internal validation. It evaluates the consistency of a clustering result by comparing it with the clusters obtained after each column is removed, one at a time.

3. Dicriminant Function Analysis (Supervised learning)

Discriminant function analysis is a statistical analysis to predict a categorical dependent variable (called a grouping variable) by one or more continuous or binary independent variables (called predictor variables). The original dichotomous discriminant analysis was developed by Sir Ronald Fisher in 1936. Discriminant function analysis is useful in determining whether a set of variables is effective in predicting category membership. Discriminant analysis is used when groups are known a priori (unlike in cluster analysis).

Each case must have a score on one or more quantitative predictor measures, and a score on a group measure. In simple terms, discriminant function analysis is classification - the act of distributing things into groups, classes or categories of the same type.

The assumptions of discriminant analysis are the same as those for MANOVA. The analysis is quite sensitive to outliers and the size of the smallest group must be larger than the number of predictor variables. The major assumptions are:

- Multivariate normality: Independent variables are normal for each level of the grouping variable.
- Homogeneity of variance/covariance (homoscedasticity): Variances among group variables are the same across levels of predictors. Can be tested with Box's M statistic.
- It has been suggested, however, that linear discriminant analysis be used when covariances are equal, and that quadratic discriminant analysis may be used when covariances are not equal.
- Multicollinearity: Predictive power can decrease with an increased correlation between predictor variables.
- Independence: Participants are assumed to be randomly sampled, and a participant's score on one variable is assumed to be independent of scores on that variable for all other participants.
- It has been suggested that discriminant analysis is relatively robust to slight violations of these assumptions, and it has also been shown that discriminant analysis may still be reliable when using dichotomous variables (where multivariate normality is often violated).

Discriminant analysis works by creating one or more linear combinations of predictors, creating a new variable for each function. These functions are called discriminant functions. The number of functions possible is either N_g-1 where N_g = number of groups, or p (the number of predictors), whichever is smaller. The first function created maximizes the differences between groups on that function. The second function maximizes differences on that function, but also must not be correlated with the previous function. This continues with subsequent functions with the requirement that the new function not be correlated with any of the previous functions.

Summary

Unsupervised learning is a heuristic technique for classifying cases into groups when knowledge of the actual group membership is unknown. Unless there is considerable separation among the inherent group, it is not realistic to expect very clear results with

unsupervised learning. In particular if the observations are distributed in a nonlinear manner, it may be difficult to achieve distinct groups. Cluster analysis is quite sensitive to outliers. The data should be carefully screened before running cluster programs.

Discriminant analysis is a multivariate technique concerned with classifying distinct set of objects (or set of observations) and with allocating new objects or observations to the previously defined groups. It involves deriving variates, which are combination of two or more independent variables that will discriminate best between a priori defined groups.

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CHAPTER 28

OPTICAL CLASSIFICATION

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Marine Optics

Optical oceanography or Marine optics is the study of light propagation in the ocean surface through absorption or scattering processes. Marine bio-optics is the term used when the absorption and scattering by particles and dissolved substances are of biological origin. Ocean color is defined as the spectral variation of the water leaving radiance that can be related to the optical constituents present in the medium (Jerlov, 1976; Morel, 1974). Visible Spectral radiometry or Ocean colour remote sensing is the study on spectral signals of optically active materials using satellite observations. When sunlight reaches the upper water column or the photic zone of the ocean surface, the light propagation is determined by the optical properties of seawater. It depends on concentration of the optical constituents of seawater containing Coloured dissolved organic matter (CDOM), suspended sediments and phytoplankton (IOCCG, 2000). The contribution of particulate and dissolved constituents to the variability of optical properties and ocean color in coastal waters requires a better understanding of the linkages between the concentration of these constituents, the inherent optical properties (IOPs) of absorption and scattering coefficients, and the apparent optical properties (AOPs) such as the spectral attenuation for downward irradiance $K_d(\lambda)$ and remote sensing reflectance $R_{rs}(\lambda)$. Knowledge of these relationships is important for characterizing the marine optical environment and developing remote sensing ocean color algorithms for coastal waters.

The approach of Optical classification is the analysis on identification of a water type in terms of dissolved and suspended organic and inorganic materials, biological substances or the phytoplankton diversity. It has practical applications including the quantitative description of ocean color and the satellite remote sensing of chlorophyll (Wozniak and Pelevin, 1991). Based on the optical properties, different versions of optical classification of water types were proposed by many authors (Jerlov, 1976; Kirk, 1976; Morel and Prieur, 1977; Sathyendranath and Morel, 1989; Smith and Baker, 1977). Jerlov (1976) introduced a classification of water bodies based on their spectral optical attenuation depth. Jerlov classified his observations into a set of five typical oceanic spectra and nine typical coastal spectra. Morel and Prieur, (1977) carried out an independent analysis of spectral irradiance with the aim of describing ocean color in terms of dissolved and suspended material, in particular, phytoplankton pigment concentrations. Morel's analysis makes use of the inherent optical properties of water (Preisendorfer, 1976). Morel and Prieur (1977) presented the rationale for separating all water masses into two types: Case 1 and Case 2 waters. According to the classification system used in remote sensing studies, Case-1 represents the phytoplankton-dominated waters and the clear waters with algal or biological materials, and Case-2 represents all other possible water bodies rich in organic and inorganic substances. In Case-1 water, simple algorithms to retrieve pigment concentrations are used globally, but for Case-2 waters, the use of site-specific algorithms is necessary. Smith and Baker, (1977) used the apparent optical property K_T, the optical parameter that relates the spectral irradiance just beneath the ocean surface E_d (0, A) to the downwelling spectral irradiance at depth E_d(Z,A). Their classification also provides direct input to mathematical models of phytoplankton dynamics. Sathyendranath and Prieur, (1989) used a triangular plot, on which a point would represent the relative contributions from phytoplankton, non-algal particles, and CDOM to the total absorption coefficient (excluding that of pure seawater), at a specific wavelength. A point at the center of the triangle designates equal contributions by each component, while each point at the apex designates cases where all the contribution is from a single component. There are several studies on optical classification of the water types based on insitu optical measurements by Hoepffner, 2005; McKee and Cunningham, 2006; Reinart *et al.*, 2003; Roff *et al.*, 2003. Babin *et al.*, 2003 gave results based on absorption at various wavelengths for European coastal waters. The study explains how at different wavelengths different constituents (dissolved material, algae and non-algal particles) dominate absorption. Mélin and Vantrepotte, (2015) classified the global ocean into sixteen optical classes using the normalised remotely sensed reflectance data, an apparent optical property. He also classified the water types of each class into Case-1 and Case-2 using the mean spectral reflectance values. Recent studies on optical classification in the Indian coast using the empirical algorithms for the retrieval of chl-*a* from CZCS, MOS-B, IRS-P4-OCM and Sea-WiFS were carried out in the southeastern Arabian Sea (Nagamani *et al.*, 2008; Chauhan *et al.*, 2002; Sathe and Jadhav, 2001). Study on the phytoplankton community characteristics using absorption properties in the coastal waters of the southeastern Arabian Sea was done by Minu *et al.*, 2014; Minu *et al.*, 2016, measured the *in-situ* remote sensing reflectance (R_{rs}) and optically active substances (OAS) using hyper spectral radiometer and classified the coastal waters of the southeastern Arabian Sea. The authors proposed three distinct water types: Type-I, Type-II and Type-III based on variability in Optically Active Substance (OAS) such as chlorophyll-*a* (chl-*a*), chromophoric dissolved organic matter (CDOM) and volume scattering function at 650 nm (β_{650}).

Optical classification of Northern Indian Ocean

We made an initial attempt to optically classify the coastal waters of the Northern Indian Ocean using remotely-sensed ocean colour datasets. Monthly climatological dataset of remote sensing reflectance for the years 1998 – 2013 was obtained from the Ocean Colour

Climate Change Initiative (OC-CCI, www.oceancolour.org). Normalization and log-transformation of remote sensing reflectance values were done according to the method of Mélin and Vantrepotte (2015). Optical classification implemented uses the fuzzy logic classification method, based on Moore *et. al.,* (2009). Optimal cluster validity methods such as Xie-Beni Index and Partition Coefficient are computed to determine the optimal cluster (class) number to perform the classification.

Optical classification techniques used for the study:

Cluster validity measures

Cluster validity measures are chosen to validate the quality of clustering algorithms. Cluster validity methods are statistical functions that determine the performance of a clustering procedure. Criteria of merit for a clustering method includes the distance between clusters (separation) and the distribution of points around a cluster (compactness) (Deborah *et al.*, 2010). We can rely on multiple validity functions to aid selection of the optimal cluster number. The principal strategy used is to cluster the data over a range of cluster values (n_c) and evaluate each clustering result with each validity function (Moore *et al.*, 2009).

The Partition co-efficient and the Xie-Beni index are cluster validity methods designed specifically for use with fuzzy algorithms. These two methods are preferred to select the optimal number of clusters in fuzzy classification (Halkidi *et al.*, 2002).

Xie-Beni Index

Xie-Beni index is used to determine the best cluster number for the fuzzy classification method in a particular application. Xie-Beni index depends on the geometric properties of the dataset and the membership matrix. This index is defined as the ratio of the mean quadratic error to the minimum of squared distances between all points in the cluster. In cluster validation, the quadratic error is defined as the mean of the squared distances of all the points with respect to the centroid of the cluster they belong to (Xie and Beni, 1991).

The variation in cluster i, (i = {1,…,n_c}) is designated as $ó_{i,}$ it is the sum of the squares of the fuzzy deviation of the data points in dataset X. The average variation in cluster i, $\eta_i = (\sigma_i/\eta_i)$, η_i is the number of points in the cluster belonging to the cluster i. Xie-Beni index is defined as XB = $\eta/N^*D_{min,}$, N is the number of points in the dataset and D_{min} is the minimum distance between the centroids of the clusters.

The smallest value of index indicates the optimal cluster number. When Xie-Beni index is monotonically decreasing, the number of clusters n_c becomes very large and close to n_i. One way to eliminate the decreasing tendency of the index is to determine a starting point, the maximum of the cluster number (c_{max}) of the monotonic behavior and to search for the minimum value of Xie-Beni in the range [2, c_{max}]. Moreover, the values of the Xie-Beni index depend on the fuzzy membership values (F) and the maximum cluster number of the datasets (Halkidi *et al.*, 2002; Zhao *et al.*, 2009).

Partition Co-efficient

The Partition Coefficient is a validity function that uses the membership values (F_{ij}) to provide the best cluster number. It measures the amount of "overlap" between clusters. Partition co-efficient (PC) is defined as follows:

$$PC = \frac{1}{N}\sum_{i=j}^{N}\sum_{j=1}^{n_c} F_{ij}^{2}$$

The PC index values lie in the range [$1/n_c$, 1], where n_c is the number of clusters. The closer this value is to one the better the data are classified. The cluster number with a maximum partition coefficient is said to be the best cluster number to choose for classification. In case of a hard partition, we obtain the maximum value PC(n_c) = 1. The disadvantages of the partition coefficient are its monotonic decrease with cluster numbers n_c (Bezdek, 1974; Bezdek *et al.*, 1984).

Fuzzy C Mean Classification

Fuzzy classification evolved from classical set theory. The classical clustering approach determines whether the object is a member or non-member of a given set of that system. In contrast, fuzzy logic allows that an object or data may have partial memberships of more than one set. This method allows for overlap between boundaries of particular classes or sets, and recognizes that more than one class may be represented at a particular location at any given time. The membership F_{ij} of a class in the data from a particular point is given by ($1-F_{ij}(Z_{ij}^{2})$) where Z_{ij} is the Mahalanobis distance given by (X-M)/S where M is the mean and S is the standard deviation, and F is a cumulative χ^2 distribution (Zadeh, 1965).

Results of the study

The cluster validity measures showed that the cluster number 8 gave the best compromise, with low numbers of both under-classified and over-classified pixels. Therefore, eight classes were selected as the optimal cluster number for further analyses. Preliminary analyses of optical classification showed month-to-month variations (See Figure 1.Optical classification for the summer monsoon seasons - June to September). The mean spectra of the eight selected optical classes were calculated and shown in Figure 2. The optical classes also relates to Case-1 and Case-2 waters as defined by Morel and Prieur (1977); Prieur and Sathyendranath, (1989) based on spectral shapes. From the shapes of the spectra, it appears that classes 1-6 are representative of Case-1 waters and classes 6-8 of turbid Case-2 waters. On further, the resultant optical classes are analyzed to explore their biological significance using the available distribution datasets of different taxonomic groups of phytoplankton and zooplankton from literature.

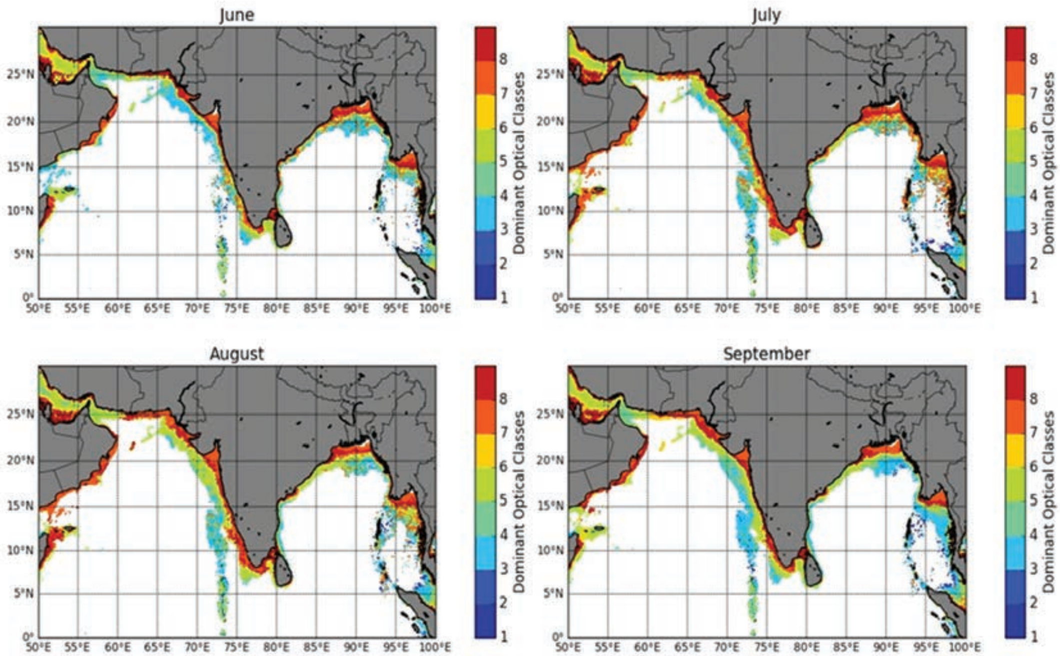

Fig. 1. Optical classification of the monthly climatology datasets of summer monsoon season

Although there have been many biogeographic studies of the ocean with various approaches and many applications of remote-sensing to partition the oceans into ecological zones or provinces, studies that integrates conventional biogeography with the results from remote sensing have been relatively few. Application of remotely sensed data to classify any optically distinct regions can result in providing understanding on the various bio-geochemical cycles and dynamics of the ocean regions.

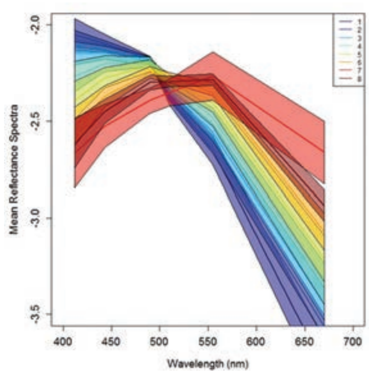

Fig. 2. Mean Reflectance Spectra of the Log10-normalised Rrs values

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CHAPTER

29

DEVELOPMENT OF INDIVIDUAL BASED MODELS IN MARINE FISHERIES RESEARCH

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Setting

Fish population dynamics describe how a stock or a combination of them changes over time as a function of growth, recruitment, mortality, immigration and emigration (Quinn & Deriso, 1999). It is the basis for understanding fish populations and associated fisheries and is the central component of any effort to assess the population dynamics so as to provide quantitative advice for fishery management (Hilborn & Walters, 1992).

Modern fisheries stock assessment models are evolving towards increasing complexity (Maunder & Punt, 2013), with capabilities to assimilate a diverse suite of data and incorporate spatial structure (Cadrin & Secor, 2009) and the influence of environmental factors. As the number of such efforts increase, the behavior and performance of these complex models need to be tested to assure a scientific basis for fishery management. These efforts to test the plethora of models have resulted in extensive simulation studies. These have been conducted to examine the robustness of the models and incorporate various process and measurement errors, including data quality and quantity (Chen *et al.*, 2003), mis-specifications of life history parameters (Deroba & Schueller, 2013; Punt, 2003), fishery characteristics (Cope & Punt, 2011), and violations of model assumptions (Guan, Cao, Chen, & Cieri, 2013).

Amongst these approaches one stream was oriented towards focussing on the habitat and ecosystem wherein the entire blend of biological dynamics are seen in action and models were built to suit them, leading to the ecosystem based models. Several approaches have been developed at the ecosystem level, motivated by the observation of some recurrent patterns of marine ecosystems, suggesting that interactions within the ecosystem are important structuring factors (Dickie and Kerr, 1982). For example, a widespread observation is the stability of the production of many marine ecosystems compared to that of individual species (e.g. Sutcliffe *et al.*, 1977; May *et al.*, 1979; Murawski *et al.*, 1991). The maximum sustainable yield (*MSY*) is extended to a set of exploited species that are considered to form a single stock (Brown *et al.*, 1976; FAO, 1978): the equilibrium production of the multispecies assemblage would then be a parabolic function of fishing effort and the *MSY* would correspond to the exploitation of half the virgin biomass of the whole assemblage. More recently, Polovina (1984) and Christensen and Pauly (1992) developed the ecosystem model ECOPATH, which is widely used among fisheries scientists. In this model, species are aggregated into functional groups, which are related by fluxes of matter. Forming the basis of the model are two equations of mass conservation, describing the production and the consumption at equilibrium for each group of species.

This leads to the most important aspect of modelling, testing the sensitivity of assessment models for mis-specifications requires an operating model to predict population dynamics with known or assumed population parameters. However, most operating models are formulated identically to the population dynamic component built into the assessment model (Cope & Punt, 2011; Deroba & Schueller, 2013; Guan *et al.*, 2013; Punt, 2003), which implicitly assumes that the dynamic processes of the population are fully understood. To avoid this problem and test the assessment rigorously, an alternatively structured operating model is necessary to simulate the population dynamics.

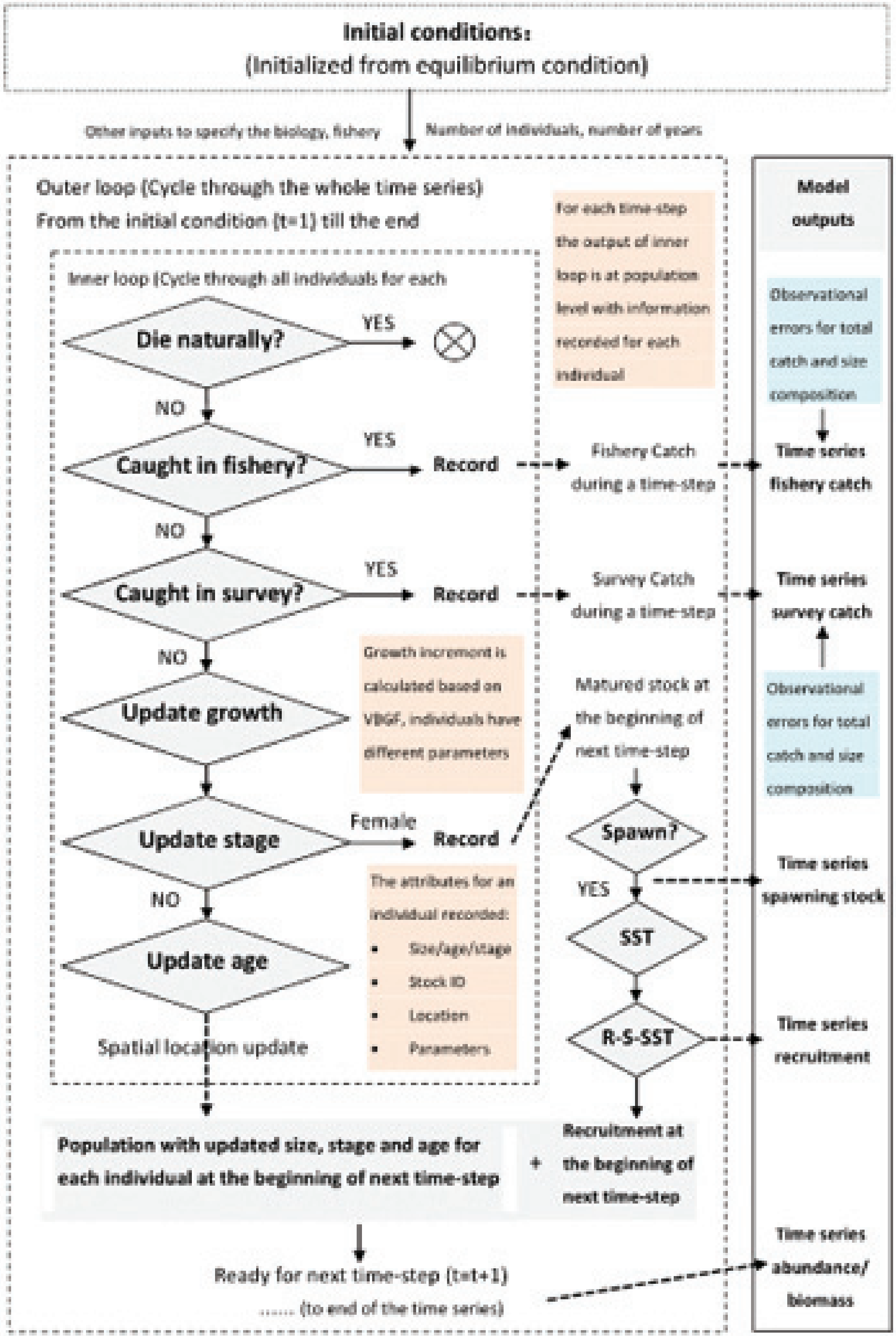
Individual-based models (IBM), which consider each individual of a population as an independent entity, have been widely used in ecology (Grimm & Railsback, 2005). The events (e.g., birth, death and predation) that occur within the simulation are at an individual rather than population level and the overall population dynamics that emerged is the sum of the individual interactions and behaviours.

The majority of individual-based models in fisheries science are developed to investigating fish behavior and fleet dynamics. They have been used to simulate the behavior of individual fish or fishermen with rules that determine their movement (Tyler & Rose, 1994; Wilson & Yan, 2009). Spatial heterogeneities in individuals and/or their environment have been added to develop spatially explicit individual-based models (Werner, Quinlan, Lough, & Lynch, 2001). However, only a few of these models have been developed for simulating fishery population dynamics. Kanaiwa, Chen, and Wilson (2008) developed an individual-based lobster simulator to simulate seasonal, sex-specific population dynamics for the American lobsters to evaluate the assessment model for that species. Further, the models that have been developed are either species-specific or focused on one particular aspect of fish life history (Kanaiwa *et al.,* 2008).

A typical IBM framework

Although many leads can be followed to formulate a framework under which IBMs could be modelled, the ringside view of the process can best be obtained from a simple depiction of an algorithm, one such being given below (Cao *et al.*, 2016).

The below figure depicts the steps and sequences alongside the checks and balances which create the sequences in a cogent way. Now the different life stages like, natural death, fishery mortality, growth , enhancement of age and stage, spawning and recruitment could have there own sub-conceptualisations of being either deterministic or probabilistic


Initial conditions:
(Initialized from equilibrium condition)
Other inputs to specify the biology, fishery
Number of individuals, number of years
Outer loop (Cycle through the whole time series)
From the initial condition (t=1) till the end
For each time-step the output of inner loop is at population level with information recorded for each individual
Model outputs
Inner loop (Cycle through all individuals for each
Die naturally?
YES
NO
Observational errors for total catch and size composition
Caught in fishery?
YES
Record
Fishery Catch during a time-step
Time series fishery catch
NO
Caught in survey?
YES
Record
Survey Catch during a time-step
Time series survey catch
NO
Growth increment is calculated based on VBGF, individuals have different parameters
Update growth
Matured stock at the beginning of next time-step
Observational errors for total catch and size composition
Update stage
Female
Record
Spawn?
YES
Time series spawning stock
NO
The attributes for an individual recorded:
Size/age/stage
Stock ID
Location
Parameters
Update age
SST
R-S-SST
Time series recruitment
Spatial location update
Population with updated size, stage and age for each individual at the beginning of next time-step
+
Recruitment at the beginning of next time-step
Ready for next time-step (t=t+1)
...... (to end of the time series)
Time series abundance/ biomass

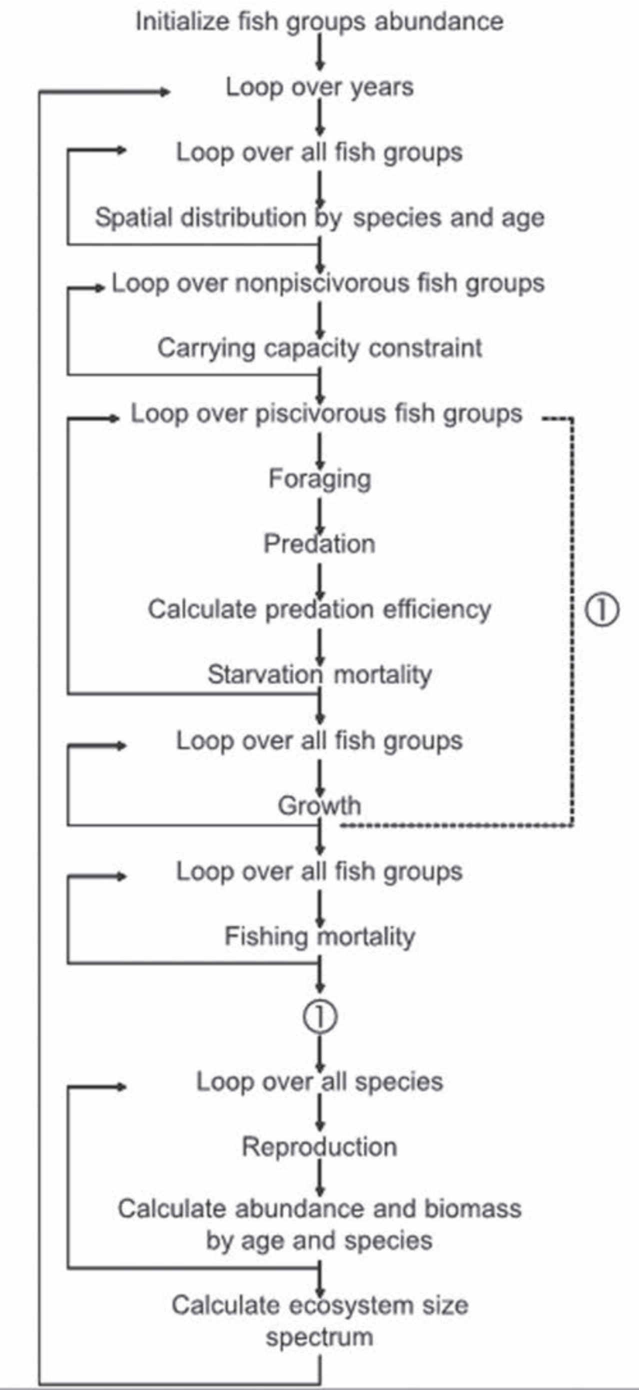
and under either whichever established process presumed, thereby leading to a combination of options in the programming and software sense. A typical look at the possibilities could result in the following steps;

Stage	Model definition
Initial condition	Equilibrium; with an assumed period to attain that
Stock spatial structure	Multiple stocks each with unique biological identities
Stock recruitment relationship	Specified functional relationship between spawning stock and its recruitment rate; Beverton- Holt, Ricker *etc*. or even incorporation of environmental parameters like SST
Recruitment	Can be directly put or could be derived from the S/R relationship with random fluctuation added; must be adjusted as per the intra annual pattern expressed by the resource(s) modelled
Natural mortality	Could be randomness added to the base value defined based on length or age
Fishing mortality	Classic method of merging catchability, effort and selectivity; random threshold could be used to simulate fishing mortality
Growth	VBGF based depiction
Life stage	Number of stages and the mean size at each stage could be the core with random normal deviations completing simulated values
Survey	Modelled similar to Fishing mortality
Observational error	A lognormal based error term added to the catch figure aggregated over time, length and area
Multi-species	Parallel replication of these steps for as many resources as planned to be simulated/ studied

A broad-based IBM

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

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



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

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

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

Conclusion

Though IBMs offer a very robust modelling crucible for complex marine ecosystems, their success rate is severely dependent on the local tuning and sensitivity testing. Further as these are trophic level flow based, proper input on the LTL front using feeder models like Nutrient Phytoplankton Zooplankton Detritus(NPZD)- Regional Ocean Modeling systems(ROMs) may have to be coupled with the OSMOSE runs for more efficient forecast/ simulation. As such for systems where good coverage on the crucial biogeochemical and productivity parameters coupled with regular sample surveys on resource biology is undertaken these type of IBMs could turn out to be real boon.

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CHAPTER

30

ECOSYSTEM MODELLING - INTRODUCTION TO TOPAZ

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1. Outline of the lecture

The lecture have three major sections. The first section will briefly discuss how important physical processes influence the biological processes in the ocean. The two important physical processes that will be discussed are upwelling and entrainment. I then briefly introduce an ecosystem model named Tracers of Phytoplankton with Allometric Zooplankton. This model is referred to using the acronym, TOPAZ [Dunne *et al.*, 2010]. This ecosystem model has the capability to be coupled to a physical Ocean General Circulation Model (OGCM) known as Modular Ocean Model (MOM4p1). Both MOM and TOPAZ are developed by the Geophysical Fluid Dynamics Laboratory. In the third section of this lecture, I'll be presenting an example of an application of the physical-ecosystem model based on MOM-TOPAZ to explain the biological consequences of inhibition of deepening of mixed layer in the northeastern Arabian Sea [Vijith *et al.*, 2016].

2. TOPAZ

TOPAZ is a widely used ecosystem model. It has been used by several researchers to address a variety of physical-ecosystem interaction that happens during large scale ocean processes such as El Nino Southern Oscilaltion (ENSO), Indian Ocean Dipole *etc*. TOPAZ includes carbon, nitrate, ammonium, phosphate, silicate, dissolved oxygen, iron, and calcium and three phytoplankton groups: diazotrophs (cyanobacteria), small (picoplankton and nanoplankton), and large (diatoms and algae) phytoplankton. The model also includes biogeochemical processes such as the atmospheric deposition of iron, nitrification, and denitrification. The parametrisation of growth rate of phytoplankton, limitation of nutrients and light, and grazing will be described using simple schematic diagrams. I'll also discuss how size considerations of phytoplankton are dealt in the model.

3. Application of TOPAZ

The seasonally reversing monsoon winds over the north Indian Ocean produce seasonally reversing currents that exchange water between the Arabian Sea and the Bay of Bengal. One such current is the West India Coastal Current that takes low-salinity waters of the Bay of Bengal into the Arabian Sea. As the current takes the waters poleward along the west coast of India, the contrast between salinity of the waters of the current with ambient waters has an impact on mixed-layer physics. This impact in the northeastern Arabian Sea was discussed by Shankar *et al.,* (2016) and Vijith *et al.,* (2016). During the lecture I'll demonstrate an how the TOPAZ was employed to investigate consequences of inhibition of mixed-layer deepening by the West India Coastal Current to winter phytoplankton bloom in the northeastern Arabian Sea.

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CHAPTER 31

IMPACT OF CLIMATE CHANGE ON MARINE SECTOR

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Climate over the Earth is showing perceptible changes over both global and regional scales and the warming effects are now being felt across many parts of the world including India (Vivekanandan, 2010). Human activities are increasing the levels of carbon dioxide and other greenhouse gases in the atmosphere leading to a rise in atmospheric temperature. Since the year 1750, the level of atmospheric CO_2 has risen from 280 ppm to 401 ppm in 2015, and if unchecked, will be at around 560 ppm by the year 2050.

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

How does the ocean affect the climate ?

The oceans play an important role in regulating climate as its heat uptake capacity is approximately 1000 times larger than the atmosphere. The world ocean has warmed substantially since 1955 and warming account for 80% of the change in energy content of the Earth's climate system (Cochrane, 2010). These deviations from normal surface temperatures can have large-scale impacts not only on ocean processes, but also on global weather and climate.

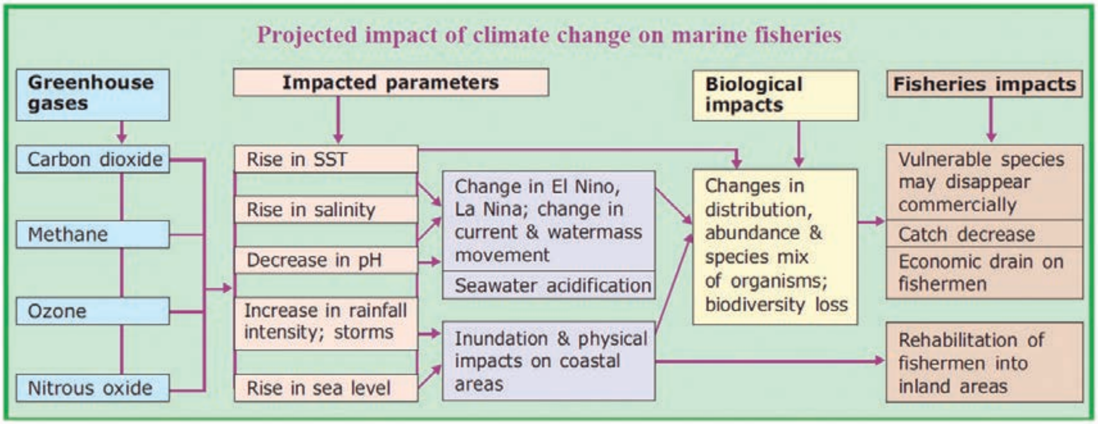
Impact on Climatic and Oceanographic Parameters

- Changes in the important oceanic weather systems such as sea surface temperature, pH, salinity, El Niño Southern Oscillation (ENSO), precipitation, sea level, frequency and intensity of cyclones and droughts are becoming evident as a result of climate change.

- El Niño-Southern Oscillation (ENSO) cycle, describes the fluctuations in temperature between the ocean and atmosphere in the east-central Equatorial Pacific.
- La Niña is the cold phase of ENSO and El Niño as the warm phase of ENSO

Climate change impact on coastal fisheries and aquaculture

World's Oceans are currently affected by global warming with likely impacts in changes in ocean currents and winds, precipitation, ocean acidification *etc*. which will have strong impact on fisheries with serious consequences on food and livelihood security of considerable section of the population. In India marine fisheries have very important roles in augmenting food supply, nutritional security and livelihood for millions. With the major share of marine fish catch coming from coastal and near-coastal waters, environmental change in this zone would have debilitating impact on the sector in specific and the country's food basket in general.



o Source: Vivekanandan E. CMFRI Newsletter No.112. October-December 2006

Climate change on fishery habitat

Marine ecosystems are not in a steady state, but are affected by the environment, which varies on many spatial and temporal scales. Fish populations respond to variation in different ways. Decadal variations may have unforeseen impacts, including cyclic changes in the production level of marine ecosystems that favor one species or group over another.

Sea surface Temperature (SST) increase: Temperature is likely the single most important factor affecting the growth and development of aquatic organisms. Earth has been in radiative imbalance since at least the 1970s, where less energy leaves the atmosphere than enters it. Most of this extra energy (~90%) has been absorbed by the oceans (IPCC,2014). The variation of Sea surface Temperature (SST) along Indian seas during the 40 years from 1976 to 2015 revealed that SST increased by 0.602°C along the northeast India (NEI), by 0.597°C along the northwest India (NWI), by 0.690°C along the southeast India (SEI) and by 0.819°C along the southwest India (SWI). However, the rate of change in SST was highest in northwest India (0.0156/annum) followed by southwest India (0.0132/annum), southeast India (0.005/annum) and northeast India (0.001/annum) respectively. The rate of change in SST over Indian Seas revealed that west coast has more impact than in the east coast of India. Northern Indian Ocean has been identified as one of the 17 climate change hotspots among world oceans. These areas will warm faster than 90% of the world oceans. Long-term climate change is likely to impact the marine environment and its capacity to sustain fish stocks and exacerbate stress on marine fish stocks.

***Ocean acidification*:** The ongoing reduction in the pH of the Earth's oceans presents a significant challenge to the survival of marine fish. Seawater, by absorbing carbon dioxide and forming carbonic acid, is slowly dropping in pH from its natural, slightly basic state towards pH neutral conditions. The pH of the oceans has dropped to around 8.069 from a pre-industrial age state of 8.179. A total change of -0.355, to 7.824 by 2100 has been estimated by various studies.

Studies indicated an increasing trend in the annual number of instances when pH of surface waters off Kochi was less than 6. Analysis of the instances of low pH values of surface waters in three depth zones *viz*., 10m, 20m and 30m during the period 2005 to 2012 has indicated that in the year 2012, pH of surface water at 10m depth zone was low for a considerably longer period than in the previous years (CMFRI-NICRA, 2013).

***Coral bleaching*:** Warmer water temperatures can result in coral bleaching that resulting in the expulsion of the symbiotic zooxanthellae from the tissues of coral. Between 1979 and 1990, sixty major episodes of coral bleaching were recorded, and in 2016 the longest coral bleaching event on record was observed. Several studies relate bleaching events with global warming and climate change during the last few decades (Lix *et al*., 2016), and 70% of the reports of coral bleaching at that time were associated with reports of warmer than normal conditions (Glynn, 1991).

Observations on bleaching events have shown that individual species respond differently to this change in thermal environment, with higher degrees of mortality typically seen in branching corals such as *Acropora*(Mohanty *et al*., 2013). Successive bleaching events could lead to a reduction in the species richness of corals in certain global warming hotspots.

Coral reef ecosystems support a great diversity of benthic organisms, of which zoanthids, commonly found among degraded reef ecosystems, compose the dominant fauna in the rocky intertidal regions. On the Saurashtra coast, in Gujarat, studies carried out on the distribution and community structure of Zoanthids indicated higher adaptive capacity to changes in environmental and abiotic conditions in comparison to their counterparts. Coral reefs continue to suffer due to high nutrients inputs, bleaching and other anthropogenic activities, leading to shift in reef pattern towards more aggressive and rapidly growing benthic communities such as zoanthids (Kumari *et al.,* 2015).

Sea level rise**:** Sea level rise at long time scales is mainly due to thermal expansion and exchange of water between the other reservoirs (glaciers, ice caps, *etc.*) including through anthropogenic change in land hydrology and the atmosphere. The global average sea level rose at an average rate of 1.8 mm per year over 1961 to 2003. Additionally the rate of rise accelerated during 1993 to 2003, to 3.1mm per year. The total 20thcentury rise is estimated to be 0.17 m. The movement of the saltwater/freshwater interface further inland will cause reduction and extinction of estuarine associated habitats that are common nesting and breeding grounds for a wide variety of marine fish.

Sea-level rise estimates for the Indian coast are between 1.06–1.75 mm per year, with a regional average of 1.29 mm per year, when corrected for GIA using model data (Unnikrishnan and Shankar, 2007). These estimates are consistent with the 1–2 mm per year global sea-level rise estimates reported by the IPCC. Northern Indian Ocean has been identified as one of the 17 climate change hotspots among the world oceans (Hobday *et al*., 2008). These areas are recognised to warm faster than 90% of the oceans. These regions are expected to provide the potential for early warning and evidence of the response by natural resources to climate change. A one metre sea level rise is projected to displace approximately 7.1 million people in India and about 5,764 km2 of land area will be lost, along with 4,200 km of coastal roads (Ministry of Environment and Forests, 2004). Approximately 30% of India's coastal zones will be subjected to inundation risk with sea level rise and intensified storm surges (Dasgupta *et al*., 2009).

Changes in wind speed and direction**:** As winds are generated by differences in temperature, rising surface temperatures on the earth's surface are causing winds worldwide to slow dramatically. Reductions in wind speed by 1-3% are expected over the next 50 years, and as high as 4.5% over the next 100 years.

Changes in rainfall**:** Changes in average precipitation, potential increase in seasonal and annual variability and extremes are likely to be the most significant drivers of climate change in aquatic systems. Analysis of historical rainfall data in the Andaman and Nicobar islands revealed that while there has been no change in the amount of rainfall received, the patterns of rainfall have changed with increase in number of extreme rainfall events.

Variations in annual rainfall intensity, dry season rainfall and the resulting growing season length are likely to create impact on shrimp/ fish farming and could lead to conflict with other agricultural, industrial and domestic users in water scarce areas.

Impact on fish stock

A metabolic increase of 10% corresponds to a 1°C increase in temperature, implying of seawater as low as 1°C could affect the distribution and life processes of fish. This constraint in physiology will result in changes in distributions, recruitment and abundance. Changes in timing of life history events are expected with climate change. Species with short-life span and rapid turnover of generations such as plankton and small pelagic fishes are most likely to experience such changes. At intermediate time scales of a few years to a decade, the changes in distributions, recruitment and abundance of many species will be acute at the extremes of species' ranges. Changes in abundance will alter the species composition and result in changes in the structure and functions of the ecosystems. At long time scales of multi-decades, changes in the net primary production and its transfer to higher trophic levels are possible.

Changes in timing of life history events are also likely to result from the warming of the Earth's waters. Many tropical fish stocks are already exposed to high extremes of temperature tolerance, and already face regional extinction, and some others may move towards higher latitudes. Shifts in spawning periods of fishes have already been observed in a number of commercially important fish stocks, such as threadfin bream (Zacharia *et al.*, 2016). Changes in distribution patterns of two key species in Indian fisheries have already been established-migration patterns of the Indian oil sardine and Indian mackerel have changed greatly over the past 50 years (Vivekanandan *et al.*, 2009).

Ocean-atmospheric coupled climate models predict changes in the ocean circulation and hypothesize that changes in the ocean circulation will stimulate phytoplankton biomass production in the nutrient depleted areas in the open ocean. The effect on atmospheric CO_2 is uncertain because the relationship between the enhanced primary production and air sea exchange of CO_2 is not understood.

Most models show decreasing primary production with changes of phytoplankton composition to smaller forms, although with high regional variability. Marked effects in plankton distribution have also been noticed concurrent to changes in sea surface temperature. These changes may affect the distribution of fish stocks that predate on plankton. Ocean acidification is believed to have negative consequences for marine denizens, particularly calcifying organisms, subjecting them to the risk of dissolution. A decline in primary productivity has also been forecast.

Impact on fish stock availability

Evidence exists for increasing damage by extreme weather events, particularly cyclones, over time. There are various explanations for this, ranging from greater population densities to the wider effects of climate change (IPCC, 2013).

Until the mid-1980s, the restricted distribution of oil sardine ensured that the entire catch of oil sardine was obtained from the southwestern coast of India. North of 14°N, little to no oil sardine was caught previously. In the last two decades, however, the oil sardine catch from 14°N to 20°N has gradually and consistently increased, contributing 15% to the all-India oil sardine catch by 2006 (Vivekanandan *et al.*, 2009). Since the catch in the Southwestern regions has not decreased in overall terms, this represents an extension of the distributional boundaries of the oil sardine.

