THIS STATUS REPORT is an outcome of succesful monitoring of Indian coastal waters through "Seawater Quality Monitoring" (SWQM) programme since 1990. Water quality parameters were monitored periodically in selected 24 locations in the coastal waters of India by NCCR with the help of the participating Institutes. This report depicts the spatial and temporal changes in physico-chemical and biological parameters along the Indian coast.

Ministry of Earth Sciences
National Centre for Coastal Research (NCCR)
Chennai

July 2018

Seawater Quality at Selected Locations along Indian Coast

MoES
NCCR

Seawater Quality at Selected Locations along Indian Coast

Status Report (1990-2015)

Coastal Ocean Monitoring & Prediction System (COMAPS) / Seawater Quality Monitoring (SWQM)

Ministry of Earth Sciences
National Centre for Coastal Research (NCCR)
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Seawater Quality at Selected Locations along Indian Coast

Status Report
Seawater Quality Monitoring (SWQM)
(1990-2015)

सत्यमेव जयते

Ministry of Earth Sciences
National Centre for Coastal Research (NCCR)
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PREFACE

India with a coastline of ~ 7500 km long including the islands is one of the fastest developing regions of the world. The position of the Indian subcontinent in the tropical Northern Indian Ocean creates a number of geomorphological and hydrological features. As a result of these heterogeneous environments, India harbours rich biodiversity and considered as one of the mega-biodiversity regions of the world. Further, the coastal regions contribute significantly to the country's economy. However, the rapid developments along the coast create tremendous pressure on this economically important and ecologically sensitive ecosystem.

The Ministry of Earth Sciences (MoES), has initiated a nationally co-ordinated Research and Development programme, "Coastal Ocean Monitoring and Prediction System (COMAPS)" to assess the coastal water quality, which was renamed as "Seawater Quality Monitoring (SWQM)" during XII year Plan period. Presently, the National Centre for Coastal Research (NCCR) is implementing this multi institutional programme with the active participation of National R&D laboratories and Academia. Under this programme, data on more than 25 different parameters related to the physico-chemical, biological and microbial characteristics of seawater, sediment and biota have been systematically collected from the monitored locations.

The consolidated report of 25 years (1990-2015) reflects the wide range of activities undertaken under the SWQM programme. Developing of baseline data available at the Indian National Centre for Ocean Information System (INCOIS) website, status of Indian coastal water quality, actions taken by the Pollution Control Board based on the information of SWQM, development and applications of Oil spill trajectory models, the Marine Microbial Reference Facility (MMRF) functional at CSIR-National Institute of Oceanography, RC Kochi with 1055 isolates, training/workshops and publication of papers in peer-reviewed journals have been some of the major achievements of the programme.

I congratulate Dr. M. V. Ramana Murthy, Director, NCCR, Dr. P.Madeswaran, Head, Sea Water Quality Group, NCCR, and expert committee for bringing out the status report. I also thank Dr. Mahesh Datta Zingdhe, Scientist in Charge, NIO, Dr. B.R.Subaramanian conceptualising this programme and Dr. V.Sampath for and reviewing the report along with other expert members.

I hope this information will be very useful to coastal managers for improving sea water quality and protection of coastal ecosystem.

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Citation: P. Madeswaran, M.V. Ramana Murthy, M. Rajeevan, V. Ramanathan, Sivaji Patra, Sanitha K. Sivasdas, T. Boopathi, M. Durga Bharathi, S. Anuradha, C. Muthukumar, (2018). Status Report: Seawater Quality at Selected Locations along Indian Coast. NCCR Publication, 2018, pp-177, available at NCCR's Web site at http://www.nccr.gov.in

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ACKNOWLEDGEMENTS

This 25 years report on seawater quality based on the data collected under SWQM / COMAPS programme is the outcome of the dedication and hard work of many renowned scientists from reputed national and State research laboratories including academia. We would like to thank all those participating centres, who contributed to this report, since 1990.

Funding for the programme was provided by the Ministry of Earth Sciences (MoES). We would like to wish our sincere gratitude to all the Secretaries during its implementation, including the present Secretary Dr. M. Rajeevan, for their constant support and encouragement. We express our thanks to the Programme Advisors, Dr. S. K. Das (Retd.) and Dr. K. Somasundar; Programme Director, Com. P. K. Srivastava, Scientist-F; and Programme Officer Shri. E. Haque, Scientist-C, for their continuous financial assistance towards smooth implementation of SWQM programme.

We record or sincere gratitude to all the members of the Steering Committees under COMAPS, Research Advisory Committees under SWQM programme and Experts Committee, who have encouraged and provided their technical support / expert guidance for its successful implementation so far..

This multi-disciplinary and multi-institutional research and development programme was formulated and implemented by Dr. B. R. Subramanian, Advisor and Project Director (Rtd.), NCCR Formerly ICMAM PD) for assessing the health of coastal marine environment for which we are grateful to him. Subsequently, Dr. V. Sampath, Advisor and Project Director (Rtd.), NCCR; Dr. M. A. Atmanand, Former Director, NIOT and Director-in-charge, NCCR; Dr. S. S.C. Shenoi, Director, INCOIS, NIOT and Director-in-charge, NCCR, gave their constant support and encouragement for which we are deeply indebted. We also express our heartfelt thanks to Dr. S.

Sundaramoorthy, Technical Head, ICMAM-PD of SWQM programme, for his untiring support and dedication for updating all the datasets.

This work could not have been completed without the cooperation of the following participating laboratories, for efficiently conducting field works, sample processing, data analysis, etc.:

1. CSIR-Central Salt & Marine Chemicals Research Institute (CSMCRI), Bhavnagar, Gujarat
2. Central Electro Chemical Research Institute (CECRI), Tuticorin
3. Central Electro Chemical Research Institute (CECRI), Chennai.
4. CSIR-National Institute of Oceanography, Goa (CSIR-NIO)
5. CSIR-National Institute of Oceanography, RC Mumbai (CSIR-NIO)
6. CSIR-National Institute of Oceanography, RC Kochi (CSIR-NIO)
7. CSIR-National Institute of Oceanography, RC Visakhapatnam (CSIR-NIO)
8. National Centre for Earth Science Studies, Thiruvananthapuram (NCESS)
9. CAS in Marine Biology, Annamalai University, Parangipettai
10. Institute for Minerals and Materials Technology, Bhubaneswar
11. Andaman Nicobar Centre for Ocean Science and Technology, NIOT, Port Blair
12. Central Pollution Control Board (CPCB), West Bengal.

We express our gratitude to all the Scientists for their dedications including our colleagues, Finance / Administrative Officers and staff at NCCR for their co-operation.

Last but the most important aspect of dissemination of quality data to the user agencies, for which we acknowledge the Director, INCOIS, Hyderabad.

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EXECUTIVE SUMMARY

India has national and international obligations to prevent adverse effects to marine ecosystems caused by various anthropogenic activities. To assess the impact of various activities on the coastal ecosystem, it is necessary to monitor long-trends along the coastal waters for important environmental and biological parameters. In view of this, Ministry of Earth Sciences (MoES), formerly the Department of Ocean Development (DOD) has been implementing a nationally co-ordinated research programme on, "Coastal Ocean Monitoring and Prediction System (COMAPS)" since 1990. Any monitoring programme that collects data for long term data at regular intervals using consistent methods can generated valuable knowledge about the ecosystem processes. Such scientific information can help environmental managers to develop effective management plans.

In 2010, review of the programme by an expert panel resulted in restricting the number of monitoring locations from 81 to 24. Further, COMAPS programme has been renamed as, "Seawater Quality Monitoring (SWQM)". The primary objective of SWQM programme is systematic monitoring of seawater quality along Indian coast at selected locations, identified based on the sources of marine pollutants. To achieve this objective, the SWQM group of the National Centre for Coastal Research (NCCR), coordinates the monitoring activities with the participation of National institutes and academia.

Data on >25 parameters on physico-chemical, biological and microbiological characteristics of seawater and sediment were seasonally collected and analysed using standard protocols. Water (surface, mid-depth and bottom) and sediment samples were collected in each location at 0/0.5 km (shore), 2/3 km (nearshore) and 5 km (offshore) distance from the shore. A time- series sampling for 36 hrs at 3 hrs interval was carried out at the hotspot stations. The data were formatted, compiled and processed stored in Oracle database. This 25 year consolidated report has been prepared with the aims of (1) understand the ecological status of coastal waters at the 24 monitored locations and (2) to review the progress and help guide the future course of the SWQM programme. This report provides progress of the

SWQM/COMPAS programme, the ecological health status of the monitored locations, the major accomplishments and capacity building and the best way forward.

The nutrients showed an increase in most of the locations during the monitoring period. The increase in nutrients was observed upto 2 km from the shore at most of the locations with few locations showing high nutrients even at 5 km offshore. Ammonia and phosphate dominated the nutrients at most monitored locations. Dominance of phosphate indicates that untreated sewage continuous to be released into the coastal waters. Increasing nutrients in the coastal water is of concern as it may lead to ecological disturbances affecting the coastal ecosystem processes and services. Plankton (phytoplankton and zooplankton) biomass and abundance showed different patterns in the 24 monitored locations. Similarly, macrobenthos abundance and biomass showed increasing trends at some locations, while decline was observed in a few locations. The results of microbial characteristics of seawater and sediment showed increasing trends in total viable counts (TVC), faecal coliforms (FC), *Escherichia coli* and *Streptococcus faecalis* counts at most of the locations. Further, counts of health indicator bacteria declined from shore to offshore zones. The Water quality index (WQI) was developed for the monitored locations to understand and characterise the seawater quality. Based on the WQI maps, 11 locations were found to be 'poor' in condition. The WQI for Port Blair and Kavaratti alone showed 'good' condition.

Some of the major accomplishments of the SWQM/COMAPS programme include the baseline data of the various parameters collected during the last 25 years, available at the Indian National Centre for Ocean Information System (INCOIS) website. The data was also provided to the respective Pollution Control Boards for information and decision-making. Case studies are given of the actions taken by the Pollution Control Board based on the information provided by the SWQM/COMAPS programme.

Another important achievement has been the oil spill models to mitigate and protect the marine and coastal ecosystem. The *Oil Spill off Car Nicobar Islands* and *MV Rak Carrier spill, Mumbai* are two examples of the usefulness of oil spill models developed under this programme. In addition, performance of local hydrodynamic models developed based on the data collected was compared with field measured data which showed very good comparison with simulated results.

The Marine Microbial Reference Facility (MMRF) functional at CSIR-National Institute of Oceanography, RC Kochi is yet another achievement of the programme. Presently, the library contains 1055 isolates, of which 556 are health indicators. In addition, the MMRF also conducted seven training programmes and initiated new researchers programs that were published in 29 peer-review papers. The participating institutes and NCCR have published 50 papers (Impact Factor 94.24) during the year 2011-2017.

The experiences gained in the last 25 years is a step for further development of the monitoring programme by expanding the current assessment, develop science based concepts, national and international networking and use of advanced scientific tools. The continuation of coastal monitoring using an integrated approach of traditional and modern scientific tools could provide scientific products and guidance to protect and conserve the coastal ecosystem from multiple stressors including climate change.

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ABC Abundance Biomass Comparison

AN Andaman and Nicobar Island

BOD Biochemical Oxygen Demand

Chl-a Chlorophyll-a

CMFRI Central Marine Fisheries Research Institute

COMAPS Coastal Ocean and Marine Area Prediction System

CPCB Centre of Pollution Control Board

DIN Dissolved Inorganic Nitrogen

DIP Dissolved Inorganic Phosphorus

DO Dissolved Oxygen

DOD Department of Ocean Development

EC *Escherichia coli*

FBI Faecal bacteria Indicators

FC Faecal coliform

FSI Fishery Survey of India

GIS Geographic Information Systems

HELCOM Helsinki Commission (Baltic Marine Environment Protection Commission)

ICMAM PD Integrated Coastal and Marine Area Management Project Directorate

INCOIS National Centre for Ocean Information System

MoES Ministry of Earth Science

MSFD Marine Strategy Framework Directive

NEON National Ecological Observatory Network

OC Organic Carbon

OSPAR Oslo/Paris convention (for the Protection of the Marine Environment of the North-East Atlantic)

PHC Petroleum hydrocarbon

SFLO *Streptococcus faecalis*

SSC Suspended Solid Concentration

SWQM Sea Water Quality Monitoring Programme

TC Total coliform

TN Total Nitrogen

TP Total Phosphorus

TVC Total Viable Count

USEPA United States Environment Protection Agency

UT Union Territory

WQI Water Quality Index

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Preamble

1.1. General Introduction

The coastal regions are unique because of its position at the interface of atmosphere, lithosphere and hydrosphere. This interaction creates a wide variety of complex habitats, which host a rich biodiversity, energy and mineral resources. Although coastal ocean covers ~10% of the total area of the ocean, it is estimated that this system provides important ecological and economical services (Costanza et al. 2014) in the form of coastal protection, fisheries and other living and non-living resources. This has made the coastal areas centers of human activity for millennia. It is not by chance that virtually all of the world's major cities are located on coasts and an estimated ~50% of the world's population lives within the coastal regions (Sharpe 2005).

The world population is estimated to be 9.8 billion in 2050, and 11.2 billion in 2100 (www.un.org). The increasing human population and rapid boom in industrialization are putting tremendous stress on the coastal systems for their everyday needs. Halpern et al (2008), based on an ecosystem-specific, multi-scale spatial model indicated that no area is unaffected by human and large fractions of the ocean ecosystem (41%) are strongly affected. Consequently, the resources in the coastal ecosystem have become progressively depleted. In particular, it is true of the fishery resources, which has failed to recover in many parts of the world (Botsford et al. 1997). Therefore, gradual deterioration of the coast across the globe and the failure to restore the marine ecosystem, even after the cessation of human interference have demanded comprehensive and comprehensible ecological assessment from societal, economic and political heads.

1.2. The Indian Coastal Ecosystem

India's coastline of about 7500 km spans nine maritime states and five Union Territories including two Island territories. Details of coastal states are given in tables 1.1 and 1.2. The Indian subcontinent with its natural gradient in environmental features, complex oceanography (biannual reversal of surface currents) and unique geological history creates, a number of complex habitats, supporting a diverse biodiversity.

Coastal regions contribute significantly to the country's economy. Like most coastal regions of the world, coastal areas of India are densely populated and ~30% of its human population is dependent on the rich exploitable coastal and marine resources. The population of India increased from 870.610 million in 1990 to 1.211 billion (2011 Census). India's present population accounts for 17.84% of the world population and a UN study predicts that India will surpass China by 2022 to become the most populous nation. Further, three of the four megacities (Mumbai, Chennai and Kolkatta) of India are located along the coast. The pollution of coastal waters in India is mainly due to disposal of sewage, industrial wastes and agricultural runoff. During 2015, the estimated sewage generated from domestic sources was about 61,754 Million Litres per Day (MLD). However, only 22963 MLD is treated, while38,791 MLD (62%) of untreated sewage is released into the aquatic system (CPCB, 2016). There are about 490 large and medium scale industries located along the coast in addition to numerous small scale industries. It is estimated that about 390 million tonnes of industrial effluents are annually discharged into the coastal waters (http://www.cpreec.org). Industrial pollution which reaches the coastal waters either directly or through the rivers is a concern in the coastal States of West Bengal, Tamil Nadu, Gujarat, Maharashtra and Andhra Pradesh.

The oceans remain in the frontier of intercontinental trade. Study shows that ~70% of the total sea transport is ferried through the Indian coastal waters (Anon 2003). Oil pollution is a major environmental problem and is important; in particular to the Indian coastline as two main oil tanker routes pass through the Arabian Sea. This is evident from the number of accidental oil spills have increased along the Indian coast (Sivadas et al., 2008). Moreover, Alang, the largest ship breaking yard is also located along the Gujarat coast.

The country will have to further increase its productions to meet its present and future needs. The unplanned urban and industrial growth will further increase the pressure on the coastal environment. Waste management strategies have failed to keep pace with the rapid urbanization and industrial growth. Moreover, the use of fertilizers and pesticides to enhance agricultural productivity appears to be increasing every year a fraction of which is ultimately washed into the coastal regions through runoff. Aquaculture, tourism and disposal of wastes from fishing trawlers and small ships are other sources of pollutants to the coastal system. The rapid developments of the coast are thus stressing these ecologically sensitive and economically important ecosystems. However, determining and assessing the links between human pressures and coastal ecosystems remains a challenge.

1.3. Background

Marine pollution in the coastal waters of the country is caused due to discharge of largely untreated domestic, industrial and agriculture wastes either directly in to the coastal waters or through rivers and canals. Though the sea has capacity to assimilate and degrade several pollutants arising from land-based sources, often even at low concentrations the pollutants accumulate in marine organisms. Over a period of time, depending on the nature of organism, it reaches to toxic levels in the organisms leading to their mortality. When the levels of pollutants reach beyond the assimilative capacity of the sea, the quality of the seawater reaches to the level of degradation and it would take several years to restore to the safe level when remedial measures are taken. The entire biodiversity reaches to alarmingly low level and fish production declines drastically.

Monitoring the health of coastal waters is highly essential to assess the status of pollution, to detect spatial or temporal changes of pollutant levels and to alert the planners and policy makers on levels of marine pollution. The then Department of Ocean Development, Govt. of India, launched as a project namely "Survey of Environmental Pollutants in the seas around India" in the year 1986. The programme was implemented jointly with the Central Pollution Control Board with participation by 11 National, State and academic institutions. Data on 25 water, sediment and biological parameters were collected at 120 locations in selected estuarine and coastal waters of the country for pre-monsoon, post-monsoon and summer seasons. The project helped in identification of sources of pollution to the sea and also levels of pollutants to enable to classify the areas of low, medium and high pollution. The programme was reviewed in the year 1990 and renamed as Coastal Ocean Monitoring and Prediction System (COMAPS) after inclusion of prediction component to predict levels of pollution to alert in advance the chances of rising levels of pollution or to detect radical changes.

The Ministry of Earth Sciences (MoES) established the Integrated Coastal and Marine Area Management Project Directorate (ICMAM PD) on 2nd January 1998 at Chennai for implementing International Development Association (IDA) assisted

Environment Management Capacity Building project. After completion of tenure of World Bank aided ICMAM programme, the Ministry transferred the COMAPS programme to ICMAM PD, Chennai presently renamed as the National Centre, for Coastal Research (NCCR) for smooth coordination as well as implementation. Under COMAPS programme, monitoring and prediction of seawater quality are the two major components. But the then existing seasonal data sets collected so far were found not adequate for predicting the seawater quality. Hence, during XII Plan period, COMAPS programme was split into two parts. The first part is being implemented in the revised name as, “Seawater Quality Monitoring (SWQM)” with the participation of grantee institutions and the second part is implemented separately as “Prediction of Water Quality (PWQ)” by the NCCR to suggest remedial measures for minimizing the adverse impacts of the pollutants on the marine ecosystem and its resources.

Accordingly, the SWQM programme aims to ensure that the ecological quality of the coastal waters is assessed and the data generated are made available for decision making by policy makers for sustainable management of coastal zones of India. The SWQM provides the foundation for monitoring seawater quality along Indian coast. Since its inception (1990), the SWQM / COMAPS programme has continuously improved, supported planners and decision makers in developing strategies for coastal management.

1.4. Scope and Objectives of SWQM program

The objective of the SWQM program is to monitor water quality parameters periodically in selected locations in the coastal waters of India.

The program also has the following supportive components:

(i) Collection of data from selected major towns/cities on land-based sources of marine pollution, such as domestic, industrial, agriculture and aquaculture wastes;

(ii) Inter-laboratory comparison exercises on selected chemical parameters among institutions participating in monitoring programme to assess and ensure data quality;

(iii) Creating microbial reference facility to identify the bacterial pathogens by using microbial identification system, biochemical studies and other techniques, and maintain reference cultures;

(iv) Development of structured database to archive the data collected from the monitoring program from 1991 till date and to form as baseline data in Oracle for hosting in the website for dissemination to users; and

(v) Development of GIS based database, to understand long-term changes in water quality from monitoring datasets and incorporating secondary data/information such as land use changes over years, sources of pollution, socio-economics.

1.5. Sampling strategy

1.5.1. COMAPS programme from 1990-2011

The status of seawater quality was reviewed and found that among 81 locations monitored, only 24 transects showed reduced levels of dissolved oxygen and more concentrations of nutrients. Accordingly, all these 24 locations are being monitored continuously. Further in few monitoring locations in view of the non-occurrence or lack of inter-annual variations and /or emergence of new source(s) of pollution, they were excluded from the COMAPS programme. At each location, till December, 2010, the samples were collected from 0, 1, 2, 3, 4, 5, 10, 25/30 km from the shore. Frequency of sampling varied from single, bi-annual (two seasons) or all the four seasons in a year. Data were collected for 3-4 seasons (summer, pre-monsoon, monsoon and post-monsoon) a year at 20 locations, designated as hot spots (Table 1.1). The hot spots were identified based on data collected from 1989 to 1991. The data from the locations given in Table 1.2 were collected once a year during 1991 - 2002. Rests of the locations were sampled once in 2 years. During this period, data were collected in the dry months of either summer or pre-monsoon.

The seasonality along the Indian coast varies from State to State. For Andhra Pradesh and Tamil Nadu, the post-monsoon is January to March; summer from April to June; pre-monsoon from June to September and monsoon during October – December. Whereas, for rest of the coastal States, (Gujarat, Maharashtra, Goa, Karnataka, Kerala, Lakshadweep Islands, Odisha, West Bengal and Andaman & Nicobar Islands) the seasons are falling in different months as follows: summer is from January to March; pre-monsoon during April - May; monsoon from June till September and post-monsoon between October and December.

Table 1. 1. Locations for monitoring 3 or 4 seasons a year.

	State/UT	Monitoring Locations
1.	Gujarat	Veraval, Tapi (Hazira),
2.	Maharashtra	Thane creek/ Mumbai
3.	Goa	Mandovi
4.	Karnataka	Mangalore
5.	Kerala	Kochi, Veli
6.	Tamil Nadu	Ennore, Cuddalore, Tuticorin
7.	Puducherry	Puducherry
8.	Andhra Pradesh	Visakhapatnam, Kakinada
9.	Odisha	Mahanadi, Paradip, Puri
10.	West Bengal	Sandheads, Hooghly estuary, Haldia port
11.	Andaman & Nicobar	Port Blair

Table 1. 2. Locations for monitoring once a year

	State/UT	Monitoring Locations
1.	Gujarat	Mundra, Kandla, Vadinar, Okha, Dwarka, Porbandar, Pipavav and Alang
2.	Diu	Diu
3.	Daman	Daman
4.	Maharashtra	Tarapur, Bassein, Versova, Mahim, Thal, Murud, Dabhole, Ratnagiri
5.	Goa	Marmugao, Zuari, Candolim, Valsao
6.	Karnataka	Karwar, Honavar, Chitrapura
7.	Kerala	Kasargod, Cannanore, Calicut, Ponnani, Alleppey, Kayamkulam, Quilon, Paravur
8.	Lakshadweep	Kavaratti
9.	Tamil Nadu	Chennai Harbour, Coovum, Muthukadu, Karaikal, Nagapattinam, Thondi, Uchipuli, Mandapam (Palk

		Strait), Vembar, Arumuganeri, Koodankulam, Kanyakumari
10.	Andhra Pradesh	Krishnapatnam, Machilipatnam, Kalingapatnam, Bhimunipatnam, Gautami-Godavari Point
11.	Odisha	Chandipur, Dhamra, Konark, Chilka, Rushikulya, Gopalpur.
12.	West Bengal	Digha, Diamond Harbour, Saptamukhi, Matla,

1.5.2. Sampling strategy from 2011- 15

The number of locations monitored reduced to 24 from 81 during the XII Plan period (Fig. 1.1). At each location samples were collected from (i) 0/0.5 km (ii) 2 km and (iii) 5 km from the shore. In addition, to understand the dispersion pattern of marine pollutants, one stations each on the north and south at 0.0 km (at river mouth) was sampled. Further, time series data were collected at 0.0 km for 36 hrs with 3 hrs interval. The reasons for the variation and gaps in the data collection were mainly due to budgetary constraints and logistics. Therefore, based on the suggestions of the expert committee, the number of monitoring locations was reduced to 24 sites.