Studies on the seasonal distribution of skipjack tuna reveal that during winter months, when sea surface temperature is lower, migration occurs towards offshore areas, and during warmer months, migration occurs towards inshore areas during warmer months. Changes in sea surface temperature due to global warming could result in changes in the seasonal distribution of certain species, and ultimately disruption in their harvest, which is usually based on indigenous knowledge (Zacharia *et al.*, 2016). Changes in distributional boundaries also bear the potential to bring up delicate questions of fishing rights, especially within the context of geopolitics and exploitation of the resources found within neighbouring exclusive economic zones.

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CHAPTER 32

CLIMATE CHANGE IMPACTS : REFLECTIONS AND UPSHOTS ON INDIAN MARINE ECOSYSTEM

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Climate change

Intergovernmental Panel on Climate Change (IPCC) defines Climate change as "A change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use". In its Fourth Assessment Report, IPCC projects that, without further action to reduce greenhouse gas emissions, the global average surface temperature is likely to rise by a further 1.8 - 4.0°C this century, and by up to 6.4°C in the worst case scenario. Even the lower end of this range would take the temperature increase since pre-industrial times above 2°C – the threshold beyond which irreversible and possibly catastrophic changes become far more likely. The present paper elucidates the impact of climate change on marine ecosystems, fish and fisheries and suggests various vulnerability assessment methods and adaptation options to cope up with climate change. The paper also deal with the research efforts and linkages attempted in developing a climate informed fisher society.

Climate change and marine ecosystem

The marine ecosystem is constituted by an intricate set of relationships among environment, resources and resource users (Fig.1). Changing climate affects ecosystem in a variety of ways. For instance, warming may force species to migrate to higher latitudes or higher elevations where temperatures are more conducive to their survival. Similarly, as sea level rises, saltwater intrusion into a freshwater system

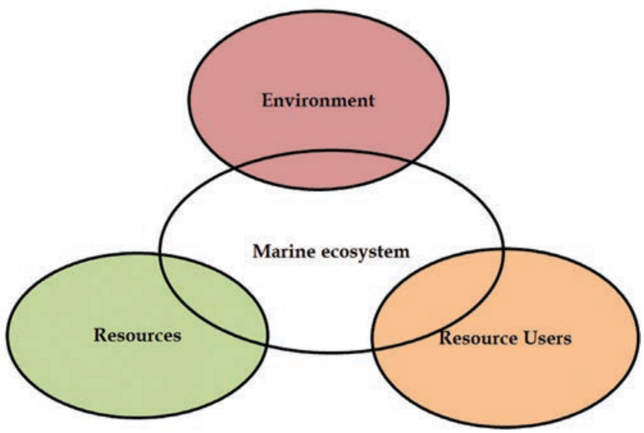


Fig. 1. Marine Ecosystem and its components

may force some key species to relocate or die, thus removing predators or prey that are critical in the existing food chain. Climate change not only affects ecosystems and resources directly, it also interacts with the general well being of resource users or community as a whole.

I. Impact of climate change on environment

Marine ecosystems are not in a steady state, but are affected by the environment, which varies on many spatial and temporal scales. Changes in temperature are related to alterations in oceanic circulation patterns that are affected by changes in the direction and speed of the winds that drive ocean currents and mix surface waters with deeper nutrient rich waters (Kennedy *et al*., 2002). These processes in turn affect the distribution and abundance of plankton, which are food for small fish. Understanding the importance and the implication of the climate changes on coastal areas may be one of the major issues for this and next centuries.

Climate changes may, indeed, impact the nearshore marine environment, as coastal areas are very sensitive to the strength and the variability of the meteorological forcings. An increase of a few degrees in atmospheric temperature will not only raise the temperature of the oceans, but also cause major hydrologic changes affecting the physical and chemical properties of water. These will lead to fish, invertebrate, and plant species changes in marine and estuarine communities (McGinn, 2002). Fishes have evolved physiologically to live within a specific range of environmental variation, and existence outside of that range can be stressful or fatal (Barton *et al.,* 2002). These ranges can coincide for fishes that evolved in similar habitats (Attrill, 2002). Estuarine and coastal regions are extremely productive because they receive inputs from several primary production sources and detrital food webs. Yet, these systems present the biota with a harsh environment, forcing organisms to evolve physiological or behavioral adaptations to cope with wide ranging physical and chemical variables (Horn *et al*., 1999). Temperature, along with other variables, causes active movement of mobile species to areas encompassing the preferred range of environmental variables, influencing migration patterns (Rose and Leggett, 1988; Murawski, 1993; Soto, 2002). The predicted increase in major climatic events, such as ENSO (Timmermann *et al*., 1999; IPCC, 2001), may have drastic effects on fish stocks, especially when combined with other factors, such as overfishing (Pauly and Christensen, 1995). It has been suggested that reduced survival, reduced growth rate, and diversions of traditional migratory routes can all be caused by ENSO events, exacerbating the effects of intensive harvesting (Miller and Fluharty, 1992). The El Nino phenomenon generates substantial changes in oceanographic and meteorological conditions in the Pacific Ocean, with manifestations impacting the Peruvian coast (Zuta *et al.*, 1976); this has mainly affected pelagic resources, producing alterations in their biological processes, behaviour, and gradual decrease in their population levels (Valdivia, 1976).

(i) **Sea level rise in the Indian seas**

The IPCC (2007) has projected that the global annual seawater temperature and sea level would rise by 0.8 to 2.5° C and 8 to 25 cm, respectively by 2050. At present, 23% of the shoreline along the Indian mainland is affected by sea erosion (Sanil Kumar *et al.*, 2006). The large inflow of freshwater into the seas around India due to rainfall over the ocean and runoff from rivers, forces large changes in sea level especially along the coasts of Bay of Bengal. During June-October, the inflow of freshwater from the Ganges and Brahmaputra into the northern Bay Bengal is about $7.2 x 10^{11} m^3$, the fourth largest discharge in the world (Shankar, 2000). Increase in sea level, in addition to causing threats to human lives, will pose problems on freshwater availability due to intrusion of seawater and salinisation of groundwater. This would also result in loss of agricultural land. A rise in sea level is likely to have significant impact on the agriculture performance in India. A one metre sea level rise is projected to displace approximately 7.1 million people in India and about 5,764 km^2 of land area will be lost, along with 4,200 km of coastal roads (Ministry of Environment and Forests, 2004). Approximately 30% of India's coastal zones will be subjected to inundation risk with sea level rise and intensified storm surges (Dasgupta *et al.*, 2009).

(ii) **Sea Surface Temperature**

Prasanna Kumar *et al.,* (2009) examined the signature of global warming using various datasets for the Arabian Sea region and found that the disruption in the natural decadal cycle of SST after 1995 was a manifestation of regional climate-shift. They propose that upwelling driven cooling was maintained till 1995 despite oceanic thermal inertia and increasing CO_2 concentrations but this system broke down after 1995 though it is not known yet how long this process will continue. Vivekanandan *et al.,* (2009a) found warming of the sea surface along the entire Indian coast. The SST increased by 0.2°C along the northwest, southwest and northeast coasts and by 0.3°C along the southeast coast during the 45-year period from 1960 to 2005. The team has predicted that the annual average SST in the Indian seas would increase by 2.0°C to 3.5°C by 2099. Upwelling in the waters of the southwest coast of India is restricted to 5 to 15°N, and the variability in physical parameters is manifested in the chlorophyll intensity [Smitha *et al.,* 2008]. Remotely sensed sea surface temperature (SST) and ocean-colour images reveal eddies and fronts. These features frequently coincide with areas where fish species aggregate as a result of enhanced primary productivity and phytoplankton biomass, which in turn is linked with increased nutrient supply. Since, higher plant biomass is associated with zooplankton abundance, this could provide supplementary information on fish stock distribution from ocean-colour pigment fields.

II. Impact of climate change on resources

Climate change will affect individuals, populations and communities through the individuals' physiological and behavioral responses to environmental changes (Boesch and Turner, 1984). Extremes in environmental factors, such as elevated water temperature, low dissolved oxygen or salinity, and pH, can have deleterious effects on fishes (Moyle and Cech, 2004). Suboptimal environmental conditions can decrease foraging, growth, and fecundity, alters metamorphosis, and affects endocrine homeostasis and migratory behavior (Barton and Barton, 1987; Donaldson, 1990; Portner *et al.*, 2001). These organismal changes directly influence population and community structure by their associated effects on performance, patterns of resource use, and survival (Ruiz *et al.*, 1993; Wainwright, 1994). Climate affects the distribution and abundance of species in ecosystems around the world. In the face of rising temperatures, the ocean may experience variations in circulation, water temperature, ice cover, and sea level (McCarthy *et al.*, 2001). Climate-driven fluctuations in regional temperature can further affect growth, maturity, spawning time, egg viability, food availability, mortality, and spatial distribution of marine organisms (Ottersen *et al.*, 2001; Perry *et al.*, 2005; Nye *et al.*, 2009). Also affected by climate change are the size and timing of plankton blooms, a major driver of marine ecosystem function with a direct impact on recruitment success and population sizes (Walther *et al.*, 2002; Fischlin *et al.*, 2007).

Studies on the impact of climate change on fisheries (fish species, stock distribution *etc.*) have been carried out mainly by the CMFRI, Kochi. Investigations carried out by the CMFRI show that different Indian marine species will respond to climate change as follows: (i) Changes in species composition of phytoplankton may occur at higher temperature; (ii) Small pelagics may extend their boundaries; (iii) Some species may be found in deeper waters as well; and (iv) Phenological changes may occur.

a. *Indian mackerel is getting deeper:* Besides exploring northern waters, the Indian mackerel *R. kanagurta* has been descending deeper as well during the last two decades (CMFRI, 2008). The fish normally occupies surface and subsurface waters. During 1985-89, only 2 percent of the mackerel catch was from bottom trawlers, the remainder was caught by pelagic gear such as drift gillnet. During 2003-2007, however, an estimated 15 percent of the mackerel has been caught by bottom trawlers along the Indian coast. It appears that with the warming of sub-surface waters, the mackerel has been extending deeper and downward as well.

b. *Small pelagics extend their boundaries:* The oil sardine *Sardinella longiceps* and the Indian mackerel *Rastrelliger kanagurta* accounted for 21 percent of the marine fish catch in 2006. These small pelagics, especially the oil sardine, have been known for restricted distribution – between latitude 8°N and 14°N and longitude 75°E and 77°E (Malabar upwelling zone along the southwest coast of India) where the annual average SST ranges from 27 to 29°C. Until 1985, almost the entire catch was from the Malabar upwelling zone, there was little or no catch from latitudes north of 14°N. During the last two decades, however, catches from latitude 14°N - 20 °N are increasing. In 2006, catches in this area accounted for about 15 percent of the all-India oil sardine catch. The higher the SST, the better the oil sardine catch (Vivekanandan *et al.,* 2009a). The surface waters of the Indian seas are warming by 0.04°C per decade. Since the waters in latitudes north of 14°N are warming, the oil sardine and Indian mackerel are moving to northern latitudes. It is seen that catches from the Malabar upwelling zone have not gone down. Inference: The sardines are extending northward, not shifting northward. The Indian mackerel is also found to be extending northward in a similar way. According to CMFRI, the catch of oil sardines along the coast of Tamil Nadu has gone up dramatically, with a record landing of 185 877 tonnes in 2006. The presence of the species in new areas is a bonus for coastal fishing communities. Assessing their socio-economic needs will greatly help in developing coping strategies for adaptation to climate impacts. WWF is currently documenting community perceptions and experiences in relation to the oil sardine fishery of the eastern coasts.

c. *Spawning: threadfin breams like it cool:* Fish have strong temperature preferences so far as spawning goes. The timing of spawning, an annually occurring event, is an important indicator of climate change. Shifts in the spawning season of fish are now evident in the Indian seas. The threadfin breams *Nemipterus japonicus* and *N. mesoprion* are distributed along the entire Indian coast at depths ranging from 10 to 100 m. They are short-lived (longevity: about 3 years), fast growing, highly fecund and medium-sized fishes (maximum length: 35 cm). Data on the number of female spawners collected every month off Chennai from 1981 to 2004 indicated wide monthly fluctuations. However, a shift in the spawning season from warmer to relatively cooler months (from April- September to October-March) was discernible (Vivekanandan and Rajagopalan, 2009). These changes may have an impact on the nature and value of fisheries (Perry *et al.*, 2005). If small-sized, low value fish species with rapid turnover of generations are able to cope up with changing climate, they may replace large-sized high value species, which are already declining due to fishing and other non-climatic factors (Vivekanandan *et al*., 2005). Such distributional changes might lead to novel mixes of organisms in a region, leaving species to adjust to new prey, predators, parasites, diseases and competitors (Kennedy *et al*., 2002), and result in considerable changes in ecosystem structure and function.

d. *Vulnerability of corals:* In the Indian seas, coral reefs are found in the Gulf of Mannar, Gulf of Kachchh, Palk Bay, Andaman Sea and Lakshadweep Sea. Indian coral reefs have experienced 29 widespread bleaching events since 1989 and intense bleaching occurred in 1998 and 2002 when the SST was higher than the usual summer maxima. By using the relationship between past temperatures and bleaching events and the predicted SST for another 100 years, Vivekanandan *et al.,* (2009b) projected the vulnerability of corals in the Indian Seas. They believe that the coral cover of reefs may soon start declining. The number of decadal low bleaching events will remain between 0 and 3 during 2000-2089, but the number of decadal catastrophic events will increase from 0 during 2000-2009 to 8 during 2080-2089. Given the implication that reefs will not be able to sustain catastrophic events more than three times a decade, reef building corals are likely to disappear as dominant organisms on coral reefs between 2020 and 2040. Reefs are likely to become remnant between 2030 and 2040 in the Lakshadweep sea and between 2050 and 2060 in other regions in the Indian seas. These projections take into consideration only the warming of seawater. Other factors such as increasing acidity of seawater are not considered. If acidification continues in future as it does now, all coral reefs would be dead within 50 years. Given their central importance in the marine ecosystem, the loss of coral reefs is likely to have several ramifications.

III. Impact of climate change on resource users

Climate change poses a great threat to resource users, in particular, the fisher communities who are emotionally attached to their living environment as their livelihood is heavily dependent on sea. The impact of climate change in marine resource users includes, displacement of family members, food security issues, Migration of fisherfolk, fall in income level, seasonal employment, change in employment pattern, increased fishing cost, reduction of fishing days *etc*.

a. Demography and Social standards: Displacement of family members increased over the years, the young generation has a tendency to move out of fishing, Food security issues increased rapidly in recent years. Disguised unemployment is rampant in all sectors since earnings from marine fisheries are not proportionate to the increase in fishers. This has instigated labour migration induced by the earning potential in the distant waters coupled with limited resources in their vicinity.

b. Infrastructure sensitivity: Increased frequency and severity of storms or weather, and sea conditions are, unsuitable to fishing as well as damaging to communities on shore through flooding, erosion, and storm damage. There is proximity to hazard areas the fisher household are highly prone to disaster dwellings and the property loss increased over the years.

c. Income Effect: The income levels of fishers decreased substantially over the years. The employment pattern has been mostly seasonal, and alternate avocation options are minimal, there is also economic loss due to loss in number of fishing days. Changed fishing ground caused increased cost of fishing and fish storage. The fuel cost, the cost of fishing gear and boat are increasing significantly over the years.

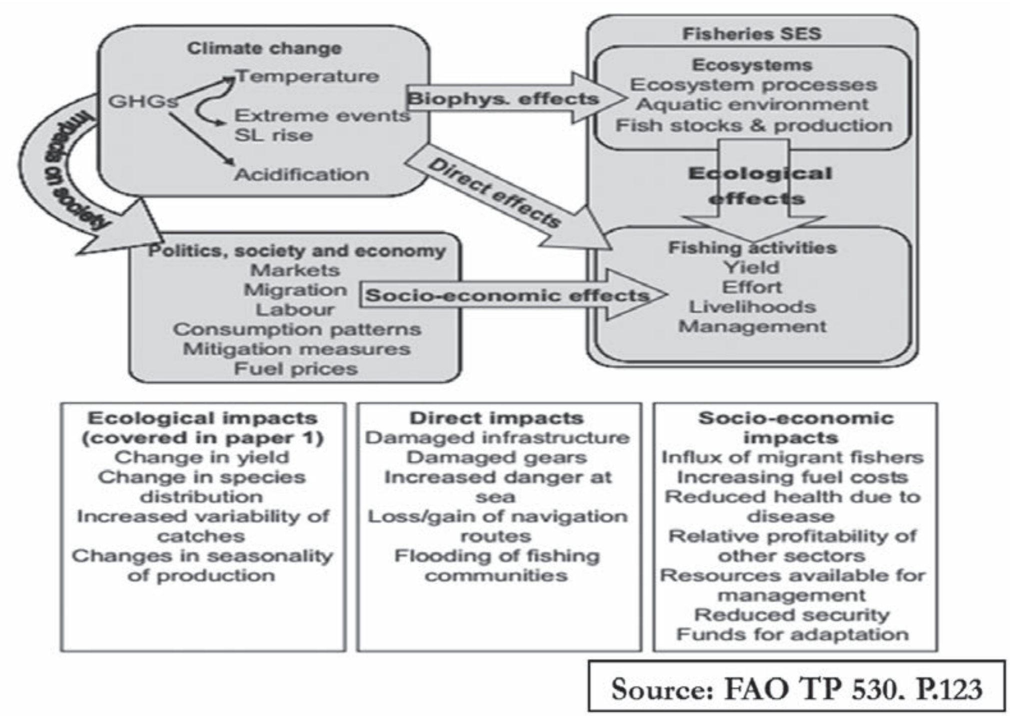


Fig. 2. Ecological, direct and socioeconomic impacts of climate change on fisheries

Climate Change and Coastal Communities – Need for awareness

Coasts are experiencing the adverse consequences of hazards related to climate and sea level, extreme events, such as storms, which impose substantial costs on coastal societies (Shyam and Manjusha, 2015). The coastal regions around globe are more prone to the impacts of climate change than the inlands, fishing being one of the primary occupations of the coast, the fishermen community is the most vulnerable group to be affected by the Climate change. Adaptation for the coasts of developing countries will be more challenging than for coasts of developed countries, due to constraints on adaptive capacity. Climate change has the potential to affect all natural systems thereby becoming a threat to human development and survival socially, politically and economically. Beyond basic findings about levels of concern, awareness and belief in human impact on the climate, some recent studies have attempted to delve deeper into public attitudes about climate change. Furthermore, awareness on climate change is a prerequisite to kick start any adaption and mitigation plans and programs in any community. In addition, it is quiet relevant to take advantage of the key informants within the community to disseminate the need for long term and short term adaptation and mitigation options to combat the climate change impacts and thereby making the community more resilient to climate change issues.

Community perception on climate change

A study was carried out to assess the level of awareness of vulnerable fishing communities of Ernakulam district of Kerala, about climate change and to identify the level of adaptation and mitigation strategies available and adopted by them (Shyam *et al.,* 2015). Njarackal (highly vulnerable village) and Ochanthuruth (moderately vulnerable village) were selected for the study. This was done by carrying out Vulnerability assessments- by employing vulnerability indices and preparing awareness schedules. Across the villages it was found that 98% of the respondents have heard about climate change at a time or the other but however it was found that awareness about climate change was less than 40 percent. There is discrepancy between hearing and awareness about climate change stems from the fact that hearing means it is only superficial knowledge about climate change. The major sources of information about hearing climate change could be different media, friends, relatives *etc*. but awareness involve an in depth understanding about climate change which indicate that the people know the causes , impacts, consequences, the society need and commitment towards its preparedness, adaptation measures *etc*. The perception of the visible features consequent to climate change is the extent of their agreement to the variables such as sea level rise, temperature increase, change in wind pattern, extreme weather events, sea water intrusion, water scarcity, property loss, erratic weather, diseases *etc*. affected them.

More than 72 percent of the respondents strongly believed that climate change is due to the aftermath of industrialization which can be attributed to urbanization, habitat destruction, pollution and transportation, which they held as equally important sources of causes of climate change.

Respondents' perception on the major impact of climate change on resources including catch reduction, increased efforts in fishing, migration of fishes, varied catch composition, shift in spawning seasons, temporal shift in the species availability, loss in craft and gear, occurrence of invasive species, alterations in fishing seasons, depletion of farm and inventories, non-availability of regular species *etc*. In the context of the study, resources

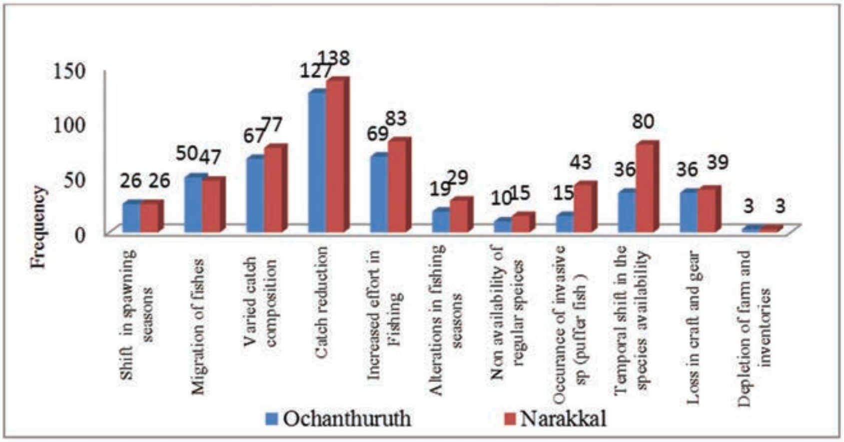


Fig. 3. Perception of climate change impact on resources

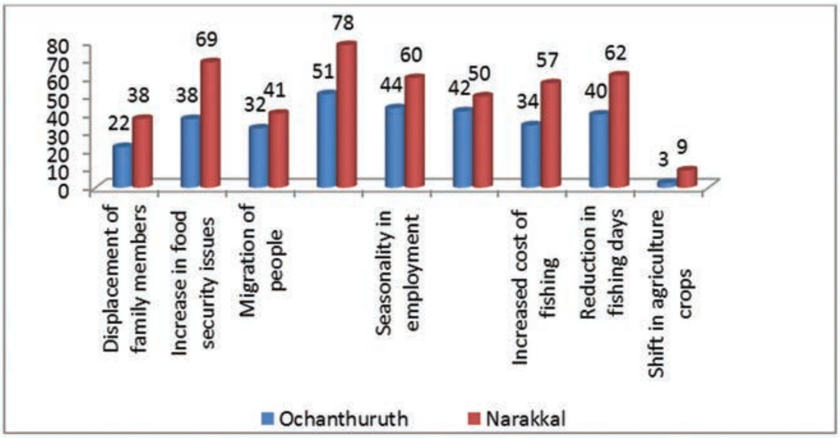


Fig. 4. Perception of climate change on resource users

indicate the fisheries sector and allied activities and the inventories involved. Climate change in every fisherman has a feeling that the fish catch has abridged. Fisher households are dependent on coastal and marine goods and services to a great extent, which serve as an important indicator as to how sensitive they could be in relation to climate events. There is a close association between climate change issues affecting the fishery resources and resource users. Respondents' perception on major impacts of climate change on resource users include displacement of family members, increase in food security issues, migration of people, substantial reduction in income, seasonality in employment, shift in employment pattern, increased cost of fishing, reduction in fishing days, shift in agriculture crops.

The knowledge on climate change among the respondents of both these villages was very shallow and pertained to short term happenings. Awareness on climate change is a prerequisite to initiate steps in combating negative impacts of climate change. Though changing climatic condition is a global concern, the possible mitigation options for improving adaptive capacity needs to be local. An integrated approach comprises of actions for addressing long term and short term concerns of the community, through grass root level actions which would have to be initiated in materializing local solutions to compact the cumulative impact of climate change.

Vulnerability assessment, Adaptations and Mitigations

Shyam *et al.,* 2014 constructed the vulnerability indices using Parameter, Attribute, Resilient indicator and Score (PARS) methodology, a conceptual framework developed for assessing the climate change vulnerability of coastal livelihoods under the initiative "National Innovations in Climate Resilient Agriculture" (NICRA). Under this initiative, the vulnerability of 318 fisher households in Alappuzha District of Kerala were assessed using PARS methodology (Shyam *et al.,* 2014). The methodology provides prioritisation and ranking of the different impacts as perceived by the fishers on environment, fishery and socio-economic parameters. The vulnerability indices were worked out for the fisher households. The fisher's perception revealed that fishery was most impacted followed by economic and environmental impacts. Social impact was the least as opined by fishers. The study indicates that long term effects of climate change aren't realised/perceived/impacted much among the fisher households. The fishers were more prone to loss in fishing days due to erratic monsoon.

The methodology was employed across the Theme III of IDLAM (Integrate District level Adaptation and Mitigation)and was adopted across the coastal villages of the country. The results suggest a bottom up approach with the proactive participation of the the primary stakeholders awareness by involving them in disaster preparedness, management and mitigation planning as well as implementation process.

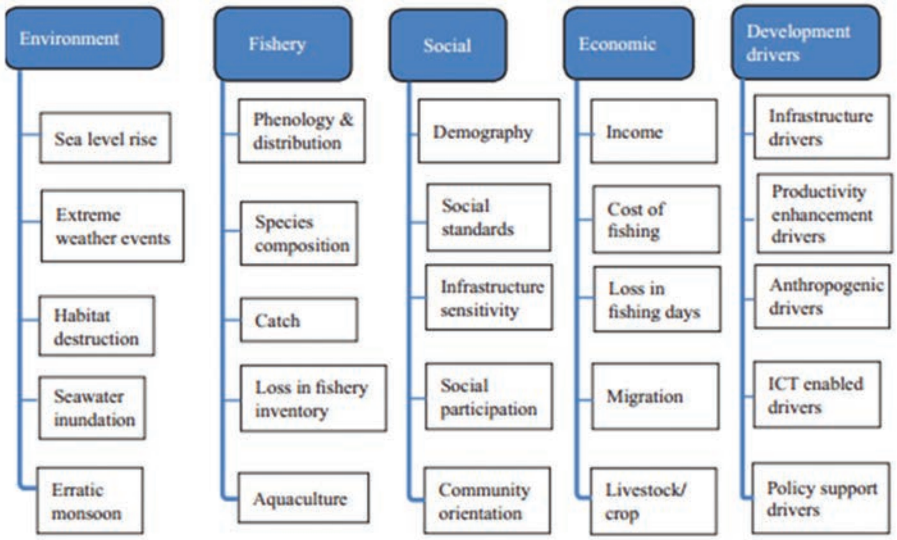


Fig. 5. Parameter and attributes used in PARS methodology frame work (Shyam *et al.*, 2014)

In general the fisher folk of Kerala are emotionally involved in their livelihood activities pertinent to their homestead habitat and are sensitive to the changes in their surroundings. Due to the lack of awareness about the big picture – The climate change, the fisherfolk are naïve in context to the source of the problems including temperature rise, extreme weather events, reduction in fish catch over years, change in fish composition over years and sea level rise. The process of providing right and comprehensive knowledge on climate change is the need of the hour; this can be achieved through a bottom up approach involving the primary stakeholders along with the community which will eventually position them to adequate climate change adaptation and mitigation by augmenting their traditional knowledge (Shyam *et al.*, 2014).

Climate change research - A GULLS initiative

The CMFRI research project on "Global understanding and learning for local solutions: Reducing vulnerability of marine-dependent coastal communities" (GULLS) under the theme on Coastal Vulnerability was sanctioned under an MoU of Belmont Forum and G8 Research Councils International Opportunities Fund. Focus areas of GULLS project include Southern Africa, Southern Australia, Western Australia, Mozambique channel, Southern India and Brazil. The GULLS project addressed the Belmont Challenge priorities in the area of coastal vulnerability – specifically the challenges that arise in food security and sustaining coastal livelihoods as a result of global warming and increasing human coastal populations. The project is contributing to improving community adaptation efforts by characterizing, assessing and predicting the future of coastal-marine food resources and identification of suitable adaptation options. The rationale for selection of the focus area included early observation of the impacts, strong incentives to initiate adaptive strategies, developing models for early prediction and validation, developing adaptation options and testing for challenges to be met efficiently and effectively.

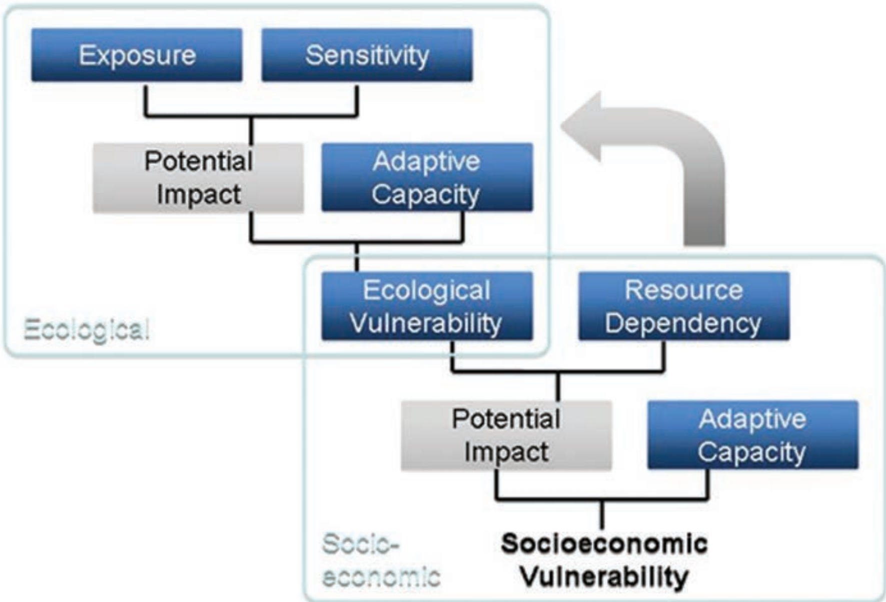


Fig. 6. Vulnerability model

Identification of climate change hot spots

Since hot spots in climate change parlance has not been identified yet in Indian context, it is high time to define and identify climate change hot spots in India to initiate comprehensive planning for adaptation and conservation measures. In this context Climate change Hot spots –can be defined as the "live *labs'* where the manifestation of the climate change impacts are observed "first". The identification of the climate change hot spots would help policy makers in priority setting and in planning adaptation and conservation measures.

The coastal vulnerability assessment in GULLS project underlines, a demarcation between fishery hotspots (based on fish abundance, phenology, distribution, range shifts, recruitment success *etc.*) and social hotspots (determining vulnerability, displacement, marginalization of traditional community) would be a novel idea to have representation of diverse factors in the project. Consistent with the objectives of GULLS, the activities will be aiming at assessing the current status of the fishery resources and ecosystem services and would attempt at predicting the future impacts of climate change on these resources and services apart from identification of key vulnerable marine species to climate change and assessing the community vulnerability.

The review done in addition to the discussions with the Belmont team resulted in boiling down the hotpsot region to (South West and South East Region of India).The South East India encompassing Ramanathapuram and Tuticorin districts of Tamil Nadu could be one of the Hotspot and the other be South West India(coastal districts of Kerala including Ernakulum, Alappuzha, Kollam and Trivandrum) with fisheries abundance and distribution shifts.

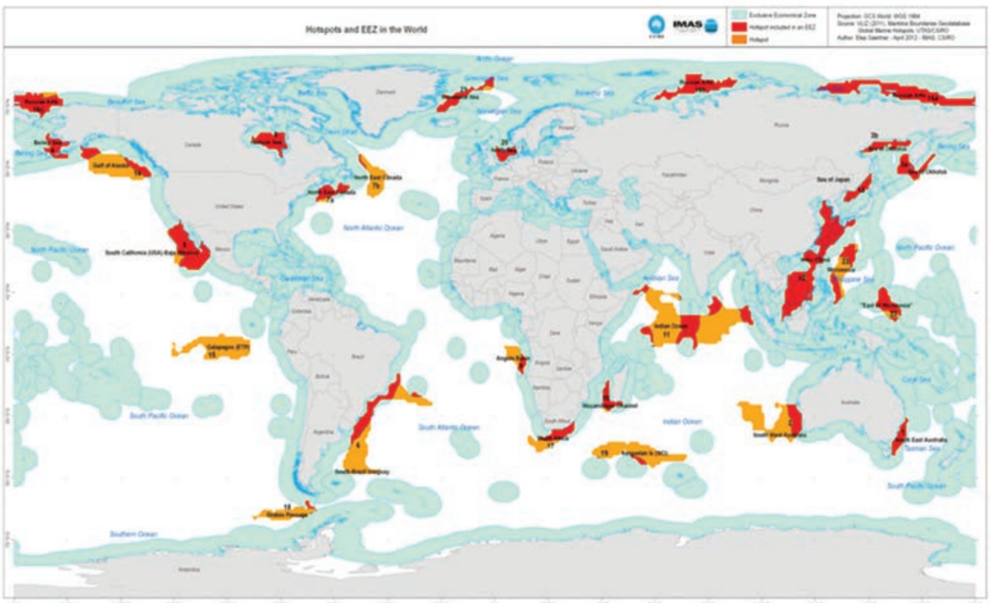
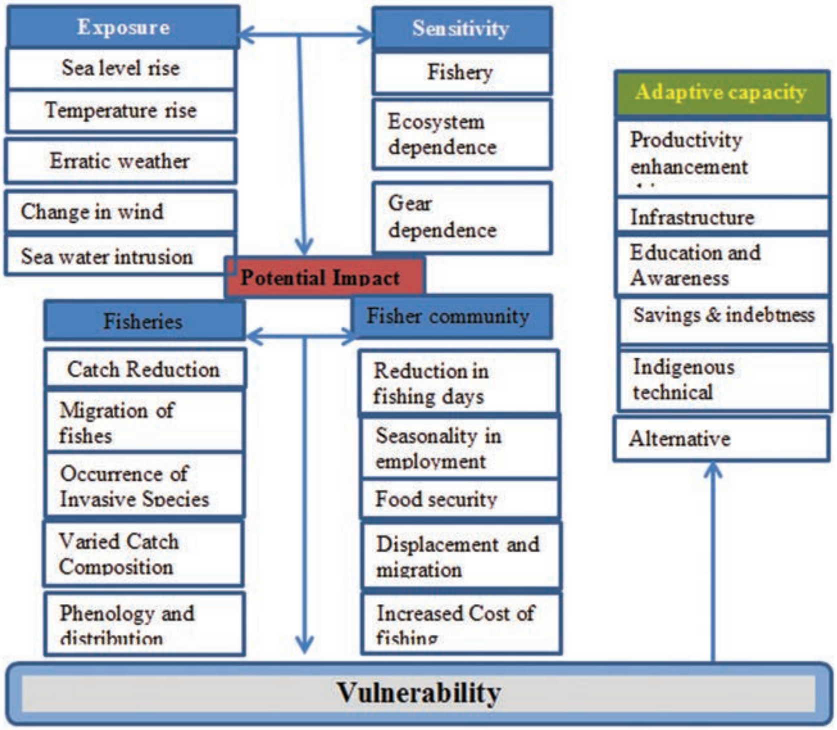


Fig.7. Hemisphere hotspots ocean regions experiencing fast warming and those with heightened social tensions as a result of change.

Vulnerability of coastal regions will be characterized using a linked socio-economic and ecological vulnerability model .The project will be in operation in the different hotspots and will lead to build regional skill-sets that can reduce coastal vulnerability by evaluating and characterizing likely impacts, create predictive systems that will inform decision makers about the expected consequences of coastal changes; deliver alternative options in terms of adaptation and transformation within coastal communities; and to define the long-term implications of selecting a particular option in terms of economic, social and environmental



(Modified form IPCC climate change vulnerability frame work)
Fig 8 . Conceptual Frame work of GULLS Fisheries Climate Change Vulnerability Assessment

outcomes. Thus, along Kerala, two major fishing villages namely Elamkunnapuzha of Ernakulam district and Poonthura of Thiruvananthapuram district in the south west hotspots of India was selected under GULLS project to assess the overall vulnerability of fishery based livelihood due to the impact of climate variation.

A composite vulnerability index approach was used in this study to evaluate relative exposure, sensitivity, and adaptive capacity (Islam *et al.,* 2014). The mean values of the three sub-indices of Exposure (E), Sensitivity (S), and Adaptive Capacity (AC) were combined to develop a composite vulnerability index by using the following additive (averaging) equation (Islam *et al.,* 2014).

Vulnerability (V) = Exposure (E) + Sensitivity (S) - Adaptive Capacity (AC)

The overall vulnerability values indicate that Poonthura village is slightly more vulnerable than Elamkunnapuzha . The proximity of Poonthura village to the sea can be attributed as the major factor contributing the increase in vulnerability compared to Elamkunnapuzha. In addition higher exposure on account of environmental changes, occurrence of drought and shoreline changes is also attributed to higher vulnerability in Poonthura. However, the sensitivity values are high in Elamkunnapuzha when compared to Poonthura due to high social dependence, economic dependence on other resources as well as historical and cultural dependence on fishing. The adaptive capacity of the selected villages were low when compared to exposure and sensitivity values, indicating the urgent need for developing appropriate adaptive interventions. Therefore, more adaptation options like better policy framework, proper planning measures, and effective disaster management techniques should be implemented to increase the adaptive capacity of the fishermen community to climate change. Improvement of natural capital like steps to curb marine pollution, maintaining prey-predator relationship in the oceans, promoting the culture of species in marine habitats (Cage culture), regulation of fishing rights across the Indian seas, extending the period of trawl ban so as to prevent the recruitment of juveniles entering the fishery maybe looked into as major elements while framing adaptation options.

CReVAMP' – "Climate Resilient Village Adaptation and Mitigation Plan"

A new framework titled 'CReVAMP' – "*Climate Resilient Village Adaptation and Mitigation Plan"* conceptualised for planning and implementing village level adaption and mitigation plan which is given in the figure no 9. Consistent with the project objectives, CReVAMP is developed to identify existing climate adaptation and mitigation- probing alternatives and their trade-offs, sensitizing and improving the resilience of community towards climate change and initiating a multi stakeholders platform for developing a climate knowledge and information systems. The 'CReVAMP' framework presents major elements and approaches through which the desirable outcome is envisaged across different players including individuals, community and the government. This also offers room for defining the 'elements' and 'approaches' in accordance with the village scenario and also for iterative planning of participatory as well as systems-based approaches under which different activities could be implemented with stakeholder engagement for achieving desirable outcome. Considering the sustainability of the adaption and mitigation activities even after the project period, involvement of the climate change agents in the entire process is vital and we have identified a group of people with representation from different age, gender and experience, encompassing articulate children, proactive youth, experienced fishers and committed women as climate change agents in the project. This framework is centered on people and it would help different practitioners to synergize their thoughts and ideas towards planning and implementing different adaptation and mitigation programs thereby helping the community to become climate resilient. In GULLS project we are adopting an integrated approach which would synergize the knowledge system of scientific and indigenous knowledge between the researchers and different stakeholders of the community. It is a balancing act between (i) 'Top Down and Bottom up Approaches', (ii) Prioritized needs of experts and felt need of the communities, (iii) Scientific Knowledge and Traditional wisdom,

(IV) Community Solutions and Policy Solutions. This process would be facilitated using multi stakeholder governance model by bringing different stakeholders together to participate in the dialogue, decision making, and knowledge sharing and there by instigate knowledge generation process within the community during the course of the process. The whole process is directed to create village information system within the community, enable green fishing practices and prepare A&M plan for a community which would in turn helps in community empowerment, thus enabling in building resilient community /Climate Change Informed Fisher Community (CCIF). The CCIF is expected to influence the society and government in decision making and actions related to climate change mitigation and would eventually be able to influence the policy making process.

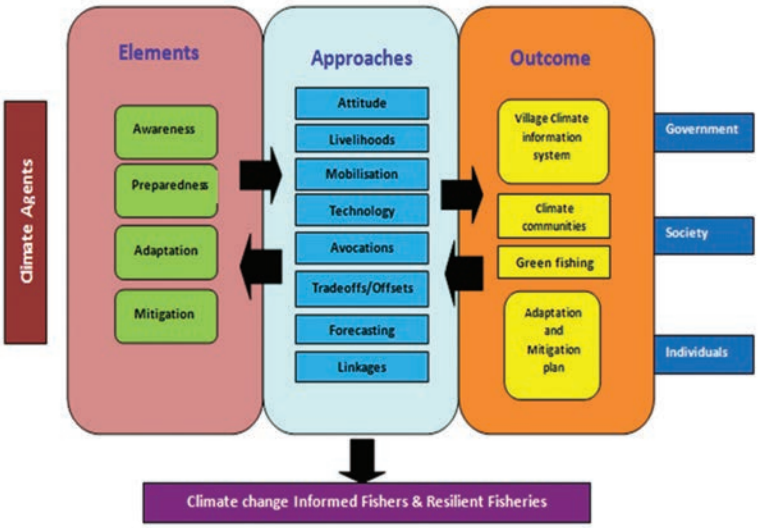


Fig. 9. CReVAMP Model- Climate Resilient Village Adaptation and Mitigation Plan

Various Phases are involved in the implementation of CReVAMP which are listed below in the table. These phases could be made operational with

Phase I	Identification of hot spot areas / districts/ delineation of villages
Phase II	Linkages with Department of Fisheries (DoF, Local Self Government(LSG)
Phase III	Conduct baseline and household vulnerability survey
Phase IV	Developing reports / Conducting awareness workshops / Engagement of fishers in climate change activities
Phase V	Creation of Climate Information Kiosks
Phase VI	Formation of climate change communities
Phase VII	Planning and implementation of Adaptation and Mitigation plans
Phase VIII	Climate resilient village adaptation and mitigation plan (CReVAMP) with Climate Change informed fishers.

Way Forward

Climate change is no unidirectional issue, it brings along with its effects on both the resources and resource users, thus the adaptation to it should ensure that the multifarious impacts it brings along can be tackled. Development cannot be ceased, nor can exploitation be hailed, the key to successful climate change adaptation is implementing sustainable development through incentive based polices and empowering the economically weaker sections of the society with environmentally friendly livelihoods. This could be achieved through 'blue economy' which is a recently developed business model which will shift society from scarcity to abundance "with what is locally available", by tackling issues that cause environmental and related problems in new ways. Blue economy could enhance the ocean technologies, provide marine governance, helps to improve ocean health and manage coastal urbanization. It is the marine based economic development which improves the human well -being and also social equity which in general greatly decreases the environmental risks and ecological scarcities.

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CHAPTER

33

CHANGES IN ENVIRONMENT: IMPLICATIONS FOR FISHERIES IN INDIAN WATERS

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Introduction

The coastal and marine ecosystems are dynamic and the seasonal and inter-annual fluctuations of the abiotic ecological parameters reflect on the biological functioning of the plankton, nekton and all other biota. Apart from the natural variations, anthropogenic impacts including climate change and habitat degradations and alterations have affected the sustainability, productivity and diversity of almost all critical habitats like the mangroves, sea grasses and the coral reefs. Each critical habitat has its own unique characteristics and the biota which depend on these have suitable adaptive characters to survive, grow and reproduce in these. However, variations which are significantly wide and large lead to mis-matches eco-biological links. These affect the recruitment of the species which cascades down the food web and the fisheries. Some of the major environmental factors are the monsoon and upwelling and specifically, if we take environmental variables like sea surface temperature, oxygen, salinity and nutrients. Similarly habitat alterations due to marine litter and shrinking of habitats due to land filling and other activities have severely affected the estuarine fauna.

The Indian fisheries is composed of major small pelagic fishes like sardine, mackerel and anchovies; the large pelagic like the tunas and bill fishes, several demersals and shellfishes. Also, the ecological characters of the west coast which is influenced by upwelling is different from east coast. A brief description of the variations in environmental factors and their impact on the fisheries is given below.

Natural variations in ecosystems and impacts on fisheries

Upwelling and fisheries

Upwelling is a process in which deep, cold water rises toward the surface. Upwelling occurs when winds push surface water away from the shore and are replaced by cold, nutrient-rich water that wells up from below. Deep ocean water is more nutrient-rich than surface water as nutrients, dead and decaying plankton and other fish carcasses sink to the bottom. During upwelling these are brought back to the surface and these fertile systems support blooming of diatoms and zooplankton. This rich food supports growth and maturation of several fishes. Along the Indian west coast, upwelling is strong along Kerala coast and is known to occur in varying intensities. El-Nino has been found to affect the intensity of upwelling.

Along Kerala –Karnataka coast upwelling sets in by May –June and the rich food available prepares the pelagic fishes especially sardine for spawning. When upwelling is poor, the major factors supporting gonad development like blooming of diatoms and lowering of ambient temperature does not happen and this can lead to poor maturation or delayed maturation. In 2015, upwelling was poor and maturation was affected.

Upwelling can also bring in low oxygen water which can lead to hypoxic conditions. Sometimes along Kerala coast, low oxygen in upwelled waters can be seen in the sardine habitat during August –September. If the dissolved oxygen levels are below one ml /l then this has been found to affect recruitment and the fishery. Low mixing of waters can cause stratification and along with hypoxic conditions cause stress to the early life stages.

Monsoon and Fisheries

When maturation is largely influenced by upwelling, the onset and intensity of southwest monsoon has a good influence on spawning and recruitment of pelagic fishes like sardine. Though there is no direct affect, the changes triggered by monsoon especially the blooming of plankton in near-shore waters supports early larval development. The high levels of phosphate, nitrate and silicate in the river runoff triggers and supports blooming of diatoms. These support the large shoals of early life stages of sardine. Similarly, there will be negative impacts when the river runoff is high and there is no proper mixing. This can lead to stratification and adversely affect recruitment.

Temperature-Food combination and links with El nino

Globally, 2015 has been considered as a warm year with high temperature and low food. The average seawater temperature in sardine habitat was 29.8^{o} C during 2015, which is nearly 1.1 ^{o}C higher than the average observed (28.6^{o} C) for the last 5 years. Positive SSTA exceeding 0.6 ^{o}C dominated in the tropical Indian Ocean. There was a substantial warming in the tropical Indian Ocean, partially due to influences of the 2015 El Nino. The mean SST in the tropical Indian Ocean was reported to increase by 0.13-0.2^{o}C in 2015. Phytoplankton density was also low during April/ May 2015 compared to the high during 2012. This low food availability in the habitat was found to affect maturation which resulted in poor recruitment.

Environment changes and recruitment

Two important theories in ecology have been found to be applicable to the Indian fisheries scenario. The theory of Optimal Environmental Window (OEW) states that in upwelling.

Systems, wind, storm, and other energetic events cause turbulence that, within an optimal range, increase larval recruitment; dependent upon the presence/ absences of Ekman transport. When the optimal ranges are absent, the larvae does not get recruited to the fishery. Similarly, the Match-mismatch hypothesis of the British biologist cusing where the success of larval recruitment is linked to a temporal alignment of fish reproducing, larvae hatching, and plankton blooming has also been found to be relevant in the Indian context.

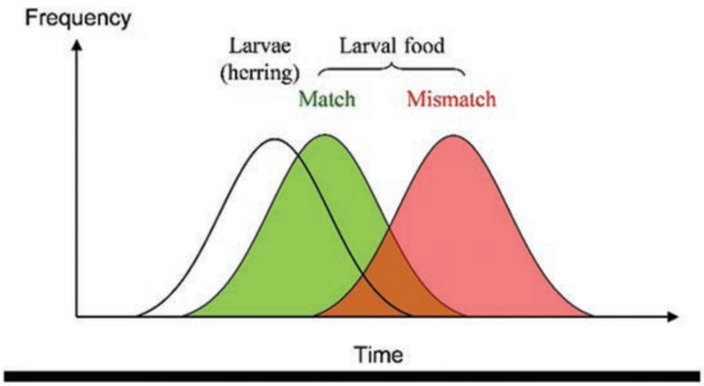

Fig 1. An increase of the time-lag between the two populations leads to a low match. Adapted from Cushing (1990)

Anthropogenic impacts on Environment and fisheries

Impact of litter – physical changes

Light weight articles which are discarded on land or directly into the aquatic systems float (floating litter) and are transported as per the direction of wind and slowly with attachment of silt they sink down (Column litter) and float in the water column. (*Example- The weight of a plastic cover which is approximately 3.8 g has been found to increase to 8 g and float in the column before settling)*. With time, it sinks and spreads on the bottom and creates anoxic conditions which prevent oxygenation and lead to anoxic conditions thereby displacing the benthic community (Bottom litter). Within the aquatic systems, floating litter can also get accumulated in certain pockets where water movement is less, especially near the shore and remain there for years together, these can be called “Biologically Dead Zones”.

When water flow is less like in the dead zones, growth of zooplankton will be less and prevent light penetration which is essential for a healthy ecosystem. This will affect fishes and fish larvae. Evidently this reduces the beauty of the area and if uncontrolled, can lead to decline in visits tourists, thereby affecting those who depend on tourism industry. Globally it has been estimated that 70% of the litter sinks down and destroys the substratum.

Fishes which substrate spawners like Karimeen (Pearl spot/*Etroplus suratensis*) have drastically declined and this has affected the small scale fishery. The breeding areas of such fishes have been affected by dumping of solid waste and poor water quality. These fishes attach their eggs to rocks or hard substrates and need shady and protective areas for rearing their young ones. Now severe destruction of benthic habitat has reduced congenial area for breeding and nursery of young fishes. These fishes lay only few eggs, for example, one pearl spot produces about 2700 eggs per spawning which is low compared to fishes like mullets and sardines. Hence these are more vulnerable to habitat loss.

Floating and submerged debris has reduced the habitat area available for the fishes and thus has reduced the biomass of fishes. The commercially important benthic resources like crabs, shrimps and clams are the most affected by benthic habitat destruction. Dumping of solid waste from slaughter houses and its decaying also adds to poor water quality. Clogging of canals by plastics and other litter has led to increased sedimentation and reduced the depth of the estuary. Lack of water flow has caused low oxygen condition which has also reduced the quantity of plankton available as food for the fishes.

The surveys conducted on the seed availability have clearly indicated a significant decline in seed resources of all species of shrimps in Vembanad Lake. *Peneaus* (*Fennerpenaeus*) *indicus*, *Penaeus mondoan*, *Metapenaeus dobsoni*, *Metapenaeus monoceros* and *Metapenaeus affinis*. This is reflected in the shrimp catches of stake net units where the catch per unit effort has declined from 3.2 kg in 1997 to an average of 0.508 kg indicating nearly 84% decline.

The abundance of all species of shrimp seed in Cochin backwaters has declined drastically during the last two and half decades. Surveys conducted in 2013 have indicated that the major resources like white shrimp (*Fenneropenaeus indicus* and *Metapenaeus dobsoni*) have declined. Shrimp seed mainly feed on detritus; now the backwaters substrates have considerable quantity of litter. Survey results have indicated that traditional shrimp farms are affected by low shrimp seed availability.

When efforts are made to remove solid waste from land, there are no programs for removing litter accumulated in rivers, estuaries and sea. Since estuaries which are critical habitats are already impacted by untreated effluents from industries, direct dumping of solid wastes, invasion of aquatic weeds, reduced water flow, high siltation and landing filling there is an urgent need to initiate programs to control these and start restoration programs.

Fig. 2. A branch of estuarine canal completely clogged by invasive aquatic weed in Cochin backwaters

Habitat alterations

Shrinking of estuarine areas due to reclamation, sand mining, excessive sedimentation due to physical manmade barriers and degradation of critical habitats like mangroves and sea grasses have affected the structure and ecosystem services of these aquatic systems. The most affected areas are the coastal wet lands. The increase in floating weeds and clogging of estuarine branches by the invasion of these weeds have affected fishers, especially the clam fishers.

Increasing incidences of harmful algal blooms

Globally, the intensity and frequency of occurrence of HABs have increased. Indian fisheries is also affected by blooms of *Noctiluca* sp, *Tricodesmium* sp and other dinoflagellate blooms. These reduce the diversity of phytoplankton community and create imbalances in the plankton community. These are found more during the late monsoon or early pre monsoon which is a major spawning period of both pelagic and demersal fishes.

Increasing incidences of jelly fishes

Along both the coasts, the jelly fishes have increased in number. Only few species bloom. But the occurrence of hydrozoan and schyphozoan medusae in the coastal waters have led to decrease in fishing days and also low fish catches in seines and trawlers. The spread of jelly fishes in the estuarine areas due to salinity intrusion has also created considerable problems to inshore gill netters. Globally jellyfishes are considered as a threat to fisheries. The major reasons for this new problem is considered as eutrophication, increased episodes of hypoxic conditions and spread of underwater structures which serve as a niche for the dormant stages of jellyfishes.

Conclusion

The influence of environmental variations on the productivity of the aquatic systems and the fishery of the area has become more evident now. The impact of fluctuations in seasons and intensity of natural ecological variations on the recruitment of major fishery resources is slowly being understood. There is an urgent need to have deeper understanding of these eco-biological links and develop the skill to predict the impacts under different scenarios. This would help to increase the preparedness of the fishers against fishery declines.

Though, there are rules protecting the habitats from unplanned human activities, these are not strictly implemented. Understanding the need to reduce the anthropogenic activities on habitats, it is suggested that micro- level environment management plans are developed in close association with the researchers and the coastal villagers. Effective implementation of co-management systems would help in effective governance.

CHAPTER 34

EL NIÑO AND ITS IMPACT ON CORAL REEF ECOSYSTEM IN THE EASTERN INDIAN OCEAN

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Introduction

The coral reef bleaching associated with the elevated Ocean temperature has been widely reported in the last three decades from different regions of the world. The rising temperature and acidification of Oceans makes a big challenge for the survival of reefs in the world. The other important stresses for the reefs include increased UV radiation, sea level variations, suspended sediments and increased turbidity of water. There are different studies which relate bleaching events with global warming and climate change. However, the increased frequency of mass bleaching events could not be sufficiently explained with current warming rates of the Ocean. Stone *et al.,* (1999) put forward a new theory that recent increases in mass bleaching events were in response to the relative increase in El Niño experienced over the last two decades. The bleaching threshold temperature is site dependent and it may vary from one reef region to other. The threshold temperature for the Indian reefs is approximately 31°C (Vivekanandan *et al.,* 2008). In the Indian Ocean, the coral reefs around the Andaman Islands suffered bleaching events during 1998, 2002, 2005, 2010 and 2016. In the Andaman Sea, the rise in temperature was abnormal during 1998 and 2010 and hence mass bleaching events were happened during that period (Krishnan *et al.,* 2011; Vivekanandan *et al.,* 2008). The coral reef bleaching associated with warm water anomalies in the Pacific Ocean during an El Niño period is well studied and documented. However, the link between the massive bleaching events in the Indian Ocean and El Niño is not straightforward as in the Pacific. For example, the massive bleaching event of 1998 in the Indian Ocean was happened in May and that was a transition period from a strong El Niño to a strong La Niña in the Pacific. Hence, in the Indian Ocean, the role of El Niño in the mass coral reef bleaching event of 1997-98 was not clear (Wilkinson, 1999). Moreover, the ocean temperature variability in the Indian Ocean can be significantly modulated by the different regional processes in the Indian Ocean itself such as Indian Ocean Dipole, formation of cyclone, early arrival of monsoon *etc*. However, a recent study shows that massive bleaching events in the Andaman reefs of the Indian Ocean is directly linked with the strong El Niño events in the Pacific Ocean (Lix *et al.,* 2016). The atmospheric teleconnections between the two Ocean basins is the primary reason for this link.

Hot spot Method

By using long term satellite data sets, Goreau and Hayes (1994) developed a 'hot spot' method to predict the possibility of bleaching events in the reef region. A hot spot is the area of the ocean with sea surface temperature anomalies over 1°C above long-term averages of monthly maximum. AVHRR Pathfinder SST with 4x4 km resolution that available from 1982 onwards can be used to estimate the hot spot area.

Hot Spot = Weekly average SST – Monthly Mean Maximum Climatology

Hot spot products based on satellite data sets is also directly available from NOAA coral reef watch program. The details of the NOAA products such as hot spot, degree heating week, bleaching alert area, SST anomaly are available in the NOAA website https://coralreefwatch.noaa.gov/satellite/index.php. If the hot spot anomaly greater than 1°C exists for greater than or equal to 4 weeks, there is a strong chance for severe bleaching. Hot spot region around the Andaman reefs for a mass bleaching event (2010) and non bleaching event (2011) is shown in figure 1 and figure 2.

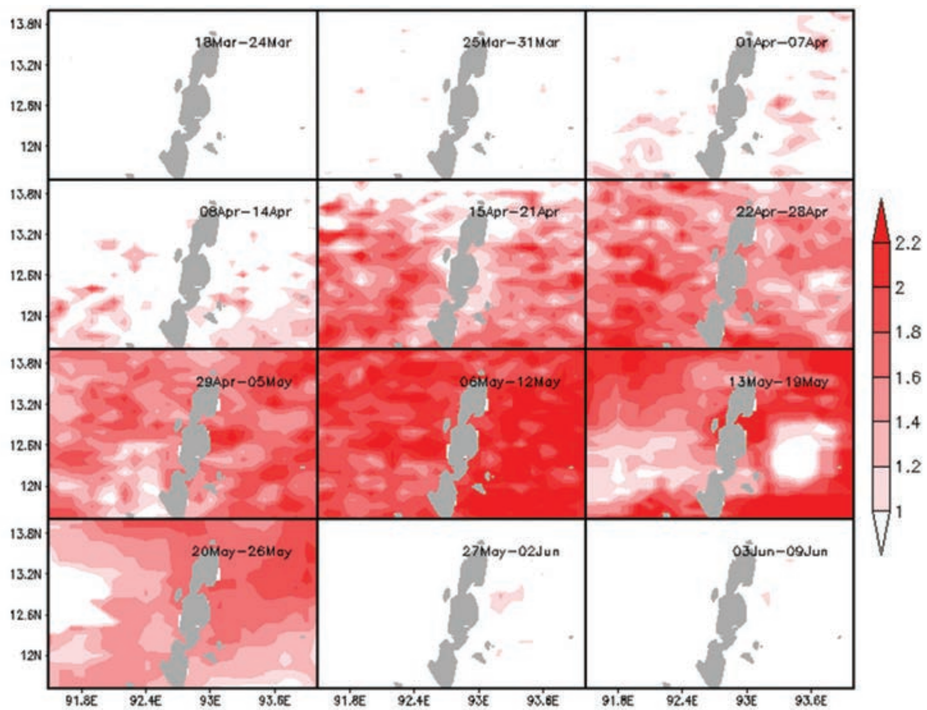

Figure 1. The spatial distribution of the weekly hot spot images from March 18 to June 9, 2010 around the Andaman Islands (Lix, Venkatesan, Grinson et al., 2016)

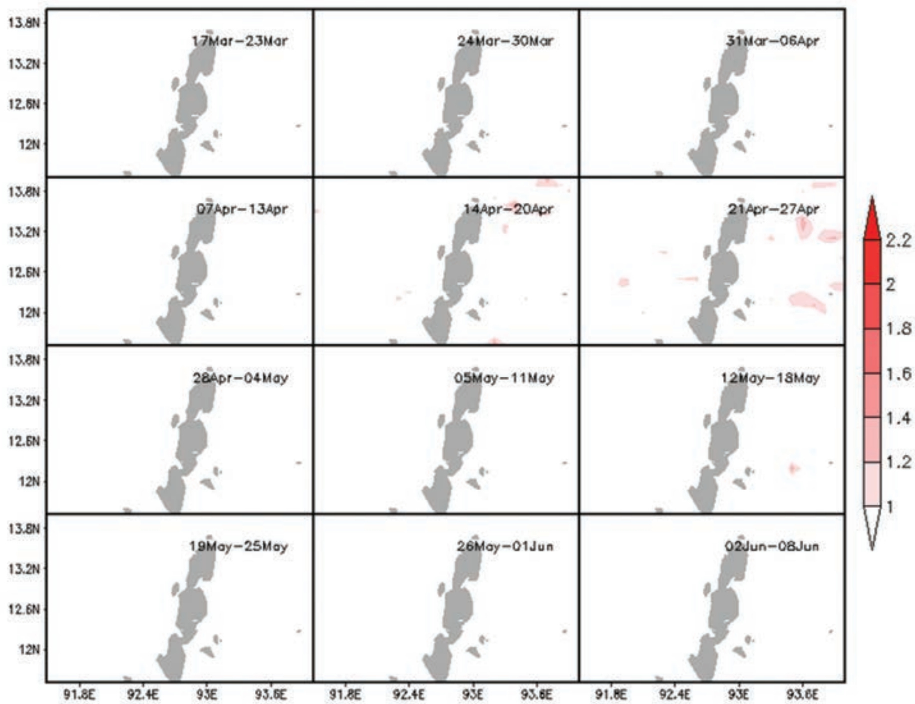

Figure 2. The spatial distribution of the weekly hot spot images from March 17 to June 8, 2011 around the Andaman Islands

El Niño and its impact on Andaman Sea temperature and coral reefs

El Niño is a warming of the tropical Pacific that occurs roughly every three to seven years and lasts for 12 to 18 months (McPhaden, 2002). During El Niño, trade winds weaken along the equator and that causes for the reduction in the upwelling and subsequent warming in the central and eastern Pacific. For more detail of El Niño physics see McPhaden (2002). A strong El Niño in the Pacific causes a similar warming in the Andaman Sea and Eastern Indian Ocean and that warming may lag the peak of El Niño by 4 to 6 months. The delayed response of Indian Ocean to an El Niño event leads to the formation of unusual warm anomalies during the pre monsoon months of an El Niño followed year. Niño 3 index and Niño 3.4 index are the most commonly used indices to define El Niño events which are based on SST anomalies averaged across a specific region. The Niño 3 Region is bounded by 90°W-150°W and 5°S- 5°N. The Niño 3.4 Region is bounded by 120°W-170°W and 5°S-5°N. The change in cloud cover can significantly modulate the incoming solar radiation that reaches the Ocean surface. The net incoming shortwave radiation is the primary factor that determines the heat budget of a shallow reef region. Hence the change in cloud cover due to the change in the large scale atmospheric circulation can significantly alter the net heat gain and hence the sea surface temperature of a reef environment. A schematic diagram for an altered Walker circulation and its role on the warming of Eastern Indian Ocean is given in figure 3. The altered Walker circulation and the resultant atmospheric forcing on the Ocean surface has a significant role on the warming of the Indian Ocean during an El Niño followed year (Klein *et al.,* 1999).

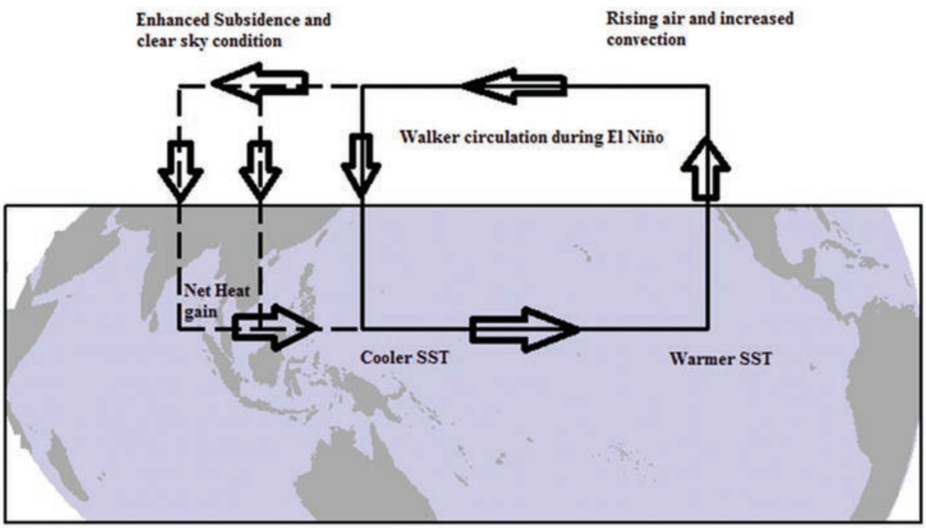

Figure 3. The altered Walker circulation for a typical El Niño event

Summary

The formation of hotspot pattern and its existence for a prolonged duration can induce bleaching in Indian reef region. A strong El Niño as in 1997-98, 2009-10 and 2015-16 can cause for the abnormal warming and resultant massive bleaching events in the Indian reefs. However, the thermal environment of Indian reefs can significantly affected by the regional atmospheric and oceanic processes. The regional processes can enhance or reduce the El Niño related warming in the Indian Ocean and hence regulate the intensity of bleaching. There is a considerable increase in the intensity and frequency of El Niño in the last four decades. At present, the impact of global warming on El Niño frequency and intensity is unknown. However, recent modeling studies indicate that frequency of El Niño may increase in the future. Hence, Indian reef may experience more mass bleaching events in future. Among all the reef regions of India, the effect of El Niño is more severe on Andaman reef because the perturbation associated with El Niño arrives at the climatological maxima in the seasonal heating cycle of the Andaman Sea.

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CHAPTER 35

CORAL REEF ECOSYSTEM-MONITORING AND ASSESSMENT USING SATELLITE DATA SETS

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Introduction

Remaining in splendid isolation, the Andaman and Nicobar Islands have a great relevance in the study of marine ecosystems. The islands, though remotely located in an ostensibly pristine environment have born witness to serious issues with regard to their ecosystem health. There are significant changes in the temperature and rain fall pattern in the islands and predictive modelling has forecasted further damage in the near future. The inundation of saline water into inland terrestrial ecosystems has created salinity stress to freshwater species while reducing the water available for domestic consumption. Terrestrial flora and fauna are vulnerable to the intruding saline waters. The marine ecosystem also faces grave challenges. There are issues of anthropogenic pollution resulting in damage of corals, regime shifts in community structure, water quality deterioration and other damage to marine fauna. Climate change has taken a toll on the ecosystem with coral bleaching which was observed during 1998, 2002, 2005, 2010 and most recently in 2016. An interactive digital database on corals has been developed to address the regular health status of corals. With the help of satellite remote sensing data, mechanisms of reef bleaching can be uncovered and the probable threats can be addressed by providing advisories developed in collaboration with INCOIS, Hyderabad. The increased incidence of tropical cyclones in the region is also wreaking havoc in the reef and related ecosystem. There are recent changes in the community structure due to the aforementioned challenges and changes are notable in all marine related ecosystems such as reefs and mangroves. There are instances of reefs exposure due to tilting of islands, proliferation of unwanted island flora and fauna due to inadvertent human interventions, wastage of natural resources due to unscientific policy decisions and illegal poaching of island resources by neighbouring countries. Despite all these issues the fishery in the islands remains under-utilized. There is a huge scope for utilizing the fishery to the benefit of the island community. Possible methods of harvesting these resources will also be discussed in the lecture.

Status of coral reefs in Andaman after two major catastrophic events - tsunami of December 2004 and bleaching of May 2005 (Dam Roy *et al.*, 2014)

The 26th December 2004 tsunami, caused by a massive earthquake off the west coast of Sumatra, resulted in widespread devastation of coral reefs in the Andaman and Nicobar Islands. A reef survey carried out in January 2005 indicated that many exposed corals were dead and corals that suffered breakage were precariously living. Dislocated corals and cracks in the coral reefs were also noted. Coral composition remained the same in protected bays as most of them were shielded from the brunt of earthquake and tsunami.

Shortly after the tsunami, the same area was subjected to a bleaching event in the month of May 2005. Surveys revealed that the live coral cover amounted to only 6.5%. The partially bleached, fully bleached, dead and other coral components were 4.8, 13.3, 19.7 and 55.7% respectively. The extent of coral damage and their subsequent recovery was studied during the following months in order to monitor reef health and it was observed that live coral had increased to 17.9% and the total amount of dead coral was 22.7%, suggesting the recovery of partially bleached corals and the death of fully beached corals. The bleaching was similar to the 1998 bleaching event. Satellite Remote Sensing (SRS) data sets was unable to be utilised during the study. In the subsequent years SRS data was employed for monitoring corals in Andaman Sea. Later on, compilations of SRS data were used to develop a coral reef bleaching alert system with the help of a team from INCOIS, Hyderabad.

Assessment of the coral bleaching during 2005 to decipher the thermal stress in the coral environs of the Andaman Islands using Remote Sensing (Mohanty, P. C. *et al.*, 2013)

SST values derived from NOAA AVHRR satellite data were used to generate both Degree of Heating Weeks (DHW) and Hot Spot (HS) products. Combination of the cumulative temperature anomalies and the thermal stress values were utilized to synoptically identify the probable areas of bleaching. Areas with Hot Spot products > 1°C were assigned a warning. Any areas assigned a warning with Degree of Heating Weeks between 4 and 8° C- week were elevated to *Alert Level-1*, with areas having Degree of Heating Weeks greater than 8° C- week assigned status *Alert Level-2*. At Havelock Island, a bleaching status up to *Alert Level-1* was recorded with a maximum HS of 3° C and DHW 6° C- week. Simultaneous in-situ reef observations conducted in the Andaman Sea confirmed coral bleaching event at this site. The highest rates of mortality in the region due to coral bleaching were shown by the *Acropora* species (43%) followed by *Montipora* species (22%) and *Porites* species (14%). This study focused on facilitation of a coral bleaching warning system based on the SST in complement with *in-situ* observationsfor verification carried out at selected sites.

Elevated sea surface temperature during May 2010 induces mass bleaching of corals in the Andaman (P. Krishnan *et al.*, 2011)

In a study taken up to asses bleaching the 2010 bleaching event, surveys of sites in the Andaman revealed that significant bleaching occurred during April and May 2010. As much as 70 % of certain sites suffered the effects of bleaching. While similar bleaching events occurred in 1998 and 2002, this has been judged to be one of the most devastating events of this kind to have occurred in the Andamans. Through Line Transect studies, it was found that the fully bleached corals as a percentage of total coral cover were highest at Havelock Island (69.49), followed by South Button Island (67.28), Nicolson Island (56.45), Red Skin Island (43.39), North Bay (41.65) and Chidiyatapu (36.54). SST maps for selected time periods for the areas surrounding these Islands showed consistently high temperatures in the range 31–32° C during the last two weeks of April 2010 in the sites, except in Chidiyatapu, where it ranged from 32.1° C to 33.3° C. Branching corals were the worst affected, whereas the massive corals were found to have relatively withstood the elevated SST. The status of reefs and the variability in bleaching with the fluctuations in SST with respect to different coral species could be studied in detail during 2010.

Studies on the Recovery of Bleached Corals in Andaman: Fishes as Indicators of Reef Health (P. Krishnan *et al.,* 2013)

This study evaluates the degree of recovery of the coral reefs and reef fishes at three sites – North Bay, Tarmugli and Chidiyatapu - a year after the bleaching event in 2010. It was observed that all sites were severely affected during the bleaching period with more than 95 % of the corals being fully or partially bleached. Out of the bleached corals surveyed at the study sites, only 54 % recovered at North Bay, whereas Tarmugli and Chidiyatapu showed significant recovery - 81 and 86% respectively. Live coral cover, which was densest at North Bay prior to bleaching,was most strongly affected at North Bay among the three sites - most likely due to the higher percentage of branching corals such as *Acropora* sp. in this area. Chidiyatapu exhibited significantly fainter signs of bleaching owing to the higher percentage of boulder corals such as *Porites* sp. in these areas. Recovery patterns indicate that the rapid recovery rate of fast growing corals such as *Acropora*, however, have resulted in greater dominance by these species suggesting that climate forcing of coral communities may initially favour coral species with rapid recovery potential, rather than slow growing corals that might otherwise have greater resistance to bleaching. Due to this recovery and new recruitment of corals, live coral cover has increased, resulting in an increase in an apparent abundance of fishes. Understanding the associations between fish and corals could lead to the designationof certain species of fish as indicators of reef health. The results of the study lead to the hypothesis that obligate corallivores, such as those belonging to the families Chaetodontidae, Pomacentridae, Acanthuridae and Scaridae, are strong potential candidates to serve as indicators of reef health.

Tropical storm off Myanmar coast sweeps reefs in Ritchie's Archipelago, Andaman (P. Krishnan *et al.*, 2012)

The reefs in Ritchie's Archipelago, Andaman suffered severe damage following a tropical storm in the Bay of Bengal off Myanmar coast where maximum wind speeds of 11 m/s was observed during a tropical storm that occurred in March 2011. Satellite Altimetry-based Map of Sea Level Anomaly (MSLA) data of Near Real Time (NRT) available with the Archival, Validation and Interpretation of Satellite Oceanographic Data (AVISO) was used to study the Sea Level Anomaly and Surface Geostrophic currents in the region during 13–23 March 2011. Sea level anomaly and surface geostrophic current vector data were processed to generate sea level anomaly and current maps using ARC-GIS software with the data for the period 13–23 March 2011. Satellite surveys of South Button Island clearly showed the progression of the storm. Physical damage to corals was greater in the northern and northwestern side of the island, which corroborated with the direction of the storm.

Corals in the shallow inshore reefs were broken and dislodged by the thrust of the waves generated in the wake of these winds. Significant damage in the deeper regions and offshore reefs were caused by the settlement of debris and sand brought down from the shallower regions. The fragile branching corals (*Acropora* sp.) were reduced to rubble and the larger boulder corals (*Porites* sp.) were toppled over or scarred by falling debris. Reefs on the windward side which were directly in the path of the storm winds were the worst affected. The investigation exposes the vulnerability of the reefs in the Andamans to oceanographic features which generally go unnoticed unless there is associated damage caused to coastal habitats in these regions.

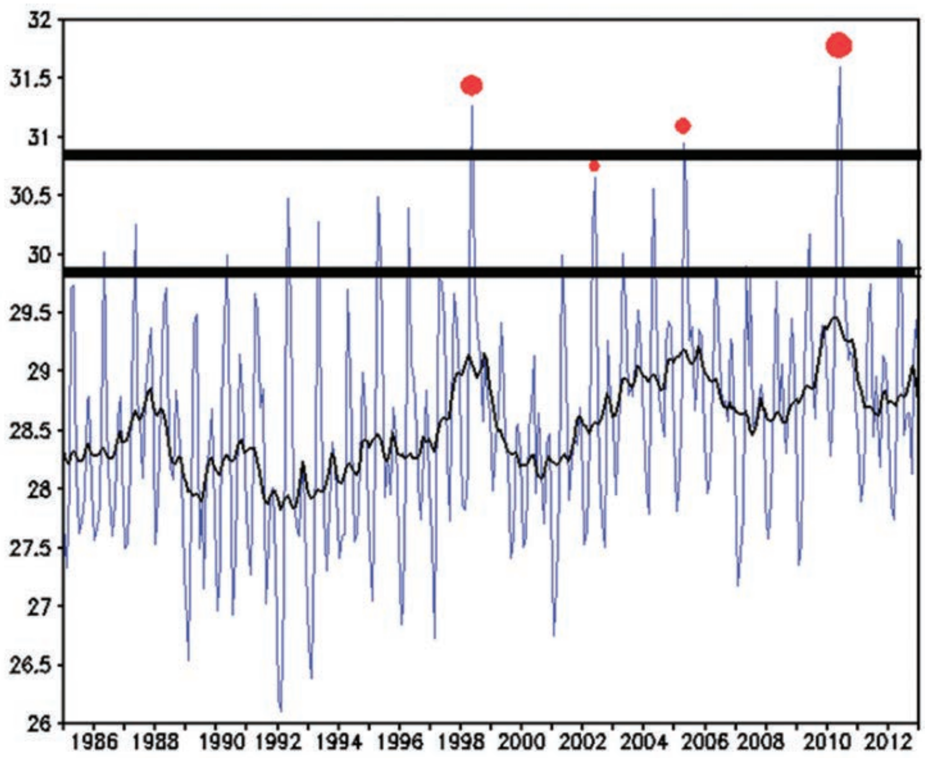
Differential bleaching of corals based on El Niño type and intensity in the Andaman Sea, southeast Bay of Bengal (J.K. Lix *et al.,* 2016)

The purpose of this study was to investigate the role of the El Niño in the coral reef bleaching events of the Andaman region.Both Niño 3.4 and 3 indices were examined to find out the relationship between the mass bleaching events and El Niño, and correlated with sea surface temperature (SST) anomalies in the Andaman Sea.

Inter-annual variability of SST around the Andaman Islands was investigated with NOAA AVHRR Pathfinder V4.1 SST (1985–2002) and AVHRR (GAC) SST (2003–2012) with data averaged over the study area. This data was coupled with monitoring of reef benthic compositions at two stations – North Bay and Chidyapatu during 2010-2012. Areas around the Andaman Islands where the SST exceeded long-term averages by more than 1 °C during the warmest months (March–June) were identified for the mass bleaching during 1998 and 2010.

Field surveys conducted before, during and after bleaching in 2010 show that there have not been any additional bleaching episodes in the Andamans since 2010. Salient observations made at different zones of selected coral reefs aided in identifying the indicators that give information on the health status of the reefs and to identify the reefs at risk.

The analysis demonstrates that a strong El Niño in the Pacific causes a similar warming in the Andaman Sea which leads to mass coral bleaching events around the Andaman Islands. The result shows that abnormal warming and mass bleaching events in the Andaman Sea were seen only during strong El Niño years of 1997 to 1998 and 2009 to 2010. The Andaman Sea SST was more elevated and associated with El Niño Modoki (central Pacific El Niño) than conventional El Niño (eastern Pacific El Niño) occurrences. It is suggested that the development of hot spot patterns around the Andaman Islands during May 1998 and April to May 2010 may be attributed to zonal shifts in the Walker circulation driven by El Niño during the corresponding period. It can be concluded from this study that the effect of El Niño on a particular coral reef region will depend on the timing when the El Niño perturbation propagates to those reefs. The effect is typically more extreme if timing corresponds to the climatological maxima in the seasonal heating cycle.



Box averaged (11.5–14° N; 91.5–94° E) monthly mean SST (°C) for the Andaman region during 1985–2012 with the corresponding 13-month moving average shown as a black curve. The line drawn at 30.84 °C represents a bleaching threshold temperature and line drawn at 29.84 °C represents the climatology in May. The corresponding bleaching events are represented by red dots and their size indicating the intensity of the bleaching event.

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CHAPTER 36

HARMFUL ALGAL BLOOM MONITORING USING SATELLITE OBSERVATIONS

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Introduction

Satellite based Earth observations on ocean color provides an efficient tool for monitoring primary productivity in the oceans in terms of phytoplankton abundance, *i.e.,* the Chlorophyll-a (Chl-a) concentration. Occasionally the phytoplankton species 'blooms' to form extensive patches covering large surface area of the coastal and off shore waters. Information on the presence, absence and timing of plankton blooms are prerequisites for estimating the marine productivity and the temporal seasonality of particle fluxes in to the deep sea. The algae blooms can form rapidly and it is often difficult to assess their development and extent from traditional sampling methods mainly due to inadequacy of proper techniques other than classical sea truth data analyses.

The increasing number of harmful algal blooms (HABs) in the past few decades have received a lot of attention due to their negative impact on the marine environment (Hallegraeff *et al.,* 2003). HAB events are characterised by two main features; they are caused by micro algae and they have a negative impact on human health and/or activities such as fisheries, aquaculture, and tourism. In addition to these common features, HABs are very diverse in terms of harmfulness, causative organisms, dynamics of blooms and types of impact. The harmfulness of algal blooms could be toxic or just massive in abundance that causes the harm. The impact of toxic blooms can vary from mass mortality of invertebrates and fishes to serious threat to human beings. Local residents of the coastal area who depend on clams, mussels, fishes *etc* as a major food source would be seriously affected.

In the case of non-toxic algal blooms also, the damage done to the environment is severe. The anoxic conditions developed due to the blooms and the foul smell of the surroundings affect the aesthetic value of the area. They also pose damage to the fishing gear. Therefore, in order to monitor HAB events, the first step is to create a regional database from available scientific information regarding the diversity of the common bloom causing algae growth, the extent of damage caused by each of them and the physico-chemical factors affecting the growth and multiplication of these harmful algae.

Satellite ocean colour sensors provide estimates of concentrations of the phytoplankton pigment chlorophyll-a (Chl-a) in the water. Since 1998 ocean colour data has been regularly used to monitor the daily algal status in many oceanic waters particularly in Norwegian coastal waters (Pettersson and Pozdnuyakov, 2013, Durand *et al.,* 2000, Folkestad *et al.,* 2006). Initially, data from the NASA Sea-Viewing Wide Field-of-View sensor (SeaWiFS, Hooker 1992) were used and the data products were obtained from standard global operational algorithms. In the event of a HAB, early warning and subsequent prediction of the bloom evolution are essential for national fishery authorities and for the aquaculture/fisheries industry in order to implement mitigation actions. Therefore, a routine monitoring of the productivity and environmental parameters of the coastal and open ocean waters would be of immense help in evaluating and predicting algal blooms, including HAB.

In this context, Indian fishery industry is not an exception, faced major challenges in the last few years due to natural calamities affecting the marine environment like cyclones, tsunami, storm surges and also threats from Harmful Algal Blooms (HAB). All these events have created the need for evolving disaster management strategies for early implementation of adequate mitigation measures. Field studies have revealed their inefficiency in assessing the sudden occurrence and extent of such blooms by *in situ* sampling. It is in this context, satellite based observations on ocean colour find relevance for monitoring the bloom events in the marine environment. Since the spectral behaviour of phytoplankton species differ, high spectral resolution satellite like MODIS (Moderate resolution Imaging Spectroradiometer) probably would help in delineating species responsible for the blooms. Such attempts to identify, understand and demonstrate the application of Earth Observation data from different ocean colour sensors can lead to improved monitoring of bloom events and henceforth serve as a tool in predicting hazards of the marine environment (Pozdnyakov *et al.*, 2017).

International programmes like ECOHAB(The Ecology and Oceanography of Harmful Algal Blooms), EUROHAB (Harmful Algae Blooms in European waters)and GEOHAB (Global Ecology and Oceanography of Harmful Algal Blooms) were initiated by many countries to understand HAB population dynamics. Similarly, in India, such initiatives were already been taken and an integrative study on the distribution of the Toxic Algal Blooms along the EEZ of India under the Marine Living Resources Programme sponsored by the Department of Ocean Development, Govt. of India (MLR-DOD) from 1998 onwards signifies the need for monitoring of HAB events in Indian waters. As a follow up on this programme, the Oceansat-2 OCM products from Space Application Centre of ISRO are operationally available for local area coverage (LAC) at 360m resolution and Global coverage(GAC) at 1 km resolution are being used to study the HAB events.

A satellite based information service for Detection and Monitoring of Harmful Algal Bloom (HAB) based on three key parameters: rolling chlorophyll anomaly (RCA), rolling sea surface temperature (SST) anomaly (RSA) and bloom index (BI) is in operational at INCOIS. The information on occurrences of HABs has been provided daily on experimental basis

(Fig.1) at near real-time (NRT) to regions: North Arabian Sea, Goa, Mangalore, Kochi, Gulf of Mannar, Perrangipetai and Visakhapatnam.

Nansen Centre, Norway has already established an algal bloom monitoring service web-site http://HAB.nersc.no under GMES MarCoast for North European waters in the 1990s. Daily, running 7-days and monthly average EO based information products are generated, for a wide range of water quality and SST ocean products, using both global and regional tuned processing algorithms for retrieval of the water constituents.

Reprocessed global ocean color data are available through the European Space Agency (ESA) Climate Change Initiative (CCI) currently updated until the end of 2016 at http://www.esa-oceancolour-cci.org/ and similarly from ChloroGIN (Chlorophyll Global integrated Network) for the Indian waters (http://www.incois.gov.in/portal/ChloroGIN).

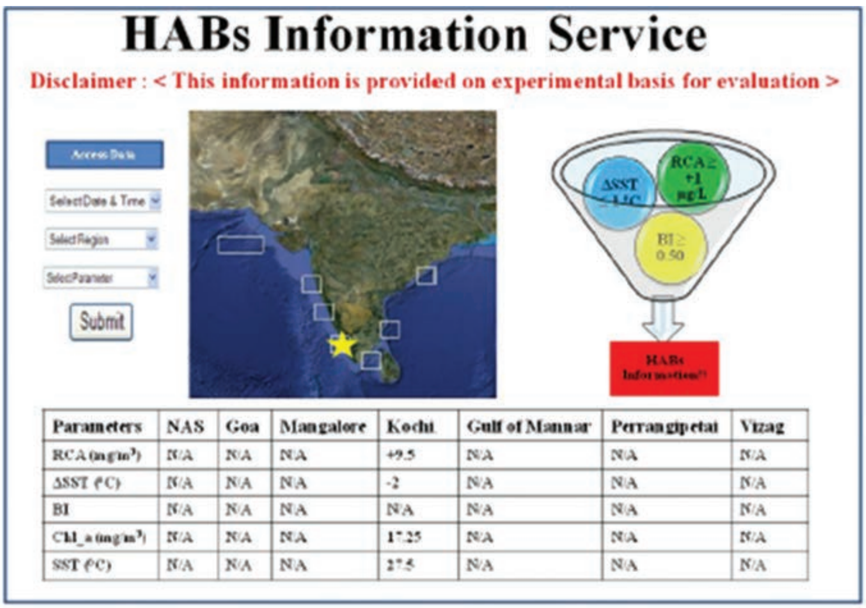

Fig. 1. A conceptual framework for operational monitoring and dissemination of HAB information service by INCOIS (Courtesy: http://www.incois.gov.in)

Literature Review

Phytoplankton blooms are considered, generally, as a nuisance to the coastal community. Blooms mostly occur in shallow coastal waters during spring season in the presence of light and enrichment of water by nutrients. The source of the nutrients may be from river runoff or coastal upwelling. The blooms are often reported with a variety of colors from green to red depending on the dominant species of plankton and algae, reflecting their spectral absorbing or scattering characteristics. Blooms of blue-green algae, *Trichodesmium erythraeum,* are more common in the coastal waters of India. Red tide blooms caused by dinoflagellates have also been reported (Sasamal *et al.,* 2005). The following paragraph illustrates the various studies carried out in abroad and in India, using ocean color data, which incidentally reflects the capability of ocean color data for studying algal blooms in the marine environment.

Tang *et al.,* (2004) have studied the oceanography of a harmful algal bloom off the coast of southeastern Vietnam using remote sensing tools. Harmful algal blooms (HABs) in the southeastern Vietnamese coastal waters have caused large economic losses in aquaculture and wild fisheries in recent years; however, there have been few oceanographic studies on these HAB events. This study reports an extensive HAB off southeastern Vietnamese waters during late June to July 2002 with *in situ* observations and subsequent analyses of the oceanographic conditions using satellite remote sensing data. The HAB, which covered 200 km off the coast and 200 km northeast of the Mekong River mouth for a period of 6 weeks, had high chlorophyll a (Chl a) concentrations (up to 4.5 mg m-3). The bloom was dominated by the harmful algal haptophyte *Phaeocystis cf. globosa* and caused significant mortality of cultured fish and other marine life. In the same period, sea surface temperature (SST) imagery showed a cold water plume extending from the coast to the open sea, and QuikSCAT data showed strong southwesterly winds blowing parallel to the coastline. This study indicated that the HAB was induced and supported by offshore upwelling that brings nutrient rich waters from the deep ocean to the surface and from coastal water to offshore water and that the upwelling was driven by strong winds and Ekman transport when prevailing winds were parallel to the coastline. This study demonstrated the possibility of utilizing a combination of satellite data of Chl a, SST, and wind velocity together with coastal bathymetric information and *in situ* observations to give a better understanding of the biological oceanography of HABs.