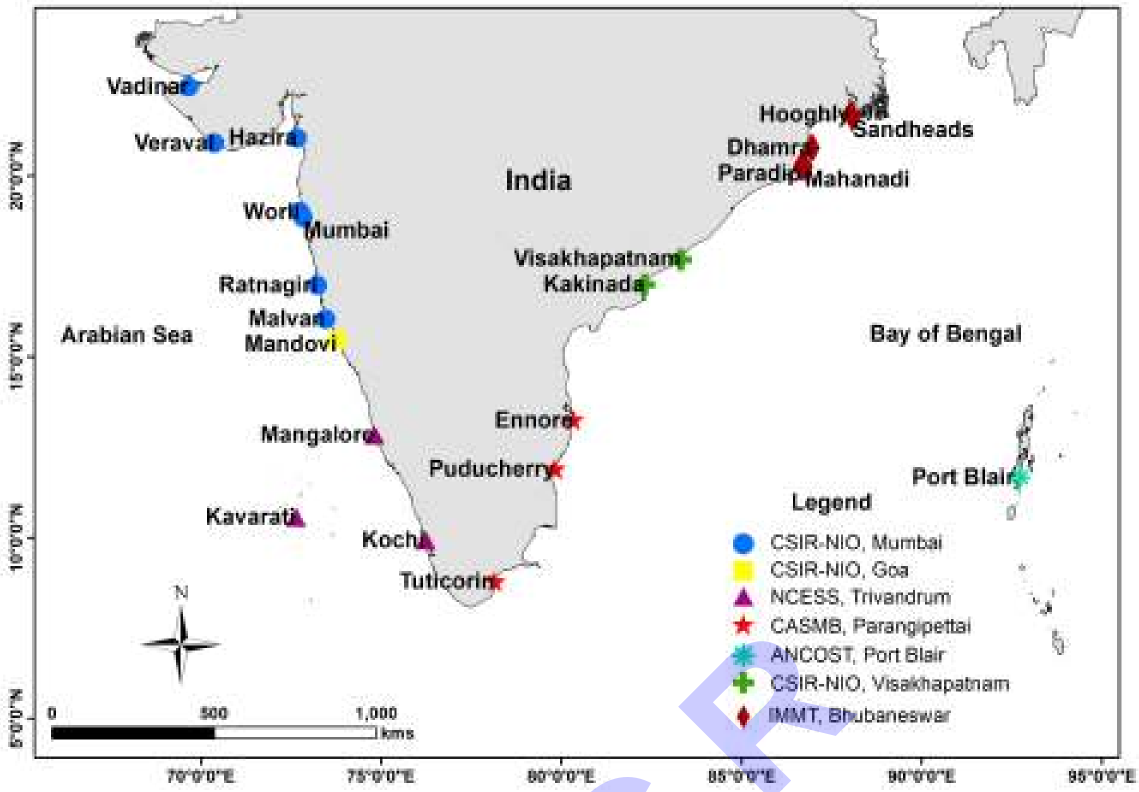

Fig. 1.1. Map showing the monitoring locations (2011-present) and participating centers. CSIR-NIO-National Institute of Oceanography; NCESS-National Centre of Earth System Science; CASMB-Centre of Advanced Study in Marine Biology; ANCOST- Andaman and Nicobar Centre for Ocean Science and Technology; IIMT-Institute for Minerals and Materials Research.

Collection of samples and processing for physico-chemical, biological and microbiological variables, prescribed under the SWQM programme by the participating institutes showed variations in data sets. Amongst the physical variables, most of the institutes collected data for temperature (air and water) and salinity, while suspended solids concentration and transparency are collected only by a few participants. Chemical variables are restricted to DO, Nutrients (nitrate, nitrite, phosphate, silicate and ammonium), whilst metals and petroleum hydrocarbon are analyzed by a very few laboratories.

The biodiversity component is restricted to a few groups, such as phytoplankton, zooplankton and macrofauna. Identification of biota is mostly restricted to genus or higher taxonomic level. Phytoplankton identification is done to genera/species level by most of the participating institutes. Zooplankton identification is restricted upto group /genera level. For macrobenthos, except for few locations, identification was restricted to group level. Meiofauna is collected at few locations with group-level identification. Monitoring microbial diversity was carried out by traditional culture method of total and pathogenic bacteria counts. The higher trophic group such as fish, birds, mammals and reptiles are not a component of the present monitoring programme.

1.6. Participating Centers

The SWQM programme conducts the monitoring in collaboration with National institutes and Universities located in the different coastal states of India. The institutions involved in the programme include, CSIR- National Institute of Oceanography and its Regional Centres (Mumbai, Kochi, Visakhapatnam); Central Salt and Marine Chemical Research Institute, Bhavnagar; National Centre for Earth Science Studies, Thiruvananthapuram; Central Electrochemical Research Institute Units; Madras and Thoothukudi; Institute for Minerals and Materials Technology (IMMT/RRL-B), Bhubaneswar and Regional Research Laboratory, Thiruvananthapuram; Central Pollution Control Board (Zonal Office), Kolkata; Andaman and Nicobar Centre for Ocean Science and Technology, NIOT, Port Blair. The list of participating centres during the XII Plan is given in Fig.1.1.

1.7. Structure of the Report

The rest of the report is structured as follows: The second chapter presents a short review of the methodology adopted under the SWQM programme for collection and analysis of the various parameters. This chapter also describes the data processing and details of statistical work carried out for assessing trends at the selected locations on limited parameters during the last 25 years. Chapter 3 contains the result and discussion of the trend analysis. In the present report, results of two locations (Kochi and Ennore) are presented, while detailed results for rest of the locations are being provided online. The assessment of the coastal waters of India using the Water Quality Index is presented in Chapter 4, followed by the accomplishment of the program. In the Way Forward chapter, the future plans for the SWQM program are discussed. The final chapter contains concluding remarks.

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2. Methodology

2.1. Survey methods

The workflow of the SWQM programme is represented in the schematic diagram (Fig 2.1). Site specific datasets were originally generated by the participating centres on seasonal basis (summer, premonsoon, monsoon and postmonsoon) (Subramanian 2011). Water samples were collected from three zones: (i) shore (0.5 km), (ii) nearshore (2.0 km) and (iii) offshore (5.0 km) at each location (www.icmam.gov.in). Sampling was conducted on-board fishing boat or/and Coastal Research Vessels (CRV), *viz.*, Sagar Purvi and Sagar Paschimi. Water samples were collected from surface, mid-depth and bottom, depending upon the depth of the sampling station using Niskin's water sampler. The samples collected were either analysed immediately on board the vessels or preserved and stored in ice boxes for detailed analysis in the laboratory.

Sediment samples were collected with Van Veen grab for benthos (macro and meiobenthos), sediment texture, organic carbonand metals studies. Macrofaunal samples were sieved on board, whenever possible using a 500 µm sieve and material retained was preserved in 5% buffered formalin-Rose Bengal solution. Meiofauna samples were collected using an acrylic core and immediately preserved in 5% formalin-Rose Bengal solution. For microbial community, water and sediment samples were collected in sterile bottles and preserved in ice box for further analysis in the laboratory. Samples were analysed based on the standard protocols provided by the SWQM Group, NCCR. Sampling and analytical procudres were periodicaly updated by a team of experts based on the globally accepedmethodologies (Burkwall and Hartman 1964; Gledriech et al., 1965; Stirckland and Parsons 1972; Grasshoff et al. 1999 and JGOFS protocols). Updated manuals were circulated to the participating centers for their adoption. Periodical Interlaboratory Calibration Exercises (ILCE) were conducted for selected parameters, since inception of the programme. Participants from the partner organisations were periodically trained for generation of quality data.

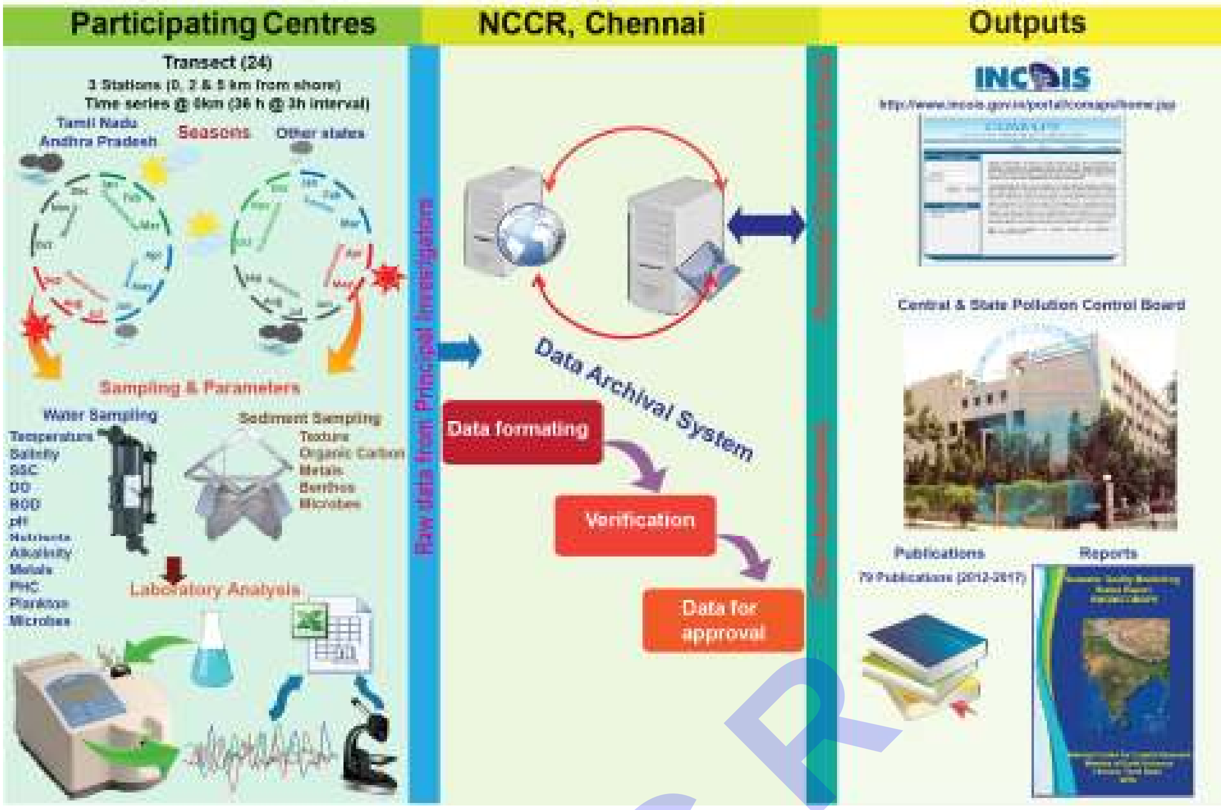


Fig.2.1. Schematic diagram of working of SWQM/COMAPS (SSC Suspended Sediment Concentration; DO Dissolved Oxygen, BOD Biological Oxygen Demand; PHC Petroleum Hydrocarbon; PP Primary Productivity).

2.2. Laboratory Analysis

The various water parameters were analysed using standard protocols (Strickland and Parsons 1972; Grasshoff et al. 1999). Phytoplankton samples were concentrated and 1 ml of concentrate was used for analysis of their population on a Sedgwick-Rafter counting cell. Zooplankton samples was split by Folsom splitter and 25% aliquots were used for estimating the abundance and identification. Macrobenthos samples were sieved again through 500 μm sieve, identified, counted and weighed for biomass. Meiofauna was sieved through 500 μm sieve and 63μm sieve. The material retainedon the 63 μm sieve was used for meiofaunal analyses. Meiofauna was identified up to the group level. Abundance of health indicator bacteria in the samples were analysed following standard procedure mentioned in the technical mannual prepared by Microbial Reference Facility (MMRF), CSIR-National Institute of Oceanography.

2.3. Data Analysis

Data collected from 24 locations during the period from 1990 to 2015 were used for trend analysis. Since the data is available from 0 to 30 km from the shore, three sectors, i.e. 0/0.5km (shore), 2/3 km (nearshore) and ~4/5km (offshore) from shore line were considered after discussions and consulation with experts. Although, some of the databases had observations prior to 1990 the analysis was restricted to 1990 – 2015 for consistency across regions. Sampling in Malvan was initiated during the XII Five Year Plan and hence, data is availabe for only five years.

As first step to ensure the quality of data, the available data was filtered to remove “anomalous” values which can also be treated as outliers. If the reported values were abnormal, the data were re-assessed before accepting into the database. Despite taking precautions (including ILC excercise), if abnormal values were found in the submitted data, those values were checked with other environmental variables or for any unique phenomena. If any such abnormal values were not found in other parameters, the datawere excluded. For example, if extremely high values of Suspended Solid Concentration were observed during the monsoon period in the shore zone (0/0.5 km) the value was retained, however if such values were reported during the non-monsoon period or in 5 km sampling it was not accounted in database. Other examples include high chlorophyll values due to occurrence of any blooms, and high pathogenic bacteria against flash release of untreated sewage at the time of sample collection. In case, the data could not be correlated, they were flagged and not used for the present report.

If such high values are found as the single record in the dataset, those data were also not considered. Therefore, based on the locations, season and comparison with the other parameters, the quality of the data were judged and only such data were used for detailed analysis to derive long-term trends. Further, locations with <5 years observation were not considered in the report. In case of inequality in data size between the years, it may not affect the analysis as the data are available for several years.

For the present report, DO, nutrients (nitrate, ammonia, phosphate and silicate), phytoplankton abundance and biomass (Chl-a), zooplankton (abundance and biomass), macrofauna (abundance and biomass) and Total Viable Count (TVC) and health indiator bacteria such as *Escherichia coli* (*E. coli*) and *Streptococcus faecalis* (*S. faecalis*) have been used to assess the health of the coastal waters. These variables are considered to be primary water quality indicators of coastal system. Plankton (phytoplankton and zooplankton) and macrobenthos species/ genera that contributed to **>**10% of the total species were used to identify the dominant species.

2.4. Statistical Analysis

The data were processed using Microsoft excel, Statistica 13.2, OriginLab and Grapher software's and Graph Pad Prism for spatio-temporal comparison. The median values were used since the sampling varied over the long time period. The median values is a more robust measure, sensible and not sensitive to outliers especially for long-term data. In long-term monitoring, data distributions may be skewed and not readily transformed to symmetry; therefore, it may be more informative to compare different patterns in terms of median rather than means. The Box-Whisker plots depict the median, 25 and 75 percentile, outliers and Standard Deviation (SD). Significance of differences between medians was assessed by the non-parametric rank test (Chi-Square test). Spearman's correlation analysis was used to relate the biological and environmental variables.

3. Results

3.1. Physico-chemical parameters

3.1.1. Long term spatial and zonal variations:

Long-term spatial and zonal variation of the physico-chemical parameters viz., temperature, salinity, pH, suspended sediment concentrations (SSC), dissolved oxygen (DO), percent oxygen saturation, nitrite-nitrogen, nitrate-nitrogen, ammonia-nitrogen, phosphate and silicate recorded at all the sampling points along the east and west coasts are represented in the box-whisker plots (Fig.3.1.1.1 –3.1.1.4). The minimum, maximum and mean values of the selected parameters are given in Table 3.1.1.1-3.1.1.4.

Surface temperature showed a north-south geographical gradient along both the coasts. Higher mean and median temperature values (Fig.3.1.1.1) were observed in the stations located towards the south than on the northern region.

Salinity ranged from 0.2 to 40 in the shore and 9.1 to 40.32 (Fig.3.1.1.1) in the offshore zones. Salinity values showed a clear variation between the stations located along the Arabian Sea and Bay of Bengal. While higher salinity values were observed for stations located in the Gulf of Kutch and Gulf of Khambhat region i.e. Vadinar and Veraval, respectively, the lower salinity values were observed in the stations dominated by perennial riverine discharges i.e., Hooghly and Sandheads in the east coast.

Higher SSC values were observed at the riverine discharge dominated stations like Hazira (653) (Fig.3.1.1.2) in the west coast and Sandheads (133) and Hooghly (114) in the east coast. Very high values (>500 mg/l) were observed even in the offshore zone of the east coast stations.

Dissolved oxygen concentrations varied from < 0.2 to 11.43 mg/l in the shoresampling points and 1.38 to 10.64 mg/l in the offshore zone (Fig.3.1.1.2). The median dissolved oxygen concentrations were observed to be the lowest at Veraval (1.29 mg/l) and the highest at Hooghly (7.35l) in the shore zone, while Zuari (4.36 mg/l) and Dhamra (7.79 mg/l) in the offshore zone. The DO value of< 0.2 mg/l was observed at Veraval, Hazira, Kakinada and Visakhapatnam.

Dissolved inorganic nitrogen {DIN (Sum of Nitrite-N, Nitrate-N and Ammonia-N)} revealed high zonal and spatial variability, with concentrations ranging from 0.22 to

395.26 µM in the shore and 0.29 to 61.70 µM in the offshore. High median concentrations of DIN in the shore region were observed at Veraval (37.74 µM), Hazira (29.61 µM) and Mumbai (23.67 µM) along the west coast. Along the east coast, Kakinada (13.49 µM), Sandheads (13 µM) andVisakhapatnam (10.61 µM) recorded high DIN values. Ammonia-N was found to be the dominant contributor for the DIN pool in most of the locations followed by nitrate-N and nitrite-N in the shore, while nitrate-N was found to be the major contributor in the offshore. DIN concentrations in the shore were always higher than offshore in all the locations in a magnitude of 1.5 – 2, whereas in the case of Veraval, the order of magnitude was 10 between shore and offshore concentrations. Hazira (22.89 µM), Mumbai (19.94 µM), Hooghly (16.18 µM) and Sandheads (10.29 µM) exhibited very high median concentrations of DIN even in the offshore locations (Fig.3.1.1.3), indicating the existence of the regional anthropogenic pressure till the offshore region.

Dissolved inorganic phosphate (DIP) (Fig. 3.1.1.3) exhibited similar trends like DIN with median high concentrations observed at Veraval (4.00 µM), Mumbai (2.70 µM) and Hazira (2.25 µM) in the west coast. Visakhapatnam (1.87 µM), Kakinada (1.81 µM). Hooghly (1.72 µM) and Sandheads (1.45 µM) exhibited high median values of DIP along the east coast. Extremely high values of DIP (20 µM) were frequently observed in the above-mentioned locations. Similar to DIN, DIP enrichment was in the magnitude of 1.5 – 6 in the shore region than in the offshore region.

The dissolved silicate (DSi) concentration ranged from 0.20 to 324.90 µM in the shore and 0.4 to 155.2 µM in the offshore regions. The spatial variation of (DSi) was less than that observed for DIN and DIP, as its distribution in higher concentrations was observed in most of the locations (Fig.3.1.1.2). However, the high median concentrations of DSi were recorded in the same locations as that observed for DIN and DIP *i.e.* Hazira (56.30 µM), Veraval (22.79 µM), Kakinada (16.13 µM),Mumbai (15.40 µM)and Visakhapatnam (13.57 µM).

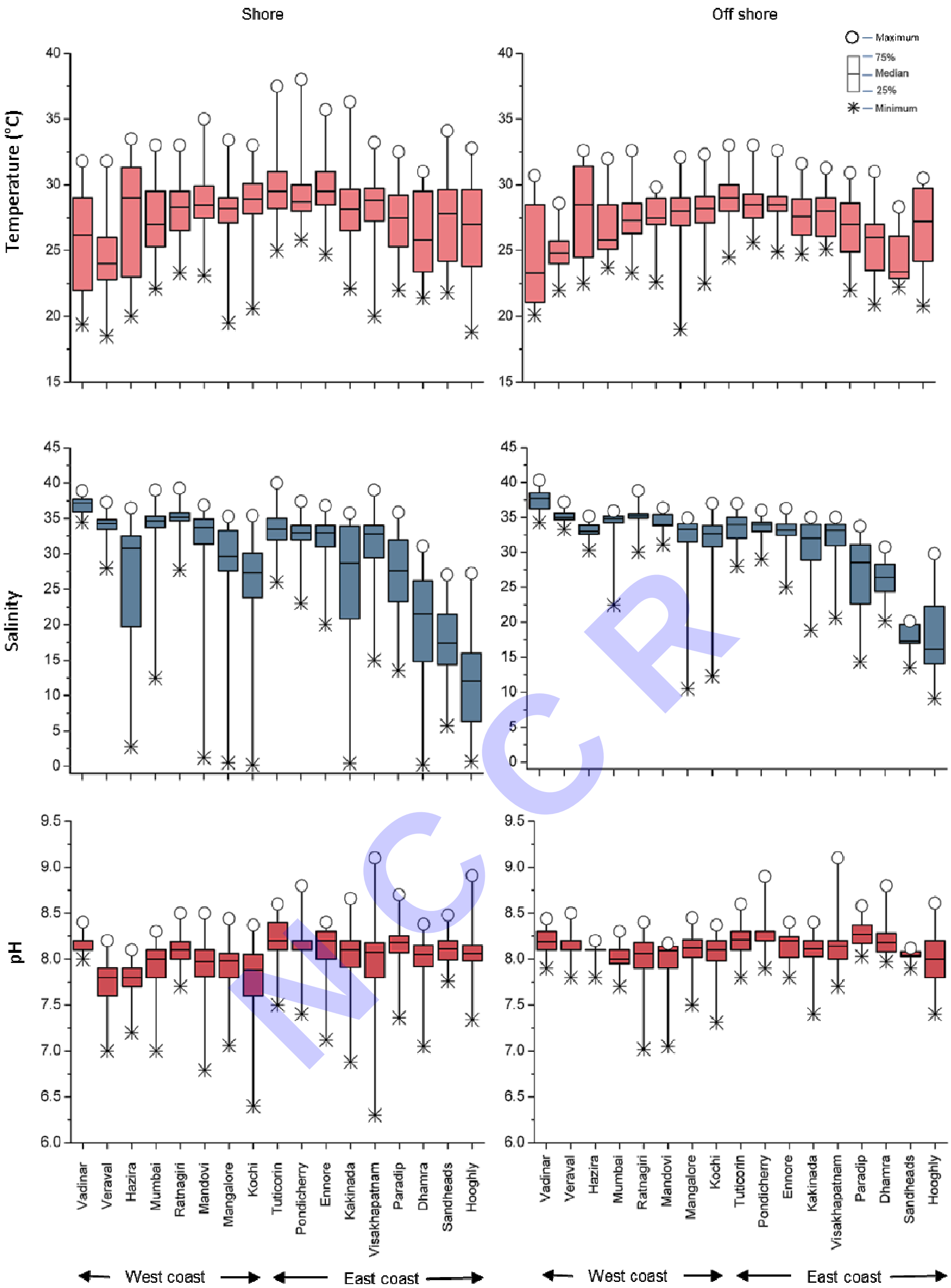


Fig. 3.1.1.1. Box-whisker plot for parameters temperature (°C), salinity and pH from the monitored locations. The plots give the median (horizontal line inside the box), 25 and 75 percentiles (boxes) and the whisker indicates minimum (X) and maximum (O) values recorded.

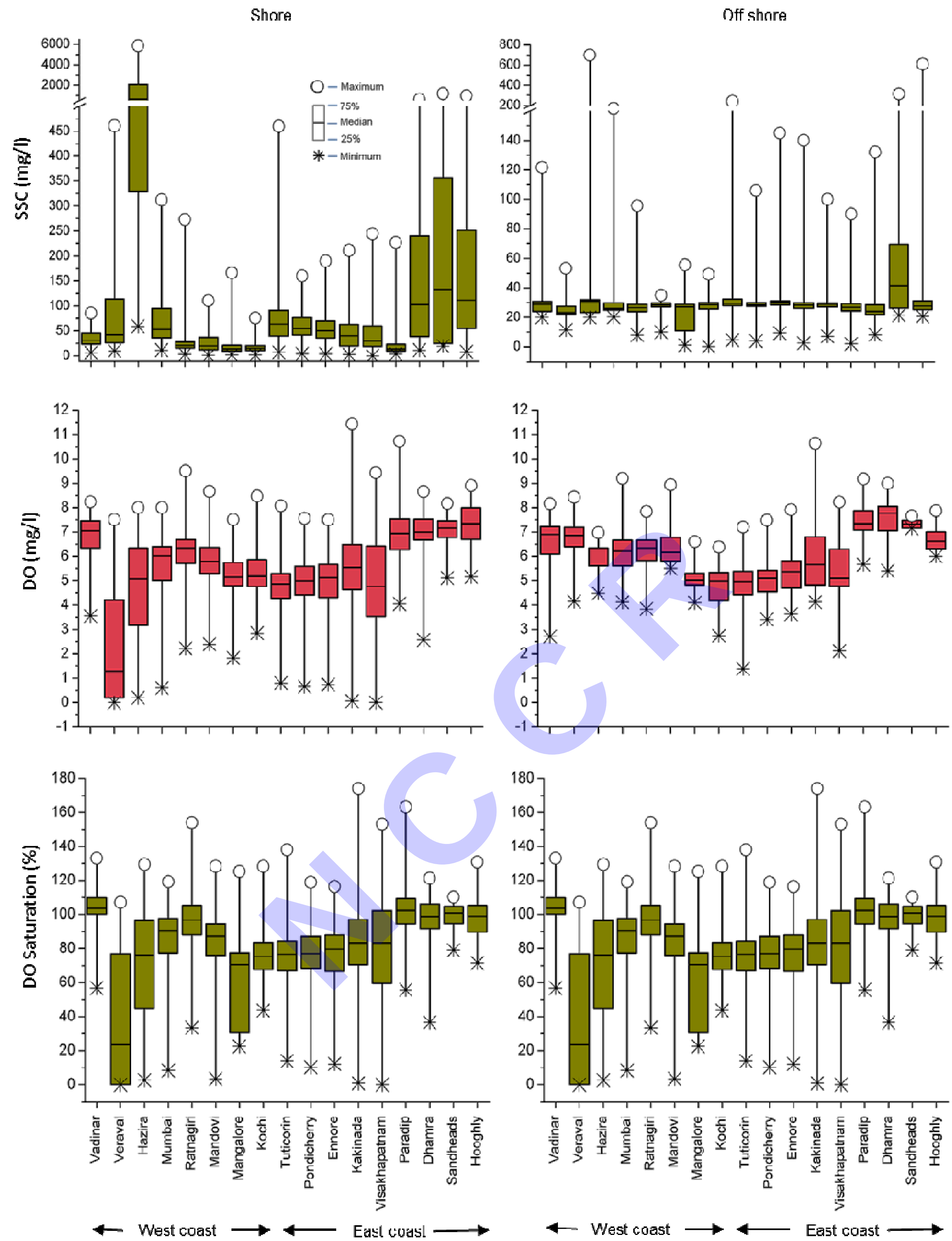


Fig. 3.1.1.2. Box-whisker plot for parameters SSC (mg/l), DO (mg/l) and DO saturation (%) from the monitored locations. The plots give the median (horizontal line inside the box), 25 and 75 percentiles (boxes) and the whisker indicates minimum (X) and maximum (O) values recorded.