Tang *et al.,* (2006) have elucidated the satellite evidence of harmful algal blooms and related oceanographic features in the Bohai Sea during autumn 1998. Some HAB occurrences are different to observe because of their high spatial and temporal variability and their advection, once formed, by surface currents. The study analyzed the formation, distribution, and advection of a serious HAB occurred in the Bohai Sea during autumn 1998, causing the largest fishery economic loss, using satellite SeaWiFS ocean color data and other oceanographic data. The results showed that the bloom originated in the western coastal waters of the Bohai Sea in early September, and developed southeastward when sea surface temperature (SST) increased to 25–26 °C. The bloom with high Chl-a concentration (6.5 mg^{-3}) in center portion covered an area of 60 × 65 km^2. By the end of September, the bloom decayed when SST decreased to 22–23 °C. It was concluded that HAB might have been initiated by a combination of the high riverine input of nutrients and increase in SST in the western coastal waters; afterwards it may have been transported eastward by the local circulation that was enhanced by northwesterly winds in late September and early October.

Costas (2004) has done the rapid monitoring for the potentially ichthyotoxic dinoflagellate *Cochlodinium polykrikoides* in Korean coastal waters using fluorescent probe tools. *Cochlodinium polykrikoides* has occurred annually in Korean coastal waters since 1982, where it has caused extensive fish mortality. Rapid and accurate monitoring is very important to reduce the economic damage caused by *C. polykrikoides*. However, before outbreaks of *C. polykrikoides* occur, single cells are often more abundant than chain-forming cells. During this period, it is very difficult to discriminate *C. polykrikoides* from closely related dinoflagellates and other phytoplankton species.

Reinart and Kutser (2006) have compared the different sensors in detecting cyanobacterial alage bloom events in the Baltic Sea. Potentially toxic cyanobacterial blooms occur in the Baltic Sea in the middle of summer. Aggregations of cyanobacteria often form dense subsurface blooms or even surface scum, which are spatially extremely patchy. It has been shown by using bio-optical modelling together with the hyperspectral sensor Hyperion image from the western part of the Gulf of Finland that chlorophyll concentration may vary between 1-100 mg m^{-3} within the 10m scale during heavy bloom. The SeaWiFS, MODIS/ Aqua and MERIS products over heavy bloom region were compared with each other, and with that of the modelling results, the bio-optical modelling data and the available *in situ* data. During the massive bloom of cyanobacteria, at the time of surface scum formation, results from different sensors were variable, the values of chlorophyll concentration exceeded the standard processing limits causing the atmospheric correction to fail. The study showed good capability of MERIS and MODIS fine resolution spectral bands to detect cyanobacterial bloom quantitatively.

Kutser *et al.,* (2006) have also done the monitoring of cyanobacterial blooms by satellite remote sensing in the Baltic Sea. The problems caused by cyanobacterial blooms were especially acute in the Baltic Sea where they occur every summer covering areas of more than 100,000 km^2. It has been shown that quantitative mapping of cyanobacteria during bloom conditions is possible with hyperspectral instruments. These sensors, however, cannot provide synoptic spatial coverage and high revisit times are needed for near real-time monitoring of potentially harmful blooms. The aim was to estimate whether spectral resolution of multispectral sensors, which could provide needed coverage, is adequate for quantitative mapping of cyanobacteria and whether it was possible to separate potentially harmful blooms of cyanobacteria from waters dominated by algae using ocean colour satellites. The modelling results showed that multispectral sensors like ALI, Landsat or MODIS were not capable of separating waters dominated by cyanobacteria from waters dominated by other algal species, as their spectral band configuration does not allow spectral separation of absorption features caused by phycocyanin (present primarily in cyanobacteria) or any other spectral features that are characteristic to cyanobacteria alone. MERIS bands 6 and 7 allowed detecting phycocyanin absorption feature near 630 nm and a small peak in reflectance spectra near 650 nm characteristic to only cyanobacteria. Thus, MERIS can be used in detecting cyanobacteria if they are present in relatively high quantities. Unfortunately it is not possible to use MERIS for early warning of emerging potentially harmful blooms as the minimum biomass needed to cause features in reflectance spectra typical to cyanobacteria is higher than the biomass already considered as a bloom in the Baltic Sea. Howerer, Pettersson and Pozdyanakov (2012) have covered the various aspects of HAB monitoring using satellite observations particularly for the Norwegian waters. A recent study by Kondrik *et al.,* (2017) observed that the particulate inorganic carbon production within *Emilinia huxleyi* blooms in sub polar and polar oceans has the impact to block the carbon uptake in the ocean waters.

In Indian waters, Rao (1969) reported for the first time a diatom bloom of *Asterionella* in the coastal waters of Vishakhapatanam. In 1983, another bloom was also observed near the Mangalore coast and several people were hospitalized due to the consumption of intoxicated shellfish and the causative species was not identified (Karunasagar *et al.*, 1984). Other algal blooms were also reported in Vellar estuary by Mani *et al.,* (1986) and later by Choudhary and Panigrahy (1989), Panigrahy and Gouda (1990), Mishra and Panigrahy (1995) along the coast of Orissa. These reports indicated that the blooming of *Asterionella* species were common in the NW Bay of Bengal during pre-monsoon months. The southwest monsoon winds and associated rainfall resulted in increased river runoff from June to September, enriching the coastal waters with terrestrial nutrients from coastal upwelling. During the Northeast monsoon, *i.e.,* from October to January, the coastal waters are enriched by upwelling of sub-surface water. This increases the productivity of the NW Bay of Bengal many times during late winter and in the early monsoon months leading to blooming of phytoplankton along the east coast of India.

In 1996, a bloom of *Gymnodinium catenatum* was reported from Mangalore coast (Godhe *et al.,* 1996, Karunasagar, 1996). In the year 1997, in the Kerala coast a paralytic shellfish poisoning was reported (Karunasagar *et al.,* 1998) causing seven deaths and over 500 were hospitalized following consumption of intoxicated mussel, *Perna indica.*

The moderate to intense blooms of the dinoflagellate *Noctiluca scintillans* occurred in Port Blair Bay, Andamans during June and July of 2000. The blooms occurred thrice in succession after short periods of waning. The second bloom in the sequence, which occurred between 11 and 20 July 2000, was subjected to scientific study by assessing the changes in water characteristics associated with the event. Results indicated that variations in dissolved oxygen concentration were fairly small, whilst nutrient levels and plankton compositions were altered. Primarily the bloom not only led to the exclusion of other phytoplankton, but also limited the zooplankton prevalence to essentially copepods. The bloom resulted in exceptionally high levels of chlorophyll-*c*, which exceeded chlorophyll-*a* levels by several folds. Nutrient levels were characterized by decrease of nitrate during active periods of the bloom, and sharp decrease in phosphate, particularly during the waning phase.

A thick bloom of the marine prymnesiophycean, *Phaeocystis globosa* was observed in the central Arabian Sea during the summer monsoon period (July–August, 1996). The cells were mostly in colonial form, embedded in gelatinous matrices. The cell diameter was approximately 7nm and showed a distinct double feature form. The intensity of the bloom was as high as 3750×10^{6} cells m^{-2} and the carbon content ranged between 33 and 550 mg L^{-1}. Almost 90 % of the phytoplankton population was composed of *P. globosa* in the bloom area. Other common forms were chain-forming diatoms like *Rhizosolenia* spp., *Nitzschia* spp. and *Chaetoceros* spp. The photosynthetic pigment chlorophyll *a* however did not show any concomitant rise with the bloom intensity probably because the bloom was sampled during a senescent phase. The carbon - chlorophyll ratio varied between 112 to 810. This was the first report on the occurrence of *Phaeocystis* from the Arabian Sea (Madhupratap *et al.,* 2000). It seems pertinent to ask whether this was a result of the genus being introduced and adapted to new environments due to human influence and whether this would influence food chains in the future.

The cruises of FORV Sagar Sampada in the year 2003 and a repeat cruise in 2004 during the same period (Feb 26 to Mar 15) and along the same location (between Goa and Porbander sector; NE Arabian sea, 10-22N and 66-75°E) together with satellite data revealed an extensive blooming of *Noctiluca scintillans* which was found gradually extending westward as far as Oman. A sudden intense bloom of *Noctiluca scintillans* was observed on 20 December 2002 in Minnie Bay (11°38.705′N; 92°42.513′E). The bloom persisted for three days and disappeared suddenly; a similar bloom was reported here earlier in 2001.

Sasamal *et al.,* (2005) have reported *Asterionella* blooms in the NW Bay of Bengal during 2004. Dark brown patches of phytoplankton bloom were observed in the near shore waters at Gopalpur in the NW Bay of Bengal towards the end of March and beginning of April 2004. During the bloom period, phytoplankton population density increased by 70 to 80 times relative to the pre-bloom situation.

On 29th September 2004, a red tide was also observed along the West coast of India. *Noctiluca miliaris* is the most common dinoflagellate, which forms red tides along the west coast (Sahayak *et al.,* 2005). The red tide observed seemed to be significant since the phenomenon had occurred within a fortnight of the stench event that had created panic among people living along southern Kerala coast. Mass fish kill was noticed on 17th September 2004 along the Trivandrum coast.

Horizontal distribution of temperature, salinity and dissolved oxygen showed interesting variations in the bloom area. Relatively low temperature and high salinity prevailed in the bloom area and the lower concentrations of dissolved oxygen found in the bloom area were apparently due to the large scale respiration by *Noctiluca*. Low nutrient content observed in the bloom area indicated the retreating phase of upwelling in the area. Upwelling weakens in the southern most part of West coast of India by October and as a result, the high concentrations of nutrients initially available at the surface waters get exhausted due to autotrophic production. Primary production was also lower in the bloom area. Abundance of micro zooplankton (ciliates) in the bloom region was low compared to other coastal stations (Sahayak *et al.,* 2005).

During the 3rd week of September 2004, particularly on 16th and 17th, an unusual and strong stench was experienced in the coasts of Kollam and Vizhinjam in Kerala, followed by large-scale fish mortality. The *in situ* measurements revealed the cause of the observed phenomenon to be the blooming of *Holococcolithophore* (Ramaiah *et al.,* 2005).

HABs, including those caused by coccolithophorids (e.g. *E. huxleyi*), arise when appropriate levels of nutrients, light and temperature, for those particular algae are present. Following the bloom, the right conditions disappear (often because the nutrients are assimilated into their cell masses), and the cells begin to decay. Many autotrophs, in particular most HAB-forming phytoplankton, form crysts that fall to the bottom and lie dormant until the right conditions arise again. It appears that the HAB off the southern coast of Kerala occurred in September 2004 peaked about the time the stench set in. The coccolithophorid HAB appears to have clogged the fish gills, leading to mass mortality as also the stench. After the HAB peaked, the conditions turned unfavorable, and apparently there was a reduction in its abundance.

Along the coasts of Goa, bloom of a dinoflagellate, *Cochlodinium polykricoides was* reported by Bhat and Matondkar (2004). This species hitherto unreported from the Indian waters is a known fish killer in Korean waters. In addition, during September 2004, the same dinoflagellate *Cochlodinium polykrikoides* bloomed in Kerala waters causing large scale fish mortality in the different coastal villages and hospitalization of over 200 school children due to illness caused by the nauseating stench from the bloom and putrefying fish. But *in situ* studies by Ramaiah *et al.,* (2005) from the bloom regions along the southern Malabar coast found that the most abundant species were holo-coccolithophorids. However studies by Sahayak *et al.,* (2005) along the coast of Kerala, during the same bloom period revealed that it was *Noctiluca* red tide which consisted of other species like *Thalassiosira, Cosinodiscus, Nitzschia, Peridinium, Gymnodinium* and *Ceratium spp*. Later Padmakumar *et al.,* (2007) made a continous monitoring of the HAB events in the southwest coast of India and observed the occurrence and dissipation of Red tide caused by the diatom *Coscinodiscus and bloom of Microcystis aeruginosa* on Southwest coast of India *(*Padmakumar *et al.*, 2008a), Green tide of *Noctiluca miliaris (*Padmakumar *et al.*, 2008b)*, Noctiluca scintillans (*Padmakumar *et al.*, 2010a) Blooms of *Trichodesmium erythraeum (*Padmakumar *et al.*, 2010b) and also Monospecific bloom of noxious raphidophyte *Chattonella marina* (Padmakumar *et al.*, 2011).

An analysis of the frequency of blooms of harmful algae in Indian waters during the period 1908-2010 has shown (Fig. 2) that there has been an increase in the occurrence of blooms during the last decade. The reasons for this could be due to changing nutrient ratios in the coastal waters, dispersal of algal introduced/alien species through currents, storms and ship ballast waters combined with the increased awareness and augmented analytical capacity to understand harmful algal species and the related phytotoxins.

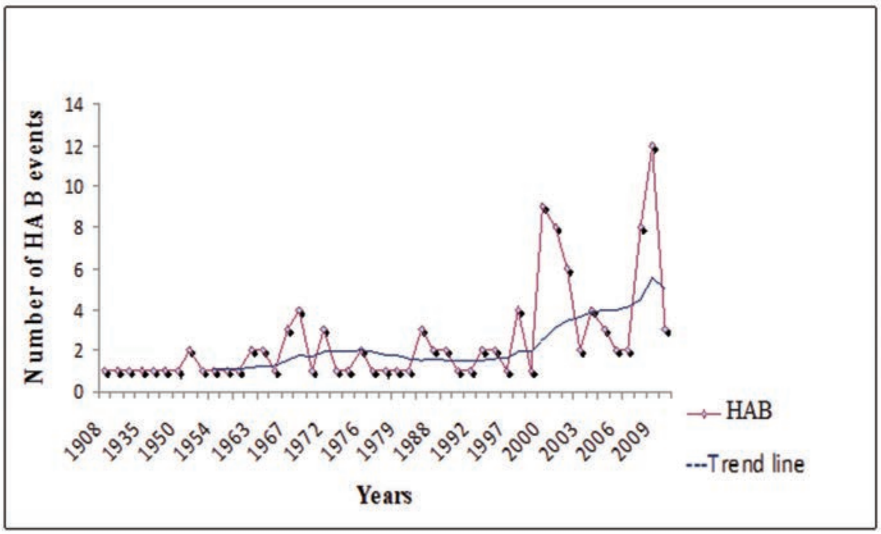

Fig. 2. Harmful algal bloom events (actual observation) and trend line from 1908 to 2010 in-situ observations (after Menon, 2010)

A series of blooms of *Trichodesmium erythraeum* was observed along the coast of Kerala during May-June months of 2009 from on board FORV Sagar Sampada (Fig.3). A qualitative analysis of the phytoplankton showed that about 90% of the surface phytoplankton was contributed by *T. erythraeum*. The distinct red or pink colouration of the sea water in the area was caused by the presence of phycoerythrin or dominant extracellular pigment leachate of this species. The presence of this pigment in the sea water signals the initial decay phase of *Trichodesmium*. As a rule the blooming of *Trichodesmium* occurs during hot weather with brilliant sunlight and stable high salinity. Normally *Trichodesmium* growth is not stimulated in classical upwelling areas. In this context the blooming of these filamentous algae during the monsoon period in an upwelling area would be considered quite unusual. Very high biomass of zooplankton (11.59 ml/m^3) clearly indicates the congenial conditions prevailing in the area for zooplankton growth. The fact that no fish mortality was observed in the bloom area probably opens up an area for further studies on the relationship between *Trichodesmium* bloom and zooplankton abundance. It is apparent that *Trichodesmium* blooms are ecologically significant to the productivity patterns of the south eastern Arabian Sea.

Fig. 3. Trichodesmium bloom off Kochi (June 2009). Courtesy: Menon, 2010.

Excessive ponderance of *Noctiluca scintillans* in a region where a multispecies diatom bloom existed was also recorded from the waters off Kochi (lat. 10°00′ – 10°3′ N and 75 °.32 E) during the peak monsoon months of August (Padmakumar *et al.*, 2010a) . The bloom was of brick red colouration and was spread over an area of 5 sq. km. The discolouration was caused by the predominance of *Noctiluca scintillans*.

Noctiluca formed around 56% of the phytoplankton and the rest was constituted of species belonging to 14 genera of diatoms. The single celled protest *Noctiluca scintillans* is highly bioluminescent and this quality is controlled by a luciferin-luciferase system located in numerous spherically shaped “micro sources”. This protist is a voracious feeder of diatoms belonging to the genera *Thalassiosira* and *Pseudonitsczhia*. Among food items of *Noctiluca*, *Pseudonitsczhia* is found to produce toxins that can cause fish kill and lead to shellfish poisoning to humans, indicating that *N. scintillans* could be a vector for transfer of phyto-toxins to higher trophic levels. Blooms of *Noctiluca* are known to prevent aggregation of shoaling herbivorous fishes especially sardines. The waters where the bloom of *Noctiluca* was observed contained very high silicate (ca. 18.20 µmol/l), which probably indicates excessive secretion of silicate by this diatom feeding protest. High primary production along the west coast of India during the monsoons probably sets the stage for blooming of non-autotrophic forms like *Noctiluca.*

The prediction and occurrence of the algal blooms and *in situ* measurements which are restricted only to the bloom period are the major practical difficulties in the studies related to it. Remote sensing of near surface pigment concentrations provides the only practical means of obtaining large scale observations of phytoplankton distributions over appropriate time scales.

Why do we need HAB monitoring?

- Regular monitoring of algae bloom situation in coastal and nearshore waters and improvement of the in situ sampling strategy is to provide information on;
- early warning of potential bloom developments.
- identification of near surface and deeper water layer algae blooms.
- geo-positioning of ocean fronts (in pigment concentrations and thermal structures) and advection of water masses of different origin.
- EO data assimilation in geobiochemical ocean ecosystem modelling for improved prediction and forecasting of HAB events.
- Map inter-annual variability on the occurrence, extent, life time, *etc*. of blooms in the oceanic and adjacent seas.

Approaches / methodologies:

Ocean colour data of chlorophyll-*a* and sea surface temperature (SST) can be accessed from satellite sensors like SeaWiFS, MODIS, MERIS (Medium Resolution Imaging Spectrometer Instrument), Oceansat I & II through Giovanni software and other GIS software and be processed after spatial sub-setting. Similarly, SeaWiFS and MODIS Aqua data on HAB events can also be accessed from GES DISC data site of NASA and processed through SeaDAS software or MATLAB. Similarly Oceansat I & II data on cloud free days can be accessed and processed using PrimeWin software developed by SAC-ISRO. Additionally ocean colour data can be downloaded from the ESA CCI Ocean Colour project http://www.esa-oceancolour-cci.org/.

The methodology includes access to Ocean colour level 2 data products for the study region by Data downloading, processing, integration, analysis and assessment visualisation which includes the following steps:

Download	**Ocean colour data download**· Data on any server
Processing	**Processing of Ocean Colour data** Application of global/ regional algorithm for the waters of the study regionPost processingGeneration of Algal bloom distribution maps
Visualisation/ Integration	**Web visualisation** Data on the screen by integrating Indian satellite data with MERIS/MODIS data

Data Collection and Analysis

Secondary data on chlorophyll, SST, CDOM and SLA by altimetry can be collected from the bloom region for visualization and integration into the webGIS. The data binning procedures are most efficient in order to reduce the impact of cloud cover contamination of the ocean colour data as well as swath limitations in the daily acquired images. In addition to graphical image products (GeoTIFF) the data can be made available in MatLab and Google Earth (KML) formats for export and other use.

GIS analysis

Geographic Information System is defined by Burrough, (1986) as "a powerful set of tool for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes. Hence it is a decision support system involving the integration of spatially referenced data in a problem solving environment (Cowen, 1988). The Geographic Information System for the particular study can be created using the GIS Software for web applications.

The study region's survey map can be digitized and the values for the particular components will be placed into the system on a grid pattern for each month based on historic data and satellite imageries. The following figure (Fig.4) describes the various components of GIS application tools for Algal bloom monitoring in the above context.

The major components of GIS application tools for Algal bloom monitoring mainly focus on the Data collection of bio-physical characteristics, SST, Chlorophyll-*a* with routine field survey. This can generate data sets that are stored for further access, maintenance and updates of the data. This is finally pooled into the major Data base which provides an input to the geo-data base of the GIS software. This will be further used for mapping information like hotspots in water quality identified in the region, siting of potential fish breeding zones which are not affected by deterioration in water quality, locating areas of harmful algae and toxic algal blooms *etc.* which are of prime importance to the management of fisheries. All

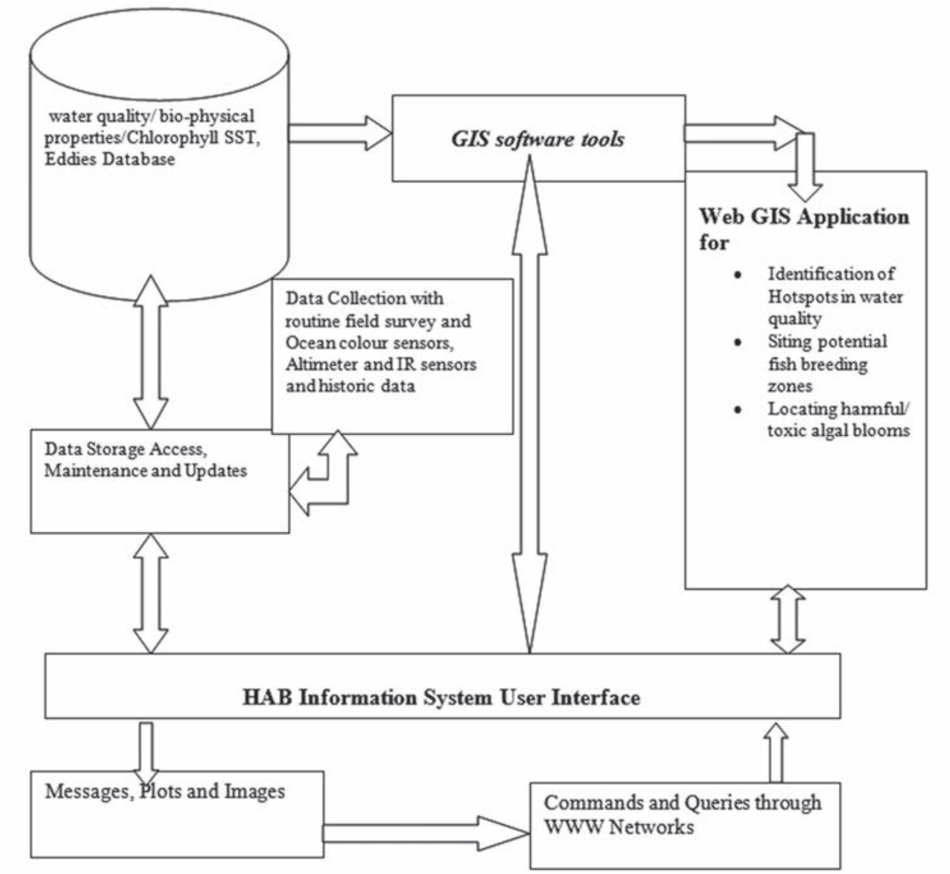

Fig. 4. Components of GIS Application tools for Algae bloom monitoring

these components are integrated into a system through a user interface, which will provide information like messages, warnings in case of any outbreaks of fish kills, blooms *etc*. This can also be made available either as images or plots whenever the stake holder puts up commands and queries through internet kiosks/WWW networks, which are linked to this networking system. Fig. 5. shows an example of HAB monitoring of *E.huxleyi* blooms in the Atlantic and Arctic Oceans.

Fig. 5. An example of HAB monitoring of *E.huxleyi* blooms in 2006 in the Atlantic and Arctic Oceans (51^0N-84^0N; 29^0W-68^0E) (after Kondrik *et al.*, 2017).

Summary

Understanding and demonstrating the application of Earth Observation Data from different ocean colour Earth observing sensors can lead to improved monitoring of alage bloom events and henceforth serve as a tool in ealy warning and accordingly predicting hazards of the marine environment. However HAB monitoring has not been taken off in tropical waters on a real time basis though routine observation of HAB events is being carried out. The challenge here is to implement a real time observation system for the tropical waters on operational mode. This requires a state of the art tool in processing in Ocean colour satellite EO – MERIS, Sentinel, MODIS & SeaWiFS, ISRO-OCM in real time mode with regional based algorithm particularly for coastal case-2 waters and integrate into the ocean circulation model with in situ observations through data assimilation and proper dissemination tools for the general public and other stake holders.

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CHAPTER 37

AIR-SEA INTERACTION AND INDIAN MONSOON VARIABILITY

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Introduction to the Indian summer monsoon

Indian southwest / summer monsoon occurs from June though September. The evolution of strong cross equatorial winds off the Somalia coast during the month of May, in response to the heating of the South Asian continent marks the beginning of the summer monsoon evolution process over the Arabian Sea. The Mascarene High and the monsoon trough over north east India are two of the major elements of the Indian summer monsoon. The pressure difference between the Mascarene High and the monsoon trough is in fact a measure of the differential heating that drives the monsoon. A schematic of the typical sea surface temperature (SST) and cross equatorial wind regimes during southwest monsoon is shown in Fig. 1. The monsoon sets over Kerala around 1 June with a standard deviation of about 8 days (Ananthakrishnan and Soman, 1988). Once the monsoon sets in, its further progress takes place due to rain bearing systems like monsoon trough, lows, depressions *etc*. These synoptic scale systems are considered as perturbations embedded in the basic monsoon current. A late or weak start to the monsoon season and extended breaks in monsoon rains

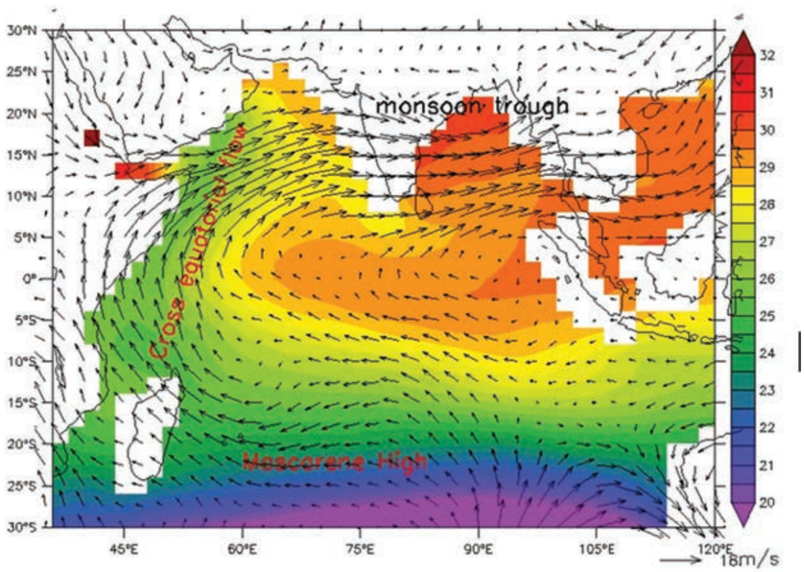

Fig. 1. Cross equatorial flow and SST during southwest/summer monsoon

could seriously impact rain fed crops. If the southwest monsoon withdraws earlier than expected, late sown crops may suffer during the mature stages from lack of moisture. A late withdrawal of the monsoon accompanied with late season rain could be detrimental to maturing crops. Understanding and predicting the monsoon variability is very important as it impacts the agriculture and economy of the country.

Variability of the Indian monsoon

The important aspects that make each monsoon unique are 1, The quantum of rainfall during the season the season 2, the monsoon onset over Kerala (MOK) and 3, the frequency and intensity of the active and break phases in monsoon conditions within the season.

1. Interannual variability of the Indian summer monsoon rainfall (ISMR)

Summer monsoon season receives about 78% of the mean annual rainfall of India (Mooley and Parthasarathy, 1984), with July and August being the peak monsoon months contributing to about 61% of the mean monsoon seasonal rainfall (Ramesh Kumar and Prabhu Dessai, 2004). The standard deviation of ISMR is about 10% of the mean rainfall of about 85 cm. The interannual variability and the interdecadal variability of the Indian monsoon are influenced by external forcings such as the El-Nino Southern Oscillation (ENSO), Atlantic Multidecadal Oscillation (AMO), Indian Ocean Dipole (IOD), Eurasian snow cover *etc*.

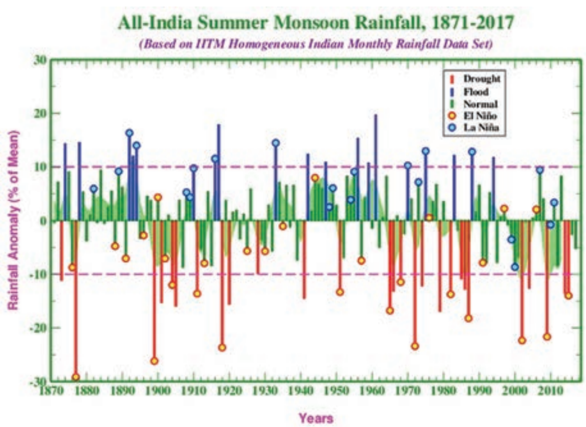

Fig. 2 The time series evolution of ISMR anomalies, expressed as percent departures from its long-term mean during the period 1871 to 2017.
(http://www.tropmet.res.in/~kolli/MOL/Monsoon/frameindex.html)

The time series evolution of ISMR anomalies during the period 1871 to 2010 is shown in Fig. 2. During the period 1871-2015, there were 19 major flood years, defined as years with ISMR in excess of one standard deviation above the mean (*i.e.*, anomaly exceeding +10%), *viz*., 1874, 1878, 1892, 1893, 1894, 1910, 1916, 1917, 1933, 1942, 1947, 1956, 1959, 1961, 1970, 1975, 1983, 1988 and 1994. During the same period, there were 26 major drought years, defined as years with ISMR less than one standard deviation below the mean (*i.e.,* anomaly below -10%), *viz.*, 1873, 1877, 1899, 1901, 1904, 1905, 1911, 1918, 1920, 1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986, 1987, 2002, 2004, 2009, 2014 and 2015 (Source: http://www.tropmet.res.in/). In addition to the interannual variability, there have been alternating periods (epochs) extending to 3-4 decades with less and more frequent drought monsoons over India. Fig. 3 shows the epochal patterns of ISMR from 1871 to 2000. During epochs with infrequent droughts, the monsoon was found to be less correlated with the ENSO and during the epochs with frequent droughts, the monsoon was found to be strongly linked to the ENSO (Parthasarathy *et al.*, 1991). The effect of ENSO on ISMR has apparently weakened during the recent decades (Kumar *et al.,* 1999). The IOD is a coupled ocean–atmosphere phenomenon originating in the Indian Ocean characterized by basin-scale SST and wind anomalies (Saji *et al.,* 1999; Webster *et al.,* 1999). A positive (negative) phase of the IOD results in anomalous cooling (warming) of SST in the eastern tropical Indian Ocean whereas the western tropical Indian Ocean tends to experience an anomalous warming (cooling). Several studies have indicated the possible role of the Indian Ocean Dipole (IOD) in the weakening of the ENSO-ISMR relationship (Saji and Yamagata, 2003, Ashok *et al.*, 2001). The relationship between positive (negative) IOD and the ISMR is rather complex with some studies indicating a positive (negative) influence over the Indian region (eg: Ashok *et al.,* 2001; Ashok and Saji, 2007) whereas there are studies that have found no significant relation between IOD and ISMR (eg: Gadgil *et al.,* 2007).

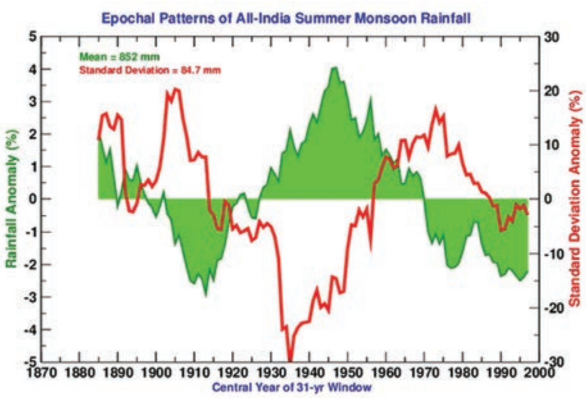

Fig. 3. The epochal patterns of ISMR during the period 1871-2000

2. Variability in the MOK and northward advancement

The onset of the monsoon occurs in many stages and represents a significant transition in large scale-atmospheric and oceanic circulations in the Indo-Pacific region. The strength of the low level jet and upper tropospheric tropical easterly jet increase rapidly during the time of the evolution of summer monsoon. There have been several studies that have focused on the ocean-atmospheric interactions during the onset of monsoon (Eg: Soman and Krishnakumar, 1993; Joseph *et al.*, 1994, Ramesh and Prabhu Dessai, 2004). The onset of monsoon is declared by India Meteorological Department (IMD) when,

a, If after 10th May, 60% of the 14 stations enlisted*, *viz.*, Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Allapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassery, Kannur, Kasargode and Mangalore report rainfall of 2.5 mm or more for two consecutive days, the onset over Kerala be declared on the 2nd day, provided the following criteria are also in concurrence.

b) Wind field - Depth of westerlies should be maintained upto 600 hPa, in the box equator to Lat. 10ºN and Long. 55ºE to 80ºE. The zonal wind speed over the area bounded by Lat. 5-10ºN, Long. 70-80ºE should be of the order of 15 – 20 Kts. at 925 hPa.

c). Outgoing Longwave Radiation (OLR) - OLR can be used as a proxy for deep convective systems in the tropics. Negative (positive) OLR are indicative of enhanced (suppressed) convection. INSAT derived OLR value should be below 200 wm^{-2} in the box confined by Lat. 5- 10ºN and Long. 70-75ºE.

Once monsoon has set in it surges northwards and covers the country by around 15th July. NLM is defined as the northern most limit of monsoon up to which it has advanced on any given day. The monsoon advancement also exhibits considerable interannual variability, for eg: in 2002 which was a severe drought year, even though the monsoon onset was on time (June 1), it covered the entire Indian subcontinent only by August 15th, a delay of almost one month.

3. Active and beak spells within the monsoon season

The rainfall distribution is not continuous within the life-cycle of a monsoon, but it is associated with multiple spells of active and break spells. There are several studies that have used the same term ‘break’, to denote diûerent features of convection and/or circulation over diûerent regions. Rajeevan *et al.,* (2010) defined active and break events as periods during the months of July and August, in which the normalized anomaly of the rainfall over the monsoon core zone (roughly from 18ºN-28ºN, 65ºE-88ºE) exceeds 1 or is less than “1.0 respectively, provided the criterion is satisûed for at least three consecutive days. Prolonged breaks can create drought conditions over the country. One of the longest recorded break spell occurred in the year 2002 and it lasted for about 34 days (Ramesh and Prabu Dessai, 2004). Fig. 4 and Fig. 5 shows the wind field at 850 hPa level (~1.5 kms above msl) during break and active conditions respectively. It can be seen that the cross equatorial flow (CEF) is stronger during active conditions and its core is directed towards the Indian subcontinent. During break conditions, winds are considerably weaker and the CEF acquires a southward curvature and appears to be blowing away from the subcontinent. Ramesh Kumar *et al.,* (2007) found that the frequency of break-spells and the number of break days showed an increasing trend during the recent decades. They also found that there was a clear increase in the number of long breaks (breaks longer than 7 days) post mid-1970s. They attributed this to the altering large-scale ocean-atmosphere processes in the tropical Indian Ocean such as weakening of the southwest monsoon winds and decreased moisture transport from the tropical Indian Ocean into the subcontinent.

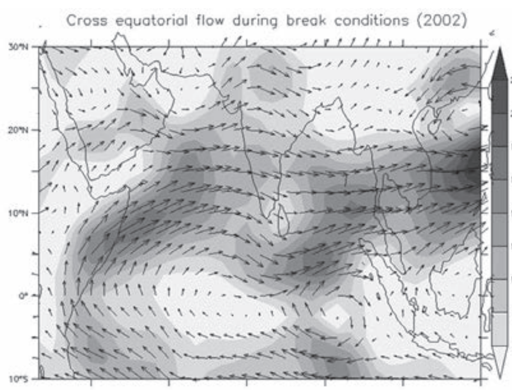

Fig. 4 Cross equatorial flow at 850 hPa level during break monsoon conditions (2002)

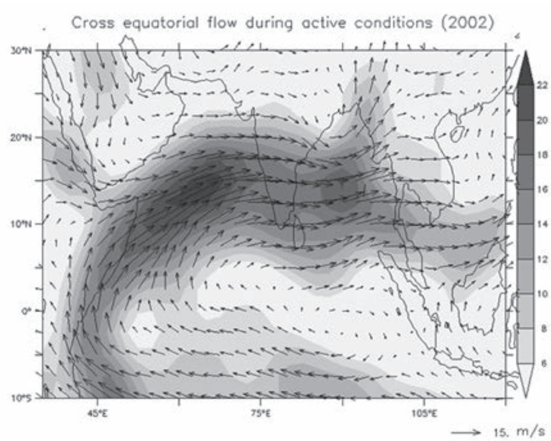

Fig. 5 Cross equatorial flow at 850 hPa level during active monsoon conditions (2002)

Air-sea interaction processes in the southeastern Arabian Sea and their influence on primary productivity/fisheries during the summer monsoon season

The Malabar upwelling zone along the Kerala coast is one of the important upwelling systems of the world (Bakun *et al.*, 1998). Under the influence of the south-westerly winds along the west coast, the surface waters move away from the coast and are replaced by colder, nutrient-rich and often oxygen depleted waters from the subsurface (Ekman pumping/ transport). This leads to phytoplankton blooms (mostly diatoms and dinoflagellates) and increased productivity (Madhupratap *et al.,* 2001). Shanker and Shetye (1997) showed that upwelling along the area 9°N to 13°N is under the combined influence of wind stress, and the upwelling Kelvin and Rossby waves. This area contributes about 20% to the marine fish catch of India (Manjusha *et al.,* 2013). An important feature of the Malabar upwelling zone is the predominance of pelagic resources such as oil sardine (*Sardinella longiceps*) and Indian mackerel (*Rastrelliger kanagurta*), which support the western Indian Ocean's largest coastal pelagic fishery (Vivekanandan *et al.*, 2005). The coastal upwelling index (CUI) during southwest monsoon increased by nearly 50% during the period 1998 to 2007 and during the same period the annual average chlorophyll_a concentration increased by more than 200% (Manjusha *et al.,* 2013). The increasing CUI and chlorophyll_a during monsoon sustained an increasing catch of oil sardine during post-monsoon season. Further studies are required to investigate the variability of fisheries/primary productivity on an interannual scale.

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CHAPTER

38

GENETIC STOCK CHARACTERIZATION OF FISH USING MOLECULAR MARKERS

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Introduction

Accurate Identification of genetic resources is necessary for detecting new species and varieties for products of commercial value. Fish, as a group, apart from their economic value from a biodiversity viewpoint, have the highest species diversity among all vertebrate taxa. They exhibit enormous diversity in size, shape, biology and in the habitats they occupy. In terms of habitat diversity, fishes live in almost all conceivable aquatic habitats, ranging from Antarctic waters to desert springs. Of the 62,305 species of vertebrates recognized world over, 34,090 (nearly 52%) are valid fish species; a great majority of them (97%) are bony fishes and the remaining (3%) are cartilaginous (sharks and rays) and jawless fishes (lampreys and hagfishes). Further, on an average, 300 new fish species are described each year, and global surveys indicate that there could well be at least 5,000 species more to be discovered.

Loss of biodiversity is one of the greatest challenges facing modern society. This environmental crisis is increasingly evidenced by the loss or deterioration of genetic resources and habitats, as well as recent attempts to highlight and address the issue at the highest international levels. Appropriate conservation efforts for protection of the natural biological wealth warrant right attention for their sustainable utilization and for posterity. Public concern for biodiversity conservation has risen in the last 50 years and led to national and international policies, legislation, and actions to conserve biodiversity, notably the Convention on Biological Diversity (CBD). To conserve and sustainably utilize the bioresources of the country and for maintaining sovereignty over them, several nations enacted the Biological Diversity Act (BDA). This encompasses guide-lines to address a wide range of issues related to the utilization of bioresources and information within the country as well as by other countries.

Management of Fish Genetic Resources

The objective of management (documentation + conservation + sustainable utilization) of species and their habitats is to maintain the genetic identity and integrity of the species in their natural habitat as well as a genetically sustainable fishery. Hence, documentation of genetic variation and diversity is of vital significance to evolve conservation strategies with long-term impact. Genetic resources can be viewed as genetic differences at three hierarchical levels of organization, *viz*., species, populations and individuals. At the highest level, species

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consist of '**populations'** or **'genetic stocks'** that are reproductively isolated from populations of other species. Each species harbours a unique set of genetic material and therefore, conservation, may aim at a specific species, which requires sound knowledge about its biology, biogeography and within species (inter-populational) level genetic diversity. At the population level of organization, the identification of **discrete genetic breeding units** (usually called a '**stock**' in fisheries biology; this is roughly equivalent to a **'population'** or **'genetic stock'** to a geneticist) has been a major theme in fisheries research. The definition of a stock can vary, as the motivations of fishery managers may be influenced by political, economic or biological mandates. **Finally, the largest store of genetic variability in most species exists as genetic differences among individuals within a population**. Hence, the goal of pre-serving genetic variability in a population coincides with the goal of maintaining large ecologically sound natural populations. A fundamental need is to define distinct entities that range from individuals to species to ecosystems and beyond.

Population/Genetic Stock Identification (GSI)

Assessment of genetic variability is important for the management of wild genetic resources of fish. Most species are composed of **populations**, also called **genetic stocks**, between which limited gene flow occurs. These populations maintain their genetic makeup or characteristics distinct from other populations of the same species because of genetic variation within the species. This differentiation depends upon forces such as migration, mutation, selection, and genetic drift, which act on the species/population during its evolution. If such units are overfished, it is unlikely that population sizes will recover because of migration, and hence a collapse of the fishery may occur. Therefore, with the loss of a genetic stock, a species also loses the animals that are adapted to a particular habitat through evolution. Moreover, interbreeding of non-native fish stocks/species with a different make up tends to reduce the genetic variation that naturally exists between genetic stocks. In other words, different natural genetic identities available for a species in different habitats are lost.

A fundamental problem for fisheries management is the identification of populations/ stock of a species and this idea has been brought together with the definition of stock for management. The term stock has been used in various management contexts with little or no genetic content. Several approaches have been advocated to solve this problem.

- Ihssen *et al*., (1981) defines a stock as '*an intra-specific group of randomly mating individuals with temporal or spatial integrity*'.
- Larkin (1972) *defined a stock as 'a population of organisms which share a common gene pool, is sufficiently discrete to warrant consideration as a self-perpetuating system which can be managed*'.

- In fishery management, *a unit of stock is normally regarded as a group of fish exploited in a specific area or by a specific method*.

If fishery managers are to include genetic considerations in their decisions, they will need information on the biological differences between discrete local groups of a species and they will need to understand the genetic and ecological processes that influence discreteness. Thus, the implementation of management strategies based on molecular genetic data can have indirect benefits for population biodiversity, as the main objective of such management plans is to avoid population crashes, which in turn benefits the maintenance of population genetic diversity.