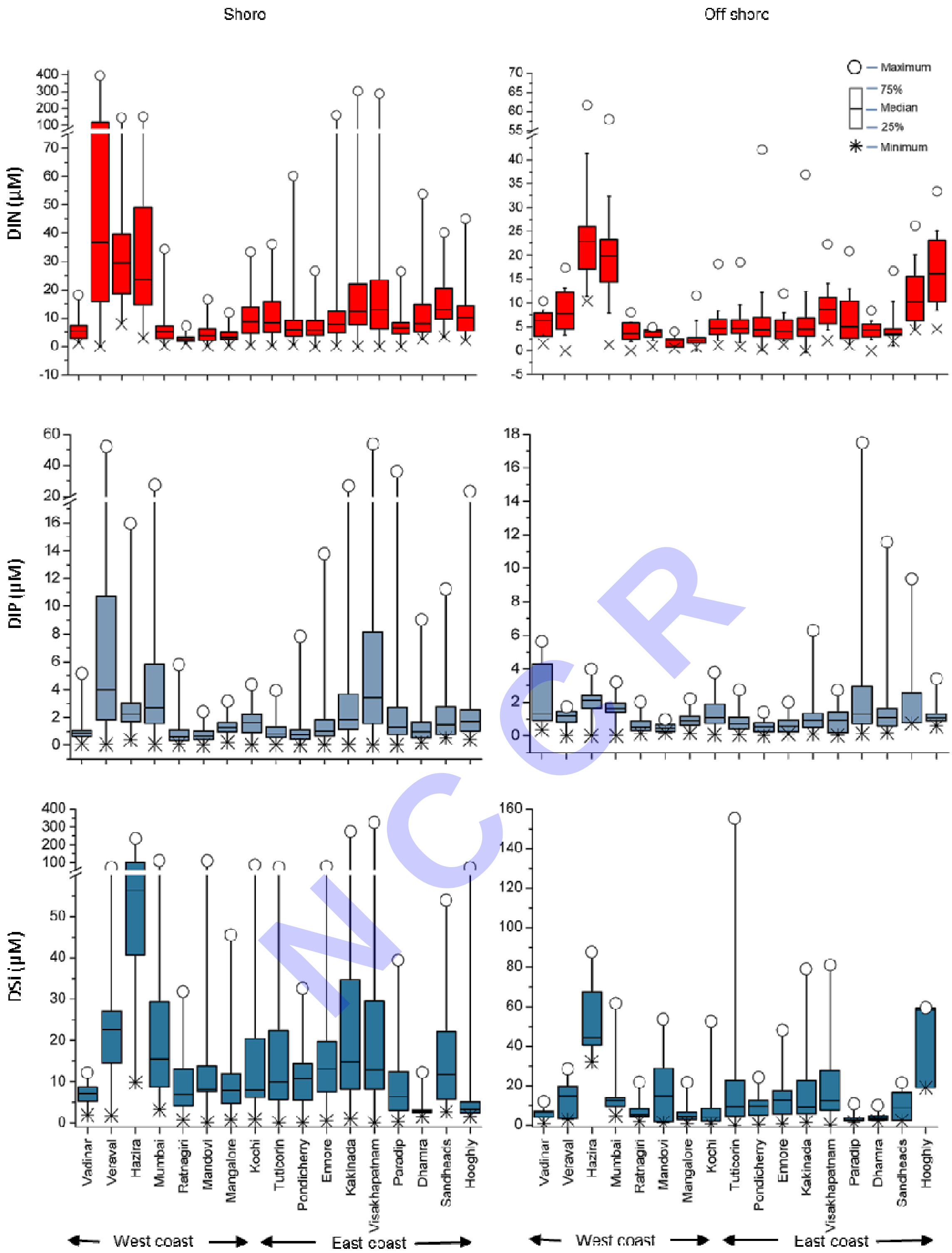


Fig. 3.1.1.3. Box-whisker plot for parameters DIN (µM), DIP (µM) and DSi (µM) from the monitored locations. The plots give the median (horizontal line inside the box), 25 and 75 percentiles (boxes) and the whisker indicates minimum (X) and maximum (O) values recorded.

Table 3.1.1.1. Minimum, Maximum and Median values of the parameters recorded (shore zone) at the stations located along the West coast

Location		Temperature (°C)	SSC (mg/l)	pH	Salinity	DO (mg/l)	DIN (µM)	DIP (µM)	DSi (µM)	TN (µM)	TP (µM)
Veraval	Min	18.50	9.77	7.00	27.96	<0.2	BDL	BDL	1.79	17.30	1.01
	Max	31.80	461.00	8.20	37.30	7.51	395.26	52.22	74.32	2,381.90	141.19
	Median	24	44.05	7.8	34.28	1.29	37.74	4	22.79	206.13	12.19
Vadinar	Min	19.40	6.40	8.00	34.46	3.55	1.29	0.10	1.90	22.68	0.50
	Max	31.80	85.68	8.40	38.90	8.24	18.23	5.16	12.22	139.53	8.13
	Median	26.3	31.12	8.2	37.27	7.04	5.49	0.9	7.14	82.15	2.38
Hazira	Min	20	58.98	7.20	2.74	<0.2	8.01	0.38	9.82	40.04	1.85
	Max	33.5	5865.2	8.1	36.46	8	145.68	15.93	234.36	441.91	9.79
	Median	29.25	653	7.8	30.78	5.07	29.61	2.25	56.3	145.91	3.83
Mumbai	Min	22.1	11.5	7.00	12.45	0.6	2.96	BDL	3.23	14.10	1.10
	Max	33	312	8.3	39	8	151.75	27.44	111.71	762.76	35.42
	Median	27	53	8	34.74	6.02	23.67	2.7	15.4	385.18	5.63
Ratnagiri	Min	23.30	6.64	7.71	27.70	2.21	0.38	BDL	0.67	4.41	0.44
	Max	33.00	273.20	8.50	38.63	9.50	34.30	5.80	31.80	417.10	13.81
	Median	28.35	20.6	8.1	35.18	6.34	5.01	0.59	6.81	47.38	1.43
Mandovi	Min	25.00	0.70	6.86	1.21	2.39	0.22	BDL	BDL	5.82	0.26
	Max	35.00	106.00	8.50	36.81	8.67	16.59	2.40	110.79	78.88	4.62
	Median	28.49	19	7.97	33.71	5.7	3.81	0.68	12.71	21.73	1.46
Zuari	Min	23.30	0.09	7.35	31.80	2.85	0.35	BDL	0.27	6.52	0.19
	Max	32.20	59.00	8.79	38.76	8.38	11.96	2.44	12.63	56.50	3.86
	Median	28.5	11.6	8.07	34.76	6.16	3.63	0.64	6.61	22.5	1.52
Mangalore	Min	20.00	1.80	7.06	0.50	1.82	0.48	0.21	0.75	4.65	0.52
	Max	33.40	147.30	8.42	35.29	7.51	33.31	3.16	45.54	47.27	8.91
	Median	28.2	14.3	7.98	29.65	5.08	8.63	1.26	8.87	19.26	2.31
Kochi	Min	20.60	1.80	6.40	0.20	2.85	0.34	BDL	0.80	2.60	0.16
	Max	33.00	1058.00	8.35	35.42	8.47	36.09	4.37	88.88	89.94	8.83
	Median	28.9	15.26	7.88	27.32	5.01	7.47	1.61	11.66	22.22	2.76

Table 3.1.1.2. Minimum, Maximum and Median values of the parameters recorded (shore zone)at the stations locatedalong the East coast											
Location		**Temperature (°C)**	**SSC (mg/l)**	**pH**	**Salinity**	**DO (mg/l)**	**DIN (µM)**	**DIP (µM)**	**DSi (µM)**	**TN (µM)**	**TP (µM)**
Tuticorin	Min	23.30	7.00	7.50	26.00	0.80	0.58	BDL	BDL	2.32	0.16
	Max	37.50	460.00	8.60	40.00	8.08	60.23	3.92	75.40	184.30	5.83
	Median	29.5	64	8.2	33.52	4.86	5.99	0.82	9.89	16.39	1.91
Puducherry	Min	25.80	4.12	7.40	23.00	0.65	0.00	BDL	0.12	2.63	0.20
	Max	38.00	160.00	8.80	37.39	7.56	26.71	7.84	32.56	76.20	9.46
	Median	28.5	42	8.1	32	5.53	9.57	1.46	13.16	30.66	3.2
Ennore	Min	24.70	3.74	7.12	20.00	0.73	0.20	BDL	0.46	4.53	0.13
	Max	35.7	190	8.4	36.82	7.5	160.20	13.76	79.83	373.77	30.18
	Median	29.5	50	8.2	33	5.12	7.83	1.04	13.2	18.48	2.14
Kakinada	Min	22.10	4.20	6.88	0.42	<0.2	0.00	BDL	1.01	4.56	0.14
	Max	36.30	211.20	8.63	35.76	11.43	302.85	26.79	274.40	527.00	135.00
	Median	28.14	40.4	8.1	28.7	5.63	13.49	1.81	16.13	48.6	4.03
Visakhapatnam	Min	23.30	0.00	5.40	15.00	<0.2	BDL	BDL	BDL	1.85	0.15
	Max	33.20	245.00	9.10	39.00	9.43	287.44	78.30	324.90	549.46	423.60
	Median	28.3	37.8	8.1	30.16	6.32	10.61	1.87	13.57	42.8	5.3
Paradip	Min	22.00	3.58	7.36	13.56	4.05	0.00	BDL	0.36	10.34	0.32
	Max	32.50	227.00	8.70	35.85	10.73	26.50	75.62	39.44	211.11	97.50
	Median	27.5	14	8.18	27.67	6.93	6.62	1.28	6.33	34.43	2.83
Dhamra	Min	21.40	11.27	7.05	0.22	2.57	2.70	0.18	1.55	15.90	0.97
	Max	31	606.06	8.38	31.1	8.66	53.85	9.05	12.27	72.09	187.00
	Median	26.05	109.03	8.05	21.51	7	8.04	0.98	2.76	40.66	3.4
Sandheads	Min	23.30	19.79	7.76	5.72	5.11	3.50	0.52	2.70	27.86	0.90
	Max	34.10	1188.00	8.48	27.04	8.17	40.15	11.25	53.92	153.69	22.50
	Median	27.8	133.62	8.11	17.58	7.16	13	1.45	12.79	72.67	2.9
Hooghly	Min	18.80	8.19	7.34	0.68	5.16	2.16	0.41	1.59	17.59	1.77
	Max	32.8	1055.25	8.91	27.24	8.9	44.95	23.44	73.21	163.49	30.62
	Median	27	114.03	8.06	12.07	7.35	10.21	1.72	3.26	59.55	4.9

Table 3.1.1.3. Minimum, Maximum and Mean values of the parameters recorded (offshore zone) atthe stations located along the West coast

Location		Temperature (°C)	SSC (mg/l)	pH	Salinity	DO (mg/l)	DIN (µM)	DIP (µM)	DSi (µM)	TN (µM)	TP (µM)
Veraval	Min	22.00	11.50	7.80	33.30	4.15	BDL	BDL	2.79	5.00	1.10
	Max	28.60	53.32	8.50	37.20	8.43	17.31	1.74	28.46	223.10	3.41
	Median	24.8	29.04	8.1	35	6.92	7.72	1.18	14.84	52	1.66
Vadinar	Min	20.10	20.96	7.90	34.27	2.71	1.51	0.36	0.89	33.66	1.12
	Max	30.70	121.60	8.44	40.33	8.16	10.38	5.63	12.00	98.46	8.91
	Median	23.3	42.06	8.19	37.7	6.9	6.36	1.31	6.78	78.02	2.19
Hazira	Min	22.50	38.00	7.80	30.30	4.48	10.42	BDL	31.92	55.86	1.86
	Max	32.60	2,247.60	8.20	35.18	6.97	61.70	4.00	87.61	167.53	5.98
	Median	28.5	500.6	8.1	33	6.34	22.89	2.13	44.42	141.89	5.15
Mumbai	Min	23.70	20.22	7.70	22.47	4.12	1.28	BDL	4.71	14.50	1.00
	Max	32.00	190.30	8.30	35.90	9.20	57.90	3.20	61.66	469.30	9.51
	Median	26.5	35.87	8	34.82	6.43	19.94	1.63	12.39	402.17	4.12
Ratnagiri	Min	23.30	8.00	7.02	30.04	0.82	0.01	0.13	0.62	5.64	0.30
	Max	32.60	95.70	8.40	38.83	7.84	9.52	2.92	27.00	210.10	3.56
	Median	27.28	17.1	8.08	35.2	6.05	3.62	0.52	5.52	33.5	1.2
Mandovi	Min	22.61	10.00	7.05	31.10	0.29	0.58	0.14	1.15	4.87	0.50
	Max	29.83	21.40	8.17	36.38	8.93	7.52	2.02	68.66	76.98	4.38
	Median	27.87	14.25	8.1	34	5.84	2.19	0.63	14.43	17.3	1.4
Zuari	Min	27.89	12.58	7.73	32.80	2.74	0.70	0.20	2.35	11.58	1.92
	Max	30.67	40.79	8.78	35.15	6.58	11.56	2.57	11.56	21.84	3.75
	Median	29.53	21.08	8.27	34.17	4.36	2.54	1.37	5.87	19.05	2.69
Mangalore	Min	19.00	1.20	7.50	10.50	3.24	0.63	0.16	0.72	4.29	0.36
	Max	32.10	55.60	8.45	34.90	6.93	18.74	2.58	23.14	44.09	6.19
	Median	28	7.1	8.12	33.3	4.83	5.14	0.92	4.38	12.3	1.83
Kochi	Min	22.50	0.26	7.31	12.30	2.63	0.28	BDL	0.68	3.04	0.31
	Max	32.30	49.20	8.37	37.02	6.38	18.55	4.06	52.63	59.00	13.00
	Median	28.2	8.61	8.1	32.71	4.62	5.28	1.12	4.05	12.64	2.39

Table 3.1.1.4. Minimum, Maximum and Mean values of the parameters recorded at the stations (offshore zone) located along the East coast

Location		Temperature (°C)	SSC (mg/l)	pH	Salinity	DO (mg/l)	DIN (μM)	DIP (μM)	DSi (μM)	TN (μM)	TP (μM)
Tuticorin	Min	24.50	4.60	7.80	28.00	1.38	0.31	BDL	BDL	1.83	0.41
	Max	33.00	240.00	8.60	37.00	7.60	42.07	2.74	155.20	73.51	13.38
	Median	29	39.6	8.21	34	4.99	4.49	0.69	9.79	15.3	1.42
Puducherry	Min	25.60	4.00	7.90	29.00	3.41	1.25	BDL	0.40	4.12	0.45
	Max	33.00	106.00	8.90	36.00	7.48	11.99	1.40	24.13	55.32	2.84
	Median	28.5	37.4	8.2	34	5.1	4.03	0.54	9.77	15.38	1.3
Ennore	Min	24.90	9.27	7.80	25.00	3.63	0.02	0.11	0.79	0.87	0.33
	Max	32.60	145.00	8.40	36.31	7.91	36.90	2.00	48.08	59.14	9.59
	Median	28.5	43.8	8.2	33.19	5.37	4.79	0.56	12.72	14.55	1.47
Kakinada	Min	24.72	2.60	7.40	18.84	3.14	2.09	0.11	1.47	7.29	0.58
	Max	31.60	140.00	8.40	35.00	10.64	29.20	6.28	79.00	104.14	17.57
	Median	27.5	26.44	8.16	29.71	6.58	7.39	1.03	9.45	36.08	2.51
Visakhapatnam	Min	25.10	7.10	7.70	20.60	2.12	1.16	BDL	0.20	3.29	0.15
	Max	31.27	100.00	9.10	35.00	8.23	28.00	2.72	80.98	97.00	36.47
	Median	28	34.6	8.15	33.35	5.64	6.35	0.97	12.54	23.46	2.5
Paradip	Min	22.00	2.10	8.03	14.36	5.66	0.00	0.13	1.48	16.48	0.68
	Max	30.90	90.00	8.58	33.76	9.18	8.50	17.50	10.69	121.11	35.00
	Median	27	8.21	8.27	28.53	7.35	4.35	1.24	2.72	29.18	2.49
Dhamra	Min	20.90	8.22	7.97	20.17	5.40	1.99	0.18	2.08	19.74	1.58
	Max	31.00	132.00	8.80	30.77	8.99	16.72	11.56	9.91	94.83	16.80
	Median	26.1	25.17	8.18	26.43	7.79	3.5	1.12	3.24	36.9	2.98
Sandheads	Min	22.20	21.33	7.90	13.52	7.15	4.39	0.74	2.30	26.79	1.35
	Max	28.30	314.97	8.12	20.14	7.66	12.17	9.37	21.50	51.79	6.91
	Median	23.85	41.54	8.06	18.33	7.35	10.29	1.25	8.78	49.06	6.05
Hooghly	Min	20.80	28.00	7.40	9.10	6.00	4.57	0.58	19.00	20.29	1.03
	Max	26.63	231.12	8.02	18.21	6.78	33.36	1.19	45.54	196.21	5.13
	Median	27.2	146	8.03	17.3	6.71	16.18	1.08	58.25	72.25	1.81

3.2. Plankton

3.2.1. ***Phytoplankton***

Phytoplankton biomass ranged from 0.1 to 58.9 mg/m^3 in the monitored locations.Considerable variability was noticed between east coast and west coast of India (Fig 3.2.1.1). Highest phytoplankton biomass (median value) was noticed in the shore region (2.1 mg/m^3) and nearshore (2.1 mg/m^3) followed by offshore (2.0 mg/m^3) region (Fig 3.2.1.1) probably due to availability of high amount of nutrients.Phytoplankton biomass in the shore region of Veraval (0.2 - 15 mg/m^3), Ratnagiri (0.2 - 21.8 mg/m^3), Kochi (0.1 - 11 mg/m^3) and Visakhapatnam (0.2 - 14 mg/m^3) showed large variability. Further, phytoplankton biomass also showed high variability in the nearshore and offshore regions of the monitoring locations situated along thesouthwest and southeast coast. In general, biomass showed a decreasing trend at some locations such as Vadinar, Thoothukudi and Puducherry, whereas in other locations it did not show much variability (Fig 3.2.1.2)

The phytoplankton abundance in the monitoring locations varied from 80 to 9477200 cells/L. In contrast, to the phytoplankton biomass, highest abundance was noticed in the offshore (20141 cells/L) followed by nearshore (18863 cells/L) and shore region (10240) cells/L)(Fig 3.2.1.1). Phytoplankton abundance showed the highest variability at locations along the northwest coast of India. Phytoplankton abundance showed increasing trend at Kochi and Kakinada, while a decreasing trend was observed in the coastal waters of Paradip and Sandheads (Fig 3.2.1.3).The spatial variability observed in the phytoplankton abundance and biomass in the monitored locations are probably due to the differences in the rainfall, fertilizer discharge from agriculture land, quantity of river discharge amongst thelocation.

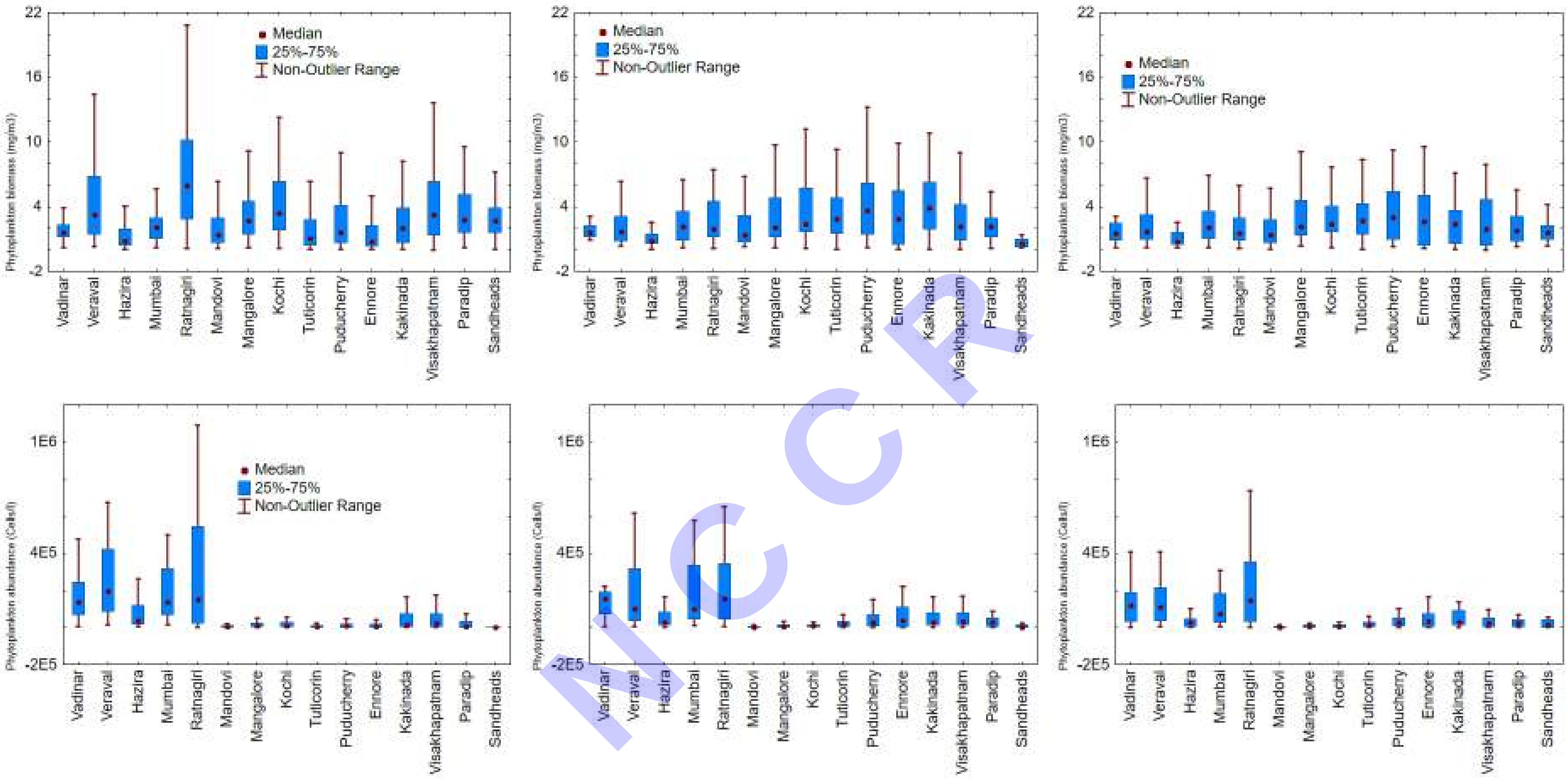


Fig. 3.2.1.1. Spatial variability in phytoplankton biomass and abundances along Indian coast

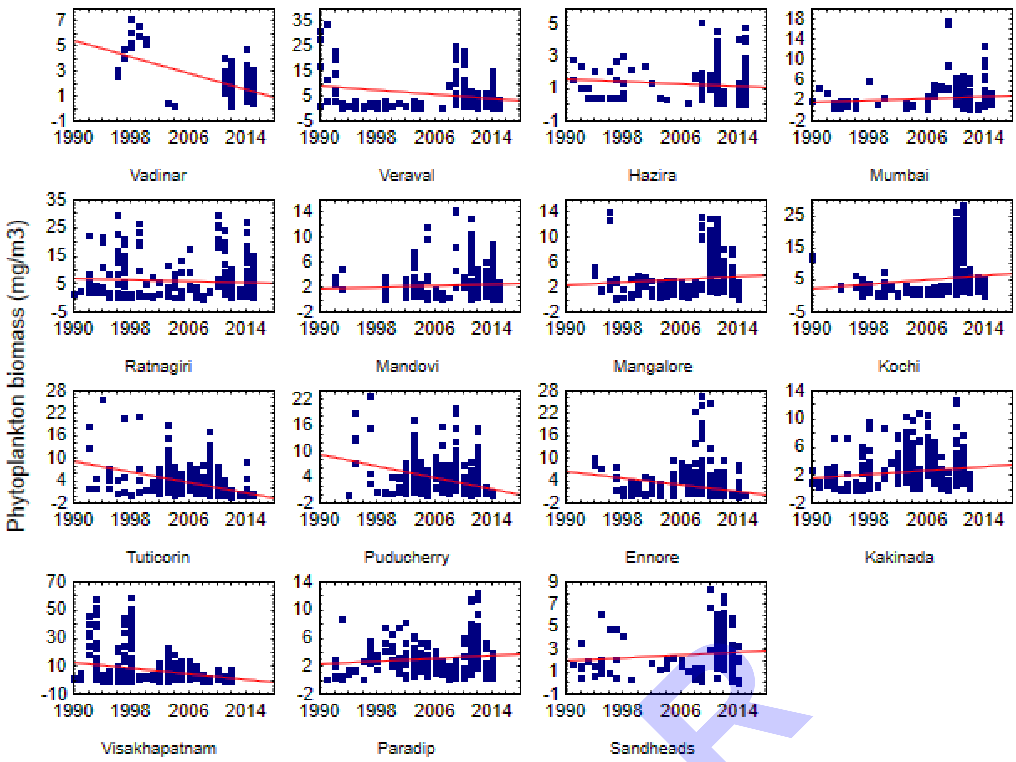


Fig. 3.2.1.2. Inter-annual variability in phytoplankton biomass along Indian coast

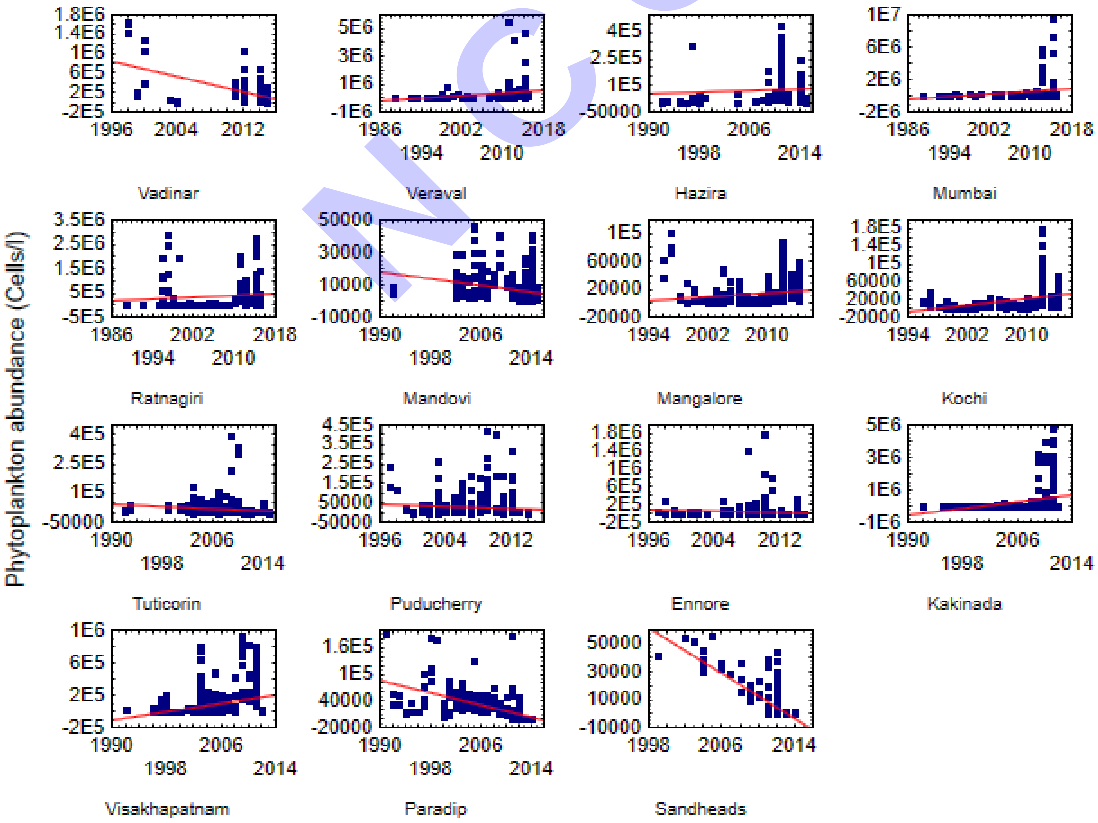


Fig 3.2.1.3: Inter-annual variability in phytoplankton abundance along Indian coast

3.2.2. ***Zooplankton***

The zooplankton biomass in the monitored locations varied from 0.01 to 25.6 ml/m^3 during the monitoring period. Biomass showed considerable variability between the east and west coast locations and, within the monitoring locations from shore to offshore (Fig.3.2.2.1).Zooplankton biomass and abundance showed their maximum numbers in the locations situated along the east coast (Fig. 3.2.2.2). The highest zooplankton biomass (median value) was noticed in the shore region (0.14 ml/m^3) and nearshore (0.14 ml/m^3) than offshore (0.11 ml/m^3) regions. Interestingly, zooplankton abundance showed the highest abundance along nearshore (2683 Nos/m^3) region, probably due to the optimum salinity and food availability, followed by shore (2160 Nos/m^3) and offshore regions (835 Nos/m^3) (Fig. 3.2.2.3). Comparatively, high variability was noticed in zooplankton biomass and abundance along the east coast of India. Zooplankton biomass showed increasing trend along Mangaluru, Kochi, Thoothukudi, Puducherry, Ennore and Sandheads (Fig 3.2.2.5), whereas, zooplankton abundance showed increasing trend at Kochi and Mangaluru coastal waters (Fig 3.2.2.6).Food availability, salinity and temperature are the major factors that controls zooplankton distribution pattern. The variability of these factors along the Indian coast could have accounted for the difference observed in the zooplankton abundance and biomass among and within the monitored locations.

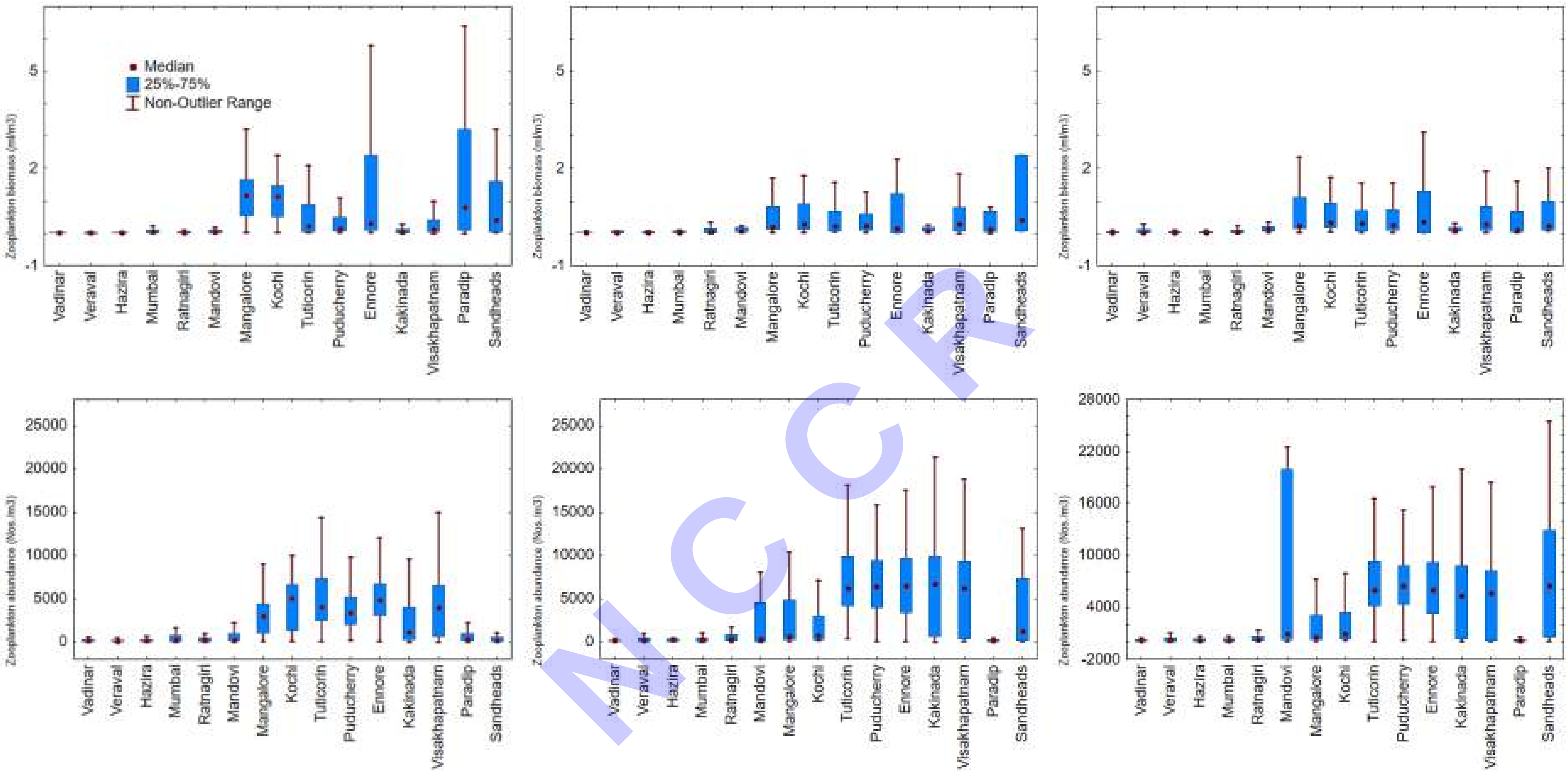


Fig.3.2.2.1. Spatial variability in zooplankton biomass and abundance along Indian coast

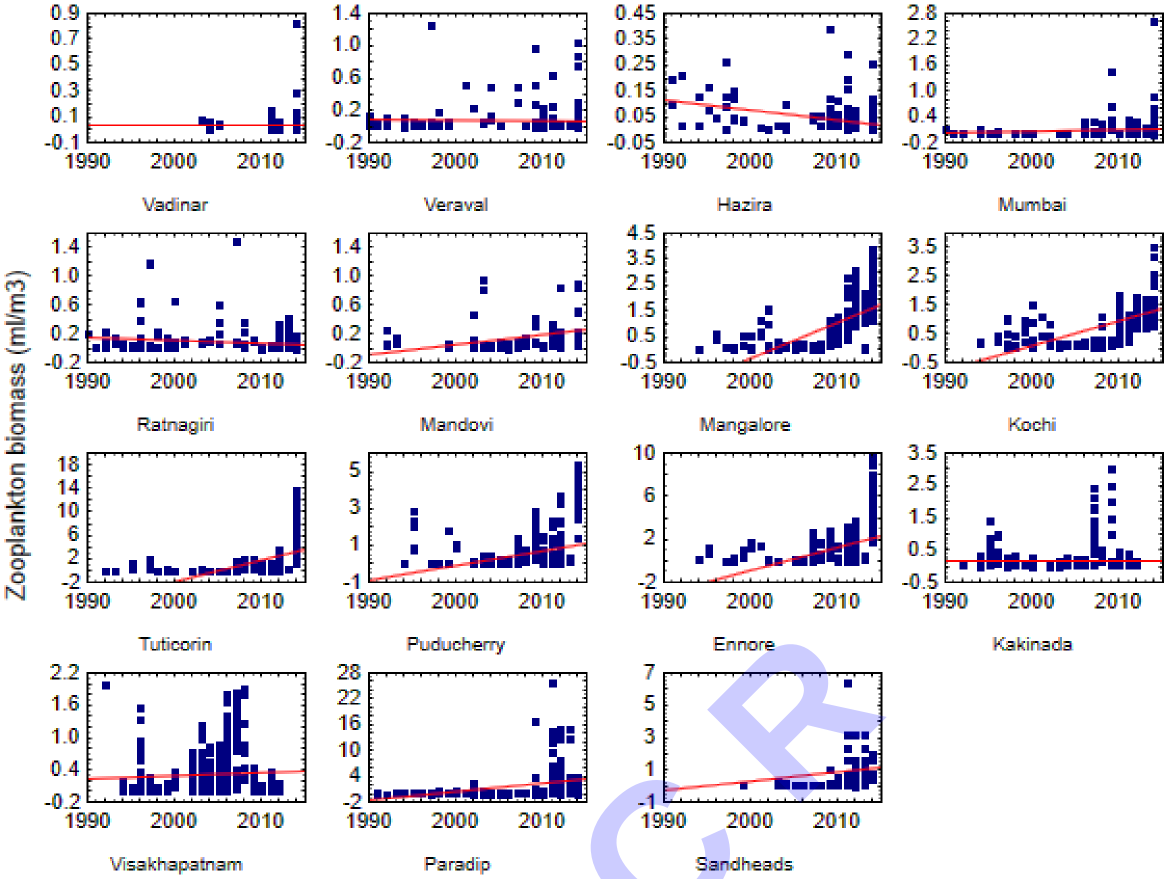


Fig.3.2.2.2. Inter-annual variability in zooplankton biomass along Indian coast

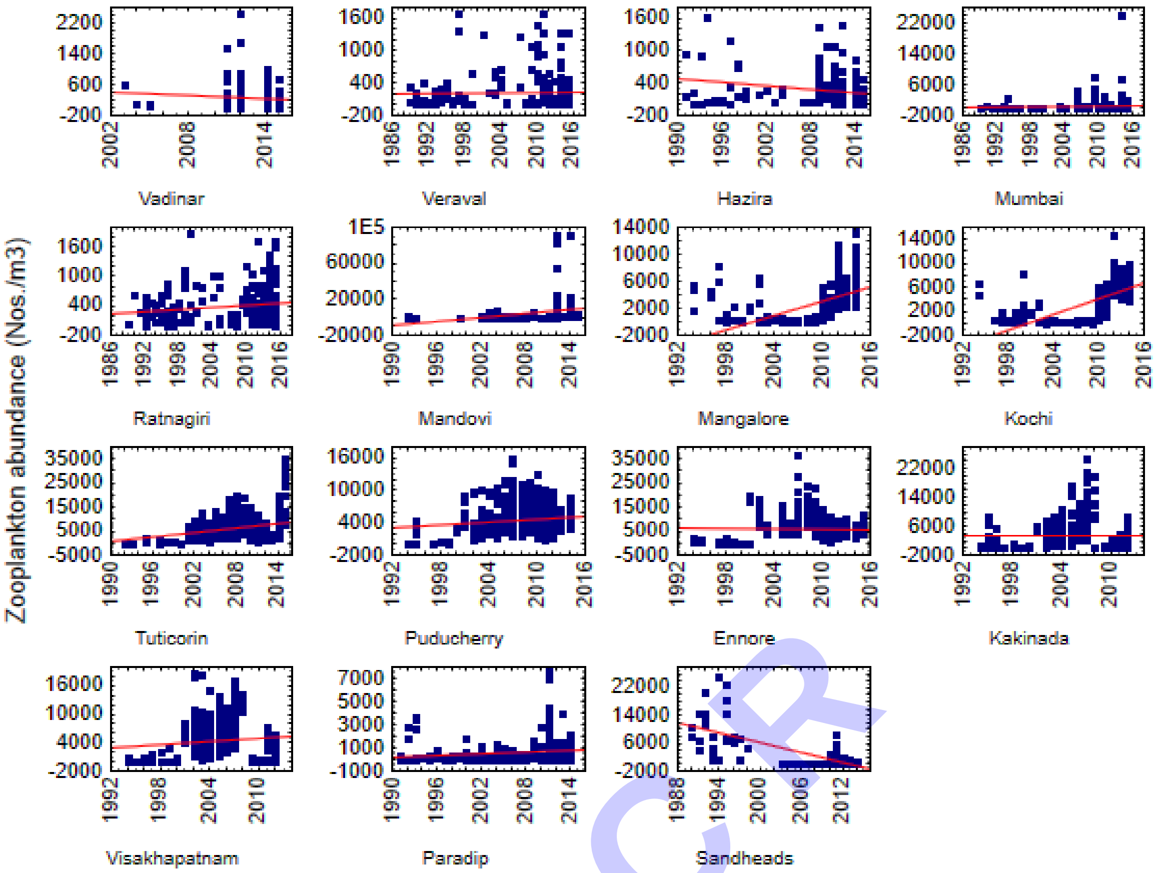


Fig.3.2.2.3. Inter-annual variability in zooplankton abundance along Indian coast

3.3. Sediment variables and Macrobenthos

Sediment Organic Matter

The variability of sediment Organic Matter (OM) at all the 24 monitored locations during the last 25 years are given in Fig. 3.3.1.1. The median values of OM were < 10 mg g^{-1} at most locations. At shore, OM values were highest at Veraval (21 mg g^{-1}), Mumbai (18 mg g^{-1}) and Port Blair (16 mg g^{-1}), while the lowest OM values were recorded at Kavaratti (0.23 mg g^{-1}). Further, OM showed highest variability at Veraval, Mandovi, Mangaluru, Kochi along the west coast and Port Blair in the east coast. In general, OM was higher in the shore locations of west coast compared to the east locations, except for Port Blair. On the other hand, OM showed a different trend in the nearshore and offshore locations (Fig. 3.3.1). In the nearshore, highest OM was recorded at Veraval (16 mg g^{-1}), Mumbai (16 mg g^{-1}), Ratnagiri (27 mg g^{-1}) and Mangaluru (26.5 mg g^{-1}), while rest of the locations had values < 10 mg g^{-1}. At offshore zone, highest median OM values were recorded at Veraval (16 mg g^{-1}), Mumbai (16.5 mg g^{-1}), Ratnagiri (28 mg g^{-1}) and Mangaluru (27.4 mg g^{-1}). Moreover, Ratnagiri, Mangaluru and Kochi showed variability during the last 25 years, a trend observed in the shore and nearshore (Fig. 3.3.1). Like the inshore, the nearshore and offshore locations of east coast also had lower values compared to the west coast.

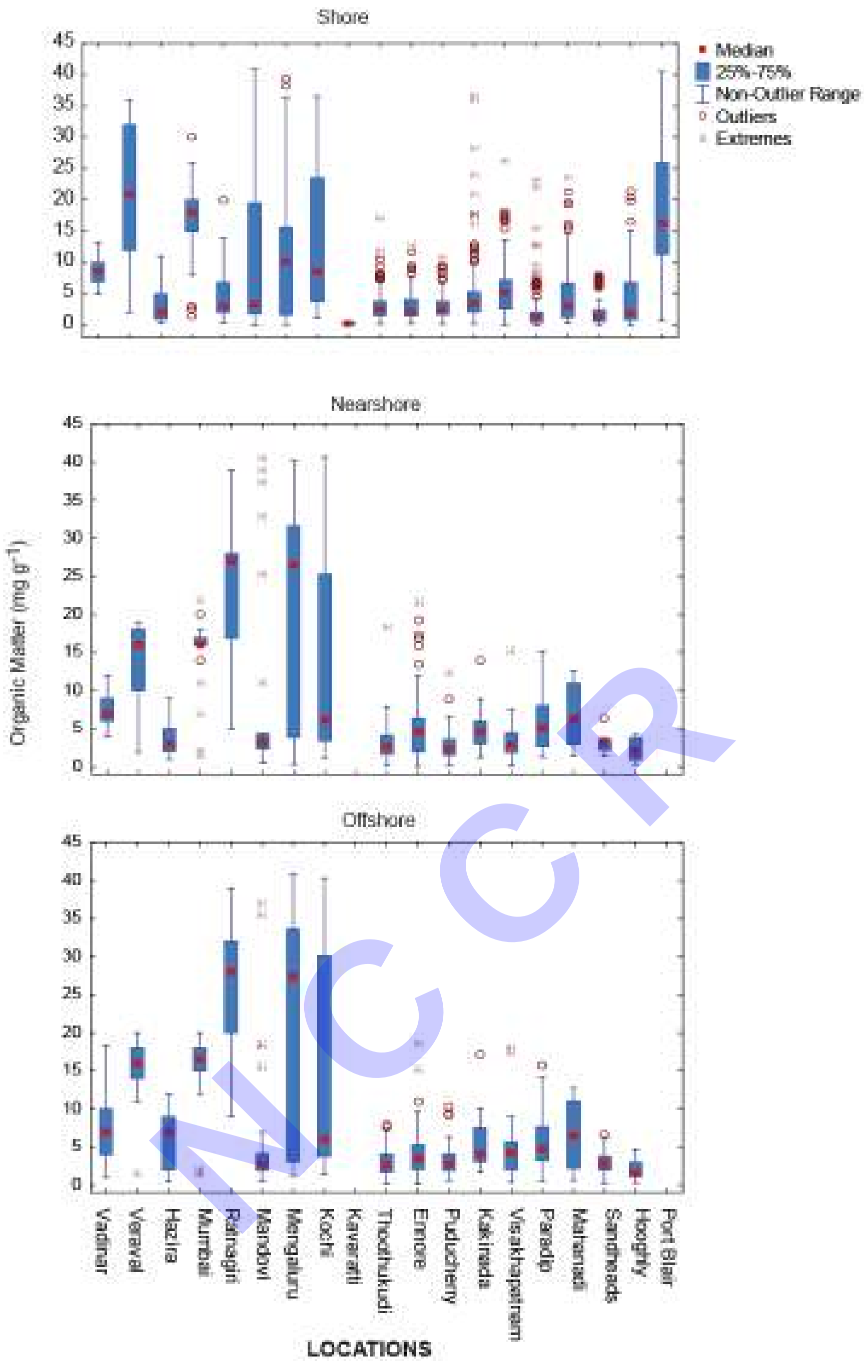


Fig. 3.3.1. Spatial variation of sediment organic matter in the monitored locations during the last 25 years.

Macrofaunal Communities

The macrofaunal abundance (median) in the shore zone was the highest at Puducherry (2600 ind m^{-2}) and Thoothukudi (2150 ind m^{-2}), and the lowest value was recorded at Hazira (34 ind m^{-2}). In general, macrofaunal abundance was higher in the east coast locations compared to the west coast (Fig. 3.3.2). Macrofaunal abundance did show much variability along the monitored locations except for Hazira and Port Blair (Fig 3.3.2). At the nearshore, highest abundance was recorded at Mandovi (1333 ind m^{-2}), Mangaluru (1296 ind m^{-2}) and Kochi (1290 ind m^{-2}). The lowest values of macrofaunal abundance were recorded at Hazira (25 ind m^{-2}). A trend observed in the nearshore zones was that the abundance was higher towards the southeast east and southwest coasts. Macrofaunal abundance in the offshore zone showed a similar trend to that of nearshore. The highest values were recorded at Mangaluru (1296 ind m^{-2}) and Kochi (1290 ind m^{-2}) and the lowest at Hazira (25 ind m^{-2}). Further, the abundance did show significant variability during the monitoring period.

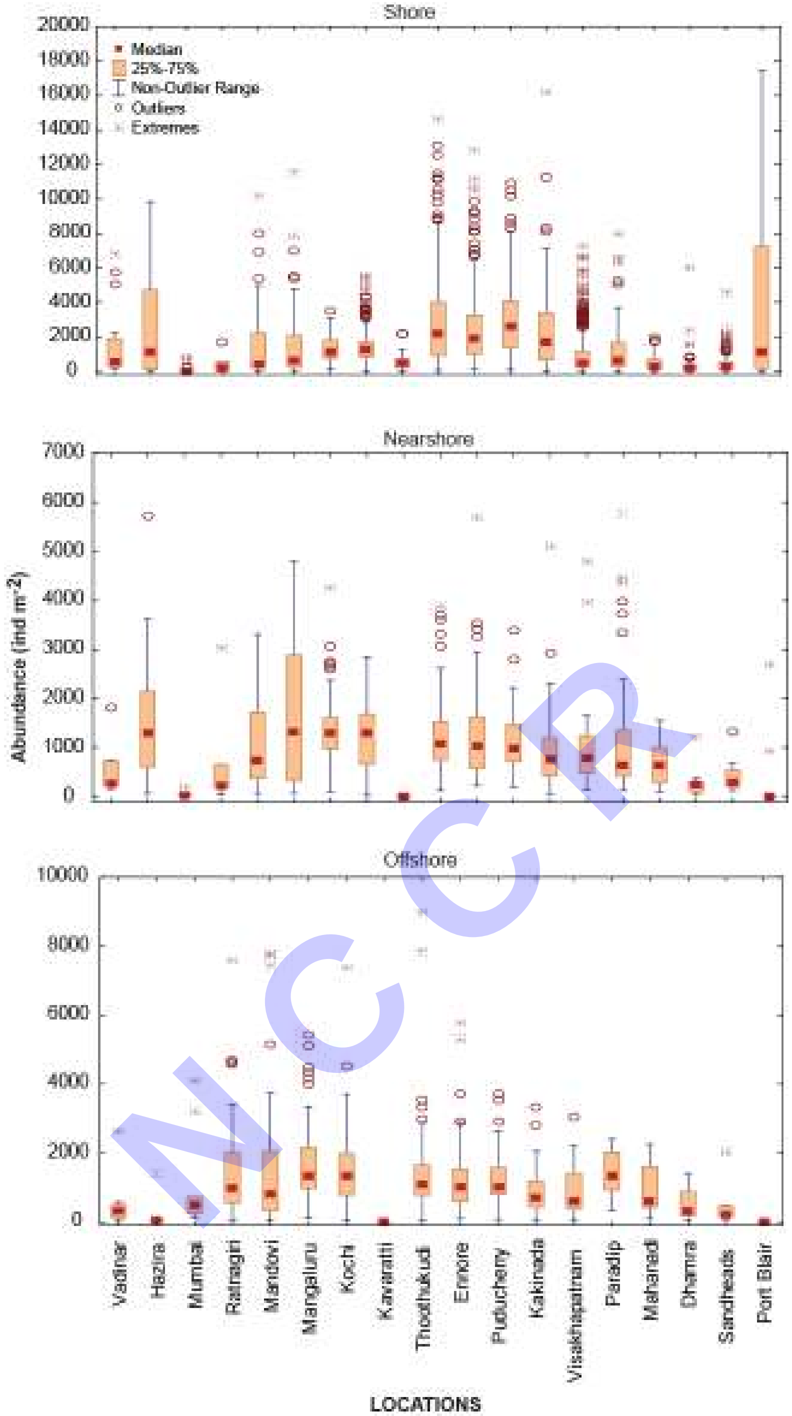


Fig. 3.3.2. Spatial variability in the macrofaunal abundance in the monitored locations during the last 25 years.