Molecular Genetic Markers: The primary objective of the **genetic stock identification (GSI)** in fish is to assess the distribution and pattern of genetic variability at intra-as well as inter-specific population levels. The first priority for such research is identification of appropriate **molecular genetic markers** to assess genetic diversity. Fish stock identification was initially based solely upon morphological and meristic differences. Because these characters can be influenced by the environment, their variations may not have a genetic basis, and hence do not necessarily provide information on genetic and evolutionary relationships. In the 1950s, dissatisfaction with performance of phenotypic methods for stock identification encouraged early exploration of genetic markers. The markers developed have spurred development of statistical algorithms and revolutionized the analytical power necessary to explore genetic diversity among populations. Methods that take advantage of naturally occurring genetic markers have attracted a good deal of attention because application of physical tags is very labour intensive, and biological markers, such as scale patterns, can vary dramatically from year to year. The first GSI methods using **soluble proteins** and **gene products** such as **allozymes** (enzymes at cellular level) for estimating the contributions of two or more salmon stocks to a mixed harvest were developed in the late 1970s. Since then, the rapidly expanding availability of highly variable genetic markers and refinements in statistical analyses have considerably increased the ability to analyze the stock structure of different fish species; but this has also led to the genetic 'marker wars' among fish geneticists during the past several decades. For many years, allozymes were the universal workhorse genetic makers, and they made many valuable contributions to basic and applied conservation and management. Around 1980, the first applications of **mitochondrial DNA (mtDNA)** analysis to natural populations were published, and gradually, it replaced allozymes and provided answers to key management questions regarding stock structure. The development of DNA amplification using the **polymerase chain reaction (PCR)** technique has opened up possibility of examining genetic changes in populations over the past 100-years or more even using archive material. In PCR reaction, a DNA sequence can be amplified many thousand folds to provide sufficient product for restriction analysis or direct sequencing. Once appropriate primers are available, large number of individuals can be assayed quickly thus facilitating large population screening for variability. Portions of the mtDNA such as, the ATPase 6 and 8 and hypervariable trans-membrane segments of cytochrome *b* (Cyt*b*) that evolve exceptionally rapidly have been used for high-resolution analysis of genetic stock structure in fish. Although mtDNA has indeed provided a wealth of new insights, it is not a solution and has some limitations with respect to fishery management (*e.g.,* it is maternally inherited, so provides information only about female migration or gene flow, and it is only a single marker and hence has much less power than a full suite of nuclear markers).

In the 1990s, **microsatellites** (**Short Tandem Repeats-STRs** or **Simple Sequence Repeats-SSRs**) muscled aside mtDNA and these highly variable **co-dominant markers** have provided greatly increased power and opened up exciting new opportunities (e.g. parentage analysis and individual assignments) that were generally not feasible with allozymes or mtDNA. Microsatellites are repeated DNA sequences having a unit length of 2-6 base pairs tandemly repeated minimum 6 times usually; maximum several times at each locus. They are found in all prokaryote and eukaryote genomes investigated to date. Individual alleles at a locus differ in the number of tandem repeats of the unit sequence owing to gain or loss of one or more repeats and they as such can be differentiated by electrophoresis according to their size.

There are four types of microsatellites

1. Perfect: Perfect tandem repeat sequences.
2. Imperfect: Tandem repeat sequences with intervening sequences.
3. Compound: More than one kind of repeats, adjacent ones.
4. Complex: More than one kind of repeats, with intermediary sequences.

Based on the number of base pairs in a repeat unit, microsatellites can be again classified into *mono* (e.g. C or A), *di* (e.g. CA), *tri* (e.g. CCA), *tetra* (e.g. GATA), *penta* (e.g. CGATA) and *hexa* (e.g. ATGGCA) repeat unit microsatellites. Microsatellites that are used in stock identification studies typically contain di- (AC)n, tri-(ACC)n, or tetra-nucleotide (GATA)n repeats. The most common ones are dinucleotide repeats. Tetra-nucleotide microsatellites are gradually replacing dinucleotide loci as the preferred genetic marker for stock analysis. Microsatellite loci are abundant in all eukaryote genomes and it has been estimated that there are from 10^3 to 10^5 microsatellite loci dispersed at 7 to 10^{10} base pair (bp) intervals or one locus at every 100-300 kilobase pair (kbp) intervals in the eukaryotic genome. Fish genomes may contain more microsatellite loci than most other invertebrate and vertebrate taxa. Mapping studies suggest more or less even distributions of microsatellites throughout genomes, although they are somewhat rarer within coding sequences.

Several features of STR render them invaluable for examining fish population structure. Microsatellites are codominant in nature and inherited in Mendelian fashion, revealing polymorphic amplification products from all individuals in a population. They contain information, which are directly related to the effective number of alleles at each locus. PCR for microsatellites can be automated for identifying simple sequences repeat polymorphism. Small amount of samples of blood or alcohol preserved tissue is adequate for analyzing them. Because they are highly variable in nature, abundant variants are ensured for characterization of populations. However, sample size in excess of 50 may be required to represent the genotype frequencies. The microsatellites are non-coding and therefore variations are independent of natural selection. These properties make microsatellites ideal genetic markers for defining population genetic diversity and distance measures. Because most STR loci are unlinked and inherited independently, the greater the number of loci screened, the greater the likelihood of selecting loci that reveal significant allelic frequency differences among populations and more statistical power is gained in quantifying the extent of genetic differentiation among populations. Additionally, analysis of a larger number of loci may provide a more accurate picture of the evolutionary history of the genetic stocks.

Analysis of microsatellite polymorphisms is a PCR-based approach in which oligonucleotide primers are designed based on unique single-copy sequences flanking the microsatellite repeats. DNA extracted from tissue samples are subjected to PCR reactions. PCR primer pairs are selected such that PCR products are of small molecular size (usually <350bp), providing relative ease in amplification from low-quality DNAs and also allowing for distinguishing small differences in the molecular size of alleles among individuals by using polyacrylamide-gel electrophoresis or automated DNA sequencers. Ideally, each individual shows a single (homozygote) or two-band (heterozygote) DNA pattern, with one band inherited from each parent. Polymorphic alleles at a locus are usually characterized by their molecular sizes. For dinucleotide repeats, these will differ by two base units. Based on the STR allele frequency data, powerful statistical tests are employed to arrive at a decision whether the genetic stocks of a species are significantly different from one another.

However, the field now seems poised to shift towards another type of marker, **single-nucleotide polymorphisms (SNPs)**. Like allozymes, SNPs are generally diallelic, so each marker has less power than a single microsatellite locus. They occur in vast numbers throughout the genome; therefore, eventually large overall increases in power are possible. Furthermore, once developed, SNPs can be assayed more reliably and cheaply than microsatellites, which could be a considerable advantage in large-scale fishery management applications. However, development of sufficient numbers of SNP markers will be neither easy nor cheap, and analytical issues such as minimizing ascertainment bias remain to be resolved. Despite growing competition from new genotyping and sequencing techniques and latest class of markers, the use of the versatile and cost-effective microsatellites continues to increase, boosted by successive technical advances. Next-generation sequencing (NGS) technologies and the rise of commercial services allow the identification of large numbers of microsatellite loci at reduced cost in non-model species. As a result, more stringent selection of loci is possible, thereby further enhancing multiplex quality and efficiency. Numerous examples also exist where microsatellite analysis is used for fish population analysis and management of Pacific salmon (Fisheries and Oceans Canada website: http://www.pac.dfo-mpo.gc.ca/science/facilities-installations/pbs-sbp/mgl-lgm/proj/ index eng. htm online.) and also for cod where microsatellites have even been used as evidence in a court cases against a fishermen claiming a false origin of his catch. **Use of 20-25 polymorphic microsatellite loci (preferably tetra-nucleotide repeats) and 70–100 individuals from each population has become the standard and scientifically accepted protocol for population genetic analysis of fish along with information on biology and morphometry (*TRUSS*) data. Sequence information of mitochondrial complete ATPase 6/8 and Cytb genes of at least 20 individuals per population are also often generated along with this**.

Genetic Stock Structure in fish

Distinct population structure has been observed in many fish species across the world indicating that propagation-assisted restoration programmes must be stock-specific to replenish declining populations. Generally, between populations of marine and freshwater species, marked differences exist in the level of genetic differentiation and genetic diversity, with marine species generally exhibiting lower levels of inter-population differentiation and greater genetic diversity. This is mainly due to the higher effective population sizes and/or higher inter-population migration rates in marine environments compared with freshwater. In addition, marine fishes and invertebrates are generally broadcast spawners and hence have large potential for movement between areas by larval drift in currents. In addition, adults of many species are capable of making long distance migrations. Early genetic studies of commercially important marine fishes using allozymes and proteins indicated that they generally had moderate levels of gene diversity and little population subdivision, often covering over several hundred kilometers. However, unexpected fine-scale population sub-structuring and deep genetic lineages have been observed in recent studies with high-resolution markers in many fishes which calls for further in-depth integrated approaches of molecular genetics with life-history traits. This will prove whether the variability is due to isolation or adaptations to particular marine habitats or as a result of non-genetic factors such as large reproductive variation among families. Regular monitoring of populations is also essential to enable a distinction between normal population-size fluctuations and those severe enough to warrant conservation measures.

The greatest genetic threats in the marine ecosystem are the extinction of genetically unique subpopulations and loss of genetic diversity primarily through overfishing and climate change. Illegal unreported and unregulated (IUU) fishing also contributes to this condition, and thus poses a severe threat to marine ecosystems. Controlling for compliance and enforcing fishing regulations is hampered by difficulties in identifying the geographical origin of fish and fish products, at point of landing and further down the food supply chain. Presently, there are no validated genetic methods for identifying the geographical origin of marine fish and investigate commercial fraud. '**FishPop-Trace**'(https://fishpoptrace.jrc.ec.europa.eu/web/fishpop trace/) is an international project, funded by the European Union (EU) framework programme (FP7), aiming to generate forensically validated reference panels of SNP markers for geographical origin assignment in four commercially important fish species, cod (*Gadus morhua*), hake (*Merluccius merluccius*), herring (*Clupea harengus*) and common sole (*Solea solea*). SNP markers are selected these are subsequently genotyped across populations to provide high resolution data to analyze genetic variation. These markers are validated to be used as tags for traceability and enforcement applications leading to a reduction in IUU fishing and conservation of remaining marine resources.

For a successful stocking programme such as sea ranching of endangered seahorse or sacred chank, genetic structure of the original wild population must be determined before any new fish are released into the waters. This information can be used to develop hatchery guidelines for breeding fish for stocking purposes. By ensuring that the stocked population is having the same genetic make-up as the wild population, re-integration of the stocked fish will likely be more successful and deviations from the original genetic structure will be minimal.

Integrating Population Genetics Data into Marine Fisheries Management

Maintaining the maximum level of genetic variations in fish stocks is vital for the preservation of genetic resources. Therefore, excessive loss of genetic variability should be avoided for sustainable management of resources. Application of molecular marker techniques to a number of species has shown that these methods can provide information on genetic stock structure that can be of direct management relevance. However, such information has not always been incorporated into fishery management and policy decisions in several countries. The complex problem requires agreement among scientists, governmental organizations and policy makers to define and implement policies on the sustainable management of these natural resources. Numerous factors (as mentioned below) have contributed to the imperfect integration of genetic data into management of aquatic species.

The fish stock assessment teams generally include quantitative fishery biologists and statisticians. In appropriate situations, the teams should be expanded to include geneticists as well as field biologists. It is always better that fish geneticists fully understand the complexities of the management process so that genetic information can be packaged in the most effective manner, and importance of GSI can be portrayed effectively for the policy makers. Also the managers involved in monitoring of fishery resources should acknowledge that GSI can provide valuable management information. Scientists, managers and policymakers could work together more effectively to foster productive dialogue to link statutory definitions and management or conservation goals.

It is difficult to develop an ideal sampling design for a genetic study without understanding the details of the life history of the target species and physical processes in the aquatic ecosystem. Genetic data can be integrated with other types of biological and oceanographical information. The sampling design of genetic studies does not always match the geographical regions to which management controls are applied. This can rarely result in discrepancy between biological and genetic management units. Implementing GSI over a broad geographical area requires extensive efforts to collect baseline data for populations from different coasts and to standardize laboratory procedures so that comparable data can be obtained by different laboratories. This requires funds, broad collaboration among laboratories and a willingness to share unpublished data.

Most fish geneticists are unfortunately, not exposed to the techniques of statistical model and decision analysis that form the basis for modern stock assessment science. Equally, managers and assessment biologists similarly would benefit from a greater literacy regarding the genetic principles that can profoundly affect the aquatic living resources for which they share stewardship responsibility. Therefore, it might be necessary to develop brief **integrated training courses** to equip geneticists and managers to work on assessment teams.

The purpose of stock assessment in fisheries is to provide timely and appropriate scientific advice on fisheries management for sustained production. Though there are few multi-species models, the assessments are almost mostly conducted for single species, whereas in reality, stocks are influenced by multi-species interactions. In addition, gears mostly harvest many species at a time, leading to difficulty in implementation of the management measures derived from single species stock assessment. Due to the lack of adequate and efficient models for multi-species interactions, stock assessments will generally continue to be based on single species models. Although the main approach in population genetic studies of natural populations still involves collecting individuals from two or more geographical locations and considering them as putative populations, *landscape genetics/ seascape genetics*—the study of spatial genetic patterns in continuously distributed species—is rapidly evolving and the methods are beginning to be applied especially to marine species as well. These studies are expected to provide important insights into biological processes leading to effective multi-species stock assessment and management of marine ecosystems.

However, considerable dialogue between geneticists, stock assessment scientists and managers, as well as creative thinking on both sides are required to develop effective ways to integrate these insights into fisheries management.

In conclusion, fish genetic stock diversity conservation requires preservation of as much variation as possible at all taxonomic levels and concerted efforts by integrating capture, culture fisheries and environmental programmes using latest technological innovations. The genetic tools will provide innovative means in the future and are an assuring approach for food security of the world and in reducing the fishing pressure on natural resources. Genetic data need to be integrated with other types of biological and oceanographical information for understanding the details of the life history of the target species and physical processes in the marine ecosystem. Although better monitoring of biodiversity, better assessment of risk and a more strategic approach to conserving biodiversity are all essential components to successful risk management, an equally important need is the open dialogue among geneticists, quantitative fishery biologists, statisticians, conservationists and planners that would help sustainable management of stocks of the world's amazingly rich assemblage of fishes.

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CHAPTER 39

ECOLABELLING IN FISHERIES: BOON OR BANE IN IMPROVING TRADE?

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Introduction

This document is a collation of information, mainly from FAO documents on fisheries ecolabelling (FAO, 2001; Sainsbury, 2010; Washington and Ababouch, 2011). Fish is one of the most highly traded commodities in the world, and as a natural resource, there is worldwide concern about long-term sustainability of the resources. Ecolabels are a new and growing feature of international fish trade and marketing. They have emerged in the context of increased demand for fish and seafood, and a perception that many governments are failing to manage the sustainability of marine resources adequately. Many mechanisms to ensure the sustainability of fish stocks have been introduced by international bodies which are binding on national governments. These include:

- The United Nations Convention on the Law of the Sea (UNCLOS) (1982);
- The FAO Code of Conduct for Responsible Fisheries (the Code) (1995);
- The United Nations Fish Stocks Agreement (1995); and
- Various regional fisheries management organizations (RFMOs).

The RFMOs facilitate international cooperation at the regional level for the conservation and management of highly migratory and straddling fish stocks. At the national level, governments are attempting to embed the principles and goals of the Code– now in its second decade of implementation – into their national fisheries management policies (FAO, 2009a). However, they are having varying degrees of success. Disappointment with the pace of regulatory measures to curb overfishing and to improve fisheries sustainability has led environmental groups to develop alternative market-based strategies for protecting marine life and promoting sustainability. These private market mechanisms are designed to influence the purchasing decisions of consumers and the procurement policies of retailers selling fish and seafood products, as well as to reward producers using responsible fishing practices. Ecolabels are one such market-based mechanism.

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The FAO Guidelines for the Ecolabelling of Fish and Fishery Products from Marine Capture Fisheries state that voluntary standards, including environmental standards, should not distort global markets and should not create unnecessary obstacles to international trade. Under the general principles and definitions, they state that any ecolabelling scheme should be consistent with inter alia the World Trade Organization (WTO) rules and mechanisms.

What is an Ecolabel ?

Ecolabelling is a market-based tool to promote the sustainable use of natural resources. Ecolabels are seals of approval given to products that are deemed to have fewer impacts on the environment than functionally or competitively similar products. The ecolabel itself is a tag or label placed on a product that certifies that the product was produced in an environmentally friendly way. The label provides information at the point of sale that links the product to the state of the resource and/or its related management regime. Sitting behind the label is a certification process. Organizations developing and managing an ecolabel set standards against which applicants wishing to use the label will be judged and, if found to be in compliance, eventually certified. The parent organization also markets the label to consumers to ensure recognition and demand for labelled products. The theory is that ecolabels provide consumers with sufficient information to enable them to recognize and choose environmentally friendly products.

A range of ecolabelling and certification schemes exists in the fisheries sector, with each scheme having its own criteria, assessment processes, levels of transparency and sponsors. What is covered by the schemes can vary considerably: bycatch issues, fishing methods and gear, sustainability of stocks, conservation of ecosystems, and even social and economic development. The sponsors or developers of standards and certification schemes for fisheries sustainability also vary: private companies, industry groups, NGOs, and even some combinations of stakeholders. A few governments have also developed national ecolabels.

The first fisheries ecolabelling initiatives appeared in the early 1990s and were largely concerned with incidental catch, or bycatch, during fishing. For example, the "Dolphin-Safe" label was based on standards developed by the United States NGO Earth Island Institute and is focused on dolphin bycatch in the tuna industry (rather than the sustainability of tuna stocks).

Marine Stewardship Council (MSC)

One of the first scientifically developed ecolabelling schemes, the MSC was set up by the WWF and Unilever in 1997, but has been independent of them for more than ten years. The MSC is arguably the most comprehensive fisheries certification scheme in that it covers a range of species and deals with all aspects of the management of a fishery. MSC sets the standard for the ecolabel through its board, supported by a Technical Advisory Board.

The MSC has qualified for membership of the ISEAL (International Social and Environmental Accreditation and Labelling Alliance) as being consistent with its "Code of good practice for setting social and environmental standards". The MSC has two standards: on "sustainable fishing" and on "seafood trace ability". The MSC owns the standards against which independent third-party certifiers assess conformance. Its "Fisheries Assessment Methodology", and "standardized assessment tree" focus on three pillars: independent scientific verification of the sustainability of the stock; the ecosystem impact of the fishery; and the effective management of the fishery. All three pillars are assessed on the basis of a range of indicators. Aspects related to the species, the fishing gear used, and the geographical area, are all included in the assessment. A study by Caswell and Anders (2009) concluded that it is the scheme most often referred to in the seafood industry media, and has variously been described as the "industry standard". Another recent study (MRAG, 2009) revealed that a significant number of retailers and brand owners refer to the MSC in their sea food sustainability procurement policies.

Some 150 fisheries around the world are engaged in some stage of the MSC assessment process (including pre-assessment) (MSC, 2009). Fifty-six fisheries have so far been certified. The MSC claims to cover "about 7 per cent of the annual global wild harvest" of fish and seafood, accounting for 42 per cent of the global wild salmon catch and 40 per cent of the global white fish catch. However, not all fish from a certified fishery will end up with the MSC label attached. The actual volume of MSC-labelled product on the market as a proportion of overall traded fish products is likely to be considerably less significant in terms of global trade. While there are no robust statistics on the proportion of MSC-labelled products on the global market, FAO estimates suggest that the volume of MSC- labelled products on the market may only be statistically significant in the context of specific European markets. Ina study carried out for FAO in 2007, Poseidon Ltd. estimated MSC products as then accounting for 0.3 per cent of globally traded seafood by value. Sales of MSC-labelled fish and seafood of an estimated US$1.5 billion is minor when seen against a fisheries commodity market amounting to US$101 billion in global export sales (FAO, 2010).

As of late 2009, more than 2 500 MSC-labelled products were available on the market (MSC, 2009); this is double the number (1 200) on sale at the beginning of 2008,and more than four times the number (600) available in early 2007,24 showing just how dynamic the market for certified fish and seafood is. Today, MSC products are sold in52 countries around the world.

Friend of the Sea

Friend of the Sea (FOS) has its origins in the Earth Island Institute. Set up in 2006, its founder is also the European Director of Dolphin Safe. It covers both wild and farmed fish and its criteria also include requirements related to carbon footprint and "social accountability". Certification is based on the sustainability of the stock, rather than whether the fishery is sustainably managed. Its certification methodology is based on existing official data in terms of stock assessment. Friend of the Sea says it will not certify stocks that are "overexploited" (based on FAO definitions of levels of exploitation), fisheries using methods that affect the seabed and those that generate more than 8 percent discards. Certification is undertaken by independent third-party certifiers. Friend of the Sea claims to be "the main sustainable seafood certification scheme in the world" covering some 10 per cent of the world's wild capture fisheries. It should be noted that 80 per cent of the 10 million tonnes of landed FOS certified product from capture fisheries (8 million tonnes) comes from Peruvian anchovies. Again, it is unclear what proportion of that product ends up as labelled products for retail sale. There are about 600 FOS products (including fish oil and omega-3 supplements) sold in 26 countries28 and covering 70 species both from wild capture and aquaculture.

Marine Aquarium Council

The Marine Aquarium Council (MAC) was established in 1998 and by 2001 had adopted a standard and process to certify the wild capture and subsequent treatment of fish for the ornamental aquarium trade. In 2004, a standard for live fish for human consumption was developed because many of the operators and communities involved with the aquarium trade are also involved in the trade of live fish for consumption. However, this standard for live fish for human consumption was not formally adopted by the MAC and no fisheries have been certified for this trade.

Other NGO schemes

Other NGO-driven schemes include KRAV, a Swedish NGO that specializes in organic farming but which has recently developed a "standard for sustainable fishing" and Naturland in Germany also with a background in certifying organic farmed seafood but now with a "Scheme for the Certification of Capture Fishery Project", which includes social, economic and ecological sustainability criteria. To date, Naturland has only certified one fishery (Nile perch from Buboka in the United Republic of Tanzania).

Fishing company in-house ecolabels

A few individual fishing companies have created their own ecolabels. For example, the Spanish group Pescanova, one of Europe's largest fishing companies, which fishes globally and has interests in the processing sector, has created a logo that appears on a limited range of its packaged products. The logo states that the fish concerned has been caught in a way that "preserves the aquatic and marine ecosystem for maintaining the quality, diversity and availability of fish resources for today and future generations". This in-house scheme claims to be based on the Code.

Fishing industry association ecolabelling schemes

The Japan Fisheries Association, an umbrella group for some 400 fishing companies, founded the Marine EcoLabel- Japan (MEL) in December 2007. The MEL operates as a non-profit part of that association. It could be seen as a response to a developing interest in ecolabelled fish and seafood in the Japanese market. Indeed the stated rationale behind the label was to "respond to the situation proactively and establish their own ecolabelling scheme, which is most suitable to the situation of the Japanese fisheries". As of January 2010, only three fisheries have been certified to the fledgling label. It is likely to have significance only in the Japanese market.

Public ecolabelling schemes

Recently, some public authorities, most notably the Government of France and Iceland, have set up their own ecolabels. The Government of France has chosen to create its own national ecolabel and related certification scheme. This decision was based on a feasibility study undertaken in 2008 by the French authority, FranceAgriMer. As part of that process, it examined existing private ecolabels, including for consistency with the FAO Guidelines for the Ecolabelling of Fish and Fishery Products from Marine Capture Fisheries. It concluded that, of the existing ecolabels, only the MSC was fully compliant with those guidelines. However, it also concluded that the MSC model would not fit all fisheries. It decided to adopt a public framework to meet the needs of its fishing industry as defined by the feasibility study; a scheme that was less costly than the MSC, easily recognized by consumers, and one that was consistent with the FAO guidelines but went beyond them with the inclusion of social and economic criteria.

The public label does not preclude the certification of French fisheries to other private ecolabels. Indeed, certification to other labels has been encouraged; a number of French fisheries are currently in assessment with the MSC.

Most of the descriptions provided in this document refers most often to the MSC and FOS, as the two schemes that – on the basis of their international scope, the number of fisheries certified and the claimed volumes of certified fish and seafood products entering international markets – stand out as the most internationally significant private voluntary ecolabelling schemes.

Principles and Criteria for Sustainable Fishing of MSC

At the centre of the MSC is a set of Principles and Criteria for Sustainable Fishing which is used as a standard in a third party, independent and voluntary certification programme. These were developed by means of an extensive, international consultative process through which the views of stakeholders in fisheries were gathered.

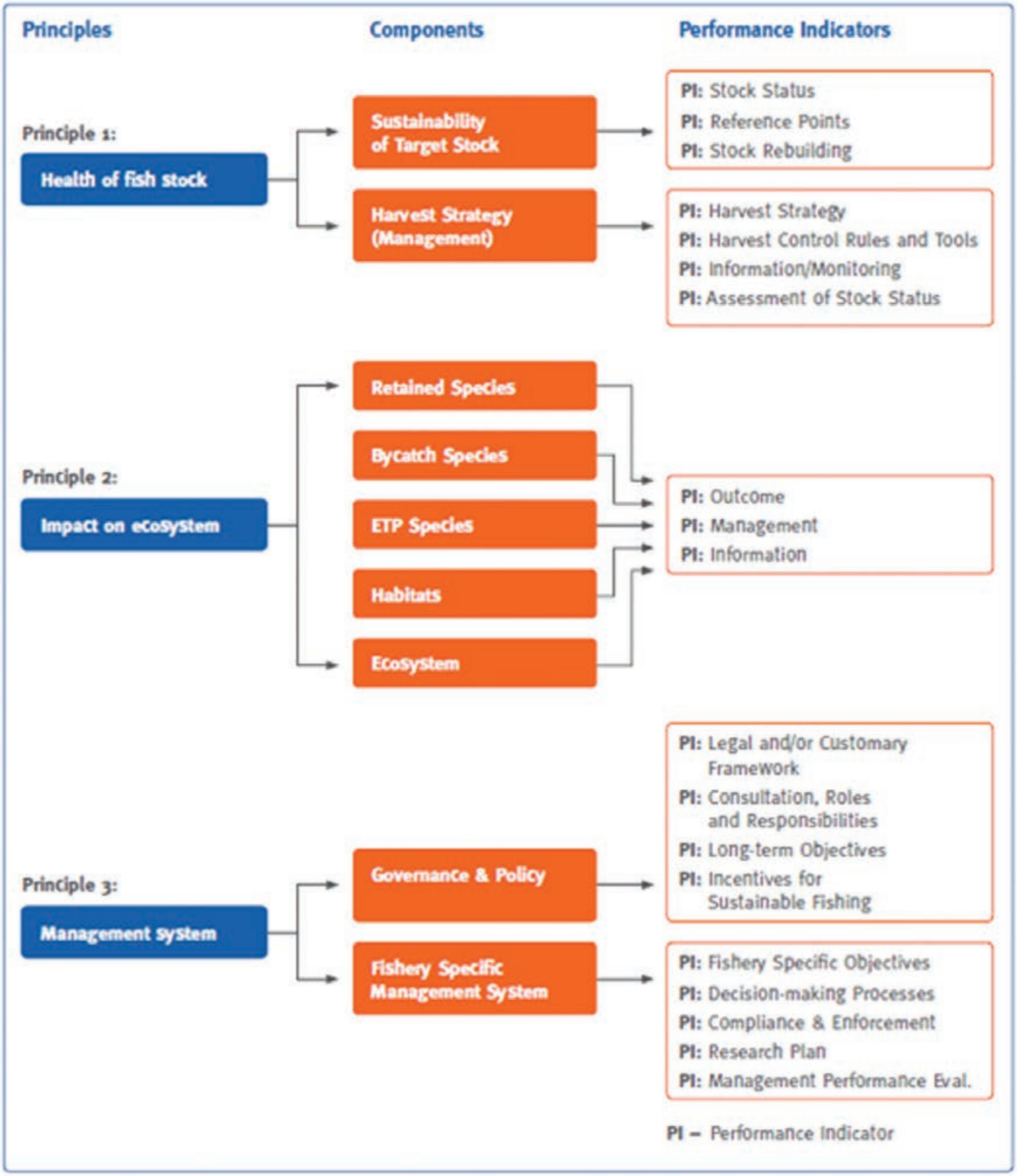

Fig. 1. Principles and Criteria for Sustainable Fishing of MSC

These Principles reflect a recognition that a sustainable fishery should be based upon:

- The maintenance and re-establishment of healthy populations of targeted species;
- The maintenance of the integrity of ecosystems;
- The development and maintenance of effective fisheries management systems, taking into account all relevant biological, technological, economic, social, environmental and commercial aspects; and
- Compliance with relevant local and national local laws and standards and international understandings and agreements.

MSC's Risk Based Framework

The MSC began work to develop suitable methodology to assess data-limited fisheries in 2005. A series of expert workshops and consultations were undertaken. These led to the development of a set of risk-based tools referred to at the time as the Guidance for the Assessment of Data-Deficient and Small-Scale Fisheries. In early 2008, a pilot project commenced to test these tools using seven pilot fisheries from around the globe, resulting in the Risk-Based Framework (RBF). In February 2009, Version One of the RBF was released for public consultation and provisional use by certifiers. Following this consultation and a subsequent final revision, the RBF was integrated into the MSC Fisheries Assessment Methodology (FAM), Version Two, and approved by the MSC Technical Advisory Board and MSC Board of Trustees for official use as of 31 July 2009. The RBF can now be used in any fishery assessment that uses the default assessment tree in the FAM as its basis.

Criteria for FOS Ecolabel

Friend of the Sea Criteria are categorical in nature and based on the most restrictive and worldwide acknowledged and accepted definition of 'sustainable fisheries'. On this matter Friend of the Sea has taken in due consideration requests from stakeholders, such as NGOs and traditional and artisanal fisheries, for a more limitative definition of 'sustainable fisheries'.

A Sustainable Fishery, of FOS is one that:

1. Does not insist on an overexploited, depleted or data deficient stock;
2. Has no impact on the seabed;
3. Has lower than average discard level;
4. Complies with all local national and international legislation
5. Apply a management system that assures the respect of above mentioned requirements.

An example of legal criteria of FOS is shown below.

4 – LEGAL CRITERIA: TAC, IUU, FOC and legislation

n°	Requirement	Level
	The fleet fishing the audited product must :	
4.1	Respect Total Allowable Catches (TACs), if in place. Last year's TAC has been respected or, in case it has not been respected, at least 2 out of the past 3 years TACs have been respected.	Essential
4.2	Include NO IUU (Illegal, Unreported, Unregulated) fishing vessels.	Essential
4.3	Include NO FOC (Flag Of Convenience) fishing vessels.	Essential
4.4	Respect national and international legislation, in particular legislation related to the reduction of the environmental impact of the fishery (such as, but not limited to:	Essential
	- vessel registration,	
	- mesh size,	
	- net size,	
	- minimum size,	
	- distance from the coast,	
	- by-catch reduction measures,	
	- no fishing on protected habitat	
	- verify onboard equipment and absence of banned fishing gears and methods, chemical substances, explosives	
	- log book if compulsory)	

Price premium – myth or reality ?

There is only spotty evidence of price premiums accruing to certified fish and seafood. Research by the URI Sustainable Seafood Initiative (Asche, Insignares and Roheim, 2009) found price premiums at the retail level but acknowledged that this did not necessarily imply that any premium would accrue to fishers. At the 2009 OECD/FAO Round Table, some participants reported, if not price premiums, then less price volatility at the ex-vessel stage of the supply chain. Often, this was related to more direct supply relationships. The MSC's recent publication, Net Benefits (MSC, 2009),which describes the experiences of the first 42 fisheries to be certified, concludes that the main beneficiaries of price premiums have been smaller-scale artisanal fisheries (all in developed countries) selling into niche markets. The price premiums described are all associated with more secure supply relationships, either with restaurants or, to a lesser extent, supermarkets.

Impact of Ecolabels on trade

It is difficult to estimate the volume of ecolabelled certified products on the international market. The MSC and FOS claim 7 per cent and 10 per cent respectively of world's capture fisheries – when put together they account for less than one-fifth of wild capture product.

It is certain that the real volume of traded ecolabelled products is significantly less than that. Indeed, of the MSC's 6 million tonnes of seafood landed from certified fisheries, only about 2.5 million tonnes ends up carrying the MSC label (MSC, 2009). A significant proportion of FOS-certified fish goes into products such as fishmeal and fish food that will not end up as labelled products on supermarket shelves(although the farmed fish they feed may do). Other schemes in existence currently cover fairly insignificant volumes of product. Overall, the market presence of ecolabelled products is likely to be modest, and significantly lower than the publicity surrounding such products would suggest (Washington and Ababouch, 2011).

Boon or Bane ?

In a world in which the demand for fishery products are increasing in leaps and bounds, and the pressure on the natural resources are rising, ecolabelling appears to be a possible way to bring about a greater degree of control and sanity in the system. The increasing proportion of aquaculture in the production system for aquatic products is also being addressed by global organizations. Following on from its involvement in the certification of sustainable forestry (Forestry Stewardship Council - FSC) and wild-capture fisheries (Marine Stewardship Council - MSC), the WWF has developed standards for aquaculture certification, with an emphasis on eliminating the negative environmental and social impacts of aquaculture called the Aquaculture Stewardship Council (ASC). It has organized a range of round tables involving aquaculture producers, buyers, NGOs and other stakeholders in an attempt to develop standards for aquaculture certification. The first ASC certificate is expected to be issued in 2012.

A recent study evaluating the effectiveness of certified seafood showed that though there are debatable shortcomings, for a consumer, it is reasonable to buy certified seafood, because the percentage of moderately exploited, healthy stocks is 3–4 times higher in certified than in non-certified seafood (Froese and Proelss, 2012).

CHAPTER 40

ECOSYSTEM CONCEPTS FOR SUSTAINABLE MARICULTURE

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Introduction

Almost 50% of all seafood eaten worldwide today is farmed, compared to only 9% in 1980, primarily from the expansion of aquaculture in China and India. Increasing seafood production in an environmentally and socially responsible way will likely require the use of policy tools, such as good management practices (GMPs) and performance standards. These policy tools are commonly utilized to reduce effects associated with the use of natural resources in commercial activities like mariculture. Although mariculture operations may expand the production of seafood without additional exploitation of wild populations, they still depend upon and affect natural ecosystems and ecosystem services. GMPs and performance standards are useful for protecting the environment while increasing mariculture production.

Mariculture can have both positive and negative ecological impacts on the marine environment. For instance, culture operations and the associated gear can alter water flow, composition of the sediment, and rate of sedimentation and in some cases can disturb the benthic flora, including sea grass, which provide habitat for fish and invertebrates. However, mariculture gear increases the availability of hard substrates, thereby supporting higher densities of fish and invertebrates that associate with structured habitat, but the presence of artificial hard substrates can also promote colonization and spread of introduced species, such as non-native ones. Such a mix of beneficial and negative effects illustrates the complexity of ecosystem responses to mariculture operations.

From organism to ecosystem, there is no free lunch-every additional animal has an incremental effect arising from food extraction and waste excretion. The scope of impacts of cultured organisms is a function of the scale and location of mariculture operations, a fact that needs to be recognized and quantified. Some effects may be beneficial to the ecosystem, while others may be detrimental, depending on the scale and location of the farm.

Economic activities in marine and coastal areas, whether fisheries, aquaculture, or tourism, depend on the capacity of marine and coastal ecosystems to provide seafood for human consumption and fish for feed production, as well as coastal and marine waters suitable for recreation.

The development of modern aquaculture has been founded on social norms and rules that rely on technology, indicators of welfare, and world views that mentally alienate people from their dependence on functional ecosystems.

Since global marine fish stocks show signs of serious overharvesting, and spawning and breeding areas worldwide are increasingly degraded, it is necessary to develop concepts and management tools that take into account the support of coastal and marine ecosystems. The marine and coastal footprint of seafood production and waste assimilation, and report on estimates of regional and global appropriation of marine and coastal ecosystems is useful in ecological footprint analyses in relation to the management of mariculture for sustainability.

The capacity of marine and coastal ecosystems to sustain seafood production and consumption is seldom accounted for. Estimates of marine and coastal areas appropriated by farming for seafood production-the ecological footprint-ranges from negligible to as much as 50 000 ha/ha activity, largely depending on the methods of farming and fishing. The area for waste assimilation ranges from 2 to 275 ha/ha seafood production. The capacity of marine and coastal ecosystems to produce seafood is not included in the signals that guide economic development. Practices that make use of this capacity without degrading it have to be developed and protected from economic and social driving forces that create incentives for misuse of coastal and marine ecosystems.

Marine and coastal ecosystem support of aquaculture and fisheries

Due to current overexploitation of the world fisheries resources, aquaculture is often promoted to be the most likely source of additional seafood production. Its expansion has been given high priority, both in developed and developing countries. However, the rapidly expanding modern aquaculture technology (predominantly monocultures) has mainly used ecosystems as a medium for culturing, and has taken the necessity of a supply of resources like feed, water *etc*. and ecosystem services like waste assimilation, for granted. Intensive aquaculture is not a substitute for fisheries and on the contrary, intensive aquaculture largely depends on fisheries to harvest the seafood that is given to the cultured species in the form of pellets unless and until suitable replacement for fishmeal and fish oil are found out.

Ecological footprints and farming intensity

The dependence on external ecosystems for resource production and waste assimilation generally decreases from intensive to extensive techniques. While intensive cage farming has been increasingly dependent on external inputs and affecting the environment through releases of waste, semi-intensive farming is characterized by a more complete utilization of material and energy and a higher recycling of organic matter and nutrients within the pond system. Semi-intensive aquaculture relies both on natural food production in the ponds, and supplementary feed, usually from locally available plants or agriculture by-products. Thus, fish can obtain a major part of their nutritional requirements from local natural sources when reared at low densities in a pond.

Integrated cultures are often based on recycling or eco-cyclic production, and have the potential to be more in tune with the processes and functions of the supporting marine ecosystem.

Integrated multi-trophic aquaculture (IMTA)

IMTA refers to the explicit incorporation of species from different trophic positions or nutritional levels in the same system. Integrated marine aquaculture can cover a diverse range of co-culture/ farming practices, and even more specialized forms of integration such as mangrove planting with aquaculture, called aquasilviculture. Integrated mariculture has many benefits, among which bioremediation is one of the most relevant, and yet is not valued in its real social and economic potential for the integration benefits derived from bioremediation. Reducing risks is also an advantage and profitable aspect of farming multiple species in marine environments. A diversified product portfolio increases the resilience of the operation, for instance when facing changing prices for one of the farmed species or the accidental catastrophic destruction of a crop.

Integrated mariculture systems must be developed in order to assist sustainable expansion of the sector in coastal and marine ecosystems thus responding to the global increase for seafood demand but with a new paradigm of more efficient food production systems. Successful integrated mariculture operations must consider all relevant stakeholders into its development plan; government, industry, academia, the general public and non-governmental organizations must work together and the role of integrated mariculture within integrated coastal zone management plans must be clearly defined.

An important issue of IMTA is to adopt management practices that avoid or reduce the likelihood of disease transmission within and between aquaculture facilities or to the natural aquatic fauna. Also, careful consideration should be paid to the selection of species used in polyculture or IMTA to reduce potential stress and suffering of culture individuals. Integrated aquaculture should be looked upon as a very important tool to facilitate the growth of marine aquaculture and promote sustainable development.

IMTA for Mariculture Sustainability

The rapid development of intensive fed aquaculture of monospecies (*e.g.* finfish and shrimp) throughout the world is associated with concerns about the environmental impacts, especially where activities are highly concentrated or located in suboptimal sites whose assimilative capacity is poorly understood and, consequently, prone to being exceeded.

One of the main environmental issues is the direct discharge of nutrient loads into coastal waters from open water systems and with the effluents from land-based systems. In its search for best management practices, the aquaculture industry should develop innovative and responsible practices that optimize its efficiency and create diversification, while ensuring the remediation of the consequences of its activities to maintain the health of coastal waters. To avoid pronounced shifts in coastal processes, conversion, not dilution, is a solution used for centuries in Asian countries. By integrating fed aquaculture (finfish, shrimp) with inorganic and organic extractive aquaculture (seaweed and shellfish), the wastes of one resource user become a resource (fertilizer or food) for the others. Such a balanced ecosystem approach provides nutrient bioremediation capability, mutual benefits to the co-cultured organisms, economic diversification by producing other value-added marine crops and increased profitability per cultivation unit for the aquaculture industry.

As guidelines and regulations on aquaculture effluents are forthcoming in several countries, using appropriately selected seaweeds as renewable biological nutrient scrubbers represents a cost-effective means for reaching compliance by reducing the internalization of the total environmental costs. By adopting integrated polytrophic practices, the aquaculture industry should find increasing environmental, economic, and social acceptability and become a full and sustainable partner within the development of integrated coastal management frameworks.

Good management practices (GMPs) and performance standards

GMPs represent one approach to protecting against undesirable consequences of mariculture. GMPs for farming have been prepared by industry groups, nongovernmental organizations, and governments with the common goal of sustainability. An alternative approach to voluntary or mandatory GMPs is the establishment of performance standards for mariculture. In mariculture, variability in environmental conditions makes it difficult to develop GMPs that are sufficiently flexible and adaptable to protect ecosystem integrity across a broad range of locations and conditions. Because GMPs address mariculture methods rather than monitoring actual ecosystem responses, they do not guarantee that detrimental ecosystem impacts will be controlled or that unacceptable impact will be avoided. Adoption of performance standards is likely to encourage innovation among growers. With performance standards, mariculture operations are managed adaptively to maintain key indicators within acceptable bounds, through direct monitoring of ecosystem indicators rather than tracking compliance with specific management practices.

Carrying capacity and aquaculture

Carrying capacity can be defined as the maximum population or biomass that an area will support sustainably, as set by available space, food and other potentially limiting resources but within the limits set by the capacity of the ecosystem to process biological wastes and by social tolerance for the change in environmental attributes. The concept of carrying capacity is increasingly and appropriately invoked as a quantitative guide to identify limits to stocking densities of finfish/ shellfishes in mariculture operations. Application of a carrying capacity concept to setting mariculture stocking limits requires a determination on what represents acceptable versus unacceptable impacts. Carrying capacity models can be used to optimize production of the cultured organisms; reduce the ecological impacts on the food web; or maintain societal values, such as scenic amenity or recreational opportunity. All carrying capacity approaches require models of the mariculture activity and its interactions with living and non-living components of the ecosystem.

Mariculture contrasted with capture fisheries

Many ecological effects of mariculture closely parallel the corresponding ecological effects of wild-stock harvests. Mariculture conducted on lines, racks, or cages does not require dredging and is thus less damaging to the ecosystem than wild-stock harvesting. Wild-stock harvests tend to be more frequent and more dispersed, thus causing greater damage to the ecosystem than the less frequent, more localized, and managed harvest of farmed animals. Basic economics suggests that increasing supply through mariculture will reduce seafood prices if other factors remain unchanged. Lower prices will tend to reduce economic incentives to harvest the wild population, thereby reducing fishing pressure on the wild stock. However, this effect can be masked in practice if wild-harvest fisheries remain profitable even at lower prices, if overall demand for the product increases, or if a strong niche market develops for the wild-harvest product.