The values of macrofaunal biomass in the shore regions were ranged from 0.04 – 24.17 g m^{-2} observed at Hazira and Kavaratti, respectively (Fig 3.3.3). In the nearshore higher biomass was observed at K ochi (11.70 g m^{-2}) and Kakinada (11.28 g m^{-2}) and the lowest at Hazira (0.10). High biomass in the offshore was recorded at Kochi (10.52 g m^{-2}) and Thoothukudi (10.56 g m^{-2}), while lowest values were recorded at Hazira (0.1 g m^{-2}) and Sandheads (0.08 g m^{-2}).

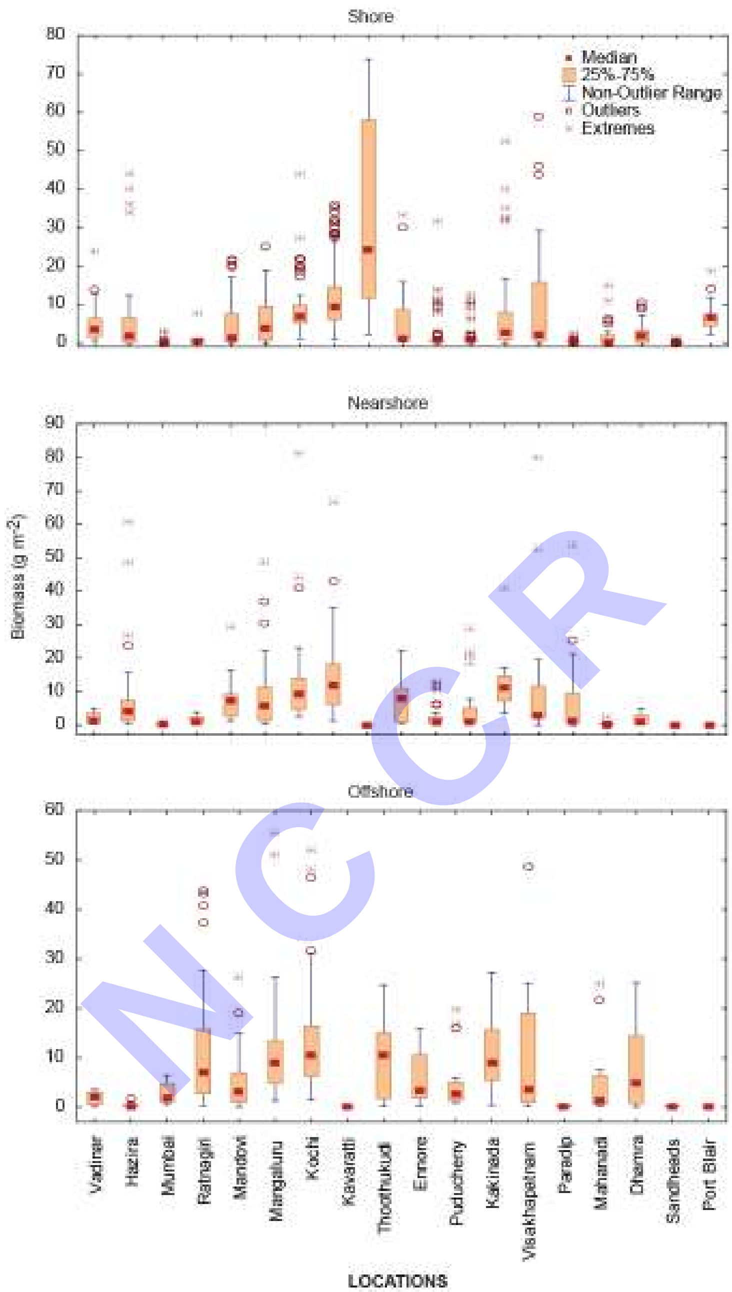


Fig. 3.3.3. Spatial variability in the macrofaunal biomass in the monitored locations during the last 25 years.

3.4. Microbiology

3.4.1. Spatial and temporal variations

In general, microbial load has increased over the years in all the monitoring stations. Total viable count (TVC) ranged from 2 to $1.4x10^8$ cfu/ml. In all the locations, TVC showed an increasing trend till 2015. Particularly, from the year of 2001, TVC started showing increasing trend in all the stations (Fig. 3.4.1.1). However, considerable drop in TVC was observed in 2013. In the monitored locations along the east coast, TVC showed increasing trend from 2001 onwards. On the other hand, location in the west coast showed much variations between 1992 and 2015. TVC was high in 2015 in the west coast ($5x10^5$ cfu/ml) (Fig. 3.4.1.1).

The counts of *E. coli* ranged from 0 to $8.5x10^5$ cfu/ml. *E. coli* count showed less variation till 2006 and high levels of *E. coli* were observed between 2007 and 2011 in all the locations. *E. coli* count was reported to be high in 2008 in all the stations, particularly in the east coast locations ($5.5x10^5$ cfu/ml) (Fig. 3.4.1.2). In addition, *E. coli* and *S. faecalis* also followed the same trend as TVC. Further, high levels of *E. coli* were observed between 2007 and 2011 in the east coast. In the west coast, *E. coli* count showed much variation between 1992 and 2015.

Count of *S. faecalis* showed less variation till 2005 in all the locations. *S. faecalis* count was high in 2012 i.e., $3.8x10^5$ cfu/ml (Fig. 3.4.1.3). Count of *S. faecalis* showed high level between 2008 and 2013. Further, *S. faecalis* counts exhibited increasing trend between 2008 and 2012 in the east coast locations. Along the west coast, count of *S. faecalis* showed low values till 2009 and was high in 2014 i.e., $2.2x10^4$ cfu/ml (Fig. 3.4.1.3).

In general, TVC, *E.coli* and *S. faecalis* levels were high in the east coast locations when compared to west coast (Fig. 3.4.1.4). In addition, the levels of *E.coli* were found to decrease after 2010, which may the result of decreased disposal of untreated sewage. However, the levels of *S. faecalis* decreased from 2013 in the east coast, but it increased in the west coast (Fig. 3.4.1.4).

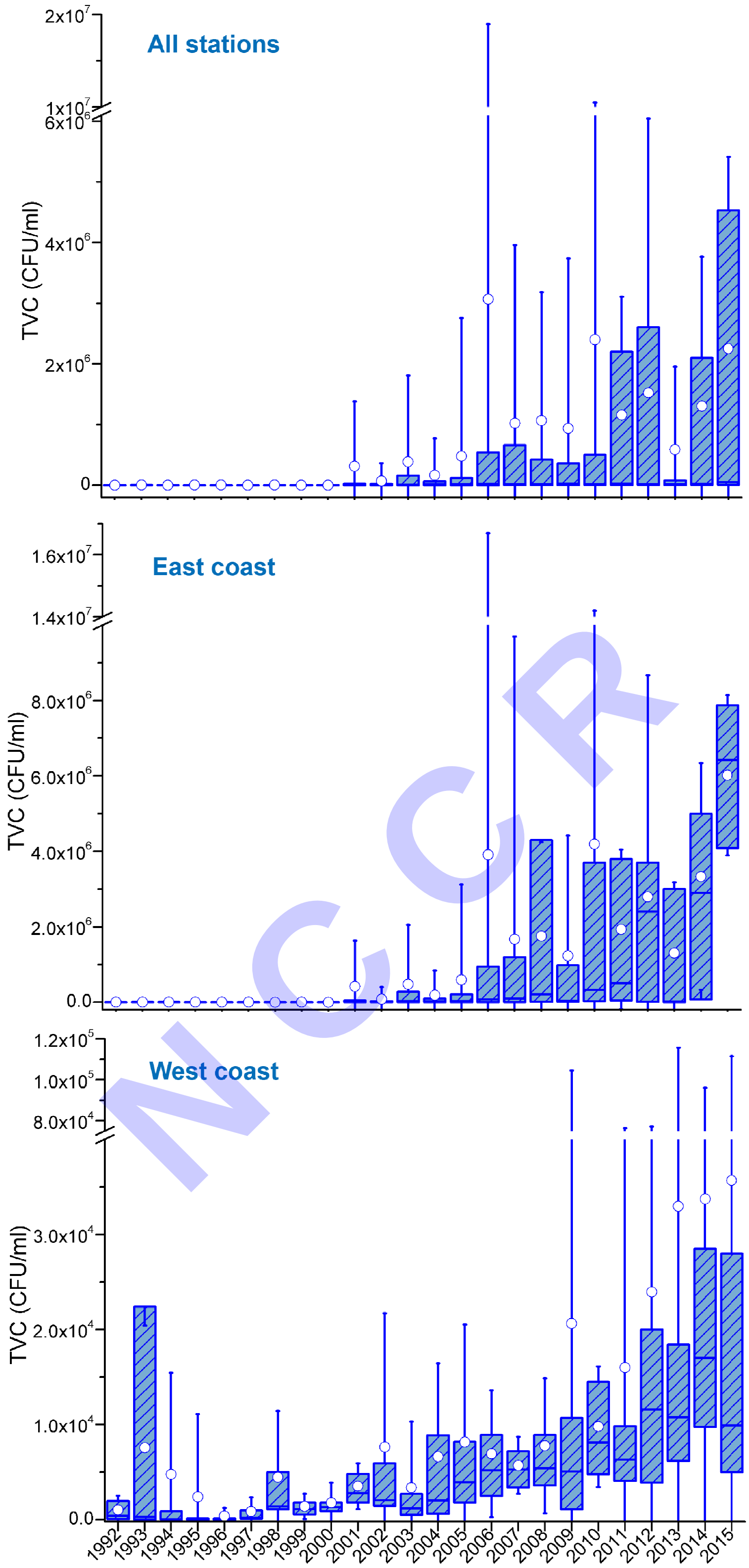


Fig. 3.4.1.1. Inter-annual variation in TVC from 1992-2015.

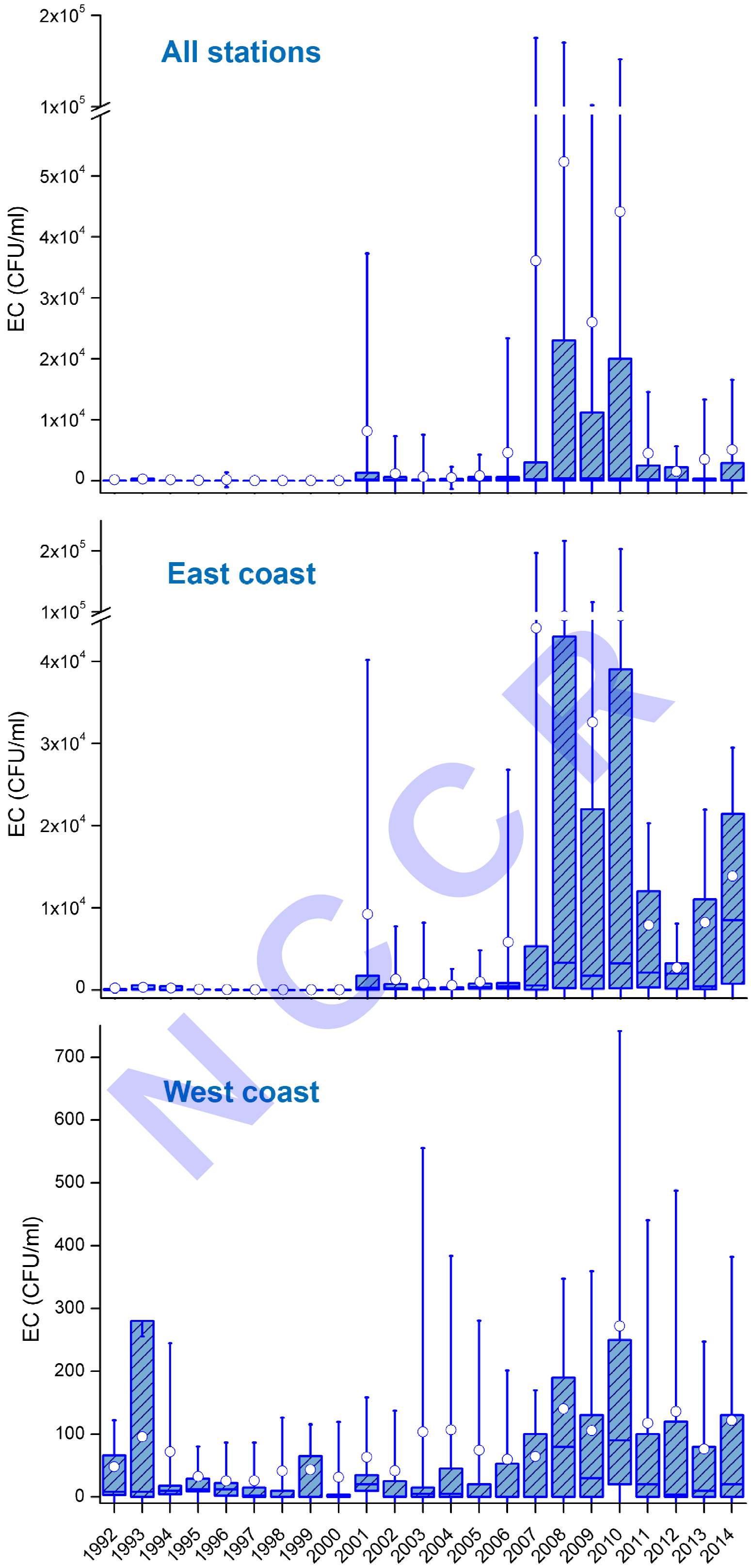


Fig. 3.4.1.2. Inter-annual variation in *E. coli* from 1992-2015

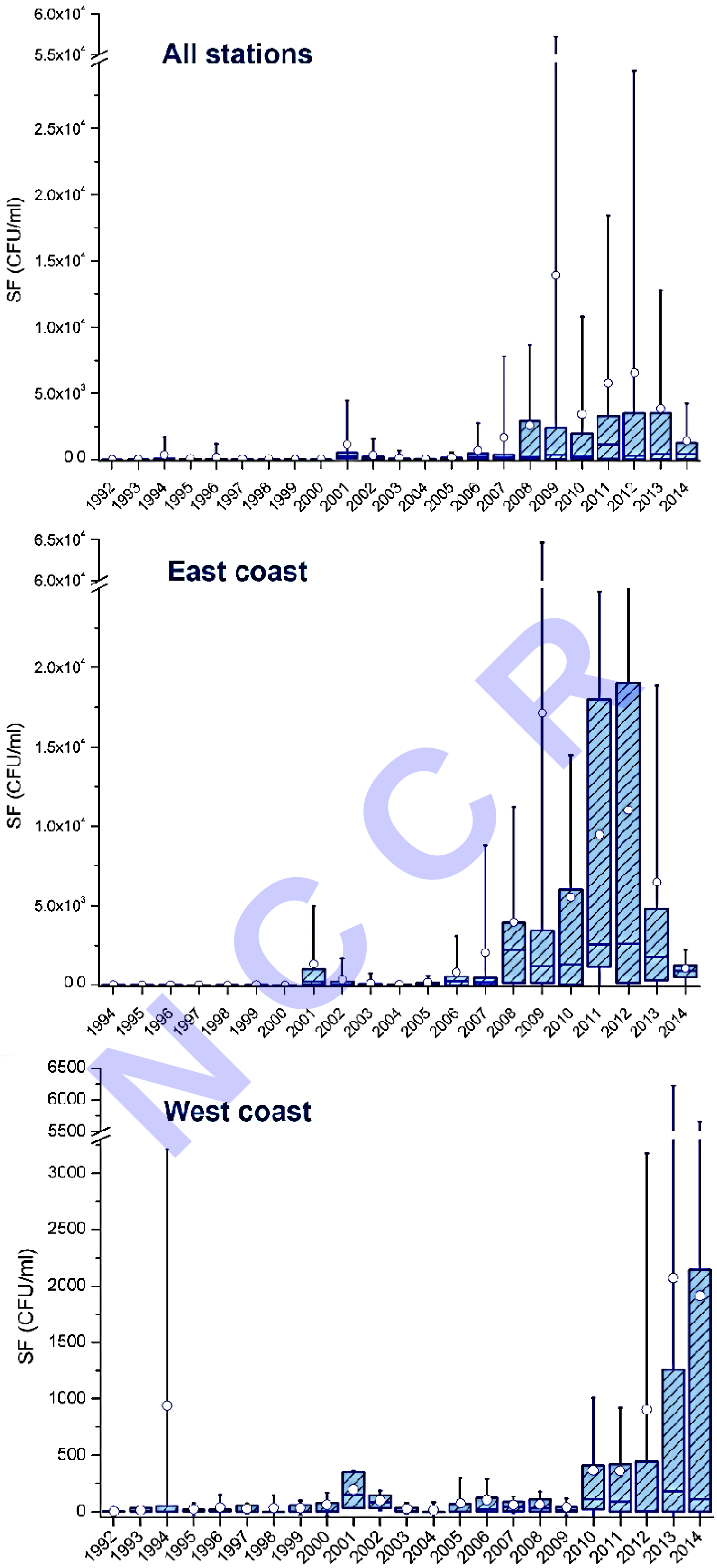


Fig. 3.4.1.3. Inter-annual variation in *S. faecalis* from 1992-2014

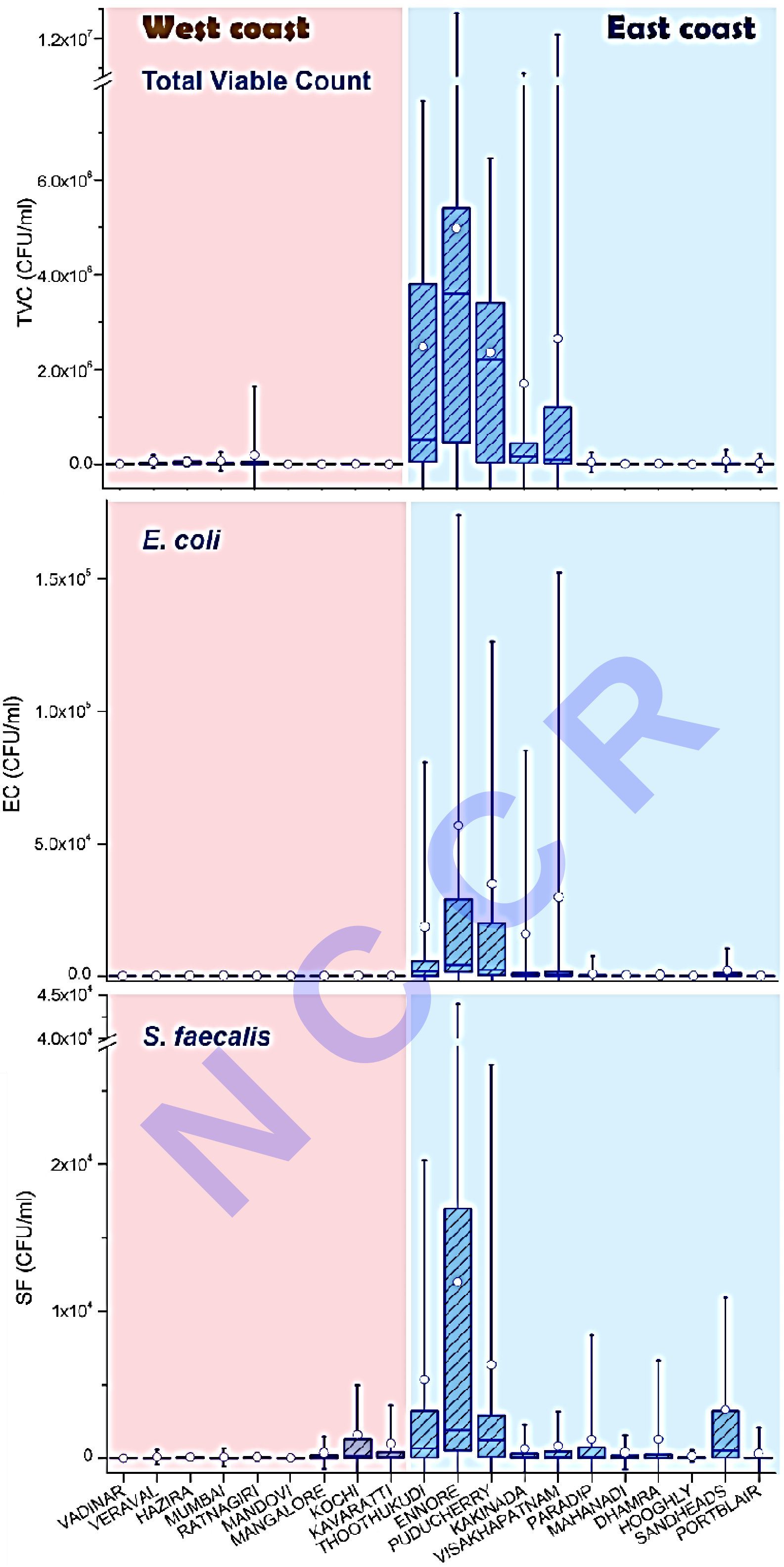


Fig. 3.4.1.4. Spatial variation in TVC, *E. coli* and *S. faecalis* from 1992-2015

3.5. Kochi

3.5.1. Physicochemical parameters

Trends of temperature, salinity, *p*H, DO and SSC recorded at Kochi are represented in the figures 3.5.1.1 – 3.5.1.10.

Temperature exhibited a drop during 2001 – 2003 and was stable thereafter, with the highest values recorded during 2010 and 2015 (Fig. 3.5.1.1). Lower temperature values were recorded during monsoon season along the nearshore and offshore region, which could be attributed to the seasonal upwelling phenomenon peculiar to the Kerala coast (Fig 3.5.1.2). Salinity in the shore region was dominated by the tides and river runoff (Fig 3.5.1.3). Salinity was low during monsoon in all the three zones. Fig 3.5.1.4). The *p*H in the coastal waters of Kochi showed a decrease over the years (Fig 3.5.1.5) and ranged between 8.4 – 6.4, Low *p*H values <7.0 were attributed to the monsoonal discharges (Fig 3.5.1.6). The DO concentration in the shore and nearshore zones showed an increasing trend and ranged between 2-8.8 mg/l in the shore, 1.5-7.0 mg/l in the nearshore over the monitoring period (Fig.3.5.1.7). No clear seasonal pattern in DO was observed in the coastal waters of Kochi (Fig 3.5.1.8).