Ecosystem services by mariculture

Filter-feeding bivalves have the ability to reduce water turbidity through their filtration, and they do fertilize benthic habitats through bio deposition, induce denitrification, counteract some detrimental effects of eutrophication in shallow waters, sequester carbon, provide structural habitats for other marine organisms, and stabilize habitats and shorelines. These ecosystem services of bivalves, along with recognition that oysters, clams, and scallops have been depleted dramatically below historical baselines in many estuaries, explain why bivalve mollusc restoration has become an important component of many programs for restoring impaired estuaries and some coastal waters.

Applying an ecosystem-based approach to mariculture

The ecosystem approach to aquaculture is defined as a strategic approach to development and management of the sector aiming to integrate aquaculture within the wider ecosystem such that it promotes sustainability of interlinked social-ecological systems.

An ecosystem approach to aquaculture (EAA) is not a new approach, and has been in a way practiced since the early stages of aquaculture in small-scale inland aquaculture activities particularly in Asia where poultry wastes (or other organic wastes) are commonly used as feed resources for the culture of carps and other freshwater fish. However, the EAA becomes more difficult and a real challenge in the case of intensive, industrial production but also as a result of the added effect of many small-scale aquaculture. It is not uncommon that nutrient cycling and re-utilization of wastes by other forms of aquaculture or local fisheries, is not allowed, or is discouraged.

An ecosystem approach accounts for a complete range of stakeholders, spheres of influences and other interlinked processes. In the case of aquaculture, applying an ecosystem-based approach must involve physical, ecological, social and economic systems, in the planning for community development, also taking into account stakeholders in the wider social, economic and environmental contexts of aquaculture. The first principle for an ecosystem approach, as described by the Convention on Biological Diversity (CBD), is that the objectives of management of land, water and living resources are matters of societal choice (UNEP/CBD/COP/5/23/ decision V/6, 103-106).

Key principles

The EAA can be regarded as "the" strategy to ensure aquaculture contribution to sustainable development and should be guided by three main principles which are also interlinked:

Principle 1: "Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society". It is only realistic to expect that aquaculture, being a human activity, will lead to some loss of biodiversity or affect ecosystem services to some extent. Integrated Multitrophic Aquaculture (IMTA) has been practised in Asia/China since the beginning of aquaculture, this due to their ancient concept of treating effluents and residues from farming practices as resources rather than as pollutants.

In the case of biodiversity, local declines may be acceptable (e.g. below fish cages) as long as such losses can be compensated and restored, at least at the water body scale, in order to preserve ecosystem functions and services. For example after a cage farm operation is halted it is expected that the relevant biodiversity recovers if there is enough green infrastructure, that is conservation areas or more pristine areas to provide relevant colonization and restoration. Efforts need to be made in order to permanently monitor aquaculture effects on biodiversity to make sure that such effects do not result in serious/ significant losses of ecosystem functions and services. In this respect real values of ecosystem "goods" and services should be integrated into micro and macro environmental accounting.

Principle 2: "Aquaculture should improve human well-being and equity for all relevant stakeholders". This principle seeks to ensure that aquaculture provides equal opportunities for development and that its benefits are properly shared, and that it does not result in any detriment for any groups of society, especially the poorest. It promotes both food security and safety as key components of well being. Improving human well-being should go beyond the direct contribution of aquaculture (or the attempts to use it for the purpose) to solve hunger especially in the regions where this activity is newer. In these cases its main contribution to local livelihoods comes from the increase in employment opportunities and also from the direct small business, local marketing of products.

Principle 3: "Aquaculture should be developed in the context of other sectors, policies and goals". This principle recognises the interactions between aquaculture and the larger system, in particular, the influence of the surrounding natural and social environment on aquaculture practices and results. Aquaculture does not take place in isolation and in most cases is not the only human activity – often leading to a smaller impact on water bodies than other human activities e.g. agriculture and industry. This principle also acknowledges the opportunity of coupling aquaculture activities with other producing sectors in order to promote materials and energy recycling and better use of resources in general. Such integration has existed mostly in Asia. There are indeed many examples of integrated production systems e.g. livestock-fish farming and fish-rice production. As mentioned above, most terrestrial food producing systems have been achieved after drastically transforming landscapes, but society historically grew used to this while aquaculture is a rather new development worldwide. Therefore worldwide norms and regulations, policies *etc*. have been made well adapted to agriculture sector but not so much to aquaculture. Thus, aquaculture needs an enabling policy environment to grow in a sustainable manner and to be integrated into the agro-ecosystem and also minimizing conflict occurrence. Aquaculture can compete for freshwater and for land with agriculture but it can also use agriculture products for feeds. Plans for aquaculture development also need to be included within wider development and management schemes, e.g. integrated coastal zone management (ICZM), integrated water resources management (IWRM). Cooperation and integration of sectors in a better planed landscape particularly caring for water resources could yield greater benefits.

The connection with the fisheries sector is obvious from various perspectives e.g. production of fishmeal from fisheries (a fishery service to aquaculture), aquaculture based fisheries (where fisheries is benefiting from aquaculture) but often such connections are not formally dealt with or operational. Some of the potentially negative interactions deal with the competition for common markets, the potential damage to fisheries from the escaped farmed individuals (e.g. the case of escaped Atlantic salmon in Norway). On the other hand, terrestrial food production systems and other industrial activities can impact on aquaculture deteriorating water quality and quantity; they can also affect feed's quality and potential safety (Hites *et al*., 2004).

Some management measures to assist policy-making that ensure environmental, social and economic sustainability of the aquaculture sector In general and at all levels, policies should be generated from a participatory processes, they should be adaptive, transparent and open to the general public; they must ensure and promote people consciousness of the value of ecosystem approach. They should also reconcile temporal scales facing the fact that aquaculture growth/development and governance capabilities have been moving at two different speeds. It is also important to consider that management measures should aim to the compliance of the three EAA principles in order to ensure aquaculture contribution to sustainable development.

A precautionary approach to aquaculture production should involve developing strategies to avoid specific undesirable outcomes. Overloading of a waterbody's carrying capacity will affect the biodiversity or ecosystem services and a management plan should include estimates of the carrying capacity and mechanisms to monitor and control further loading of the system. Another example is that of culturing exotic species or genotypes, where plans should be developed or revised to incorporate precautionary elements; adaptive management practices and tools such as risk analysis and geographic information systems. Adaptive management (AM) has emerged as the "best practices" approach to ecosystem management. Adaptive management is an iterative process of taking actions, evaluating the consequences of those actions and adjusting future actions in the light of changed conditions.

Existing management models, hydrodynamic circulation/deposition models and the knowledge of local institutions, universities *etc*. can be used for the estimation of carrying capacity and use of indicators. For example, be aware of local regional particularities when importing technological packages developed in other regions as it may be necessary to develop proper management models or other tools that are more appropriate to specific local characteristics. Farm scale research should focus on developing tools to evaluate externalities of inputs and outputs, to estimate carrying capacity for individual farms, and tools and technologies for improving the feeding process and conversion ratios. It is also very important to promote permanent and proactive research on new species and strains offering enough information for the selection of the right species based on ecosystem functions and market demands, considering species requirements and ecological/nutritional efficiency.

Different kinds of incentives can be developed in isolation or in combination. *E.g.* improve the institutional framework (definition of rights and participatory processes); develop collective values (education, information, and training); create non-market economic incentives (e.g. tax mechanisms and subsidies) such as special advantageous licences (for example for integrated aquaculture, polyculture or for implemented better management, *etc.*); and establish market incentives (eco-labelling and aquaculture concessions).

Promote education and disseminate information on better practices considering ecosystem based management. At the farm scale it is important to target education and training to the stakeholders (farm owners, workers, site managers) focusing on EAA and emphasizing on management-oriented knowledge. The development of collective values and the understanding of externalities of the farming process are very relevant at this scale. The valuation and understanding of ecosystem services has to start at this scale. To develop a sustainable production in aquaculture EAA should be followed as early as possible in India also.

CHAPTER

41

ECONOMIC VALUATION OF MARINE ECOSYSTEM SERVICES

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Introduction

The marine and coastal ecosystem provides a variety of services. Fisheries is an important provisioning service with supplements from supporting and cultural services. The potential services that can be provided by the marine coastal ecosystem includes, sustainable catch, which provides assured income to the fishers, regulates natural phenomena as certain marine fauna acts as bio-filters, provides a rich treasure of marine bio-diversity.

Types of ecosystem: Structure of the Ecosystem

The different types of ecosystem are presented below. (Figure 1)

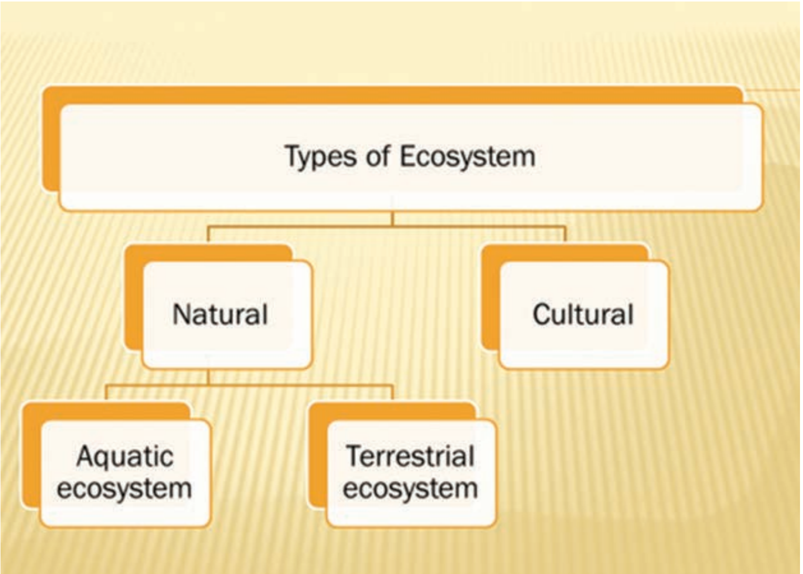

Fig. 1. Types of ecosystem

The marine and coastal ecosystem is coming under the aquatic ecosystem. The coastal ecosystem includes following component like estuaries, salt marshes, rocky/sandy shores, mud-flats, coral reef, mangrove, nesting Grounds/Habitats (Birds, Horse Shoe Crab and Turtle), sea grass, marine parks and sanctuaries, archeological and heritage Sites (Bhatta, 2015).

In general the services provided by the ecosystems include, provisioning, regulatory, supporting and cultural services (MEA, 2005). These services are described for each ecosystems.

Economic valuation of ecosystems

Ecosystem have three distinct characteristics in valuation namely (i) Existence value; (ii) Intrinsic value and (iii) Option value.

Productive use value: It is the value assigned to the products that can be **harvested for exchange in formal market** and is the only value of biological resources that appears in the national income account. Example: Fuel wood, fodder, timber, fish, medicinal plants

Consumptive use value: The value assigned to natural products that are consumed directly *i.e.*, the goods that do not enter normal channels of trade; Example: A variety of Non Timber Forest Products (NTFP)

Intrinsic value: It is the value related primarily with the functions of the ecosystem but sometimes outweigh the consumptive/non-use values like, maintenance of ecological balance, Prevention of soil erosion *etc*.

Types of values

The various types of values that are used in environment and ecological economics parlance are given below (Table 1).

Table 1 Types of values

Value type	Sub type	Example
Use value-Direct	Consumptive Productive	Variety of home consumed forest products Plant breeding
Indirect use value	Non-consumptive	Tourism
Option	Non-consumptive	Ecological process , future values of drugs
Quasi-option	Non-consumptive	Value of being able to ascertain option value
Non-use values	Non-consumptive	Existence value of elephants, turtles

Why economic valuation?

The link between economics and ecology/environment is vital to understand their value. Most of the natural resources that we use have value but not priced and also not traded in the market. eg., Air.

The natural resources (NRS) need valuation because they do not have a regular market for trading, the NRS has various alternatives and alternative uses; there is uncertainty in demand and supply of NRS. The policies for conservation of NRS need to be defined properly and for use in NRS accounting (Kadekodi, 2001). The ultimate out-put namely the green accounting has a significant role to play in the days to come.

Methods for valuing provisional services (Bhatta, 2015)

PROVISIONING SERVICES	METHODOLOGY
Fish	Direct Market Pricing
Fuel wood	Direct Market Pricing
Aquaculture	Direct Market Pricing
Industrial Cooling	Direct Market Pricing
Fresh Water (Desalination Plants)	Direct Market Costs of Production
Ornamental Resources	Direct Market Pricing
Sand Minerals	Direct Market Pricing
Seaweed/Sea-grass Production	Direct Market Pricing
Salt Production	Direct Market Pricing

A case study: Economic valuation of Seasonal Fishing Ban (SFB) on marine ecosystem services

Fishery resources are renewable natural resources but exhaustible if harvested indiscriminately. There are examples wherein certain resources have become extinct due to unsustainable harvest. Hence we have to formulate fishery management policy considering the domestic situations and promote sustainable fishing practices that will not decrease the stock level, but will ensure livelihood security, resource sustainability, economic efficiency and ecosystem integrity.

Seasonal Fishing Ban (SFB) was introduced with the purpose of protecting the spawners during peak spawning season, reducing the fishing effort, giving respite to the sea floor and safety at sea. Since the inception of ban, the marine fisheries sector has undergone immense technological, economic and social changes. However, even after several years of implementation of SFB, there are no specific answers to the following questions: Has the natural capital asset and its value increased? Has the ban improved marine ecosystem services? What is the management cost *vis-a-vis* benefits? How does each maritime state perform? Answers to these questions are needed to arrive at effective management decisions to sustain this sector.

The thematic approach of the present study is to quantify the following potential benefits due to implementation of SFB, which include, increase in catch, which provides high income to fishers; less fuel use and CO_2 emission; impact on biodiversity; and net social benefits.

The Impact of SFB on resource group-wise and sector-wise marine fish landings was assessed for major resources (fish species/ groups) and for different craft types. The craft type (sector) categorization assumes significance as SFB applies to all mechanized boats, which operate trawls and gillnets, but only partially at varying proportions for motorized boats which operate gears like seines. The methodology involved the following two approaches:

(i) Regression approach aims at studying dependence of landings and catch rates (catch per unit craft trip and catch per hour of actual fishing) upon effort (boat trips or actual fishing hours) and an indicator variable signalling the initiation of SFB in respective state.

(ii) The second approach was more general wherein the catch rates were considered a parameter of fishery health/ wealth as well as fisher's success and its compound growth rate in pre SFB and post SFB periods were computed using semi logarithmic model (Power function).

The economic benefit of SFB was assessed by estimating the value of incremental growth attained due to fishing ban. The incremental weight (in tonnes) of each species was multiplied by price/tonne (geometric mean of the last three years at landing centre and retail price level) of respective species and final values were estimated. The impact of SFB on various resource group/species caught including small pelagics, large pelagics, demersal finishes, crustaceans and cephalopods were assessed by their growth rates of catches during pre and post ban period). The annual compound growth rates (ACGR) were estimated for depicting variation in catches/ catch rates over a time period, here pre and post SFB period.

Post fishing ban registered an overall increase in volume of fish catches as well as their species diversity across all states. Stock status also indicates that states with higher level of mechanisation such as Karnataka and Gujarat have higher percentage of exploited stocks that are seriously depleted and require serious attention to rejuvenate stocks compared to states like Andhra Pradesh and Tamil Nadu.The analysis indicated that incremental biomass due to SFB ranged from five to nine per cent in the selected states. This indicated that the SFB has a positive impact on the fish harvest after the ban and need to be recommended for continued implementation as a tool for sustainable marine fisheries management.

The estimated value of the incremental biomass due to SFB ranged from Rs.1,266 lakhs in Andhra Pradesh to Rs.2,809 lakhs in Tamil Nadu at landing centre price level. In Andhra Pradesh, all the resource groups showed a positive trend after the ban while in Tamil Nadu, except crustaceans, all other resource groups exhibited a positive trend after the ban period. The net social benefit was positive in all the States (Kerala-Rs.2,480.86 lakhs, Andhra Pradesh -Rs.1.097.42 lakhs). (Table 3)

Table 3 Incremental economic benefit due to SFB

Parameters	Kerala	Karnataka	Gujarat	Andhra Pradesh	Tamil Nadu
Catch (t) in 45 -60days (if there is no fishing ban)	49,344	35,900	35,523	22,265	67,015
Catch (t) in 45-60 days (if there is fishing ban)	53,785	39,131	38,720	24,046	72,377
Increment in catch during ban period (t)	4,441	3,231	3,197	1,781	5,361
Increment rate (%)	9	9	9	8	8
Value of incremental catch estimated at landing centre price (Rs. in lakhs)*	2,729	1,701	2,129	1,266	2,809
Value of incremental catch estimated at retail market price (Rs. In lakhs)	4,053	3,781	2,897	1,980	4,620

The SFB has led to reduction of carbon emission due to the absence of mechanised and motorized fishing during the period. About 103.6 lakh fishing hours (fishing effort) is reduced due to SFB, which is equivalent to 4.08 lakh tonnes of CO_2 emitted and a savings of 1,565.8 lakh litres of diesel. This indicates that an amount of Rs.82, 988 lakhs is saved (which otherwise would have been spent on diesel) during fishing ban in the year 2014.

The impact of SFB on resource-groups (specie-wise comparison) indicated that across the states, there has been an increase in the post-ban growth rate in the catches of the resource groups. In Andhra Pradesh, all the resource groups showed a positive trend after the ban while in Tamil Nadu, except crustaceans, all the other resource groups exhibited a positive trend after the ban period.

The fishermen in the mechanized sectors were willing to accept an amount for the enforcement of the ban. It varied across the centres and across the duration of ban which was simulated from 30 days to 120 days.

The attitude of the fishermen (motorized and traditional sector) towards willingness to pay (WTP) evinced mixed response in their willingness to pay for the SFB.

The study concluded that the incremental biomass due to SFB ranged from five per cent to nine per cent in the selected states. The SFB has led to reduction of fishing effort and hence carbon emission. There was a positive net social benefit due to SFB. The fishermen in the mechanized sectors were willing to accept an amount for the enforcement of the ban depending on its duration**.**

The relative performance of the seasonal fishing ban varies across the study States and the ranking will be Gujarat, Tamil Nadu, Kerala, Andhra Pradesh and Karnataka in that order.

But it is important to note that the period of ban in Gujarat and Karnataka are different from that of the remaining three states.

The above findings indicate that the SFB is having predominantly a positive impact on the resources and on the fishers who are dependent on the sector for their livelihood. It was also found that, the net social benefit was positive in all the States (In Kerala Rs.2,480.8 lakhs and in Andhra Pradesh Rs.1.097.4 lakhs). It can be concluded that there is substantial positive net social benefit due to enforcement of Seasonal Fishing Ban in the selected States and hence SFB can be recommended to continue.

Implications and Recommendations of this study

SFB has resulted in a positive net social benefit in the study states. This indicated that the enforcement of SFB can be continued in the study states, which will facilitate sustainability of resources as well as an increase in catch and income to the fishers. SFB can also be considered as a measure to reduce carbon emissions. While it is recommended that the SFB may continue in future, considering the complexities of the economic valuation of SFB, it is recommended that the present analysis may be improved in future by taking into account several externalities which have not been included in the present analysis. It is also recommended that the analysis may be extended to other maritime states not considered in this study.

It has been recognized that SFB alone could not be a complete measure to sustain the fisheries. SFB should be considered as one of the tools in a bundle of several input and output management measures, such as ecosystem approach, Marine Protected Area, No-take zone, regulated entry, catch quotas, certification, minimum legal size at capture *etc*. In a combination of several other measures, SFB will become more effective for sustaining marine fisheries. (Narayana Kumar *et al.,* 2015, 2017)

Payment for ecosystem services (PES)

This is an important aspect that needs to be looked into seriously. The PES includes both demand and supply side. This includes identification of potential buyers (users) of the ecosystem and the payment charged. This also requires to undertake social cost benefit analysis. This is one of the important policy instruments in the field of ecosystem valuation which will ultimately lead to green accounting. The Economics of Ecosystem and Biodiversity (TEEB) has undertaken lots of studies in this aspect across major continents.

Conclusion

In this lecture, an attempt is made to give an insight into the structure, functions and economic valuation of ecosystem services. This can be further expanded to study the different components of ecosystems and incorporate into the green accounting frame work.

It is also important to note that Economics helps to put the things in proper perspective to the policy planners by assigning value to the ecological or environmental services or benefits. However not all services can be brought under valuation as this is a subjective concept. The dynamic nature of the system and the related developments should be considered thoroughly before applying any of these methods to formulate practical policy measures**.**

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CHAPTER 42

MARINE MICROBIAL DIVERSITY AND ITS ROLE IN ECOSYSTEM FUNCTIONING

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Seas and oceans cover more than 70% of the Earth's surface, host the majority of its biomass, and contribute significantly to all global cycles of matter and energy. All life on Earth most likely originated from microbes in the sea. Microbes such as Bacteria, Archaea, viruses, fungi and protists (including microalgae), dominate the living biomass. On the tree of life, the Eukarya (including plants, animals and protists) comprise only a tiny branch; Bacteria and Archaea encompass virtually all genetic diversity, notwithstanding their limited morphological diversity. Marine microbes thrive not only in the surface waters of the sea, but also in the lower and abyssal depths from coastal to the offshore regions, and from the general oceanic to the specialized niches like blue waters of coral reefs to black smokers of hot thermal vents at the sea floor. Marine microorganisms occur in vast numbers and represent a huge genetic diversity: ocean water contains up to one million microorganisms per milliliter and several thousand microbial types. These numbers may be an order of magnitude higher in coastal waters with their higher productivity and higher load of organic matter and nutrients.

Marine microorganisms are the key to all biogeochemical cycles and are crucial for the functioning of marine ecosystems. The element carbon which forms the basis of all organic matter undergoes a constant cycle in nature by various heterotrophic bacteria. Nitrogen, a constituent of the protein, is cycled in aquatic environment by several bacteria. Nitrification is an aerobic process, whereas denitrification is the process used by facultative anaerobic bacteria. Microbial oxidation progresses to sulphate, represents the terminal step of mineralization of organic sulphur compounds and serves as a source of sulphur for plants.

Most importantly, marine phototrophic microorganisms (Cyanobacteria, diatoms and pico- and nanophytoplankton) are responsible for more than 80% of the oxygen production on Earth. Marine microorganisms and their activities are, and will continue to be, affected by global change and may also promote or alleviate climate change. Marine microbial communities are an integral part of the ocean and are also responsible for the uptake of a large part of the anthropogenic carbon dioxide from the atmosphere that causes global warming. The biological pump transports CO_2 to the seafloor, a process entirely driven by microbes. The constantly increasing level of atmospheric CO_2 would otherwise result in the acidification of the ocean leading to the dissolution of carbonates, and the change of the carbonate equilibrium. Marine microbial communities through the biological pump and microbial carbon pump sequester CO_2 and helps in the storage of carbon in the deeper oceans, thereby influencing the climate change.

Additionally, they are responsible for the degradation of organic matter in the ocean and are thus the key for maintaining the balance between produced and fixed carbon dioxide. Bacteria play a decisive role in the cycle of matter in water, as they are able to breakdown all natural organic compounds into the components from which they have originated. The heterotrophic bacterial action promotes organic degradation, decomposition and mineralization processes in sediments and in the overlying water, and releases dissolved organic and inorganic substances. The mineralization of organic matter, which is derived from primary producers, results in its being recycled, so that these substances are again available for primary producers. Heterotrophic microorganisms are the major agents shaping the organic composition of the ocean. The bulk of microbial populations are constituted by heterotrophic bacteria inhabiting the oceans which are responsible for much of the biological transformation of organic matter and production of CO_2. Bacteria also serve as an important source of food for a variety of marine organisms.

Society relies on marine microbial communities for its own health as well as for the health of the environment. Marine microbial communities are the source of a large variety of bioactive compounds which may have medical applications and, as such, contribute to human health. Marine microbial communities also provide a variety of services, such as bioremediation of polluted environments

Although microbial diversity is one of the difficult areas of biodiversity research, estimation of microbial diversity is required for understanding the biogeography, community assembly and ecological processes. Recent developments in molecular ecology, metagenomics and ecological modeling illustrate that microbes represent the most important biological group on Earth in terms of phylogenetic and functional diversity. In addition, interdisciplinary research has uncovered new and unexpected roles of microbes in the biogeochemical cycling of carbon, nitrogen, sulphur, iron and many other (trace) elements in our seas and oceans. Study of marine microbial biodiversity is of vital importance to the understanding of the different processes of the ocean. As the microbial communities have a complex ecosystem process, biodiversity study explores the distribution and roles in the habitat. The presentation would cover the marine microbial diversity, discuss the various conventional and modern approaches for better understanding the genetic and functional diversity, and their roles in major elemental cycling in the ocean.

CHAPTER 43

FORMATION MECHANISM OF MUD BANK ALONG THE SOUTHWEST COAST OF INDIA

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Mud bank formation during southwest monsoon along the southwest coast of India remains an enigma to the researchers and coastal community in spite of several earlier studies. The present study attempts to unravel the mystery through a high-frequency, season-long time-series observation at Alappuzha, located at the southern part of the west coast of India, a region of frequent occurrence of mud bank. Using 7-month long weekly time-series observation, we identified strong winds and high waves associated with onset of the southwest monsoon and subsequent three episodic atmospheric low-pressure events (LPEs). With the help of in situ time-series data we showed that the strong winds and high waves associated with southwest monsoon pre-conditions the near shore bottom sediment to bring it into suspension. The high amplitude waves associated with the southwest monsoon, while propagating from the deep water to shallow water region, interacts with the bottom initiating bottom-sediment movement and its suspension due to wave refraction and shoaling. The sporadic occurrence of the atmospheric LPEs enhances the process of suspension of bottom sediment in the near shore region leading to the formation of fluid mud. Simulations with a cohesive sediment transport model yielded realistic estimates of sediment transport, in presence of an onshore current, a pre-requisite for transporting the fluid mud towards the coast. The prevailing onshore upwelling current during southwest monsoon provides the favorable pre-requisite conditions for transporting the fluid mud through depression channel network towards the coast. Once sufficient quantity and thickness of fluid mud is accumulated in the near shore region, it acts as a wave damper for subsequent high monsoon waves, as indicated by the time-series wave data, leading to the formation of tranquil mud bank region. Depression channel network extending from shelf to the coast off Alappuzha, Kochi, Ponnani, Beypore and Ullal were found in the bathymetric charts thus explains why mud bank occur only at few locations in spite of the prevalence of similar monsoon conditions.

CHAPTER

44

MUD BANK BIOLOGY

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Introduction

Mud banks are unique, clearly demarked naturally occurring calm areas which occur mainly in the inshore waters along the Kerala coast during the southwest monsoon period. Formation of mud banks can be either just before the onset of SW monsoon or during the monsoon. Mud banks are popularly known as "*Chakara*" or "*Shanthakara* " (meaning calm area) and fishermen consider mud banks as 'gift of God' since these are safe fishing areas for launching and berthing the fishing crafts when the rest of coastal belt is surf ridden, with high swells and unsuitable for small scale fishing operations.

Though mud banks are known to occur in the region between Kannur and Kollam, the most popular is the Alappuzha mud bank which occurs every year. However, considerable annual variations have been observed on the location of mud banks even along the Alappuzha coast and the extent (area) of mud bank which can range from 10 to 50 sq km. Apart from this, the duration for which one area remains clam as a mud bank has also shown wide variation and this can vary from few days to months.

The cause for formation and dissipation formation of mud banks still remains an unsolved mystery, though several theories have been put forth by researchers including factors like absorption of wave energy near the bottom by thixotrophic drag and subterranean flow from adjoining backwaters or Vembanad Lake. The observations on the ecology of mud banks have shown presence of upwelled water with low levels of dissolved oxygen and low temperatures. The turbidity has been found to be very high and during July August, unique 'mud cones' are formed very close to the shore.

Mud bank Fishery

The productivity has been found to be high with good plankton biomass. Mud banks are considered as good fishing areas. Every year during mud bank season several small scale fishers from neighbouring districts move to Alappuzha district where mud banks are known to form.

During SW monsoon, fishing by mechanized sector comes to standstill primarily due to the ban on trawling implemented by the Government of Kerala for a period of 47 days from June 15th to July 31st every year. Rough weather also hinders fishing to a large extent. However, in the mud bank area seines, gill nets and cast nets are operated. Among these, mini ring seines with 10 to 15m OAL fitted with outboard engine of 25 to 50 hp operate gears which are popularly known as *chooda /disco vala* which are small meshed (8-10mm). Large crafts of 20 to 24m OAL with inboard engines also operate ring seines with 20mm mesh size. Each craft is manned by several fishers, ranging from 12 to 15 in ring seines with out board engine while almost double (30 to 35) the number in inboards ring seine operations.

Gill netters in 7 to 9m OAL with out board engine use slightly larger mesh net (28 to 32mm *chala vala*) and in a single craft 5 to 6 fishers will be involved in fishing. In addition to this, small (2-3m OAL) thermocol non mechanized gill netter (28-32mm *chala vala*) commonly known as *Ponthu vallam* operate in the mud bank area . These operate in very shallow areas within 2 to 20m depth. Fishing in the shallower areas is mainly by the thermocol crafts which are manned by one or two fishers.

Fishery Resources

The Indian oil sardine, *Sardinella longiceps, Stolephorus* spp and shrimps mainly *Fenneropenaeus indicus and Metapenaeus dobsoni,* form the main fishery resources of the mud bank area. Shoals of sardine and anchovies are sighted very near to the coast and these two resources together contribute more than 50 to 60% of the catch. *Penaeus monodon, Metapenaeus affinis, Parapenaeopsis stylifera. Rastrelliger kanagurta, Secutor insidiator, Thryssa mystax, Esculosa thoracata, Otolithes ruber,* A*nodontostoma chacunda, Dussumieria acuta. Opisthopterus tardoore, Leiognathus* spp, *Pellona* sp and *Johniops* spp are other main resources which occur in the fishery during the mud bank season. The catch of these resources range from few kilograms to about 50 tonnes per season. Apart from these, about 50 other resources occur in negligible quantities in the fishery. Mud bank fishery is also observed in Ernakulam, Thrissur and Malappuram districts of Kerala and the same resources are seen in these mud banks also. However, formation of mud banks is not common in these districts.

Mud banks are not major feeding or breeding grounds of the finfish and shellfish resources. Wide fluctuations have been observed in the mud bank fishery. The dominant fishery resource on each day of the mud bank has shown wide variation in the past and the same trend continues now also. If sardine shoals are observed one day, the following day it may be anchovy shoal or there may not be any shoal at all. Very high variability has been observed indicating that these are shoals are moving and they accidently reach the mud bank area. Shoals of sardine and anchovies are sighted in the non mud bank areas also and most often the non mud bank areas are more productive with higher catch rates than mud bank areas.

During a targeted study on mud banks conducted by CMFRI during 1966 to 1975, it was observed that the catch from the mud bank area of Alappuzha was higher than the non mud bank area from 1966 to 1970 and was considerably lower than the non mud bank area during 1971-72 and 1974-75 (CMFRI Bulletin 31, 1984). The average catch during the monsoon season (June-August) during the period 1966 to 75 was estimated at 2868 tonnes. In 2012, the catch for same season was estimated at 5240 tonnes from Alappuzha district (MFIS, 217; 2013). The increase in landing can be attributed to the increased effort and gear efficiency.

The landing centres adjacent to mud banks are the main markets during monsoon. These landing centres are used by merchants to auction and market the catch fished from the mud bank and non mud bank areas also, hence it is difficult to estimate catch from mud bank areas separately. Experimental fishing by CMFRI in mud bank (MB) and non mud areas (NMB) in 2014 have shown that mud banks are not special fishing areas. Usually more fishes are in the adjacent non mud bank areas.

In recent years, fishermen communicate to the merchants through mobile phones as soon as the catch is hauled and the catches are landed in mud bank areas where berthing the fishing craft is easy. Several fishery related ancillary small trade units like the ice plants in the village and other temporary units including tea stalls are set up in beaches where mud banks usually form and the coastal villages of Alappuzha become festive during mud bank. More than 8000 fishermen are actively involved in fishing in mud bank area. Mud banks play a significant role in improving coastal village economy and many villagers clear off their debts during this period. The Government of Kerala has protected the country crafts and provided permission to fish during the monsoon.

Targeted study on the trophic links in the mud bank area

Experimental trawling mud bank (6m depth) and non mud bank area (6m and 12 m depth)-RV Silver Pompano was conducted during 2014 from April to October. The catch obtained were analysed and species wise contribution of fish, shellfish and other invertebrates in each haul were studied. The feeding and reproductive biology of these resources were investigated and the trophic levels identified. Apart from this the occurrence of sea birds and their links with the major fishery resources identified. Biological details of the major resources landed during 2013 and 2014 were also analysed.

Primary and secondary productivities

Analysis of phytoplankton of the 3 sites mud bank and non mud bank indicated very high densities of diatoms like *Fragilaria, Skeletonem, Melosira, Biddulphia. Chaetoceros* and other groups. In one sampling, even shrimp guts were found to have *Fragilaria* spp. which was in full bloom. Zooplankton biomass was also high with dominance by copepods, Lucifer, bivalve larvae, *etc*. The benthic community was dominated by bivalves in the beginning.

Twelve trophic groups were identified based on diet, size and habitat preference (Fig 1). Among these the community was dominated by small pelagic omnivores (eg. anchovies, mackerel), small benthic omnivore (eg. shrimps, crabs etc) and small pelagic herbivore (oil sardine)(Fig 2).

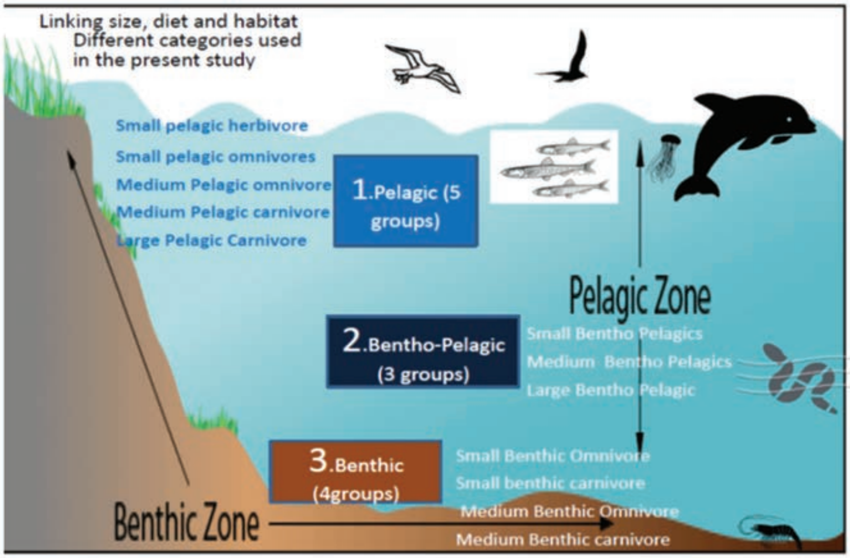

Fig. 1. Schematic diagram of the trophic structure of mud bank of Alapuzha

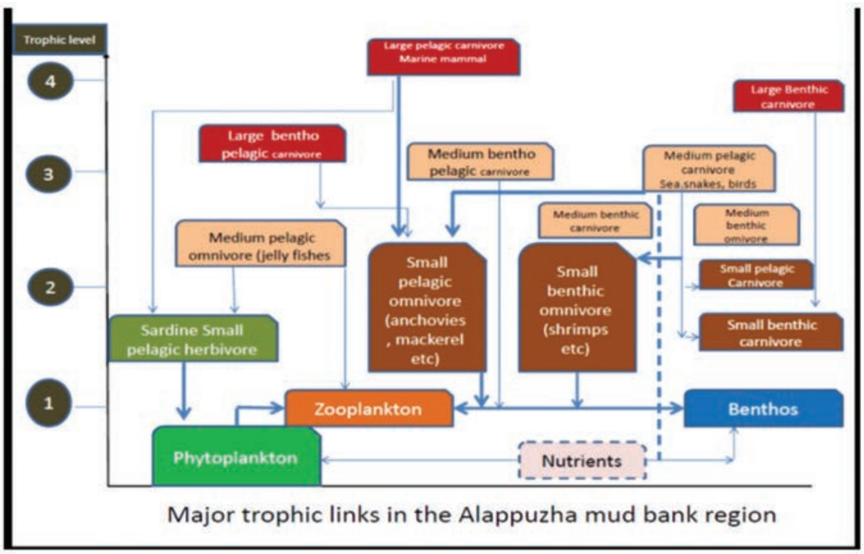

Fig. 2. Major trophic links in the mud bank of Alapuzha.
The size of the box indicates relative abundance

Anchovies, mackerel and sardines were found to be in actively feeding state, indicating the rich plankton in the MB and NMB area which supports the high biomass of these resources. Very strong similarity between gut contents and plankton & benthos. Other trophic groups found to feed on these resources (eg Ribbon fishes, Indo-Pacific humpback dolphin *etc*).

The large biomass of **shrimps i**n the upper column water masses indicates disturbance in the bottom, mainly due to cold and low oxygen upwelled water. Their half filled stomach indicated active feeding. The shoals of all the three groups were found beyond the calm area. **Beaked sea snake** *Enhydrina schistosa* (Daudin, 1803) was caught in the experimental hauls. It was observed that in the snakes caught at 6 m depth the main food item was cat fishes while the stomach of snakes caught at 12 m depth had more puffer fishes.

The teleost ***Trypauchan vagina*** was present just before the formation of mud bank and was present throughout the mud bank period. This species lives in a self made burrow and when the bottom is disturbed, it comes up and gets caught in the fishing gears. Not only mud bank, any region which is disturbed either by low oxygen, churning , low temperature or any other abiotic or biotic stress would make it rise to the column waters. Presence of *Trypauchan vagina* which is called chakara mani just before the onset of mud bank and all through the mud bank period indicates disturbance in the bottom. This species can be considered as an indicator of upwelling /mud bank.

Flocking of sea birds (migratory) especially terns and gulls for foraging on anchovies, sardines and shrimps was observed all along Ernakulam-Alappuzha area and their role in nutrient enrichment was also observed.

Conclusion

The targeted study on mud banks of Kerala indicated that though mud banks are physically different from the adjoining areas by their calmness, biologically they are comparable. The resources found within the mud bank and outside were similar and the main reason for the high catch of shrimps was the disturbance due to low oxygen condition at the bottom. Active feeding by small pelagic and bentho-pelagic fishes indicated that the rich plankton and benthos support these groups. Their presence in the inshore waters supports good fishery.

CHAPTER 45

MUD BANKS FISHERY ESTIMATES

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Introduction

Most of the natural processes are common to all coastlines and their physico-chemical characteristics are quite well known. But, there are some localised and seasonal process, have significant role in socio-economic benefit of coastal habitant and require continuous study to understand for sustainable exploration. Mud banks are such an inquisitive coastal phenomenon which occurs only at a few locations in the nearshore waters of the world ocean. Muddy shores and adjacent shore faces are found along several open coasts of the world including south west coast of India. They are generally associated with the dispersal pathways of rivers that discharge large quantities of fine-grained sediment. The high mud supply also has considerable coastal ecological and economic impacts on several coastal countries. In the world, the mud bank formation has been identified at the area between Cabo Cassipore and Cabo Orange (Capes region), between the mouths of the Amazon and the Orinoco: Brazil, French Guiana, Surinam, Guyana and Venezuela and Kerala coast under the influence of rivers and surface oceanic circulation. These mud bank may show the migration at nearby region. The longest of these muddy coasts, however, is the 1500 km long stretch between the mouths of the Amazon and the Orinoco Rivers in north-eastern South America, which is strongly impacted by the mud supply from the Amazon. Mud banks constitute the overarching control on the morph-dynamics and the ecosystems of the coastal area.

Mud Banks at Kerala

Mud banks of Kerala can be defined as those areas of the sea adjoining the coast, which have a special property of dampening the waves resulting in clearly demarcated areas of calm water even during the roughest monsoon conditions of the sea. These areas become distinct from the other areas which may have a muddy bottom, and the tranquillity is caused as a result of dissipation of wave energy in the large quantity of mud kept in suspension. Mud banks are seen within a water depth of 15 m, often in a semi-circular shape with a radius ranging from 4 to 8 km. Due to the prevalence of calm waters within the mud bank during south west monsoon, which is a period of very high wind and wave activity, fishermen use this region for launching and landing of small boats for fishing activities and large numbers of canoes are brought to the mud bank areas, even from far off places.

The fisheries sector is a vital component in Kerala's economy. It is an important source of food and cheaper animal protein, besides a major root of avenue generation through providing employment for coastal populations. The fish consumption of Kerala is four times than that of the national average. But, the south west monsoon period is generally an off-season for the fisher folk on the west coast of India due to seasonal closure of mechanized fishing and also fishermen do not have courage to take risk of fishing venture in very high rough of sea condition. In this period, the calm areas created by the mud banks to attract fishermen from far and wide.

'Mud bank fishery' is very popular among the fishermen as 'Chakara'. Though mud banks are reported at several places along the Kerala coast, the most prominent and persistent one occurs at Alappuzha. The formation of mud bank plays a major role in moulding the social and economic set up of the coastal people of that region by providing a stable fishing ground during the monsoon season. Mud banks have scientific and societal attention from time immemorial, predominantly due to the large fisheries associated with them. Mud banks, as they appear and disappear in the sea, have been considered as unique formations and seem to occur nowhere else except along the Kerala coast. Therefore, the existence of mud banks along Kerala coast is known as God's gift for Kerala fishermen.

Types of Mud Banks

There are some following types of the mud bank:

1. Active mud banks - This is area where the waves are dampened by the special property of the mud bank along its periphery during the south west monsoon and calm water demarcated within the mud bank.
2. Passive mud banks – These are the same areas at a time when the characteristics in the region are similar to those of other areas.
3. Persistent mud banks – Persistent mud banks are those mud banks which become active every year during the south west monsoon or whenever there is strong wave action. These mud banks are not permanent at a particular place. When active they can shift from one inshore region to another, but maintain their form. Hence the word persistent indicates their recurrence year after in a particular area.

Hypothesis

Various hypotheses have been postulated for explaining the formation of mud banks along the Kerala coast, which can be broadly, classified into two, (I) Local water-column dynamics in the near shore region and (II) Remotely mediated processes such as subterranean flow of mud and fresh water from hinterlands or adjacent lagoons.

There are four hypothesis under the former classification, which are;

1) Formation of fluid mud due to upwelling and Ekman divergence
2) Suspended sediment transport under littoral current and rip current system
3) Wave-induced oscillation and wave dampening and
4) Infra-gravity waves interacting with undertow and reflections from shore leading to mud suspension.

Similarly, there are five hypothesis under the remotely-mediated processes. The central premise of the remotely mediated process hypothesis is the fresh water from either the adjacent lagoon or from hinterland through underground facilitates mud suspension in the mud bank region. There are following hypothesis;

1) Passage for soft mud from rivers and backwater during monsoon through subterranean channels as evidenced by the mud cones observed in the beaches of Alappuzha
2) Water-bearing subsurface strata churning up mud within the region of mud bank
3) Seepage of methane gas, produced by marsh deposit, due to injection of fresh water from lagoon following heavy monsoonal rain or due to the pressure fluctuations of the short-period storm waves associated with the monsoon
4) Existence of submerged trending faults from Achankovil shear zone to Alappuzha
5) A combination of subterranean fresh water flow from the adjacent Vembanad Lake through the shallow trending faults over the lime shell bed during summer monsoon.

Fishery

Mud bank fishery can be observed at various localized coastal area of Kerala. For example, During the period of 25th to 30th June, 2012, mud bank fishery was observed in Thrissur District. During the six days of mud bank fishery, the landings of the district concentrated only at five centres, namely Puthan Kadapuram, Blangad, Chettuva, Kaipamangalam (Companykadavu) and Perijanam (Bhajanamadam). The phenomenon was first noticed along the west coast, off Chettuva and Kaipamangalam, mostly in 5 to 16 m depth range. Very low fish catch may be seen at nearby landing centre prior to the formation of mud bank, but a sudden increase may be observed in catch after onset of mud bank. Fishing at the mud bank area is done normally from the early hours of the day till noon. On heavy fishing days, fishing may be observed to continue till late in the afternoon.

Crafts and gears

Fishing by mechanised trawlers is prohibited at the mud bank and nearby areas. Ring seiners, motorised mini trawlers and non-motorised crafts are operated at mud bank region. Motorised wooden mini trawlers with either double or single outboard motor, each boat having 9.9 hp power are also employed for fishing. Dugout canoes and rigged canoes called locally as 'Vallam' or 'Vanchi' are the crafts used as non-motorised crafts in fishing operations. Mainly two lengths of canoes are operated in the mud bank areas, a larger one of 9.5 m manned by 15 persons and a smaller one of 6 m manned by 9 persons. The main gears of operation at the mud bank regions are ring seine (Choodavala and Thanguvala) and gill nets. Since mini trawl is operated with two attached crafts, it was locally known as double net.

Catch compositions

Mud banks fisheries are often rich in penaeid prawns, oil sardine, mackerel, Stolephorous and various other soles. Around fifty species of fish and six species of prawns have been identified from the mud bank areas. The different species may land from mud bank area include Oil Sardine - *Sardinella longiceps,* Croaker- *Otolithes cuivre*, Malabar Anchovy -*Thryssa malabarica*, Mustached anchovy - *Thryssa mystax*, Flower shrimp- *Metapenaeus dobsoni*, Hilsa Shad -*Tenualosa ilisha*, Indian White Prawn - *Fenneropenaeus indicus*, Silver bellies species, Indian Anchovy -*Stolephorus commersoni,* White sardine- *Escualosa thoracata*. Indian Mackerel - *Rastrelliger and* Bigjawed jumper- *Lactarius lactarius*. The pattern of fish distribution in the mud banks has been observed to change very frequently even ranging from day to seasonal. Catch was dominated by shrimps including in the landings *Penaeus indicus*, *Metapenaeus dobsoni, Parapenaeopsis stylifera, Metapenaeus monoceros* and *M. affinis*. Fishes belonging to the families Carcharinidae, Clupeidae, Dussumieridae, Dorosomidae, Engraulidae, Chirocentridae, Tachysuridae, Hemiramphidae, Sphyraenidae, Mugilidae, Polynemidae, Ambassidae, Theraponidae. Sillaginidae, Lactaridae, Siganidae, Carangidae, Gerridae, Leiognathidae, Pomadasydae, Sciaenidae, Trichiuridae. Scomberomoridae, Stromateidae, Cynoglossidae, Chirocentridae and Drepanidae may be encountered in mud bank fishery.

Socio-economics

Majority of the fishermen who used to engage in fishing at the mud bank area are not permanent dwellers of this region; but have come from far off places for the sake of fishing during monsoon season and stay with their relatives, friends or in rented apartments or on the beach itself. For an instant, if mud bank forms near chethua, many fishers from nearby fishing villages such as Kalamukku (Ernakulam district); Chettuva, Azhikode and Thalikulam

(Thrissur district) and Ponnani (Malappuram district) to temporarily migrate to these fishing grounds during the period. They come with own or hired crafts and gears. The fisher folk who assemble at the mud banks are not a homogenous group. They belong to various castes and religions and speak different languages, but they all live in perfect harmony. Mud bank formation commensurate with the fishing holidays or closed season in fisheries in Kerala. The fishermen who are devoid of fishing activities finds this as an opportunity to gain the sole income during this particular period. Revenues depend on species and quantities caught and prices obtained, which again depend on marketing channels and markets, seasonal fluctuations and other factors. For example, a huge landing of *Stolephorus* sp. may lead to steep fall in prices.

General considerations

The monsoon fishery along the coast of Kerala in calm area by traditional and motorized craft is often called as mud bank fishery. There is a common belief that mud bank and fishery are interrelated *i.e.,* a good mud bank means a good fishery to the public. The fishermen believe that a good mud bank formation will provide them a good catch. In fact, it has been found that the mud bank and the fishery are independent. Similarly, there have been cases of heavy catch from the coastal waters even when there was no mud bank formation.

Estimation of catch

Even though, mud banks appear at localized area for a certain period, but the information about its appearance spreads very fast among fishermen. The appearance of mud bank able to harbourage a large number of fishing crafts, resulted a large quantity of marine fishes are landed even in lean fishing season. Therefore, estimation of fish catch from mud bank area is essential. The harvested fish catch from mud banks region may land either at regular landing centre or at other place according convenience landing and marketing facilities. Thus, the monitoring and data collection of marine fish catch during mud bank is done by the field staff of the Fishery Resources Assessment Division, CMFRI. The survey duty for field staffs is assigned to these centres to collect the details of the catch and effort for mud bank fisheries. They record the information about craft and gear combinations, species caught, quantity, price, duration of fishing, *etc*. as well as the period of the mud bank in that particular centre. The survey can be repeated in the same landing centre depending on the intensity and the duration of mud bank fishery. As the appeared mud bank may shift to another nearby region, the survey field staffs may also shifted accordingly to collect the catch details. After the mud bank ceases, the collected data is entered in computer and estimated separately for each centre of mud bank fishery.

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CHAPTER

46

IDENTIFYING MESOSCALE EDDIES-RELEVANCE TO MUD BANKS AND FISHERY

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Mud bank fisheries - an introduction

The most popular fishing area during mud bank formation in Kerala is off Punnapra coast in Alapuzha district. This place is equipped with unique crafts such as one-man operated expanded polystyrene thermocol made gill netters, and several other traditional crafts. The fishermen community along this coast is vigilant against any mechanized fishing during mud bank period which falls in the southwest monsoon months when there is a ban on mechanized crafts. There are comparable datasets, from mud bank vis-à-vis non mud bank in this region, which indicate that, the catch per unit effort (CPUE) do not vary significantly. Fishing in Thrissur and Malappuram districts are not restricted by the formation of mud banks. In these districts modified outboard crafts such as pair trawlers operating double net and the high horse power of the out board engines are generally on a look out for non-mud bank resources also. In Malappuram district, the occurrence of the mud bank fishery is for limited days and generally less reported. Therefore, the analysis of data sets indicated better production and CPUE from non-mud banks in Malappuram. In general we can say that there is no significant increase in abundance of fishes reported from the mud bank regions. But the calm waters generated at certain pockets of the otherwise disturbed coastal waters act as areas for seasonal landings of fish.

The pattern of occurrences of different fish species during the mud bank season is also associated with the physical formations. A highly benthic fish *Trypauchen vagina* which is not a commercial fishery is considered as an indicator of mud bank formation. The possible triggering for the upward movement of this benthic fish is due to the physical presence of anoxic or low oxygenated waters associated with upwelling which is setting along with the physical formation of mud banks. There is a progressive succession of other benthic crustaceans such as *Metapenaeus dobsoni* of higher size popularly known as 'Poovalan Chemmeen' and *Fenneropenaeus indicus,* Indian white shrimp. During certain years there are notable landings of Indian oil sardines in the mud bank which are the dominant pelagic fishes in these regions. But during sardine deficient years, mackerel, lesser sardines and anchovies tend to dominate in the pelagic fishery of mud banks.

Table: Fishing pattern and catch per unit effort (kg/hr) in mud bank and non-mud bank regions in Kerala

District	Year	Mechanized		Non-motorized		Motorized		p-value
		MB	NMB	MB	NMB	MB	NMB	
Alappuzha	2013	0.00	633.48	10.15	13.43	269.18	208.09	0.267
	2014	0.00	924.32	18.20	17.37	364.05	163.27	
	2015	777.03	460.75	23.74	16.33	329.66	121.61	
Thrissur	2013	948.57	2094.54	163.42	12.85	218.58	64.24	0.77
	2014	1090.91	1204.93	29.35	8.17	207.14	26.46	
	2015	493.10	1904.58	22.63	13.43	148.60	32.63	
Malappuram	2013	1874.65	1526.33	0.00	10.24	385.60	43.58	0
	2014	1814.81	716.16	0.00	18.86	222.82	34.41	
	2015	1083.53	1116.15	9.81	21.12	258.73	34.83	
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	2014	0.00	924.32	18.20	17.37	364.05	163.27	
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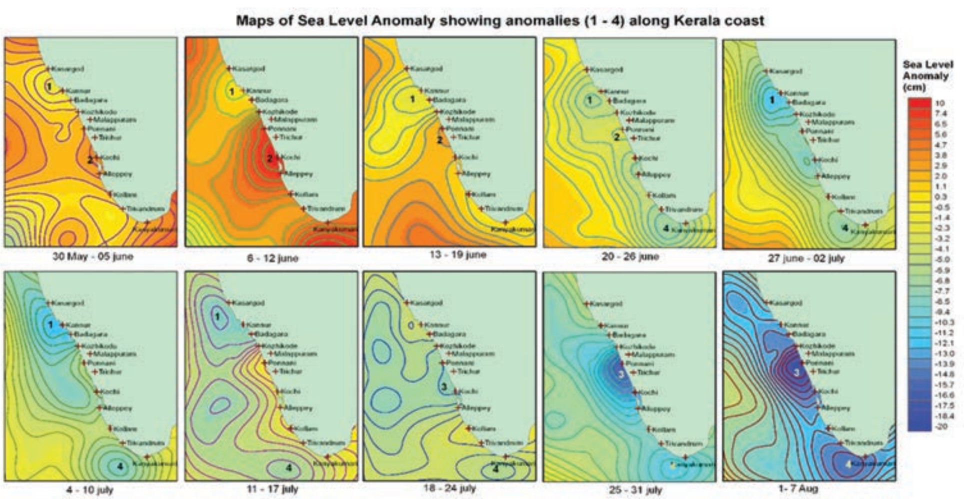
	2015	493.10	1904.58	22.63	13.43	148.60	32.63	
Malappuram	2013	1874.65	1526.33	0.00	10.24	385.60	43.58	0
	2014	1814.81	716.16	0.00	18.86	222.82	34.41	
	2015	1083.53	1116.15	9.81	21.12	258.73	34.83	



Map 1. Map showing the sea level anomaly along Kerala coast

The mean sea level anomaly was slightly positive along Malappuram coast of Kerala before second week of June in 2013. During second of June, the mean sea level anomaly started to become negative (fall) at Malappuram, while same was positive in southern coast. The intensity of fall in sea level further increased in third week of July and at same time drop in sea level anomaly appeared at Thrissur, Alappuzha and Kanyakumari. The appeared fall in sea level was further intensified at these coasts and reached a peak during the first week of August (Map 1).

Coastal eddy forms in Malappuram Thrissur, Alappuzha and Kanyakumari coast during southwest monsoon. Coastal eddies pumping nutrients and biogenic material from deep to shallow waters, whereby generate large productivity in the centre of upwelling cyclonic eddies and at the periphery of convergent anticyclonic eddies (Oschlies and Garcon, 1998; Mordasova *et al.*, 2002, Kahru *et al.*, 2007 and Waite *et al.,* 2007). The change in the West Indian coastal current (WICC) is associated with the change in season. By early January, positive anomalies of sea level spread offshore and northward along the west coast of India and by April, positive anomalies in the sea level are seen all over the Arabian Sea. But the sea level anomalies become low during south-west monsoon (Shetye, 1998), which was observed in current study, the mean sea level anomaly was slightly positive along Malappuram coast of Kerala before second week of June in 2013, while sea level anomalies drops in second week of June at Malappuram coast. Similar result was observed in south west coast of India by (Shetye, 1998). Negative Sea Surface Height Anomalies (SSHA) associated to a negative Indian Ocean Dipole phase induce a shift in the intensity and position of the tropical eddies (Palastanga *et al.,* 2006), which support our result where last week of May, coastal eddy started at Malappuram region. Further, the oceanographic feature might have changed comparatively in southern coast of Kerala and favoured the development of coastal eddy at Thrissur, Alappuzha and Vizhinjam region. The chlorophyll-a concentration in seawater is increased during upwelling, associated with negative mean sea level anomalies, while positive sea level anomalies create down welling in the sea (Kahru *et al.*, 2007). Coastal eddy enhances biological production in the ocean by increasing the net upward flux of limiting nutrients. Here, we examine temporal and spatial relationship between satellite-derived eddy appearance and sea surface anomalies.Temperature inversion takes place 30-50 metres depth due to the eddy (Beena *et al.*, 2005), which might favour the several poikilothermic fish species in the eddy region. We have examined that fishermen are involved in fishing up to 40 m depth by comparatively high inboard seine netter, where there was no significance difference in the catch per unit effort between mud bank and non-mud bank region at Alappuzha and Thrissur. Mud banks are seen within the depth 15 m (Muraleedharan *et al.,* 2017), provide a favourable and calmness water condition even roughest monsoon season for traditional fishermen. Thus, our result show that the appearance of eddy improves the productivity rather than only the mud has the role in enhancement of fish biomass. We examine that mud bank is dominated by small pelagic resources such as *Sardinella longiceps*, Anchovy, other clupeids, sciaenid, carangid and *Rastrelliger kanagurta*, which are planktivorous fish and directly associated with primary productivity in the eddy occurrence zone (Cury *et al*., 2000). The high biomass of *M. dobsoni* in the mud bank area might be linked with high load of detritus organic material in the mud bank where sunlight penetration is less (Reghunathan *et al*., 1981). The mud deposition focus on physical and geological aspects of the process rather than on biodiversity (Mont'Alverne *et al*., 2012). This is supported by our result that there are no statistically significant (p values > 0.05) in CPUE of mud bank is same as CPUE of non-bank for Alleppey and Thrissur districts. However, large number of different types of non-mechanized and motorized crafts are engaged in mud bank area due to calmness of surface in mud bank region.

A localized eddy started to appear in last week of May along the coast of Malappuram, before the monsoon strike in India at first time at Kerala. But by the entering of monsoon in Kerala, the expansion of eddy at pre-existed area is taken place and at the same time the formation of eddy is taken place on different possible zone such as near Thrissur, Alappuzha and Vizhinjam. By the starting of monsoon, a huge river discharge brings the mud through the coastal region of Kerala coast, but appear at northern coast due to the demarcation in coastal topography. Therefore, southern part of Kerala does not show the appearance of mud bank even though there is an existing negative sea level anomaly and eddy during the south west monsoon. Muddy/sandy bottom of northern part of Kerala support to form calm sea surface, which provide the stability of fishing craft in monsoon season, but the primary productivity might be enhanced by localized appearance of eddy and negative level anomalies with huge nutrient rich river discharge rather than only mud bank formation in the area.

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CHAPTER

47

PERUVIAN ANCHOVY FISHERY: FACTORS AFFECTING THE RESOURCE

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Introduction

The Peruvian anchovy fishery is constituted by the species *Engraulis ringens* (Engraulididae: Clupeiformes) and is locally known as 'anchoveta peruvana'. The species distribution extends from northern Peru to central Chile (5^{O}S – 25^{O}S. Lat.) along the west coast of South American. A marine coastal species distributed within 30 km off the coast. These fishes are seen in huge shoals mainly in surface waters and during day time may descend down to 50 m.

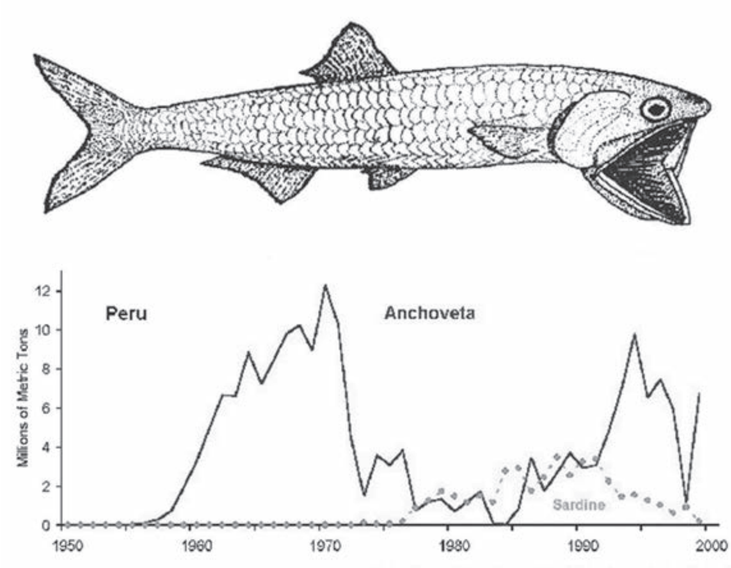
Bionomics

The anchovy is a very efficient filter feeder. The early larvae (apterolarvae) consume phytoplankton, late larvae (pterolarvae) and juveniles mainly feed on small zooplankton. The adults are entirely phytophagous, more than 90% of the diet

consisting of diatoms. The species breeds throughout the year along the Peru coast with two peaks. The first peak is shown during the southern summer in January -February and the major one during late winter in August– September. The absolute fecundity ranges from 10,000 to 20,000 for the fish length range of 10 to 15 cm. The longevity is three years and the growth potential is around 20 cm. The growth is 8.0 cm Standard Length in six months, 10.5 cm SL in 12 months and 12.0 cm SL in 18 months. The interesting aspect is that the fish is recruited to the fishery at around 8.0 cm SL from the sixth month onwards. Three fishery stocks are identified, one off Peru and two off Chile. The Peru stock is the most productive.

Hydrography

The southeast Pacific FAO fishing region constitutes the west coast of South America along the coasts of Ecuador, Columbia, Peru and Chile. Off the coasts of Peru and northern Chile lies one of the richest marine environments on earth – the Peruvian upwelling region – a typical west coast upwelling zone. This is the region of the cold Peru or Humboldt Current. The Peru Current carries cool, nutrient rich waters to the north. The upwelling caused by the offshore drift of the surface waters (due to the trade winds and the Coriolis force) brings the cool (10 – 22^{O}C) nutrient rich waters of the Peru Current to the surface. These waters are rich in phosphates and nitrates. This is the cause of an enormous growth



of phytoplankton (up to more than 500 mg C/m^2/day) and subsequent zooplankton growth. This area supports huge populations of small cool-water pelagics like the Peruvian anchovy and the South American pilchard (*Sardinops sagax*). From December to February, the warm tropical water shifts southwards along the coasts of Ecuador and Columbia and extends in a small strip, along the coast of Peru (El Viejo). In certain abnormal years the water that is upwelled is much warmer and hence low in nutrients due to heavy warm-water incursion. As a result there is a sharp reduction in the primary production and plankton biomass. This phenomenon of unusually strong warm-water incursion is known as El-Nino (the boy child – Christ child as the phenomenon occurs during Christmas time). More recently it has come to be referred to as the El Nino Southern Oscillation (ENSO) event. Hence the inter-annual productivity varies greatly and with this the catches of the small pelagic resources namely the Peruvian anchovy. Also these fishes migrate southwards and to the deeper waters during ENSO times.

Fishery

The sediment core studies have shown that the Peruvian anchovy dominated the Central Peru coasts for more than 2000 years. From 1840s the major industry along the Peru coast has been the mining of bird droppings – 'Guano' from the rocky islands, for use as fertiliser. Large populations of the fish eating guano birds like cormorants (*Phalacrocorax bougaivilli*), boobies (*Sula variegata*) and pelicans (*Pelicanus thagus*) are characteristic of the upwelling zones. Nearly 20 - 30 million birds have been estimated to roost along the 'Bird Islands' of Peru and Chile coasts before the start of the fishing industry.

After the Second World War a small Peruvian anchovy fishery started, mainly for export as canned fish. The high oil content and hence less palatability coupled with the huge demand for an alternate cheap protein source (fish-meal) for the giant poultry and pig industry of the developed world kick-started a highly successful anchovy fishery. In 1949, seven fish meal plants started in Peru. The fish landings increased to an average of 1.0 million tonnes (m t) per year during 1955 – 1959. Anchovy trawlers and purse-seiners locally known as 'Bolicheras' are the crafts used for the fishery. From around 100 vessels and 30 fish-meal plants in 1954-'55, the industry grew to around 2000 vessels and 175 plants in 1968-69. This was the boom period for the now 'Industrial Fishery'. The fishery peaked at 13.0 m t in 1970. Many scientists unofficially peg the landings at 15.0 m t in 1970. Southeast Pacific area ranked first among the Pacific fishing areas. The total biomass was estimated to be 23.0 m t in 1970 and around 9.0 to14.0 m t in 1971.

The climate-dependent dynamics of Peruvian anchovy is affected by strong El-Nino events. The 1972-73 ENSO event led to the drastic decrease in the anchovy landings. The catches dropped to around 2.0 – 4.0 m t. After the 1975-76 event, the landings further decreased to 1.0 – 2.0 m t. The landings further crashed to 1.0 m t after the 1977-78 event. The 1982-83 ENSO, the severest of them all led to an all time low of 0.5 – 0.1 m t catches in 1983 and 1984 with a total biomass of less than a million tons. The environmental conditions stabilised after this. Thus after a protracted period (1974 to 1985) of highly fluctuating low landings the fishery started to recover. In 1986 it exploded back to 5.0 m t. The fishery fluctuated between 2.0 to 5.0 m t till it reached a peak in 1994 (12.0 m t). The strong ENSO event of 1996-97 led to a collapse in 1998 (1.8 m t), the fishery coming back strongly the next year with a catch of 8.7 mt, the year-class strength being independent of the parental population.

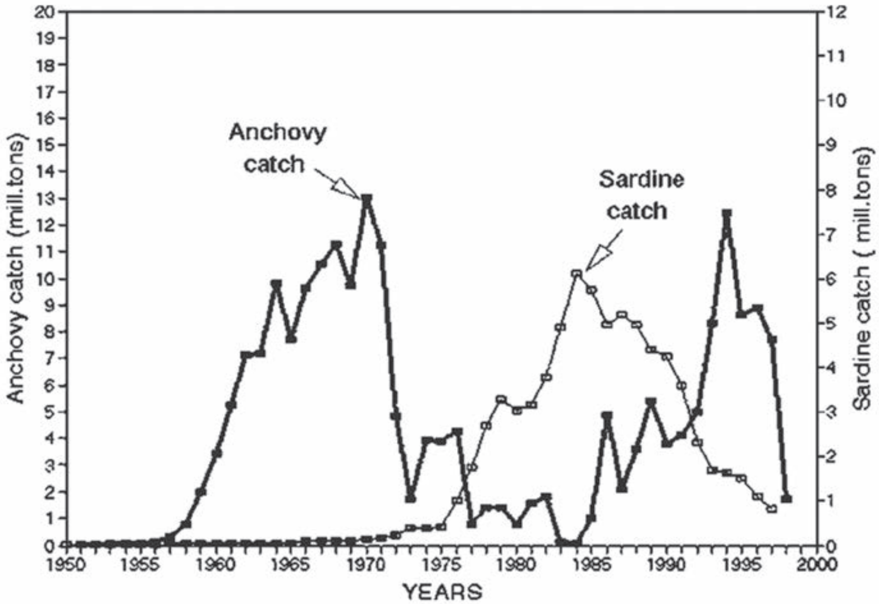
Factors affecting the resource

The question was whether it was over fishing or environmental changes or a combination of both which led to the repeated collapse of the anchovy fishery.

Environmental conditions

Drastic reduction in primary production and plankton biomass due to the El Nino events had a major impact on the biology of the Peruvian anchovy. The following causes are attributed:

a) Larvae fail to survive and get recruited to the fishery due to lack of phytoplankton food. The resultant drop in catches is felt immediately because the anchovies are recruited when six months old.



b) The adults could have starved to death for lack of diatom blooms. The interesting feature of the 1975-76 ENSO was the bloom of *Gymnodinium splendens* leading to unfavourable food conditions and adult mortality.

c) The anchovy is a cool water species concentrated in the low temperature zones (16 - 18^{O} C) of the Peruvian upwelling area. During the ENSO years the shoals remain in the cool pockets within the upwelling zone. The temperatures may go up to 28 – 29^{O} C. When these cool pockets are over- ridden by the warm waters as in the 1982 – 83 ENSO, the fishes die *en masse*. The other alternative is for the shoals to migrate to cooler deeper waters (below 100 m) or to the southern Peruvian or Chilean coasts. In the deeper waters the low productivity will not sustain such huge populations leading to mass mortality. In the southern waters the established South American pilchard populations heavily compete with migrating anchovies again leading to large scale mortality.

Overfishing

Vulnerability to these harsh environmental conditions may have been enhanced by the heavy fishing pressure of the late 1960s up to 1970. In fact studies have shown that even before the impact of 1972-73 ENSO, there was a recruitment collapse in the stocks, the total biomass estimated to be 9 – 14 m t in 1971. In 1966 the Maximum Sustainable Yield (MSY) was estimated to be 8.0 m t, which was revised as 9.5 m t in 1970.

Predation and Competition

Another interesting aspect is the heavy predation on the anchovy populations by the guano birds. Nearly 80–95% of their diet consists of the anchovies. So the huge bird populations (estimates as high as 30 million) before the industrial fishery has now dwindled to as low as 5 million, mainly due to the fluctuations in the anchovy populations. Another major predator is the Chilean jack mackerel (*Trachurus murphyi*), whose population increases during the El-Nino years due to enhanced spawning success. During El Nino years other predators like the yellowfin tuna, dolphinfish and Chilean bonito migrate southward to the anchovy domain. So the trophic dynamics is greatly affected by these events. Competition with the South American pilchard especially when the anchovies migrate southwards is another major factor. The pilchard populations are not much affected by the El-Nino. The inverse relationship between the two tandem fisheries can be clearly seen in the figure. After the 1972-73 ENSO, the pilchard stock began to increase and an important fishery developed over the next 15 years coinciding with the decline and rebuild of the anchovy fishery.

Management

In 1963, the Instituto del Mar del Peru (IMARPE) was established with a strong FAO backing to study the fishery and to advise the Government. In 1965 a five-day week fishing was established. In 1966 three months of closed season (veda) was put in place during January to March. Catch quotas were fixed as per the MSY levels (8.0 – 9.5 m t). So a second closed season was envisaged after around six months fishing when the quota would be taken. But many of these measures were hard to implement. It is now estimated that only less than 1500 vessels are required to catch around 10 m t of anchovies.

The Peruvian anchovy fishery is one example to understand how the climate and environment influence the fisheries. Another interesting parallel is the story of a warm-water species (*Sardinops melanosticta* – Japanese pilchard) and the impact of cool-water incursion into its domain in the Northwest Pacific fishing area.

CHAPTER

48

FISHERIES IN ATOLLS- TRADEOFFS BETWEEN HARVEST AND CONSERVATION

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Introduction

Atolls are ring shaped coral reefs including a coral rim that encircles a lagoon partially or completely and with or without a coral island/cays on the rim. Most of the world's atolls are in the Pacific Ocean and Indian Ocean. Lakshadweep islands, Maldives and the Chagos Archipelago are the atolls in the Indian Ocean. Lakshadweep are the only atoll islands in India. They lie scattered in the Arabian Sea between Latitude 8.26° to 12.4° N and Longitude 71.7°-73.75° E, comprising of 36 islands, 3 reefs and 5 submerged banks. These islands consist of coral formations built upon the Laccadive-Chagos submarine ridge rising steeply from a depth of about 1500 m to 4000 m off the west coast of India. While the total land area is 30 sq.km, the length of the coastline is 132 km and lagoon area of 4200 sq.km. Its territorial water spread is 20000 sq.km and it constitutes 0.4 million sq.km to the EEZ of Indian Union. Out of the 36 islands, 11 are inhabited with a population of 64,473 (2011 census). The atolls have 4 distinct biomes comprising of the islands, lagoons, reefs and the Open Ocean. Few threats to the atoll systems are sea level rise, salt water intrusion, reduced availability of fresh water, coral bleaching, disturbances to reef ecosystem, shrinking of livelihood and excessive dependence on external resources, excessive harvest of reef resources *etc*.

Marine Biodiversity of Lakshadweep: Corals are represented by 148 species; fish-126 families and 601 species; crustaceans-68 species; mollusks-227 species; sponges-91 species; mangroves-2 species; seaweeds-114 species; echinoderms-78 species, sea grass-6 species; sea turtles-4 species; 101 species of birds and 12 species of cetaceans. Pitti, a tiny sand bank situated nearly 24km northwest of Kavaratti with an area of only 1.21 ha is an Island of Birds. This is a breeding ground for 4 species of terns and therefore the island has great significance since such breeding colonies are very rare in the Indias territorial areas.

Fishes: The fishes that occur in the coralline niches of the lagoon exhibit the characteristic variety of colours and mainly consist of perches, gar-fishes, half-beaks, scarids, goat-fishes, carangids, grey mullets, antherinids, spyraenids, polynemids, balistids, blennids and globe-fishes (Balan, 1958; Kumaran *et al.*, 1989). Jones and Kumaran (1980) recorded 603 species of fish from the Laccadive archipelago. The offshore fishery is constituted by fishes *viz.*, tunnies, wahoo, sharks, rays, sail fish, flying fish, carangids *etc*. Fishes such as *Crenimugil crenilabis, Polynemus sexfilis, Naso tuberosus, Naso unicornis, Gomphousus varius,* *Novacutichthys taeniurus* and *Anampses diadematus* are common in the waters of Lakshadweep (James *et al.*, 1989). Of the 603 species of marine fishes belonging to 126 families that are reported from the islands, at least 300 species are of ornamental value. The ornamental fish such as *Abudefdus, Amphiprion, Apogon, Coris, Balistes, Platax* are common in Lakshadweep lagoons (Murthy *et al.*, 1989).

Fisheries in the islands

Present day fisheries in Lakshadweep are built on the traditional fishing and trade practices prevalent ever since settlement in the islands. Fishing here range from hand picking, cloth fishing, spear fishing, cast netting *etc.* in the lagoons to pole and line, troll line, handline, harpooning *etc.* in the deeper areas of the sea around the islands. Plank built country canoes or modified country canoes with or without outboard motors are the basic craft. Open decked Pablo type boats, motorized using inboard engines are the major fishing crafts in all the islands. Principal fishing method- Pole & Line is presently practiced in such boats. Of late, a modified version of these boats, which are larger and with wheel house on the stem are gaining popularity in the islands.

The fisheries in the islands can be broadly divided into Tuna Fishery and Non Tuna fisheries. Tuna fisheries comprise mainly of capture of oceanic tunas- skipjack (*Katsuwonus pelamis*) and Yellwofin tuna (*Thunnus albacores*). Other tunas like the Little tunny (*Euthynus affinis*), Bullet tunas (*Auxis spp*) and the Dog tooth tuna (*Gymnosarda unicolor*) also form catch at varying rates in different seasons. Non-tuna fisheries comprises of fishing for other large pelagic resources like rainbow runner, Mahi mahi, Wahoo, sharks rays *etc*. and Reef associated fishes like snappers, groupers, carangids, full beaks, half beaks *etc*. The fishing grounds for these resources are the deep sea in the vicinity of all the islands, reef areas and submerged banks. It may be noted that the principal fishing methods in the islands are hook and line based, which are considered to be the most ideal fishing tackle in view of its selectivity and harvest limitations. Use of gillnet, the only major net used for fishing are limited to reef and lagoon areas for reef associated resources like the fullbeaks and halfbeaks.

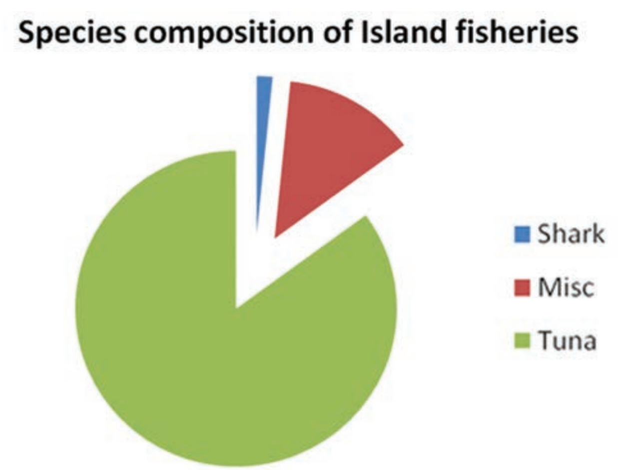

Fig. 1. Gross catch composition of island fisheries

Tuna fisheries

Lakshadweep islands have situational advantage of being located in the migratory paths of the oceanic tunas like the skipjack and yellowfin. Tunas constitute nearly 78% of the total catch with skipjack alone forming nearly 50% of the fish landing in the islands followed by Yellowfin (nearly 25%). Tunas are principally caught by the Pole & Line method contributing nearly 80% of the tuna catch followed by troll lines and handlines. Skipjack tuna is almost entirely caught by the Pole and Line method and Yellowfin by Handline and Pole & Line. Troll line fishing is used mainly for catching neritic tunas like the Little tunny and Bullet tunas though skipjack and yellowfin are also occasionally caught in this gear. The Dog tooth tuna is almost entirely caught by handlines.

Pole and Line: A sustainable fishing method

The traditional system of pole and line fishing for capturing tunas is widely employed in all the islands. Minicoy, Agatti and Kavaratti are the islands leading in pole and line fishing. This ifhsing method has been Minicoy's asset from time immemorial which was later extended to all other islands in the 1960s. Nationwide mechanization drive in the 1970s added impetus to adopting pole and line fishing by fishers of all the islands. An important mechanization in this fishing method was the replacement of hand splashing of water with mechanical water spraying system, using a pump connected to an auxiliary engine introduced by the fisheries department in 1984. This modification, besides saving labor costs improved the efficiency of the fishing method considerably.

The hook and line fishing methods are targeted fishing gears and have very less or no bycatch. All these gears catch one fish at a time, popularly known as 'one-by-one' fishing. Such fishing gears are selective as they fish from identified shoals of fishes. Bycatch, especially sensitive bycatch like turtles, mammals, birds, juveniles *etc.* don't form catch in most often. Pole & Line is an efficient fishing method catching more fishes in short time. Live-baits are essential for the pole & line fishing and hence this method of fishing has a subsidiary fishing activity for collection of live baits. Live baits are collected from the lagoons and near reef areas using boat seines and stored in the live bat tank on board. Live-bait collection is done during the early morning hours. After collecting sufficient baits, the boats set out to the deep sea beyond the lagoons scout for tuna shoals often in the vicinity of the islands. Once, a shoal is located, the boats steer close to the shoal and move in the direction of the fish shoal, splashing water continuously with occasional broadcasting of live baits. The pole & line fishermen will now swing into action and hooking of fishes will continue until the boat is filled up or till the shoal disappear.

Fig. 2. Pole & line boat

Fig. 3. Bait fishing

Fishery for Other resources

The major non-tuna species or groups that form considerable fishery in the islands are that for full beak and half beak using gillnets fished inside or outside the lagoons, especially during the monsoons months. Wahoo fishing using spear and troll lines are good fishery during post monsoon months. Mahimahi, rainbowrunner, carangids, barracudas *etc.* form minor catch in troll lines all through the year. The reef associated fishes that are caught using handlines in the near reef areas and seamounts are the groupers, snappers, grunts, sweet lips, parrotfishes, wrasses, trigger fishes *etc.*

Shark fishery: Shark fisheries are one the ancient fishery still continued though at a very low scale following traditional single or multi-hook long lines in most of the islands.

Large mesh drift gillnetting done during monsoon months also catch sharks along with other large pelagics. The most common species of sharks that occur in Lakshadweep are the Spade-nose shark/Yellow dog shark, *Scoliodon laticaudus* and the Milk shark, *Rhizopriodon acutus* (Devdoss *et al.,* 1985). The Blacktip Shark, *Carcharhinus limbatus* and Hammerhead shark, *Sphyrna mokarran* are also commonly found in the waters around Lakshadweep (Hanfee, 1997; Basudev Tripathy, *Pers. Obs.*).

Other Traditional Fishing practices in the islands

Owing to the typical geographical features of an atoll and its natural isolation from mainland, the people of the islands have used varieties of indigenous methods for catching fishes and other marine creatures from lagoon and the adjoining sea for food. Some of the important fishing activities/gears used in lagoons given in table 1.

Table 1: fishing activities/gears used in lagoons

Local Name	Description	Target Resource
Appal kuthal	Octopus hunting using sharp iron spears	Octopus
Chilla	Fishing using wooden spike	Flying fishes, Garfishes, half beaks
Chadal	Harpooning for catching fish	Wahoo
Bala adiyal	Shore seine, used mainly in the western lagoon	Juvenile and sub-adults of reef associated fishes
Bala attal	Long, small meshed nets used inside the lagoons around the island	Juvenile and sub-adults of reef associated fishes
Bala fadal	Large drag net involving 15-30 people, operated in both eastern and western lagoons together with scare lines	Juvenile and sub-adults of reef associated fishes
Bala idal	Set gillnets in the lagoon	Reef associated fishes, sharks, rays *etc.*
Cast net	Small mesh cast net operated in the lagoon from shore during low tide	Juvenile of carangids, surgeons, damsels *etc.*
Nool bikel	Baited hook and line set from shore or from a boat	Snappers, carangids *etc.*
Kalmoodal	"Boulder trap" – a net set around a coral boulder which is then agitated using rods to drive out fish.	Juvenile of reef associated fishes
Kurakkal	Light and spear or sword. Not commonly used, only practised in shallow water	Juvenile of reef associated fishes
Rod and line	Baited hook and line, used opportunistically around the island and mainly from the shore	Sub adults of Reef associated fishes
Shal kakal	Gillnet set in reef channels, used mainly during the monsoon and at spring tide.	Reef associated fishes like snappers, carangids, *etc.*

Coral reefs and their importance to island fisheries

Islands are formed inside the lagoon of atoll through continuous accumulation of coral sand due to wave action driven mainly by the South-west monsoon. Shore of these islands are protected from the hazards of the waves by the reef crest as all the waves surf on the reef crest before proceeding to the shore as low energy waves. The lagoons are doing an excellent service by way of being the nursery grounds for the fishes and other organisms besides being home to a plethora of flora and fauna, especially the corals. It is estimated that the coral lagoon of Lakshadweep is the habitat for about 75 species of marine ornamental fishes belonging to 13 families. Similarly, the lagoon is the source of live-bait fishes, which is the most essential component of the Pole & Line fishery of Tuna. The rich bio-diversity of the coral lagoon is also the base for the development of tourism in the Lakshadweep for events like coral reef diving and snorkeling. Therefore, the survival of these islands fully depends on the survival of the coral reefs and the lagoon ecosystem. Scientific management of resources within the coral reefs therefore is of paramount importance.

Conservation of the Atoll Ecosystem

Extraction of marine resources is the major anthropogenic threat to the ecosystem. Harvest of the natural resources therefore should be at levels that can be regained with natural recruitment and rebuilding. Every organism in the lagoon performs an ecological service and therefore the harvest should be balanced not affect the ecosystem functioning. Many fishes inhabiting the lagoons like the parrot fishes do the service of cleaning the coral boulders of algae and other foulers to create space suitable for attachment by the coral larvae leading replenishment of corals. Similarly, many herbivore fishes like the surgeon fishes, butterfly fishes *etc.* do such services. Dependence of lagoon for fish supply is much limited in Lakshadweep as the major commercial fishing activity is tuna based. This makes the fishing in the islands more sustainable. Besides, there are quite a lot of conservations measures adopted by the Govt in tandem with the international obligations.

Compliance to National and International Obligations

The point number 11 of the Aichi biodiversity targets, says that "By 2020, at least 17 percent of terrestrial and Inland water, and 10 percent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected area and other effective area based conservation measures, and integrated into the wider landscape and seascapes", which is integrated in India's National Biodiversity Targets, 2012-2020. The Environment Protection Act (1986) provides for identification of ecologically sensitive areas based on the sensitivity and conservation value of a spatial unit. In case of Lakshadweep islands, the Integrated Island Management Plans, prepared as per the Island Protection Zone Notification (2011), demarcate the preservation and conservation zones for spatial conservation of the coral reef areas. The Pitti Island, because of being a bird nesting area has been declared as an MPA. The report of the Planning Commission of India (2008) proposed to declare one or two reefs among the Suheli par, Baliyapani par, Cheriyapani par and Perumal par as Marine National Park to protect and preserve the marine biodiversity. The Bombay Natural History Society, based on a detailed study on the giant clam resources in the Islands proposed declaring the reefs of Agatti Island to be a conservation reserve. International Union for Conservation of Nature (IUCN) and oceanographer Sylvia Earle of Mission Blue named 31 new hope spots, among them Andaman & Nicobar and Lakshadweep islands have been named as the new "hope spots" from India. A Hope Spot is an area of ocean that merits special protection because of its wildlife and significant underwater habitats. Some are already formally protected, while others still need protection.

CHAPTER

49

RESPONSIBLE FISHERIES- A PRELUDE TO THE CONCEPT, CONTEXT AND PRAXIS

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The concept of Responsible Fisheries is synonymous with the FAO Code of Conduct for Responsible Fisheries (CCRF). CCRF is an international instrument for fisheries management which was developed and released by Food And Agriculture Organisation (FAO) functioning under the United Nations on 31 October 1995 after a series of international deliberations that began in 1992. More than 160 countries, including India are signatories to this international instrument which is considered as a landmark document symbolizing the international consensus achieved on the necessity for providing guidelines to ensure sustainable utilization of fisheries resources of the world. The most salient feature of this global instrument is its voluntary nature. The Code is often referred to as the Bible of Fisheries Management.

Why the Code?

The term “Responsible Fisheries” may evoke a doubt whether we have been irresponsible in the way we have been developing or managing our fisheries resources. In fact such a doubt is the stepping stone to understand the concept of Responsible Fisheries.

In common parlance the term “responsibility” is immediately read with the notions of rights or ownership. We tend to have a better sense of responsibility to things we own ourselves. Thus, we feel responsible in taking care of our properties or assets like land or house or vehicle. The lesser the sense of our ownership lesser will be our sense of responsibility. Thus we feel less responsible for the affairs of our ecosystem or political system because we deem them as owned by all. A property belonging to everyone tends to be nobody’s property though nobody is excluded from its utilization. This is an important point because in the case of fisheries what we are talking about is a Common Property. Or more correctly an Open access resource. An important question here is “Who actually owns the fish or who actually owns the sea? The *de jure* owner of the fisheries is the State or the government. That is, fish in our waters is owned by the people. But by all practical sense the fish , once caught by the fisher, becomes his or her property. If so, what about his or her sense of responsibility to ensure its conservation? It may sound a bit puzzling. That is why the Code makes it very clear in the very first article which is given under the general principles of the Code.

" *States and users of living aquatic resources should conserve aquatic eco systems. The right to fish carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources.* " (Article 6.1).

What is in principle a property of every one, becomes the property of none in practice. This is the most fundamental challenge in scientific fisheries management. There is a notion that if a sense of ownership is assured, the likelihood of it being taken care of in a responsible manner is more. There are people who argue that it is a misplaced notion. The above-mentioned article of the Code, in fact, is a preemptive answer to this common misunderstanding.

It is for the same reason that , of the more than 230 clauses in the Code classified under 12 articles, a large number vest the responsibility with the State. This, in a way also helps to clear the doubts regarding the real meaning of implementing the Code.