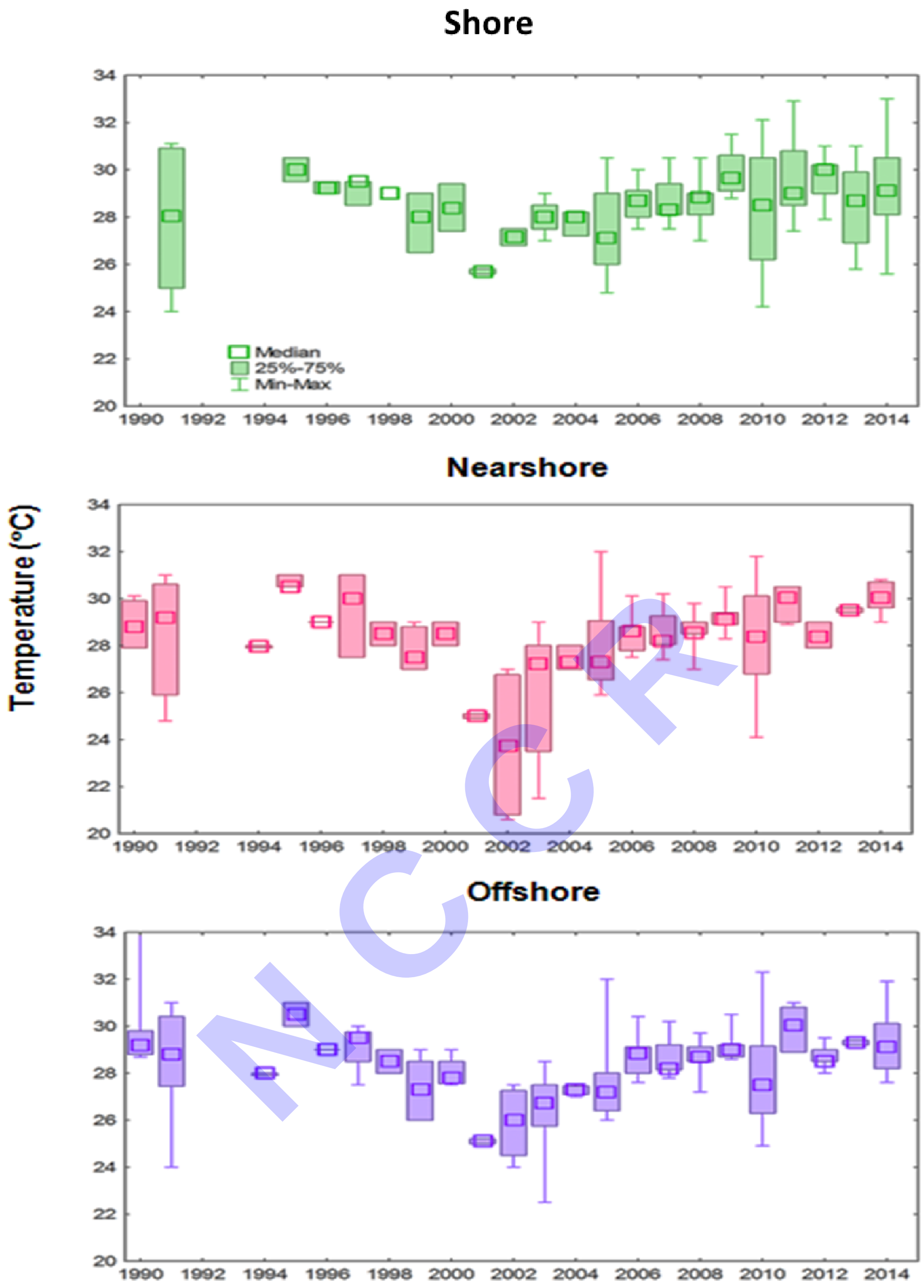


Fig.3.5.1.1. Inter-annual trend in surface water temperature at Kochi.

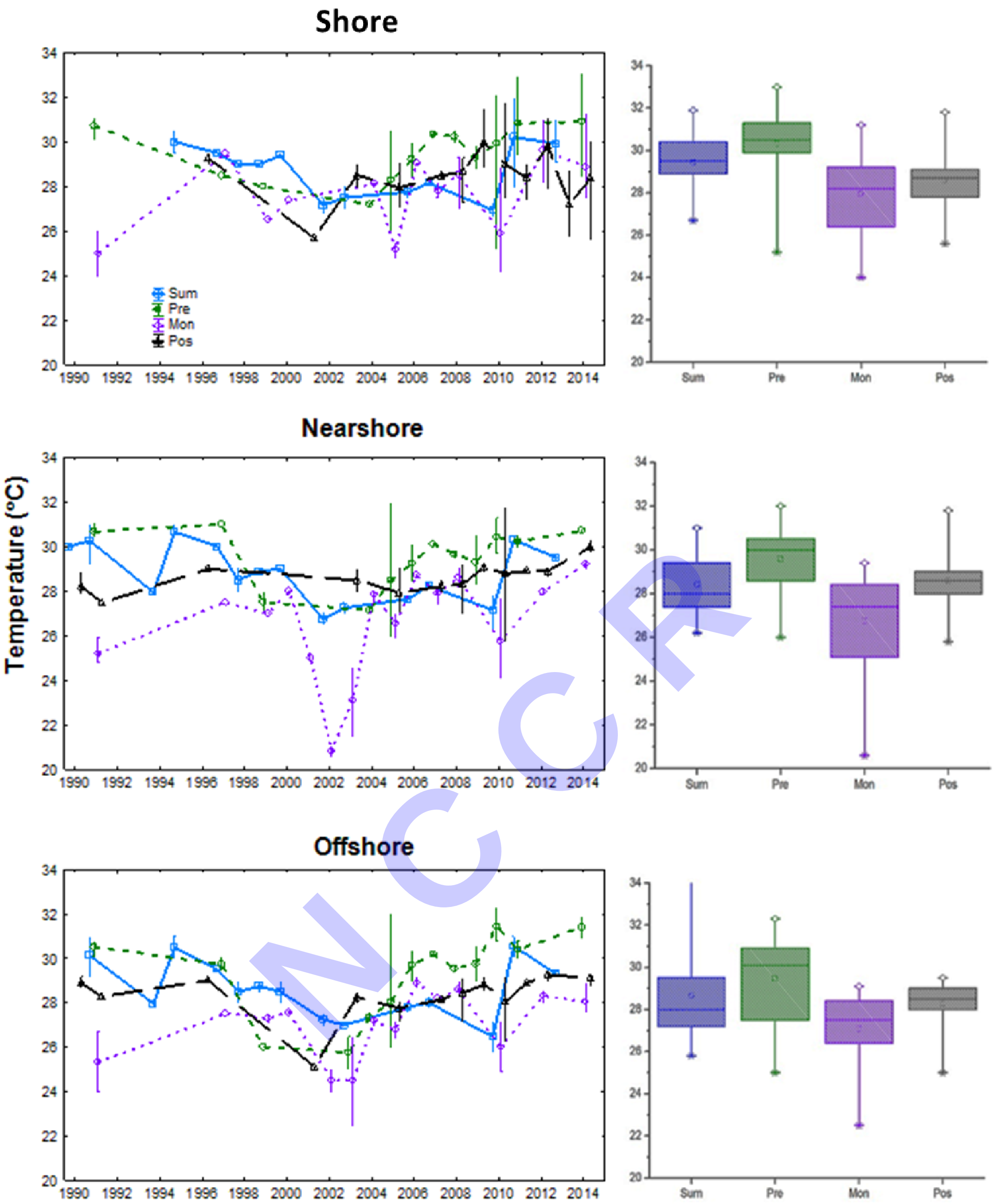


Fig.3.5.1.2. Seasonal trend in surface water temperature at Kochi.

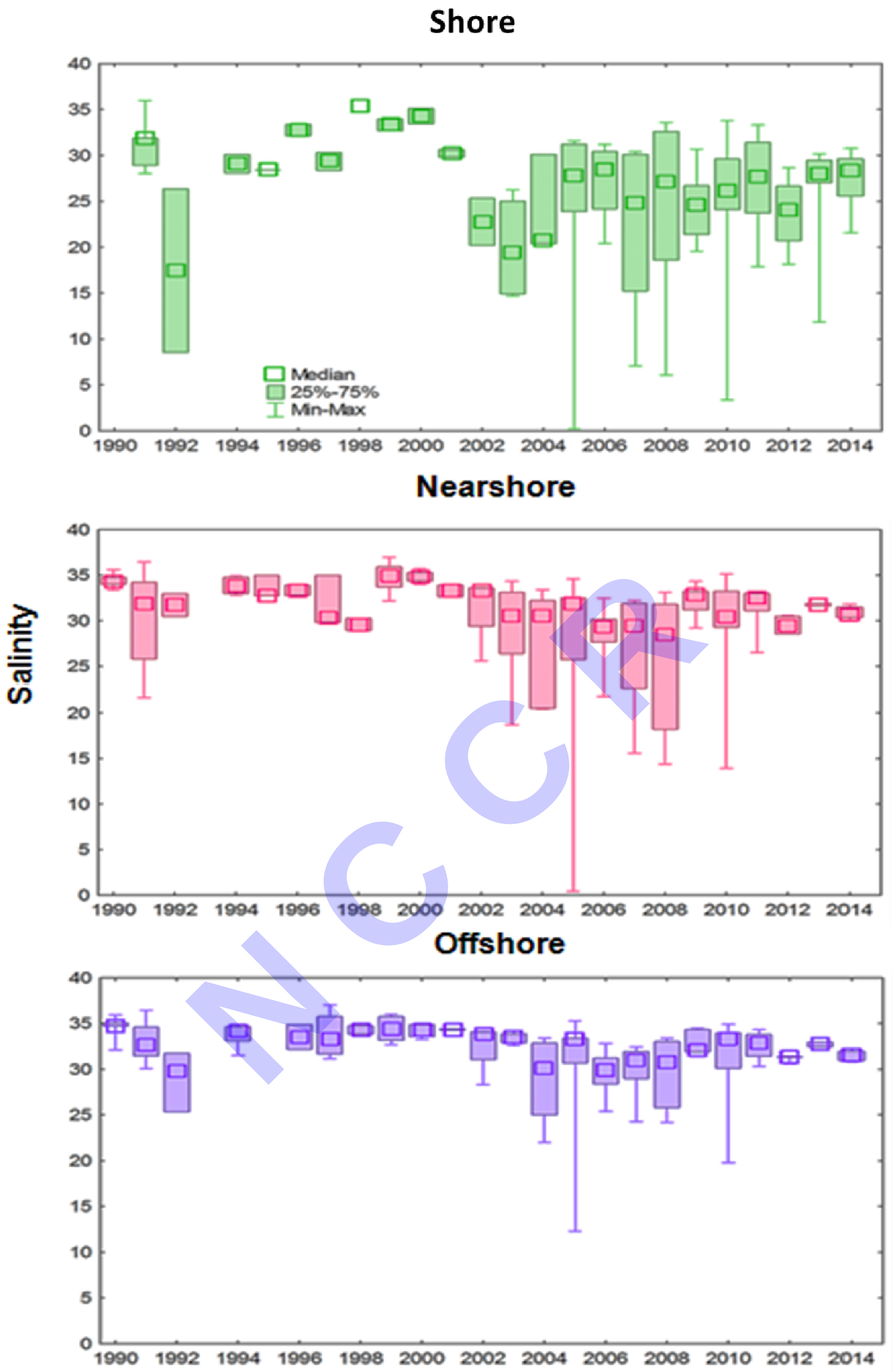


Fig.3.5.1.3. Inter-annual trend in surface water salinity at Kochi.

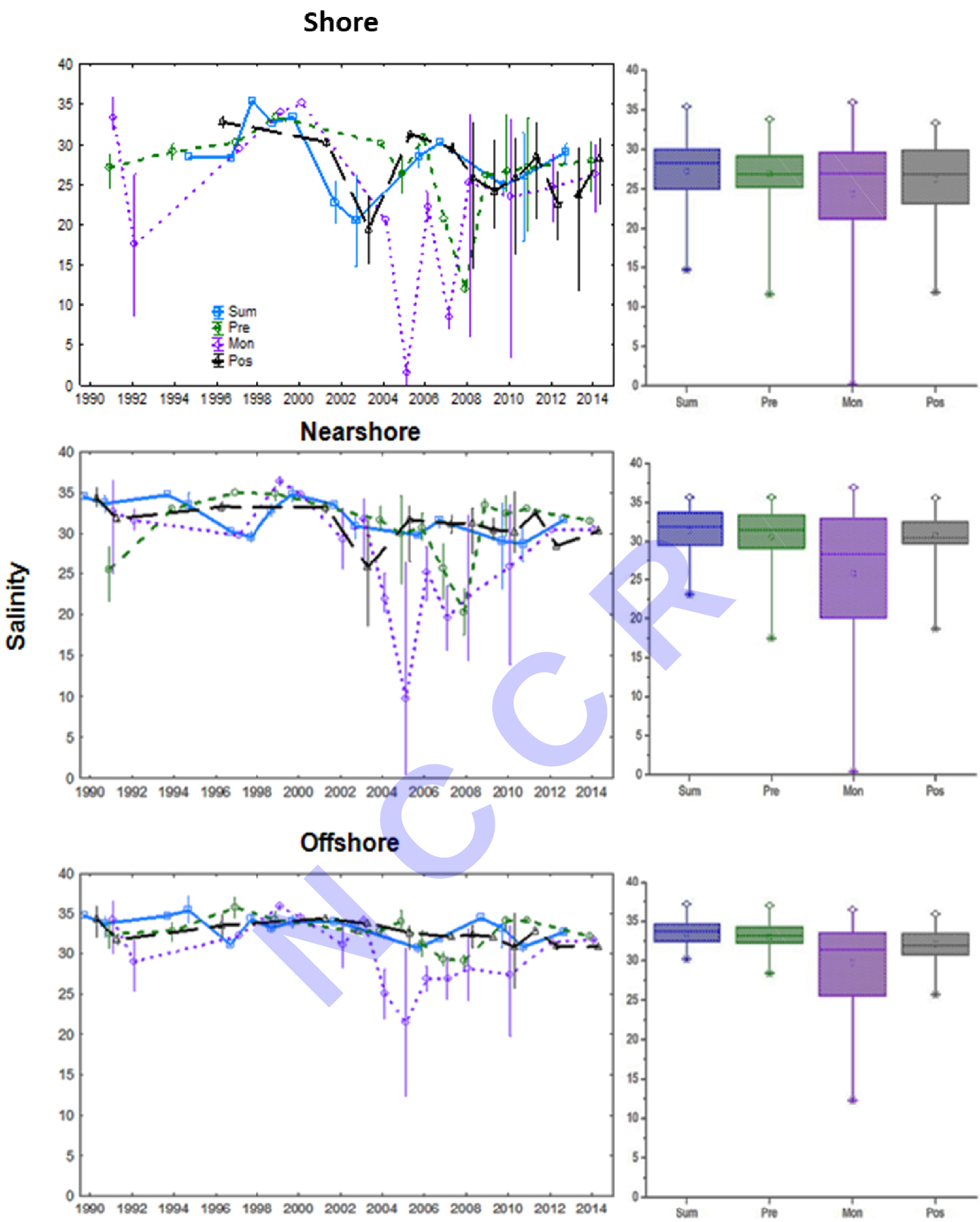


Fig.3.5.1.4. Seasonal trend in surface water salinity at Kochi.

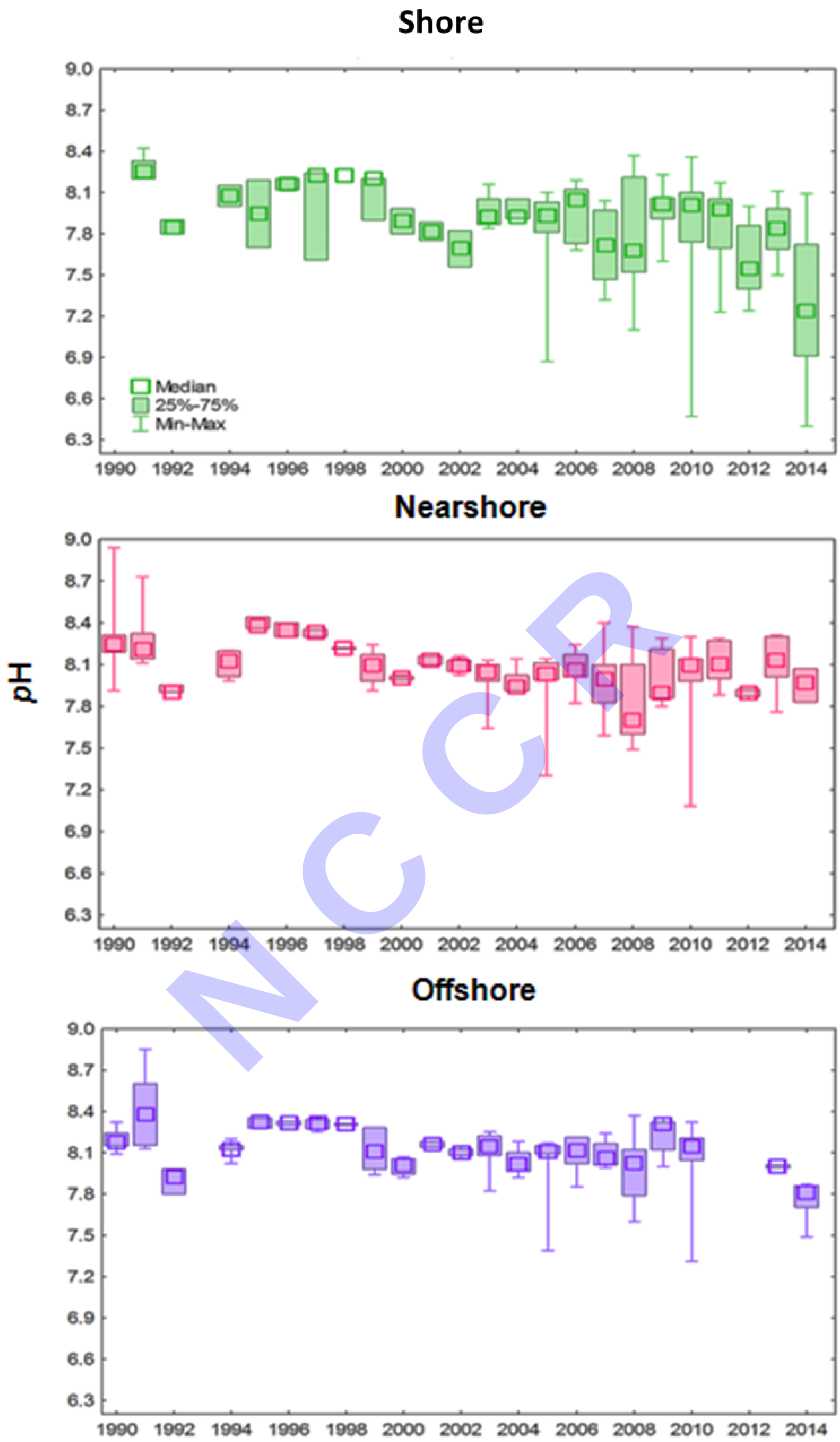


Fig.3.5.1.5. Inter-annual trend in surface water *p*H at Kochi.

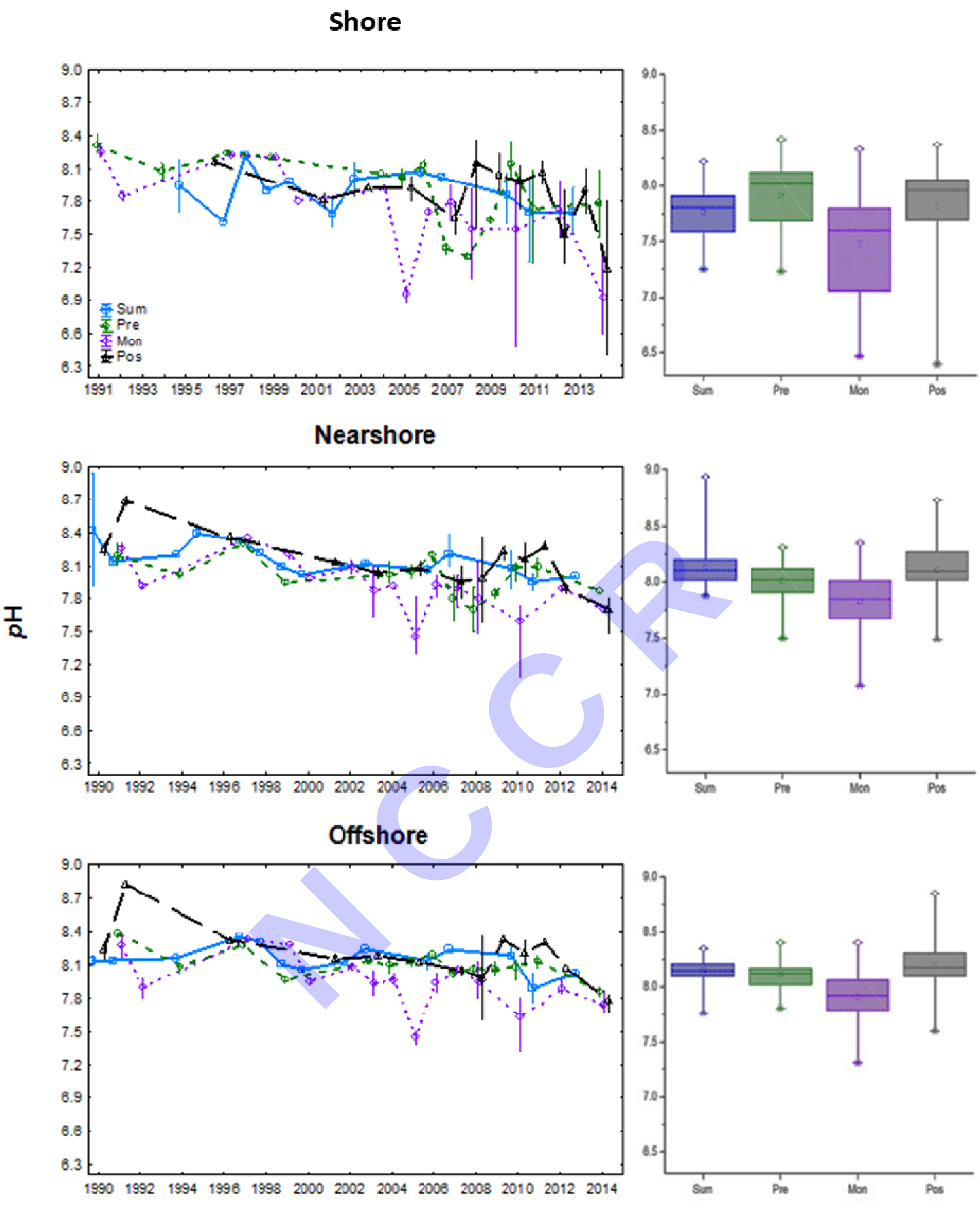


Fig.3.5.1.6. Seasonal trend in surface water *p*H at Kochi.

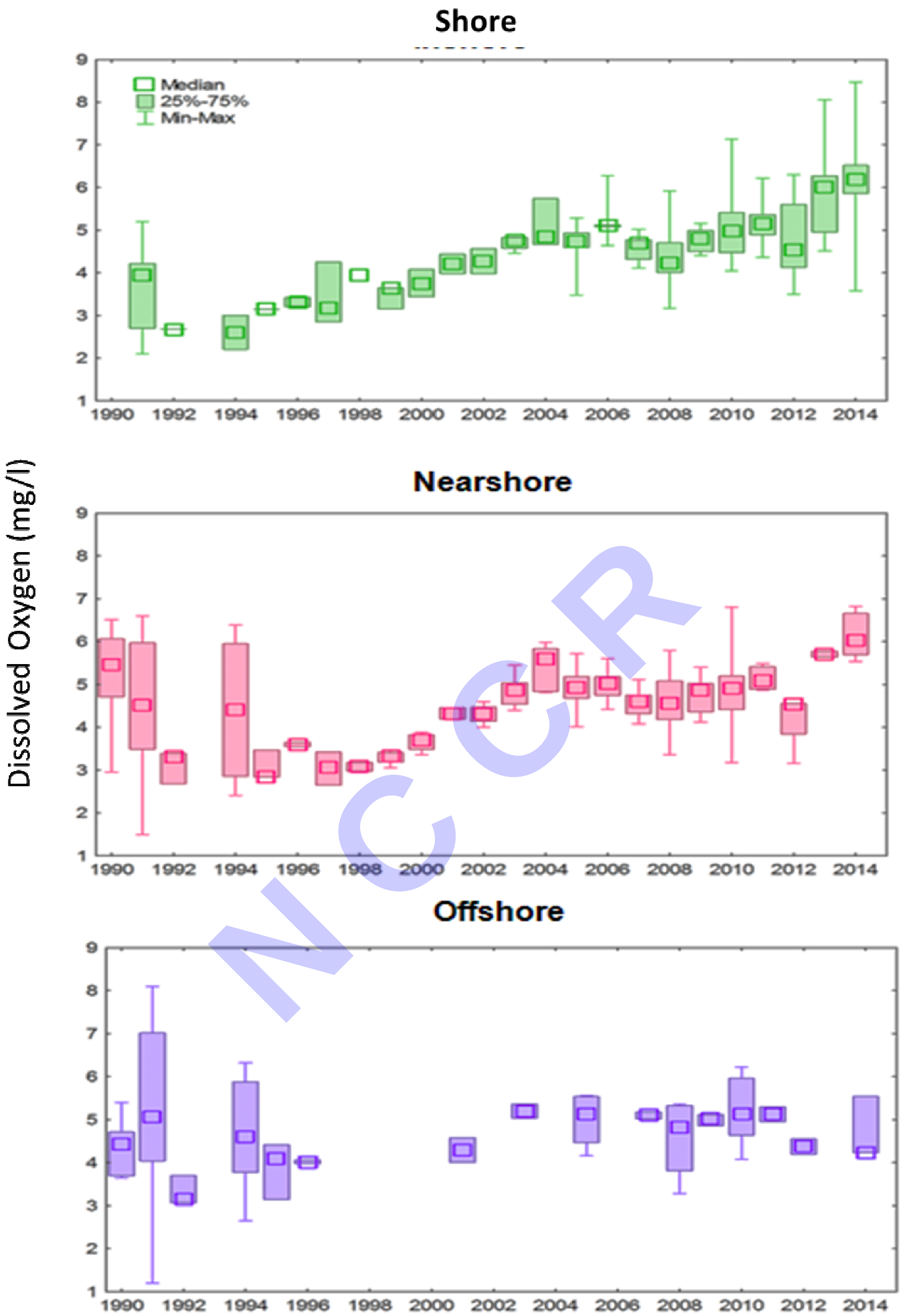


Fig.3.5.1.7. Inter-annual trend in surface water DO at Kochi.

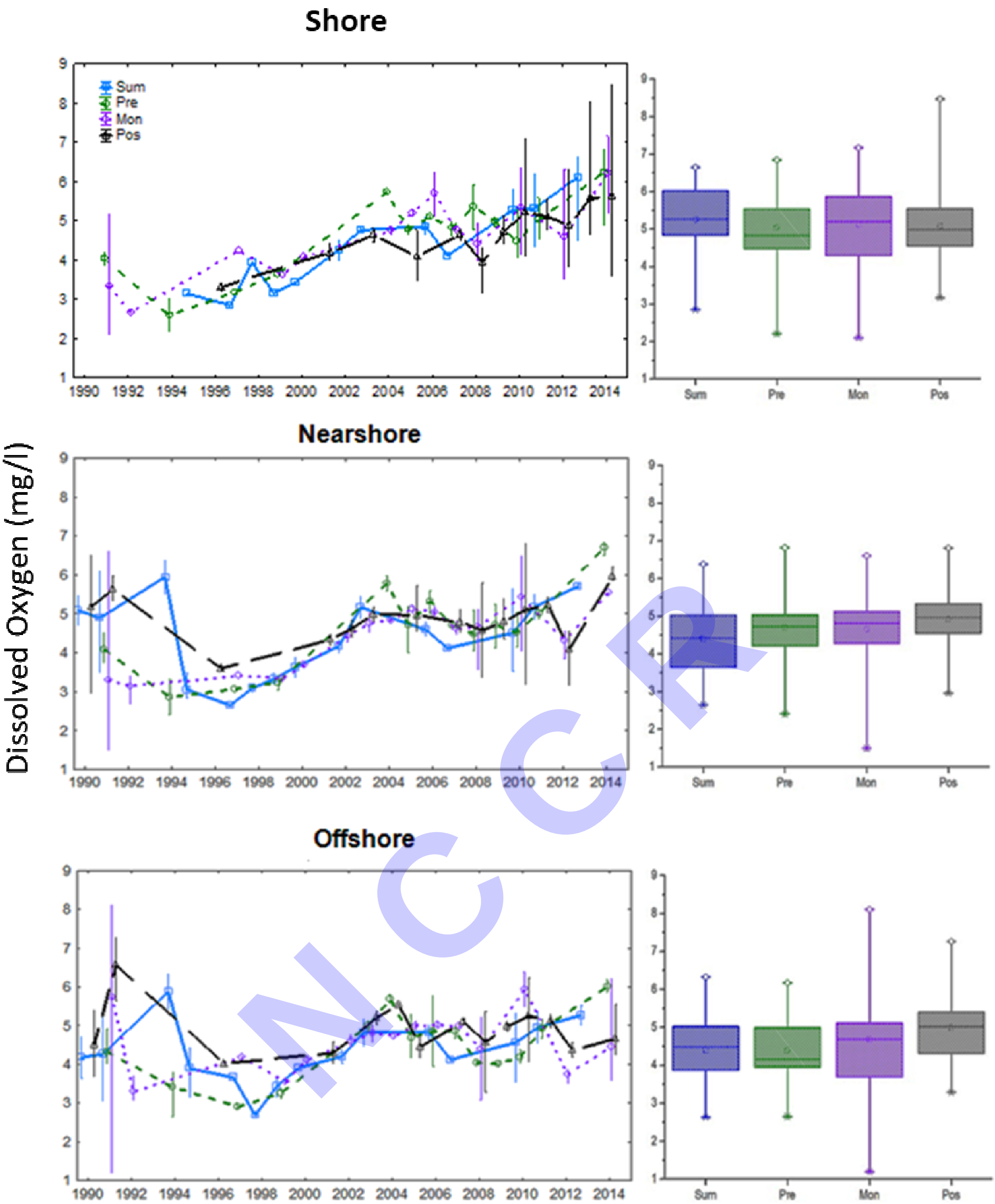


Fig.3.5.1.8. Seasonal trend in surface water DO at Kochi.

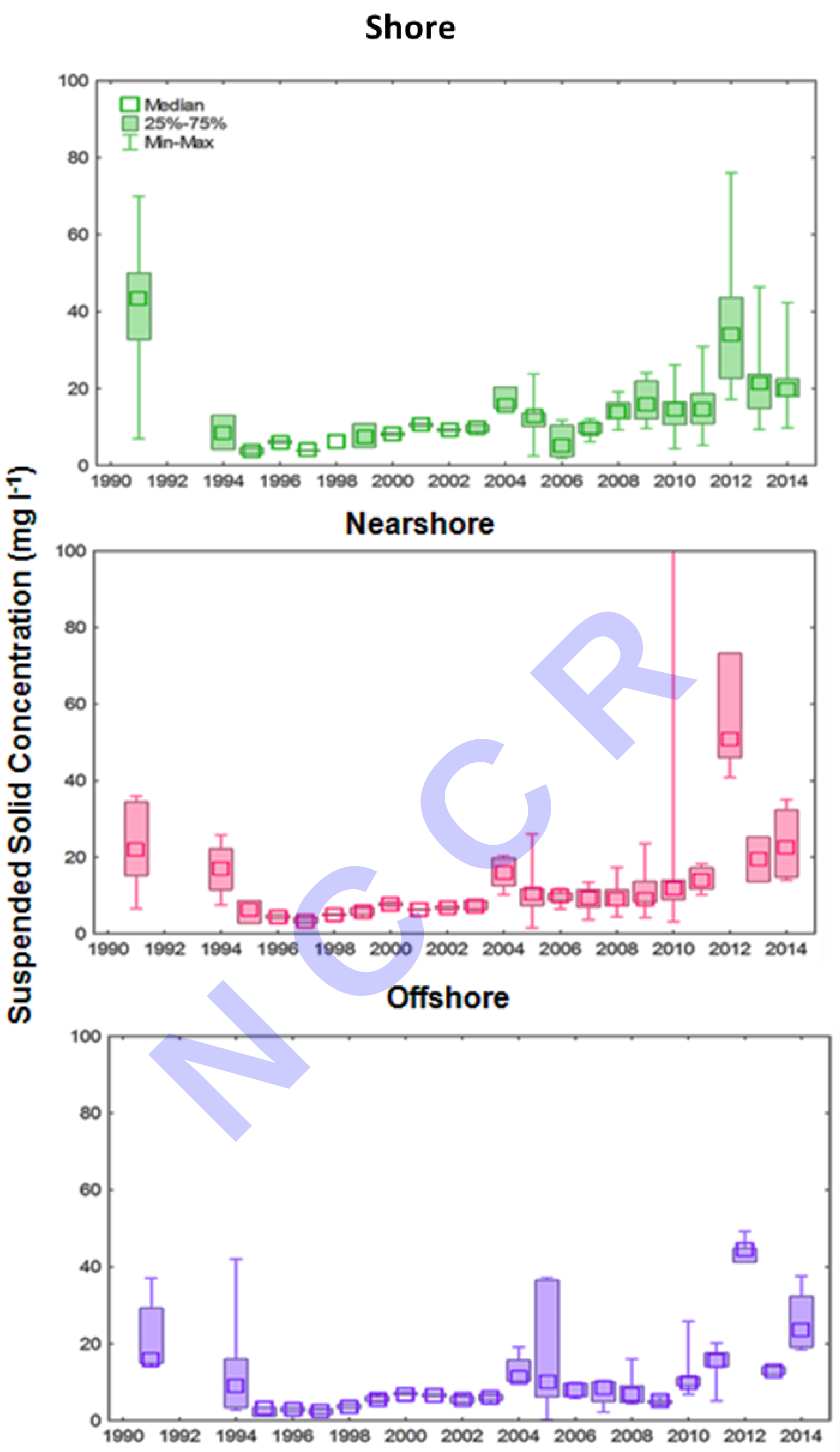


Fig.3.5.1.9. Inter-annual trend in SSC at Kochi.

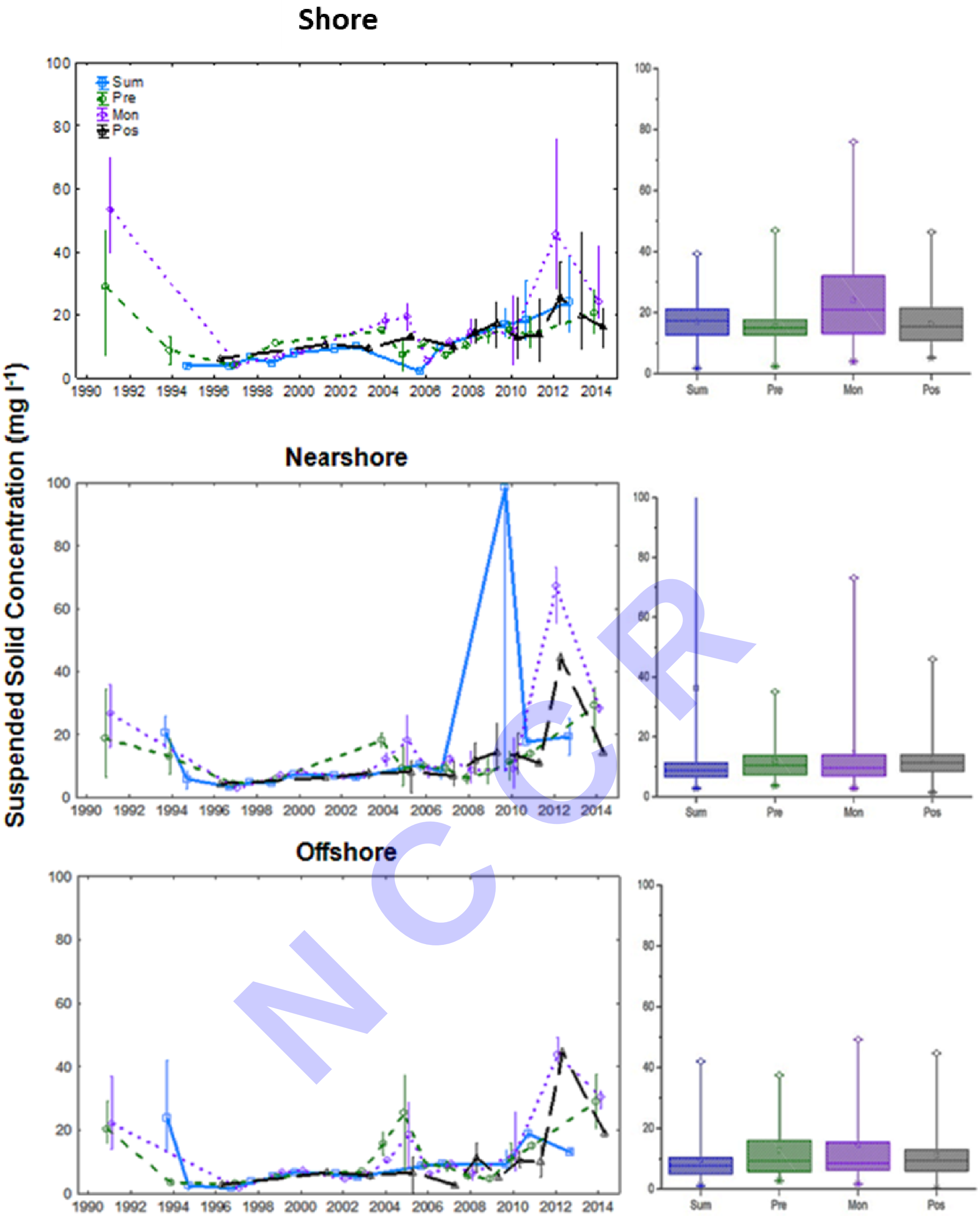


Fig.3.5.1.10. Seasonal trend in SSC at Kochi.

Nutrients

Number of data points (N), minimum (Min), maximum (Max), mean and standard deviation (SD) are presented in Table 3.5.1.1. to 3.5.1.4. Nitrate concentration ranged from 0.1 µM – 41.8 µM in the coastal waters of Kochi (Table 3.5.1.1). Nitrate ranged from ~4 µM to 24 µMfrom 1990 – 2011 (Fig 3.5.1.11). However, drastic increase (24 µM) was seen in 2012, which was also the highest value recorded over the years. Nitrate concentration showed a decline after 2012 (Fig. 3.5.1.11). Ammonium was stable over most part of the monitoring period, except in the last few years when an increasing trend was observed (Fig. 3.5.1.11). Ammonium concentration ranged from 0.008 µM – 3.95 µM and highest values were recorded during 2014. Phosphate values ranged from 0.08 µM – 4.68 µM in this location (Table 3.5.1.3). Phosphate showed variability (~0.2 µM to 5 µM) over the monitoring period and showed an increase from 1992 – 2014 (Fig. 3.5.1.12). In general, silicate concentration in the coastal waters of Kochi increased over the years. Silicate concentration ranged from 0.68 – 88.88 µM (Table 3.5.1.4). Spatially, nutrient values were higher towards the shore zone which gradually decreased towards the offshore zone.

Table 3.5.1.1. Statistical summary of nitrate (µM), Kochi.

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	38	0.24	23.20	8.33	7.29
	Nearshore	14	0.70	17.51	4.96	4.37
	Offshore	16	0.42	13.54	4.58	3.61
Pre-monsoon	*Shore*	66	0.30	28.81	4.76	4.35
	Nearshore	18	1.09	38.41	6.14	8.50
	Offshore	18	0.51	24.94	4.87	5.47
Monsoon	*Shore*	58	0.10	33.49	14.30	10.50
	Nearshore	17	0.12	34.00	9.15	8.43
	Offshore	18	0.50	41.80	7.82	9.31
Post-monsoon	*Shore*	88	1.17	19.79	7.21	4.99
	Nearshore	22	0.38	12.41	3.90	3.69
	Offshore	24	0.32	13.95	4.05	3.58

Table 3.5.1.2. Statistical summary of ammonium (µM), Kochi.

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	38	0.01	0.88	0.32	0.31
	Nearshore	15	0.01	0.76	0.21	0.26
	Offshore	17	0.01	3.61	0.42	0.92
Pre-monsoon	*Shore*	65	0.01	2.81	0.95	0.67
	Nearshore	17	0.01	1.14	0.24	0.33
	Offshore	16	0.01	0.80	0.20	0.27
Monsoon	*Shore*	58	0.01	2.05	0.59	0.45
	Nearshore	17	0.01	1.62	0.48	0.64
	Offshore	18	0.01	1.67	0.38	0.53
Post-monsoon	*Shore*	88	0.01	1.98	0.71	0.46
	Nearshore	23	0.01	3.95	0.64	0.97
	Offshore	23	0.01	3.03	0.56	0.76

Table 3.5.1.3. Statistical summary of phosphate (µM), Kochi.

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	38	0.12	3.68	1.20	0.96
	Nearshore	14	0.43	2.47	1.01	0.55
	Offshore	16	0.16	2.60	1.07	0.70
Pre-monsoon	*Shore*	66	0.52	4.18	1.59	0.76
	Nearshore	18	0.24	2.70	1.29	0.74
	Offshore	18	0.08	3.25	1.27	0.80
Monsoon	*Shore*	58	0.61	4.37	2.04	1.16
	Nearshore	17	0.60	4.68	2.08	1.27
	Offshore	18	0.60	3.77	2.00	1.16
Post-monsoon	*Shore*	88	0.59	3.56	1.86	0.68
	Nearshore	22	0.12	2.01	1.10	0.52
	Offshore	23	0.08	2.56	1.03	0.65

Table 3.5.1.4. Statistical summary of silicate (µM), Kochi.

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	37	1.28	21.74	8.39	5.08
	Nearshore	13	0.82	15.88	6.81	6.09
	Offshore	15	0.99	18.57	5.40	5.29
Pre-monsoon	*Shore*	64	1.18	34.31	18.57	9.30
	Nearshore	16	1.35	18.76	7.20	5.04
	Offshore	16	1.02	15.38	6.41	4.85
Monsoon	*Shore*	56	0.80	88.88	23.11	23.72
	Nearshore	15	0.90	71.38	17.92	23.45
	Offshore	16	0.68	52.63	13.57	18.53
Post-monsoon	*Shore*	88	1.50	40.58	13.83	11.66
	Nearshore	22	1.30	25.13	6.55	5.53
	Offshore	23	0.94	24.70	6.80	5.39

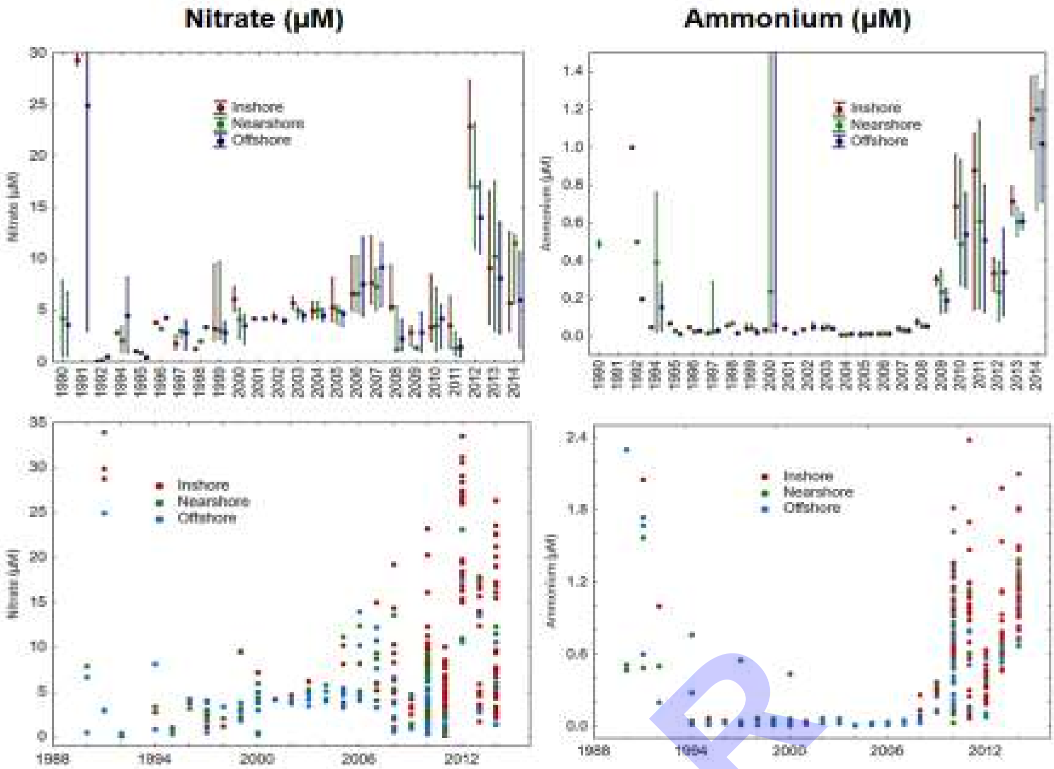


Fig.3.5.1.11. Inter-annual variation of nitrate and ammonium at Kochi.

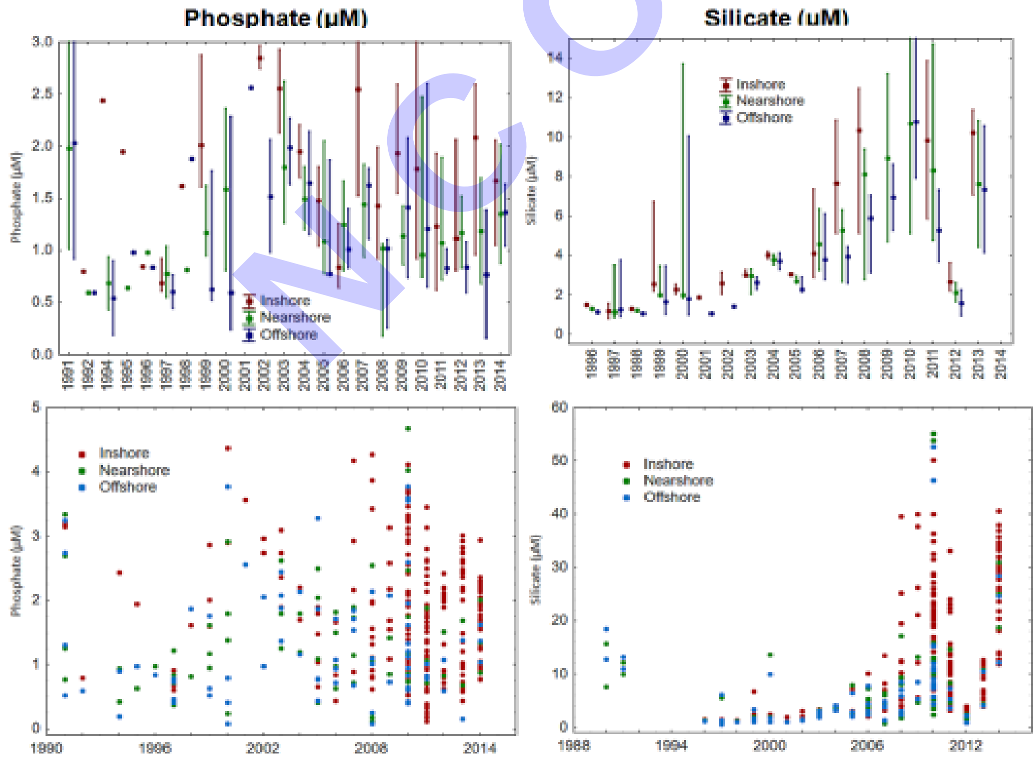


Fig.3.5.1.12. Inter-annual variation of phosphate and silicate at Kochi.

Seasonal variability

Seasonal variation of nutrients in surface water of Kochi transect are given in Fig. 3.5.1.13 (nitrate and ammonium) and Fig. 3.5.1.14 (phosphate and silicate). In all the three coastal zones of Kochi, nitrate was high during the monsoon period (Fig. 3.5.1.13). Ammonium concentration in the shore showed strong seasonal and intra-seasonal variability (Fig. 3.5.1.13). In the nearshore and offshore zones, ammonium concentration was high during post-monsoon (Fig. 3.5.1.13). Phosphate in the coastal waters of Kochi showed high and low values, during monsoon and summer period, respectively (Fig. 3.5.1.14). Silicate in the shore showed strong seasonal pattern with high values recorded during monsoon. Moreover, this season also showed considerable variability (Fig. 3.5.1.14). On the other hand, the silicate in the nearshore and offshore did not show any clear seasonal pattern. However, there was high intra-seasonal variability during the monsoon period (Fig. 3.5.1.14).

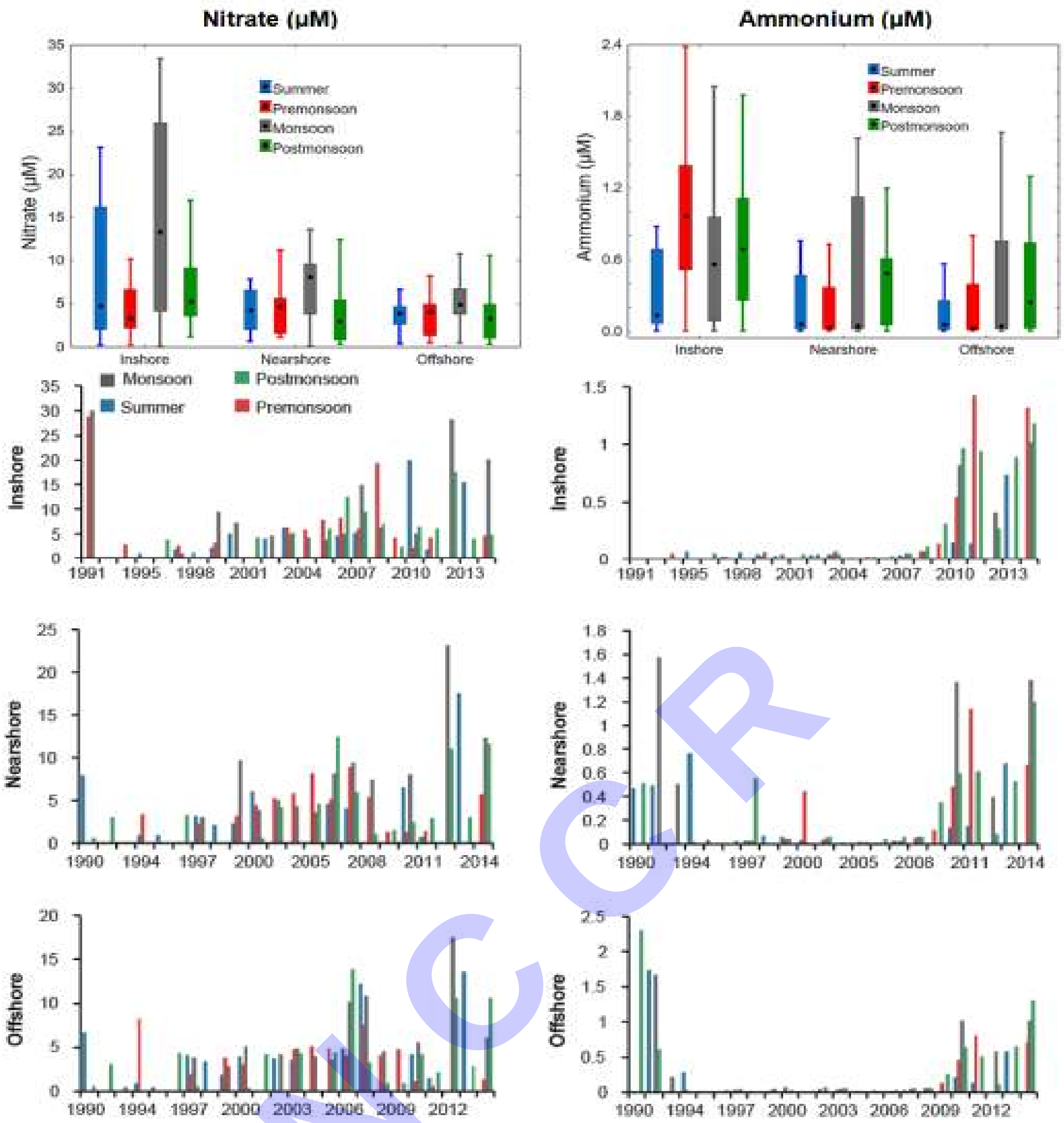


Fig.3.5.1.13. Seasonal variability in nitrate and ammonium at Kochi.