Another doubt could be on the real meaning of the voluntary nature of the Code. Being a voluntary instrument the question could be, "Is it something like a "barking dog that seldom bites"? The code answers this question in its fundamental philosophy called the Precautionary Approach, which is enshrined in Article 7.5.1.

"*The absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation and management measures.*"

In simple words what it means is " *Better safe than sorry*". It also has a deeper meaning which implies that when a person is given the license or permission or right to fish, what is being transferred is part of the stewardship obligation of the State. One needs to clearly understand this because, when individuals operate in a common property with the sole objective of making profitable livelihoods, the sustainable utilization of such a resource becomes an impossible task in the absence of mutually respected and endorsed regulations. The precautionary principle is further elaborated under the Foundations of the Code below.

Being a global guideline there is much practical sense for keeping it as a voluntary instrument too. Each nation can contextualize the code in sync with its own local realities and requirements at the same time respecting the globally agreed principles and norms. However, there are scholars who argue for making the CCRF a binding instrument given the sorry state of fisheries governance in most parts of the world.

Foundations of the Code

That the sustainability of marine capture fisheries at the current level of harvesting is at stake is no longer a moot point. It is being realized that fisheries anywhere in the world is more a socioeconomic process with biological constraints than anything else. The open access nature of the resource coupled with unregulated penetration of advanced, but not necessarily eco-friendly, harvesting technologies (a phenomenon called *technological creep*) has enacted a virtual "tragedy of the commons" in our seas. Making the issue still more complex, especially in the context of the Millennium Development Goals, is the rampant poverty/income inequality existing among our fisher folk though the capture fisheries make significant foreign exchange contribution in our country. The plateauing of the resource as revealed by recent trends in landings doesn't augur well for the ecologic and economic sustainability of the marine fisheries sector.

If there are no technological magical bullets for the current impasse what is the way out? This is precisely the question the FAO code is trying to answer. As we have seen ,"*the right to fish carries along with it an obligation to do it responsibly"* is the cardinal principle of the code. This principle is built on the foundation of what is known as a Precautionary Approach. Precautionary approach, which originally was proposed as Principle 15 of Agenda 21 the Rio Earth Summit meeting in 1992, enunciates that,

"*where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*".

While in simple terms the precautionary approach means "***better safe than sorry***", it clearly recognizes that changes in fisheries systems are only slowly reversible, difficult to control, not well understood, and subject to changing environment and human values. As Restrepo *et al.,* define, "the precautionary approach in fisheries is about applying judicious and responsible fisheries management practices, based on sound scientific research and analysis, proactively (to avoid or reverse overexploitation) rather than reactively (once all doubt has been removed and the resource is severely overexploited), to ensure the sustainability of fishery resources and associated ecosystems for the benefit of future as well as current generations".

It involves the application of prudent foresight. It is about applying judicious and responsible fisheries management practices, based on sound scientific research and analysis proactively rather than reactively to ensure the sustainability of fishery resources and associated ecosystems for the benefit of future as well as current generations.

Taking account of the uncertainties in fisheries systems and the need to take action on incomplete knowledge, it requires, *inter alia:*

a. consideration of the needs of future generations and avoidance of changes that are not potentially reversible;

b. prior identification of undesirable outcomes and of measures that will avoid them or correct them promptly;

c. that any necessary corrective measures are initiated without delay, and that they should achieve their purpose promptly, on a timescale not exceeding two or three decades;

d. that where the likely impact of resource use is uncertain, priority should be given to conserving the productive capacity of the resource;

e. that harvesting and processing capacity should be commensurate with estimated sustainable levels of resource, and that increases in capacity should be further contained when resource productivity is highly uncertain;

f. all fishing activities must have prior management authorization and be subject to periodic review;

g. an established legal and institutional framework for fishery management, within which management plans that implement the above points are instituted for each fishery, and

h. appropriate placement of the burden of proof by adhering to the requirements above.

The reversal of burden of proof means that those hoping to exploit our marine resources must demonstrate that no ecologically significant long-term damage will result due to their action. Or in other words human actions are assumed to be harmful unless proven otherwise.

Contents of the Code

The code provides a necessary framework for national and international efforts to ensure sustainable exploitation of aquatic living resources in harmony with the environment. It is achieved through 12 articles covering areas like

a) Nature and scope of the code (article 1)

b) Objectives of the code (article 2),

c) Relationship with other international instruments (article 3),

d) Implementation, monitoring and updating (article 4),

e) Special requirements of developing countries (article 5),

f) General principles (article 6),

g) Fisheries management (article 7),

h) Fishing operations (article 8),

i) Aquaculture development (article 9),

j) Integration of fisheries into coastal area management (article 10),

k) Post-harvest practices and trade (article 11), and

l) Fisheries research (article 12).

(The full text of the FAO CCRF (hereafter referred to as the Code) translated into Malayalam was published by CMFRI in 2002 under an agreement with the FAO (Ramachandran,2002). Thus, Malayalam became the second language, after Tamil, to have a translated version of this very important international fisheries management instrument. You can access it at www.cmfri.org.in. The pdf of the English full text is supplied with the Winter school CD rom).

Characteristics of the Code

As we have seen, the most salient feature of the code is that it is *voluntary* in nature. Unlike other international agreements like UN Agreement to Promote Compliance with International Conservation and Management Measures by Fishing vessels on the High Seas or the Straddling Stock Agreement, 1995, it is not legally binding and violation of the code cannot be challenged in a court of law.

It would be tempting to castigate it as an Achilles' heel and thus the futility of the code. But it should be remembered, "open access imbroglios" cannot be resolved through attempts that fail to recognize altruistic spirit of the human actors. In a situation where, "you and your enemy belong to the same eco-system", solutions must be found in managing relationships of the actors that make or move the ecosystem. It doesn't mean that the code is impractical or ineffective. What it demands is to construe responsible fisheries management as a *political process* rather than a *technical process*. This insight is a significant contribution of social scientists studying natural resource management (Wilson *et al.,* 2006).

A fundamental objective of the Code is "to serve as an instrument of reference to help states to establish or to improve the legal and institutional framework required for the exercise of responsible fisheries and in the formulation and implementation of appropriate measures." The policies of the state for managing the fisheries resources should be based on the provisions of the code.

If world fisheries are to be sustainable in the long term, structural adjustment within the fisheries sector is required. Although policy decisions in this regard must be made by national governments, effective implementation of the code requires the participation and cooperation of a wide range of stakeholders, including fishers, processors, NGOs and consumers. Implementation of the code is primarily the responsibility of states. The code will require regional and sectoral implementation in order to address the particular needs of fisheries in different regions or sub-sectors.

Relevance of the Code in our context

Before analyzing the relevance of the code in our context it is necessary to have an inkling of the historical context in which the code was developed.

The code was unanimously adopted on 31 October 1995 after lengthy deliberations and negotiations spanning about four years. One of the major triggers for the idea behind the code has been the international concern over the serious decline noted in the global catch of marine fish. The iconic cod fish of the Canadian waters collapsed in 1992. The famous *Science* magazine at that time wrote in its editorial that "Fisheries is five per cent protein and 95% politics". It was realized that the command and control regime of fisheries management, banking mainly on scientific advice, has come of age . It was realized that Fisheries management needed to be perceived more as fisher management or managing the behavior of human beings rather than that of the fish. No effective management was possible without the active participation of stakeholders. It was this realization that led to the concept of responsible fisheries. It is worth noting that the global production of marine fish after reaching a peak of 86.4 million tons in 1996 from a mere 20 million tons of the 1950s started stagnating or even plummeting down to 79.7 million ton in 2012.

The Lessons of the Code

In order to better understand the lessons we can garner from the code which is an international instrument a comparative key word analysis of the Code with the instrument we currently have namely the Marine Fisheries Regulation Acts of the maritime states in India. (Kerala MFRA is considered for the analysis here). Also given is the famous Magnuson –Stevenson Fisheries Conservation and Management Act 1976, 2007 of USA for a comparative understanding.

Table 1. A comparative Key word analysis of three instruments

Key word	FAO CCRF 1995	KMFRA 1980	MS Act 2007
Sustainability	5	0	8
Over fishing	0	0	45
Conservation	70	1	>200
Management	10	0	>200
Food security	4	0	0
Gender	0	0	0
Regulation	19	37	152
Research	46	0	64
Penalties	0	0	22
Mesh size	1	2	0
Over capacity	0	0	0

MSY	1	0	5
Fisherman	15	0	43
Justice	0	0	6
Discard	9	0	18
By catch	1	0	68
Participation	4	0	32
Fisheries development	0	0	1
Poverty	1	0	2
Conflicts	3	0	3
Rights	33	0	0
Safety	11	0	26
Ecosystem	27	0	13
Code of conduct	NA	0	0

The table reveals certain interesting things. The greater importance given to Resource Conservation both by the CCRF and the MS Act compared to KMFRA is indicative of the nature of exploitation in our waters. Remember that the KMFRA was developed in 1980. Today the situation has definitely changed given the declining trends we have witnessed in recent times. Another key word to take note of is MSY, the Maximum Sustainable Yield, which is the most fundamental creed of fisheries stock assessment science. MS act of USA has given much more importance to MSY indicating the extent to which scientific stock assessment has influenced the fisheries management regime in that country. FAO CCRF has mentioned MSY only once (Article 7.2). It indicates the lesser global applicability of MSY as a management reference point. All the three instruments give importance to fisheries regulations. CCRF obviously does not deal with penalties. But what is relevant here for us is the fact that out of the 24 keywords used in this analysis only three keywords appear in KMFRA. They are conservation, regulation and mesh size . (What are your impressions over this finding?). The absence of these key words in our Act indicates that there is a need for reforming it taking into cognizance the new ecologic and economic realities emerging in our fisheries sector.

Another interesting thing is the fact that the MS Act of USA is silent about the FAO CCRF. But, in an international study published in Nature 2009, which assessed the extent to which the FAO CCRF is being complied by different nations USA got second rank. Out of the 53 countries where the assessment was made India got 27 th position. The lesson we have to draw from this study is the importance accorded by Nation States in adopting problem -based management measures in ensuring sustainable utilization of their marine fisheries resources and the kind of policy significance these countries bestow to the importance of sustainable fisheries in the economy of those nations. It is worth noting that all of the 10 highly ranked countries belong to temperate regions of the world. The issues like overfishing are more visible in these countries and hence there is no wonder that these countries are ahead of other nations in adopting conservation oriented- fisheries management and regulations in their waters. In this context a question may creep in our minds. Should we also follow these nations where overfishing has become a reality? Can we continue our business as usual attitude in the absence of fisheries collapses or severe decline in our resources? It indeed is a challenging poser.

It is here that the science of fisheries management and the knowledge base we have accumulated so far regarding the status of our marine resources become relevant.

There are only two fundamental questions in fisheries management anywhere in the world.

i) "How much fish we can safely catch?"

ii) "How much is the fish available ?"

These questions are very simple. But answers are not so simple to come. That is precisely the reason why Precautionary approach has become the driving philosophy of the global thinking over sustainable or responsible fisheries. We should not fail to see the intellectual humility enshrined in this approach. It is the deep ecological insight that in the face of the excruciating uncertainty and ignorance attached to our fisheries management knowledge base, we need to respect the self rejuvenating capacity of the ecosystem. This realization is the basic idea behind new approaches like Ecosystem based Fisheries Management and of course this demands new and complex approaches in fisheries research and governance.

What is the Problem?

The most important problem a fishery faces is what is known as Over Fishing. It takes place over time as the fishing is intensified. It is the stage where a stock of fish loses its capacity to keep on providing the Maximum Sustainable Yield. It is at this stage that the fishery is at the verge of an almost irredeemable loss, economically and biologically. MSY as a logic is easy to understand . But as a quantitative reference point, MSY is a methodological challenge especially in our multi-species tropical water scenario. This is still considered as the Holy Grail in fisheries stock assessment science. Remember, this should not be construed as a weakness of the scientist. It is the epistemological challenge the fisheries scientists all over the world share , lament and endeavour to overcome.

MSY is like a *Laxman Rekha*. The most frightening aspect about this *Laxman Rekha* is that we need to cross it to realize that we have trespassed it. Hence we can build our defense against the specter of overfishing only on the basis of a stronger understanding and contextual analysis of its symptoms.

Will our waters also witness collapses like that of the Canadian Cod? That such a tragedy has not happened so far is not a guarantee that it will not happen here. But we have a better sense of optimism thanks to the resilience of our marine ecosystem which is mainly due to the rich bio diversity. However, we need to be concerned if recent events like the pelagic fatigue in Kerala are of any indication. The decline experienced by our fishers vouch for a serious rethinking on our laid-back attitude. Our fishers also share the veracity of different ways in which symptoms of overfishing are being manifested. They are :

a) severe decline or total absence in those fish which used to be abundant,

b) decline in the size range of major species ,

c) excessive catch of juveniles,

d) increase in fishing time and distance,

e) frequent fluctuations in the total catch, and

f) changes in species composition.

Our Tool Box

There are five types of remedies for the disease called "over fishing".

1. Based on the total catch of the fish (yield or Output)
2. Based on fishing effort or input
3. Based on time or season (temporal)
4. Based on space or depth (spatial)
5. Based on technical things

A typical example of the first type of remedies is the Quota system of fisheries management which is common in countries like EU and USA. This demands the assistance from a very precise stock assessment science. These measures which are similar to rationing of the catch, can be considered as the last ditch effort feasible in areas of lower species diversity that makes determination of MSY much less cumbersome. The second type of measures aims rationalizing the fleet size. Licensing based on an optimum fleet size is an example here. The next type of measures based on time and space is well known to us through the Monsoon Trawl Ban. Other examples are Marine sanctuaries and no-fishing zones. Technical measures include Mesh size regulations, and Minimum legal size.

For an overview of the status of the tool box (interpreted in a slightly different mode) in our context, see the table annexed. The table is taken from (Shinoj and Ramachandran 2017).

As long as a fishery remains a common property resource, a regulated fishery is more profitable than an unregulated fishery in the long run. Our fishers have started accepting this truism. But they are helpless to avoid competitive fishing due to two main reasons. One is the increase in fuel cost. And the other is the high demand for fish which has led to a situation where you are economically rewarded whatever be the catch. So fishers tend to do indiscriminate fishing. This has resulted in an illusion of super abundance which again drives more fishing effort. This is leading to a very dangerous situation. There are fishers (like Mr Jossy Palliparambil, Munambam Kerala) who characterize this ugly scenario as a phase of "Foolish Fishing" ("*mandan fishing*" in Malayalam). It is high time each fisher take more care in analyzing the fluctuations observed in the economics of their operations. As Charles Glover, the author of the book End of the Line, notes " *what makes a fisherman great now is what he leaves in the sea*".

Challenges in the praxis

Sustainable Management of resources is no different from fisheries development. They are no longer considered as dichotomous. There will be no fisheries development if there is not enough fish in the sea. There won't be enough fish in the sea, if human beings, both as harvesters and consumers, do not act in a precautionary manner which is nothing but to nurture a feeling of "better safe today than sorry tomorrow". What it means is to understand clearly the limits to which nature can be tapped. The requirements of both the present generation and future generation are to be given equal importance. It is also about respecting the co-evolutionary culture of a fisheries-resource dependent community. Thus Responsible Fisheries management takes place at the dynamic interface between the behavior of man and that of fish. So the knowledge base for responsible fisheries ought to be a convergence of different disciplines like fisheries biology, socio-politics, ecology, economics, engineering, law and communication. The aim of fisheries management is to ensure optimum utilization of a common pool resource without jeopardising the inherent regenerative ability of the resource leading to livelihood security of the dependent community.

Much has been said about rights-based fisheries, fisheries co-management and ecosystem-based fisheries management with fisheries managers, policy-makers, scientist and researchers racking their brains about the meaning of each of these fisheries management approaches. In trying to find definitions and formulating "how-to" guidelines and handbooks on such fisheries management approaches, their essential ingredient often is overlooked, namely dialogue. Whether talking of co-management and partnerships between fisheries stakeholders or of the adaptive nature of ecosystem-based fisheries management the fundamental nature of any fisheries management effort is the communication process among its various protagonists. Neither a partnership between fishing communities, fisheries managers, researchers and other stakeholders, nor the merging of the development goals of human well-being with that of ecological well-being through an ecosystem-based fisheries management approach would be possible without free-flowing information among the various partners in the management process. It thus becomes a political or governance process.

These communication processes can take many different forms and can be designed according to a diversity of purposes: (1) to meet specific fisheries management objectives, needs and aspirations for the fisheries sector; and 2) to generate new information about local fisheries systems through participatory (eg. catch-reporting) mechanisms. The experiences from these activities should encourage fisheries managers, scientists, and fishing communities to actively seek such dialogue and information exchange as a basis for improving fisheries management on an ecosystem approach.

The efforts to engender a scientifically- informed fisheries management or governance regime are always challenged by the inherent uncertainty that characterizes the epistemology of fisheries science. The complexity of an otherwise resilient tropical marine ecosystem adds fuel to the fire and on the Human dimension we have a plethora of challenges despite promising perspectives from Hardin to Ostrom.

It is here that we need to fully appreciate the multitude of challenges we face in a precautionary and participatory framework. We have the instruments/tool box. But the credo of responsible fisheries is yet to become part of the community ethos (including that of researchers and managers). What could be the reasons and how we can overcome the barriers? As a concerned stakeholder each one of us has a responsibility to be part of a collective process to not only decipher the answers but also translate them into pragmatic ameliorative strategies.

The Code and CMFRI Initiatives

Our fisheries have undergone tremendous changes during the past six decades. Before the advent of modernization, (motorization, mechanization , refrigeration, export orientation and transportation) the access to sea was limited to a few skillful and adventurous people who were by birth fishers. The community could afford to have self regulations oriented towards resource conservation which were arrived through the ecological experience of the community over generations. These concerns or tacit knowledge were institutionalized too. An example of such an institution still, surprisingly, surviving in Kerala is the *Kadakkody* of the Malabar coast (Ramachandran, 2006). The self regulations and community regulations which were rooted in the traditional wisdom have given way to technological skills. These skills, unleashed by what we generally refer to as an era modernization, most often take a dehumanized manifestation thus weakening the hold of the community. This is where the crucial role of the State comes into play in the management as well as development of the fishery. This is better known as fisheries governance.

Fisheries governance is dependent on the particular stage of economic development and local ecological status of the fishery resources. This varies with each country. It is because of this contextual nature that the Code has been made as a voluntary tool. Each government is free to make its own rules, regulations and strategies based on the guidelines and principles elaborated in the Code. Thus article 4.3 says "FAO through its competent bodies, may revise the code, taking into account developments in fisheries as well as reports to COFI on the implementation of the Code. (But in recent times an argument against this position has also emerged).

It is in this context that the actions and initiatives being taken by CMFRI, mainly through an NATP funded research project titled "Designing and validation of communication strategies for responsible fisheries –a co-learning approach" become relevant. A Responsible Fisheries Extension Module (RFEM), which consists of 13 tools including a Malayalam translation of the code, animation films in all maritime languages *etc*. developed have been widely used to create awareness among the fisherfolk. A state-wide campaign on Responsible Fisheries was launched and the RFEM was released for further scaling up by the respective State Fisheries Departments. These mass communication tools have the potential to reach almost 85 % of the fisher folk and other stakeholders in the country. It is reasonable to conclude that CMFRI has made a pioneering initiative in the cause of popularization of the concept of Responsible Fisheries in India (Ramachandran, 2004).

Though the voluntary nature of the code has been necessary in garnering the all-nation agreement when it was drafted in the early 1990s, our attitudes to the oceans have changed since then (Pitcher *et al.,* 2009). There is now widespread scientific consensus on the ecological impacts of continued over-fishing and the threats to seafood security and broad agreement on policy issues such as curtailing illegal catches and minimizing the impacts of fishing on marine ecosystems. The basic requirement for adoption of Ecosystem Approach is a dynamic knowledge base on stock assessment. The stock assessment knowledge base generated and continuously maintained by CMFRI is a unique achievement among the developing tropical context countries. But the utility of this Knowledge base in translating into management praxis is less appreciated. There still exists a communication divide between the research system and the fisheries management system in the country.

Though the communication tools and strategies already developed by the institute have been useful in creating awareness on the need for sustainable/responsible fisheries there is a need to develop and scale up specific communication interventions to sensitize the stakeholders in making a transition towards ecosystem based approaches that ensure responsible management of our waters. Fisheries management is fisher management and participatory approaches informed/initiated by a proactive research system taking place in a democratic and decentralized civil society space is globally accepted as the key to Ecosystem Based Fisheries Management. The future is decided by the capacity we build today amongst the different stakeholders responsible for sustainably utilizing the marine fisheries resources of our country. It is with this objective that we are continuing the efforts in this line through innovative research projects in Capacity Development for compliance to Ecosystem Based Responsible Fisheries Management in India through Co-Learning and Multi-disciplinary action research under the leadership of Extension scientists in CMFRI.

Pathways before us

Taking into consideration the inherent epistemological limitations of the Fisheries science, it is essential to make a transition towards more participatory efforts fisheries governance and research. There cannot be any management without measurement. What our fishers lack is the big picture on the status of our fisheries resources. The science has the tools to draw this picture. But its precision depends on the accuracy of the data on landings. We badly need a National Marine Fisheries Data Acquisition Plan. The active and informed participation of fishers in providing the catch data needs to be encouraged through proper incentive mechanisms.

Engendering a scientifically informed fisheries management governance system is the need of the hour. As recent events like the Kochi Initiative (Ramachandran and Mohamed 2015) is of any indication, formation of multi stakeholder platforms of responsible fisheries co-governance is not an impossible task in our context. The response of the State in facilitating this transition is essential. With the landmark promulgation of insisting Minimum Legal Size for 55 species of fish by the Government of Kerala (GoK, 2017) done based on the recommendation of CMFRI (Mohamed *et al.,* 2014), the State of Kerala has shown an instance of proactive engagement with responsible fisheries governance which is worthy of emulation by other maritime states. It is, however, worth remembering that regulatory measures like MLS would become impotent in the absence of strong-arm measures to eliminate (or at least rationalize) external drivers like demand for the juveniles either for reduction or consumption. As scholars of regulatory politics argue, legislative coercion though necessary can not be open to tendencies for inefficient rent seeking in a public good.

Annexure

Table 2. Capture fisheries regulatory framework in maritime states of India

Maritime State	Access controls	Temporal controls	Spatial controls	Input/ effort-based	Output/ catch-based	Legislation/s in force
Gujarat	Registration and licensing of fishing vessels	Seasonal fishing ban (Jun 1 – July 31, 61 days)	Artisanal: up to 9 km; Mechanized: beyond 9 km.	Square mesh of minimum 40 mm size at cod end need to be used for trawl net; Gillnet with mesh size less than 150 mm cannot be operated	-	The Gujarat Fisheries Act, 2003 Maharashtra Marine Fisheries Regulation Act, 1981 (Amended in 2015).
Maharashtra	Registration and licensing of fishing vessels	Seasonal fishing (Jun 1 – July 31, 61 days); Mechanized vessels with trawl net prohibited between 6 pm and 6 am	Mechanized (trawl net) : beyond 5-10 fathom depth in specified areas; Mechanized (any type with more than 6 cylinder engines): beyond 22 km	Use of purse-seine gears by mechanized vessels at specified coastal zones prohibited within territorial waters.	-	
Goa, Daman & Diu	Registration and licensing of fishing vessels	Seasonal fishing ban (Jun 1 – July 31, 61 days)	Artisanal: up to 5 km; Mechanized: beyond 5 km. Mesh-size limits of 20 mm for prawn and 24 mm for fish.	The Goa, Daman and Diu Marine Fishing Regulation Act, 1982 (Amended in 1989). -		
Karnataka	Registration and licensing of fishing vessels	Seasonal fishing ban (Jun 1 to July 31-61 days)	Artisanal: up to 6 km or up to 4 fathoms (whichever is farther); Deep sea vessels (up to 50 feet length): beyond 6 km Deep sea vessels (>50 feet length): beyond 22 km.	Ban of cuttle fish fishery using FADs	-	The Karnataka Marine Fishing Regulation Act, 1986.
Kerala	Registration and licensing	Seasonal fishing ban	Artisanal: 32-40 m	Mesh-size regulations:	Minimum legal size for 14 fish and	The Kerala Marine Fishing Regulation

	of fishing vessels	(Jun 15- July 31, 47 days)[1]	depth in the first zone[2] and 16-20 m depth in the second zone; Mechanized vessels (< 25 GRT): 40- 70 m depth in the first zone and 20-40 m depth in the second zone; Mechanized (> 25 GRT): beyond 70 m depth in first and beyond 40 m depth in second zone	code end minimum mesh size of bottom trawl net-35 mm; ring seine and driftnet minimum mesh size – 20mm.	shell-fish species notified to control juvenile fishing.	Act, 1980 (Amended in 2013).
Tamil Nadu	Registration and licensing of fishing vessels	Seasonal fishing ban April 15 to June 14, 61 days)	Artisanal: up to 5 km. Mechanized: beyond 5 km; Fishing within 100 m below a river mouth is prohibited; The number of mechanized fishing vessels permitted in any specified area subject to restrictions.	No fishing gear of 100 mm mesh from knot to knot in respect of net other than trawl net to be used; Pair trawling and purse seining are prohibited.	Tamil Nadu Marine Fishing Regulation Act, 1983 (Amended in 1995; 2000; 2011; 2016).	
Andhra Pradesh	Registration and licensing of fishing vessels.	Seasonal fishing ban (April 15 to June 14, 61 days)	Artisanal: up to 10 km; Mechanized (< 15 m OAL): 10-23 km; Mechanized (< 15 m OAL): beyond 23 km.	A minimum 15 mm limit for mesh-size for any gear;Shrimp trawlers not allowed without turtle-exclusion device (TED).	The Andhra Pradesh Marine Fishing (Regulation) Act, 1995 (Amended in 2005). -	
Odisha	Registration and licensing of fishing vessels.	Seasonal fishing ban (April 15 to June 14, 61 days)	Artisanal: up to 5 km; Mechanized (<15 OAL): 5-10;Mechanized (>15 OAL): beyond 10 km.	The Orissa Marine Fishing Regulation Act, 1981 (Amended in 2006).		
West Bengal	Registration and licensing of fishing vessels.	Seasonal fishing ban (April 15 to June 14, 61 days)	Artisanal & mechanized crafts with < 30 HP engine: up to 18 km; Mechanized crafts with> 30 HP engine: beyond 18 km.	Mesh size regulations for specific gears: minimum 25 mm for gillnet/shore seine/ drag net; 37 mm for bag net/dol net;Trawl net of standard mesh-size fitted with TED to be used.	The West Bengal Marine Fisheries Regulation Act, 1993. -	
Andaman & Nicobar islands	Registration and licensing of fishing vessels.	Seasonal fishing ban (April 15 -June 14, 61 days)	Artisanal & mechanized crafts with < 30 HP engine: up to 6 nm; Mechanized crafts with >30 HP engine:	Trawl nets of standard mesh size fitted with TED alone are permitted; Gillnets, shore seines and dragnets with mesh	The Andaman and Nicobar Islands Marine Fisheries Regulation Act, 2003 (Amended in 2011).	

			beyond 6 nm.	sizes above 25 mm only are permitted.
Lakshadweep	Registration and licensing of fishing vessels.	Seasonal fishing ban Seasonal fishing ban (Jun 1- July 31, 61 days)	Use of purse seine, ring seine, pelagic, mid water and bottom trawl of less than 20 mm mesh size, use of drift gill net of less than 50 mm mesh size and shore seine of less than 20 mm mesh size are prohibited in specified areas.	Lakshadweep Marine Fishing Regulation Act, 2000.

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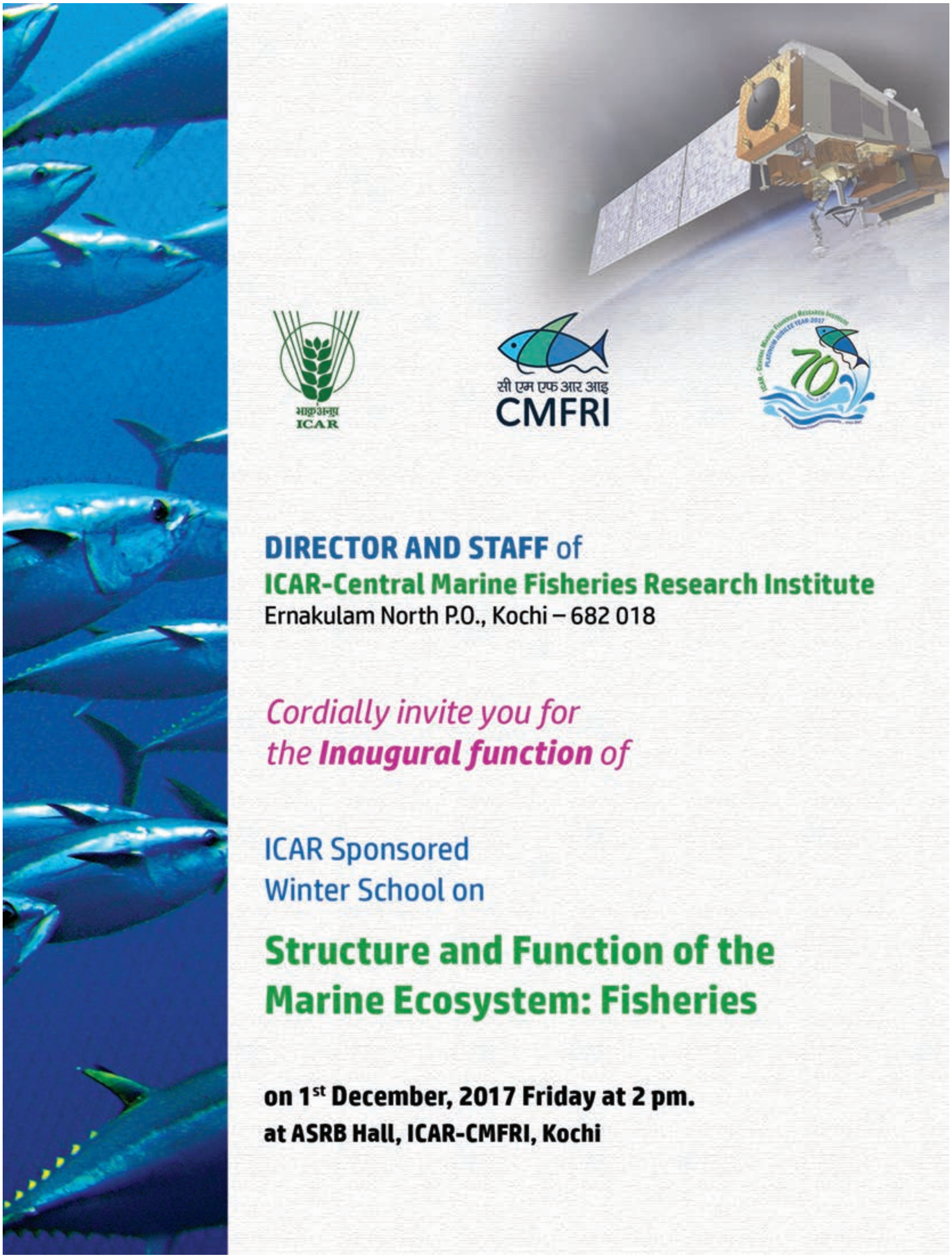
(Footnotes)

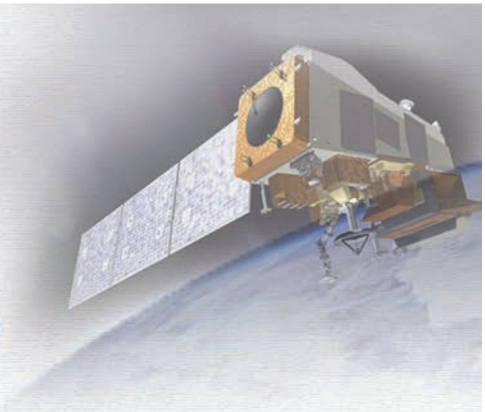
[1]While all other maritime states and UTs agreed to extending the ban to 61 days in conformity with the directive of the Union Government issued in May, 2015, Kerala continues to stick on to its earlier ban period for 47 days.

[2] The area from shore up to 32m depth in the sea along the coast from Kollencode in the south to Paravoor (Pozhikkara), a length of 78 km, is called the First Zone; The area up to 16 m depth in the sea along the coast line from Paravoor in the south to Manjeswar in the north for a length of 512 km is called the Second Zone.

ANNEXURES

INVITATION LETTER: INAUGRAL FUNCTION





Programme

2 pm - 3 pm

Invocation

ICAR title song

Welcome Address : **Dr. T.V. Sathianandan**
Principal Scientist & Head
Fishery Resources Assessment Division
ICAR-Central Marine Fisheries Research Institute

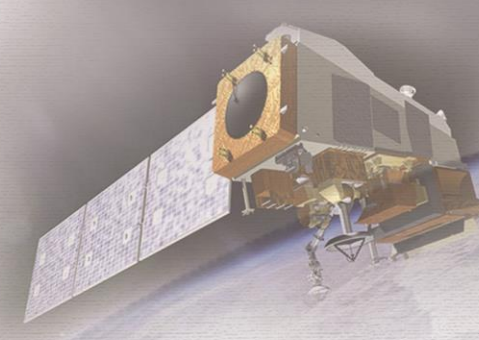
Presidential Address : **Dr. A. Gopalakrishnan**
Director
ICAR-Central Marine Fisheries Research Institute

Inaugural Address : **Dr. C.N. Ravishankar**
Director
ICAR-Central Institute of Fisheries Technology
Kochi

Vote of Thanks : **Dr. Grinson George**
Senior Scientist
Fishery Resources Assessment Division
ICAR-Central Marine Fisheries Research Institute

National Anthem

INVITATION LETTER: VALEDICTORY FUNCTION



DIRECTOR AND STAFF of

ICAR-Central Marine Fisheries Research Institute

Ernakulam North P.O., Kochi – 682 018

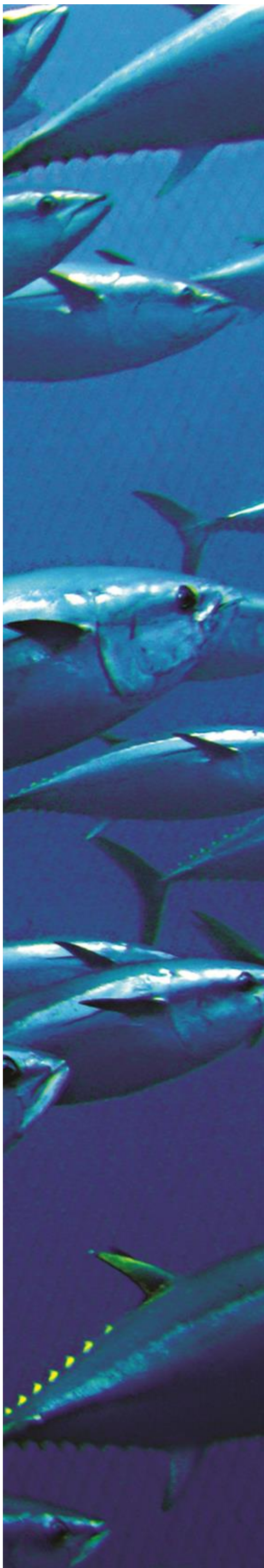
Cordially invite you for
*the **Valedictory function** of*

ICAR Sponsored
Winter School on

Structure and Function of the Marine Ecosystem: Fisheries

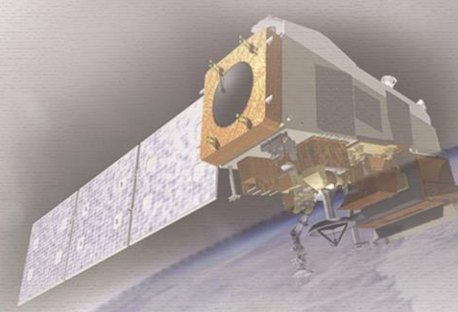
on 21st December, 2017 Thursday at 3 pm.
at Conference Hall No. 201, ICAR-CMFRI, Kochi

The programme may be seen overleaf



Programme

3 pm - 4 pm



Invocation

ICAR title song

Welcome Address	: **Dr. T.V. Sathianandan** Principal Scientist & Head Fishery Resources Assessment Division ICAR-Central Marine Fisheries Research Institute
Report on the Winter School	: **Dr. Mini K.G.** Principal Scientist Fishery Resources Assessment Division ICAR-Central Marine Fisheries Research Institute
Feedback from the participants	
Presidential Address	: **Dr. A. Gopalakrishnan** Director ICAR-Central Marine Fisheries Research Institute
Valedictory Address	: **Dr. N.R. Menon** Chairman, NERCI & Chairman, Research Advisory Committee ICAR-Central Marine Fisheries Research Institute Kochi
Distribution of the Certificates	
Vote of Thanks	: **Dr. Grinson George** Senior Scientist Fishery Resources Assessment Division ICAR-Central Marine Fisheries Research Institute

National Anthem

ICAR Funded Winter School on STRUCTURE AND FUNCTION OF THE MARINE ECOSYSTEM: FISHERIES
1st to 21st December 2017 at CMFRI, Kochi

Date	09:30 - 10:30		10:45 - 11:45	11:45 - 13:00		14:00 - 15:00		15:15 - 16:30
1-Dec-17	Registration	**Tea break (10:30 – 10:45)**	Orientation programme	Assessment of trainees	**Lunch break (13:00 – 14:00)**	Inauguration	**Tea break (15:00 – 15:15)**	Introduction **Dr. Grinson George**
2-Dec-17			**Holiday (Milad-un-Nabi)**					
3-Dec-17			**Sunday**					
4-Dec-17	Physics of the Indian Ocean **Dr. K. V. Sanil Kumar**		Regional Oceanography of the Arabian Sea and Bay of Bengal **Dr. K. V. Sanil Kumar**			Spatial and temporal variability in Chlorophyll-a concentration over the Southeastern Arabian Sea **Dr. Shalin Saleem**		Phytoplankton functional types **Dr. Nandini Menon / Mrs. Minu**
5-Dec-17	Regional and Seasonal Distribution of Phytoplankton **Dr. Nandini Menon**		Data diagnostic and remedial measures **Dr. Eldho Varghese**			HAB Monitoring using satellite datasets **Dr. Ajith Joseph**		Biogeography of the northern Indian Ocean and its Optical Classification **Ms. Monolisha S.**
6-Dec-17	Role of Calculus in Marine Sciences **Mr. Tarun Joseph**		Role of Calculus in Marine Sciences **Mr. Tarun Joseph**	Basic Statistics **Dr. Somy Kuriakose**		Phytoplankton Identification - Practical Demonstration **Dr. Nandini Menon / Mrs. Minu**		Phytoplankton Sorting – Practical Demonstration **Dr. Shoji Joseph / Mrs. Minu**
7-Dec-17	Sampling methodology employed by CMFRI for collection and estimation of marine fish landings in India **Dr. Mini K. G.**		Indian marine fishery resources - Present status **Dr. T. V. Sathianandhan**	Ocean Colour sensors **Mr. Shafeeque M**		Changes in Primary productivity and impacts in fisheries **Dr. Grinson George**		Algae culture methods : Practical Demonstration **Dr. Shoji Joseph**

Date	09:30 - 10:30		10:45 - 11:45	11:45 - 13:00		14:00 - 15:00		15:15 - 16:30
8-Dec-17	Practical session on various Remote sensing datasets and data servers **Mr. Shafeeque M. / Dr. Phiros Shah**	Tea break (10:30 – 10:45)	Fisheries Oceanography – A case study of Peruvian anchovy **Dr. J. Rajasekharan Nair**		Lunch break (13:00 – 14:00)	Classification Techniques for Remotely Sensed Data – **Dr. Eldho Varghese**	Tea break (15:00 – 15:15)	Classification Techniques for Remotely Sensed Data – **Dr. Eldho Varghese**
9-Dec-17			**Second Saturday**					
10-Dec-17			**Sunday**					
11-Dec-17	Introduction / Programming in R **Dr. J. Jayasankar**		Introduction / Programming in R **Dr. J. Jayasankar**			Statistical Methods for analyzing Ecological data **Dr. J. Jayasankar**		Contd. **Dr. J. Jayasankar**
12-Dec-17	Python: a tool for Analysis and Visualization for Remotely Sensed datasets **Mr. Tarun Joseph**		Utilizing GIS Tools for ecosystem related mapping **Dr. Shelton Padua**			Ecosystem modelling **Dr. Vijith V.**		Application of geophysical data sets to resolve ecosystem challenges **Dr. Grinson George**
13-Dec-17	Changes in Environment-implications for fisheries in Indian waters **Dr. V. Kripa**		Introduction to Marine Optics **Dr. K. H. Rao**			Fundamentals of Ocean-colour Remote Sensing **Dr. Aneesh Lotliker**		Air-sea interaction and Indian monsoon variability **Dr. Syam Shankar**
14-Dec-17	Fish biodiversity of Indian EEZ **Dr. K. K. Joshi**		Estimation of primary production by Remote Sensing **Dr. K H. Rao**			Introduction to Satellite Remote Sensing Based Marine Primary Productivity **Dr. Aneesh Lotliker**		Mudbank fishery estimates **Mr. Vivekanand Bharti**

Date	09:30 - 10:30	Tea break (10:30 – 10:45)	10:45 - 11:45	11:45 - 13:00	Lunch break (13:00 – 14:00)	14:00 - 15:00	Tea break (15:00 – 15:15)	15:15 - 16:30
15-Dec-17	Fisheries in atolls- tradeoffs between harvest and conservation **Dr. K. M. Koya**		Application of geophysical data sets to resolve ecosystem challenges **Dr. Grinson George**			*El-Nino* and its impacts on Coral reef ecosystem in the Bay of Bengal **Mr. Lix John K.**		Coral reef ecosystem - monitoring and assessment using satellite data sets **Dr. Grinson George**
16-Dec-17	Global Understanding and Learning for Local Solutions (GULLS) - Reducing Vulnerability of the Marine Dependent Coastal Communities **Dr. Shyam S. Salim**		Modelling the Pelagic Ecosystem of the Arabian Sea and Bay of Bengal **Dr. J. Jayasankar**			Ecosystem concepts for sustainable mariculture **Dr. Imelda Joseph**		Introduction to Geo-statistics **Dr. Sreenath**
17-Dec-17			Sunday					
18-Dec-17	Field visit		Field visit			Product certification and eco-labelling for fisheries sustainability **Dr. K. S. Mohammed**		Molecular methods used in fish abundance estimation/ conservation/genetic improvement **Dr. P. Jayasankar**
19-Dec-17	Species Diversity in marine fished taxa **Dr. T. V. Sathianandan**		Marine C:N:P Stoichiometry **Dr. Satya Prakash**			Marine microbial diversity and its role in ecosystem functioning **Dr. Parvathy A.**		Impact of climate change on marine ecosystem **Dr. P. U. Zacharia**
20-Dec-17	Mudbank biology **Dr. V. Kripa**		Mudbank physics **Mr. Muraleedharan K. R.**			Economics of Ecosystem and Biodiversity **Dr. R. Narayanakumar**		Climate change and Anthropogenic impacts on Marine Nitrogen Cycling **Dr. Satya Prakash**
21-Dec-17	Responsible Fisheries- A prelude to the Concept, Context and Praxis **Dr. C. Ramachandran**		Fisheries Oceanography – established links in the Eastern Arabian Sea **Dr. Grinson George** Identifying Mesoscale eddies- relevance to mud banks and fishery **Dr. Grinson George**	Synthesis **Dr. Grinson George**		Evaluation		Valedictory Function

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