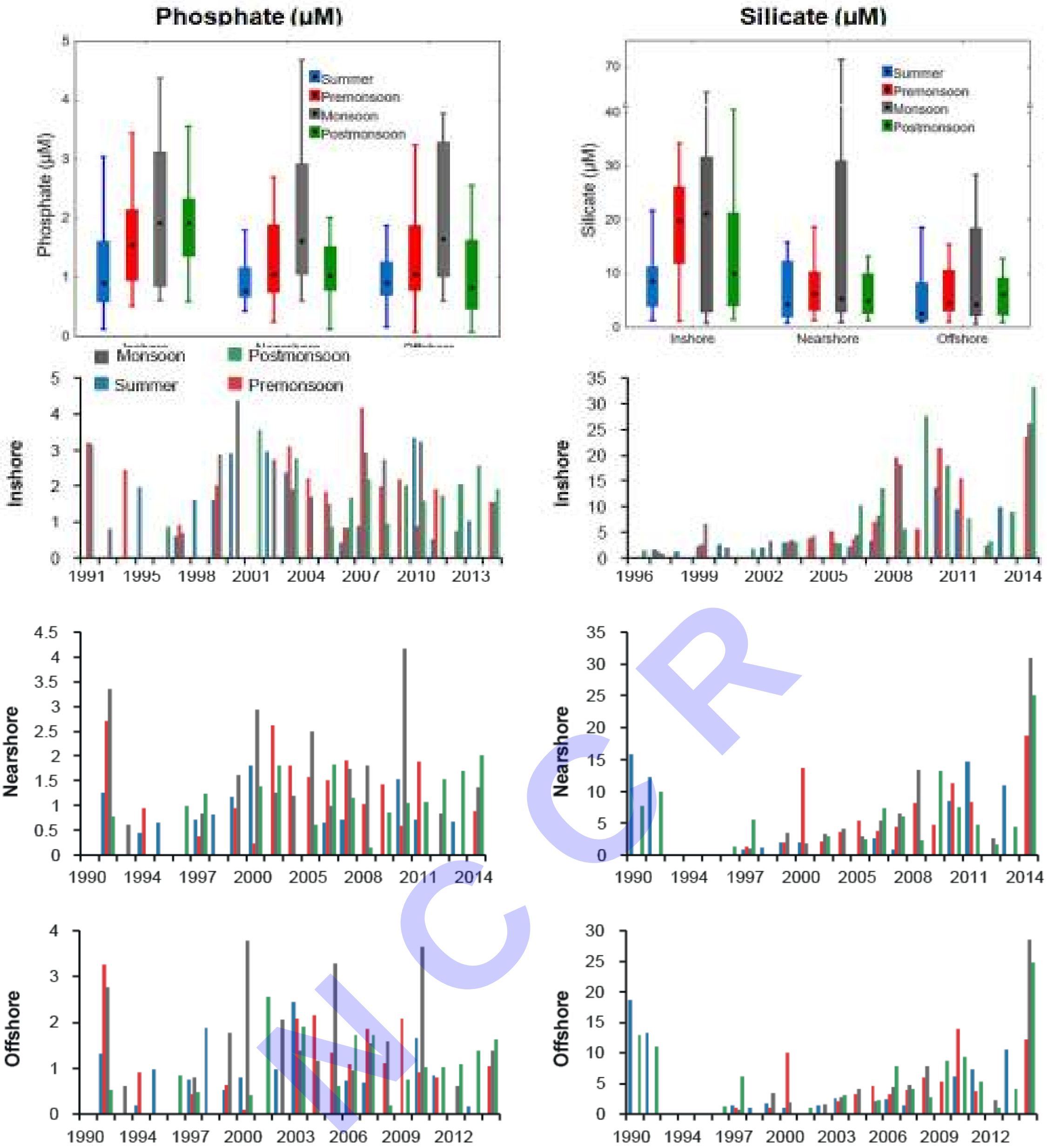


Fig.3.5.1.14. Seasonal variability in phosphate and silicate at Kochi.

3.5.2. Plankton

Number of data points (N), minimum (Min), maximum (Max), mean and standard deviation (SD) are presented in Table 3.5.2.1. to 3.5.2.4. Phytoplankton biomass and abundance in the Kochi coast ranged from 0.11 – 28.22 mg/m^3 (Table 3.5.2.1) and 585 – 181040 cells/l (Table 3.5.2.2), respectively. Phytoplankton biomass showed variability over the years with no significant change over zones (Fig. 3.5.2.1). However, phytoplankton abundance showed an increase during 2012 – 2014. Phytoplankton abundance and biomass were comparatively lower in the shore zone (Fig. 3.5.2.1). Zooplankton biomass ranged from 0.01 – 3.52 ml/m^3(Table 3.5.2.3) and 22 – 14746 no./m^3(Table 3.5.2.4). Although the zooplankton community was stable from 1994 – 2010, the values showed an increase during 2010 – 2014. The highest biomass and abundance were recorded during 2014. Further, zooplankton did not show any clear spatial pattern.

Table 3.5.2.1. Statistical summary of phytoplankton biomass (mg/m3), Kochi.

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	76	0.15	22.17	4.63	4.61
	Nearshore	17	0.12	20.66	5.72	5.89
	Offshore	18	0.18	13.77	3.98	4.10
Pre-monsoon	*Shore*	64	0.11	28.14	6.41	6.44
	Nearshore	17	0.82	14.81	4.31	4.28
	Offshore	17	0.33	17.44	4.32	4.48
Monsoon	*Shore*	56	0.46	22.75	4.22	4.46
	Nearshore	15	0.49	3.90	1.95	0.81
	Offshore	16	0.36	4.08	2.02	0.95
Post-monsoon	*Shore*	88	0.26	28.22	7.46	8.16
	Nearshore	21	1.45	18.90	6.04	5.69
	Offshore	22	0.19	19.62	6.68	6.47

Table 3.5.2.2. Statistical summary of phytoplankton abundance (Cells/l), Kochi.

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	76	1160	181040	38880	44513
	Nearshore	15	1240	72590	17993	23739
	Offshore	16	1790	26240	8968	8499
Pre-monsoon	*Shore*	64	585	113140	21460	28636
	Nearshore	16	1780	50430	10616	11628
	Offshore	16	2120	29440	10600	7148
Monsoon	*Shore*	56	900	114640	36323	35603
	Nearshore	15	2615	38790	13091	12304
	Offshore	16	870	28100	11558	9135
Post-monsoon	*Shore*	88	705	54240	11507	8902
	Nearshore	19	2210	20660	9822	4362
	Offshore	20	2301	27680	10441	7115

Table 3.5.2.3. Statistical summary of zooplankton biomass (ml/m3), Kochi

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	76	0.06	1.75	1.08	0.51
	Nearshore	16	0.08	1.41	0.49	0.41
	Offshore	17	0.06	1.44	0.55	0.42
Pre-monsoon	*Shore*	64	0.08	1.62	0.90	0.48
	Nearshore	17	0.09	1.25	0.44	0.39
	Offshore	17	0.11	1.52	0.61	0.49
Monsoon	*Shore*	56	0.06	1.84	1.04	0.58
	Nearshore	15	0.05	1.33	0.47	0.47
	Offshore	16	0.10	1.68	0.53	0.52
Post-monsoon	*Shore*	88	0.01	3.52	1.04	0.70
	Nearshore	21	0.02	2.33	0.71	0.64
	Offshore	22	0.05	2.61	0.70	0.65

Table 3.5.2.4. Statistical summary of zooplankton abundance (Nos./m3), Kochi

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	76	86	9956	5142	2744
	Nearshore	16	211	7100	2557	2482
	Offshore	17	214	7922	2559	2468
Pre-monsoon	*Shore*	64	78	9014	3995	2822
	Nearshore	17	137	5827	1563	2041
	Offshore	17	173	8451	1926	2750
Monsoon	*Shore*	56	114	8185	4246	2658
	Nearshore	15	168	7307	1624	2160
	Offshore	16	168	8764	1958	2819
Post-monsoon	*Shore*	88	22	9856	4424	2892
	Nearshore	21	136	14746	2892	3656
	Offshore	22	170	10140	2484	2861

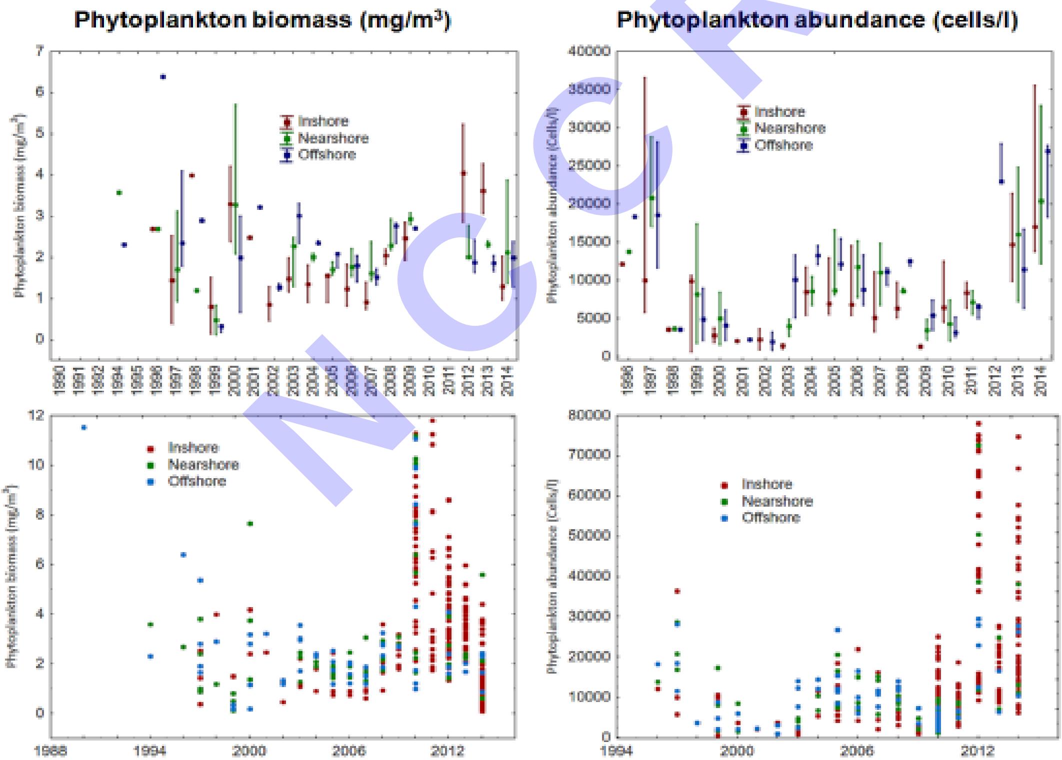


Fig.3.5.2.1. Inter-annual variability in phytoplankton biomass and abundance at Kochi.

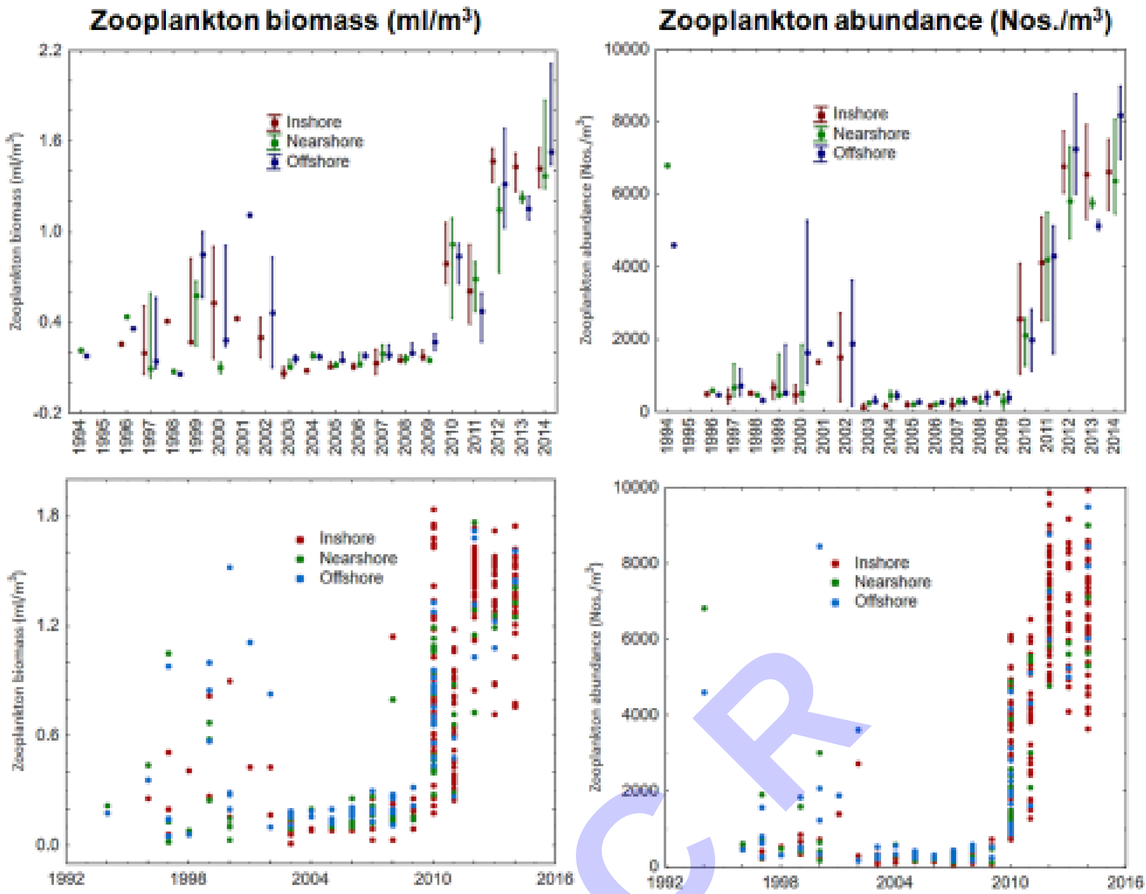


Fig.3.5.2.2. Inter-annual variability in zooplankton biomass and abundance at Kochi.

Seasonal variability

Seasonal variation of phytoplankton (biomass and abundance) and zooplankton (biomass and abundance) in surface water of Kochi transect is represented in Figs. 3.5.2.3 and 3.5.2.4, respectively. Phytoplankton community in this location did not show any strong seasonal pattern (Fig. 3.5.2.3). However, in all the three zones, phytoplankton biomass showed considerable intra-seasonal variability during summer and post-monsoon period. Phytoplankton abundance also showed substantial intra-seasonal variability in the shore zone during summer and monsoon periods. Zooplankton biomass in the shore zone showed high intra-seasonal variations (Fig. 3.5.2.4). In the nearshore zone, high biomass was generally observed during post-monsoon. In the offshore, low zooplankton biomass values were noticed during monsoon period (Fig. 3.5.2.4). Seasonal pattern for zooplankton abundance in the shore zones was weak. However, substantial intra-seasonal variability was noticed. In the nearshore zone, abundance was low during pre-monsoon and monsoon (Fig. 3.5.2.4). The offshore showed strong seasonal pattern for zooplankton abundance with low values during pre-monsoon and monsoon and high during post-monsoon. One of the possible reasons for weak seasonal pattern and high variability of plankton in the coastal waters of Kochi could be due to the increased discharge of high volumes of nutrients throughout the year.

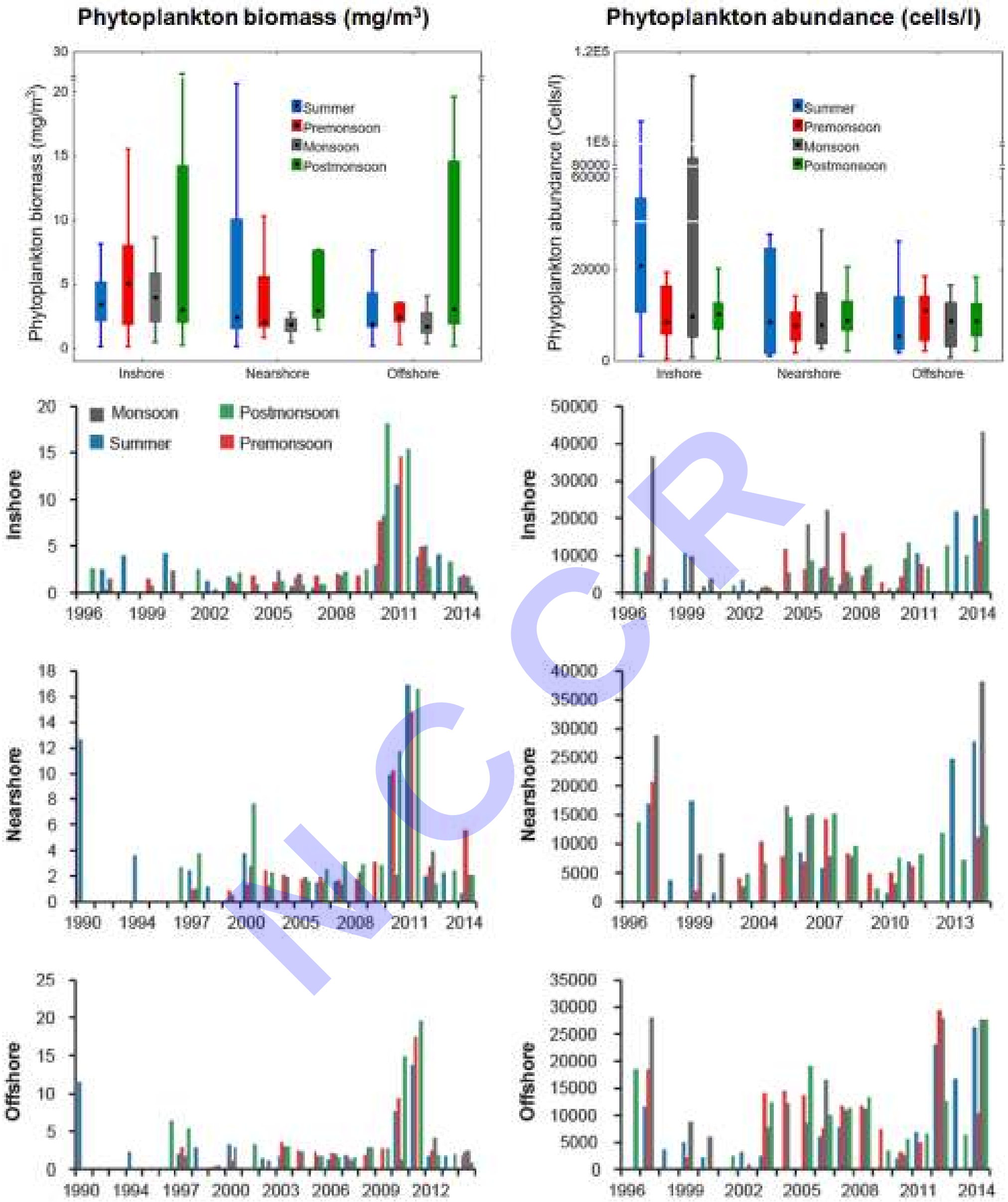


Fig.3.5.2.3. Seasonal variability in phytoplankton biomass and abundance at Kochi.

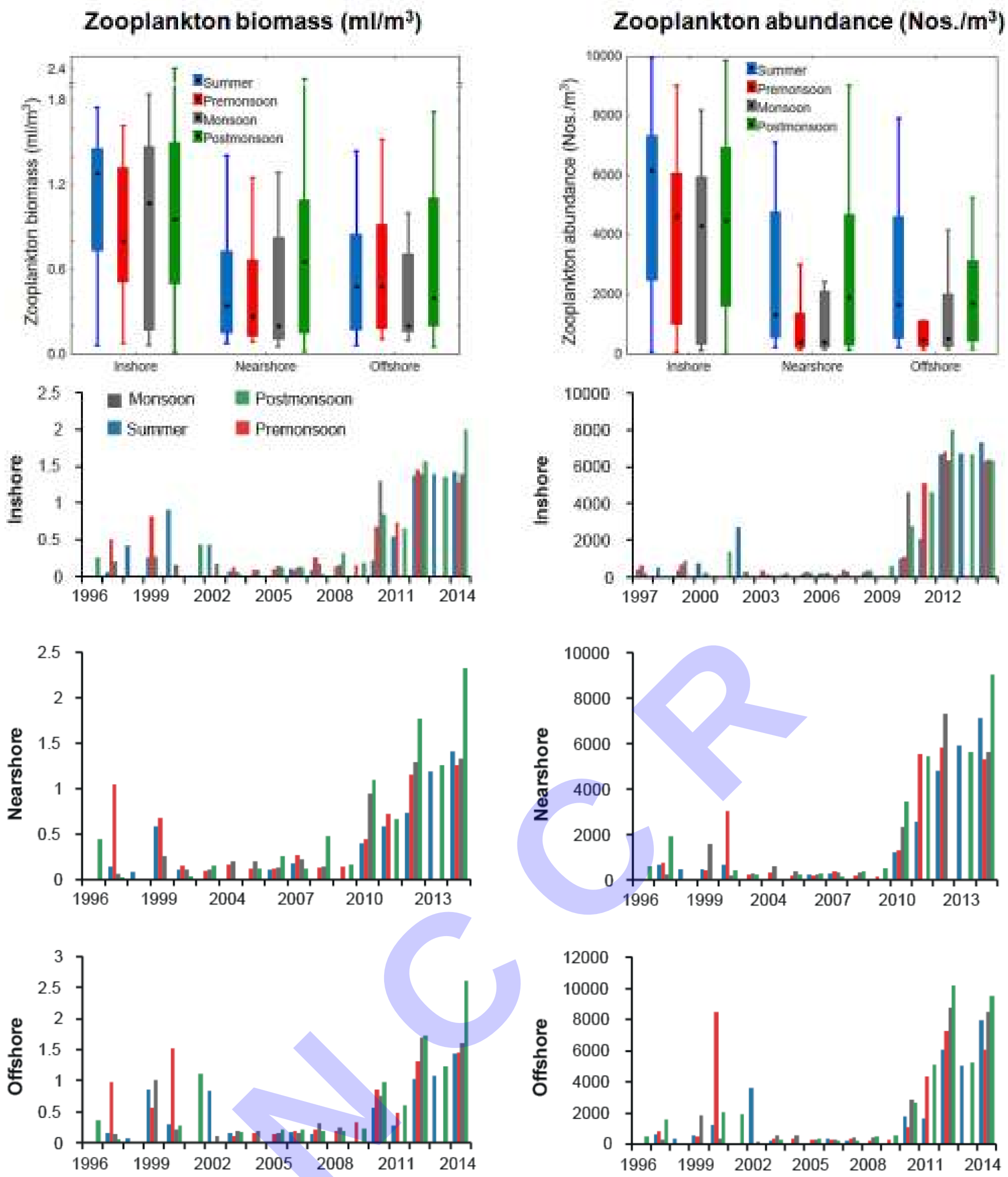


Fig.3.5.2.4. Seasonal variability in zooplankton biomass and abundance at Kochi.

Plankton species composition

Phytoplankton community of Kochi was represented by four major classes, including diatoms (14 genera), dinoflagellates (6 genera), green algae (1 genus), and blue-green algae (2 genera) (Fig 3.5.2.5-7). Phytoplankton genera/species distribution showed seasonal and spatial variability. In the shore region, *Chaetoceros* spp. and *Navicula* spp., dominated during summer, while *Skeletonema* spp., and *Cheatoceros* spp dominated during the pre-monsoon and monsoon season. *Coscinodiscus* spp. shared the dominance with *Skeletonema* during the post-monsoon season. Near shore and offshore regions were dominated by *Skeletonema* spp., co-existing with *Chaetoceros* spp., *Asterionella* spp., *Nitzschia* spp. and *Ceratium* spp. Overall, Kochi coastal waters were mainly dominated by diatoms (<75%), followed by dinoflagellates and blue green algae (Fig 3.5.2.8).

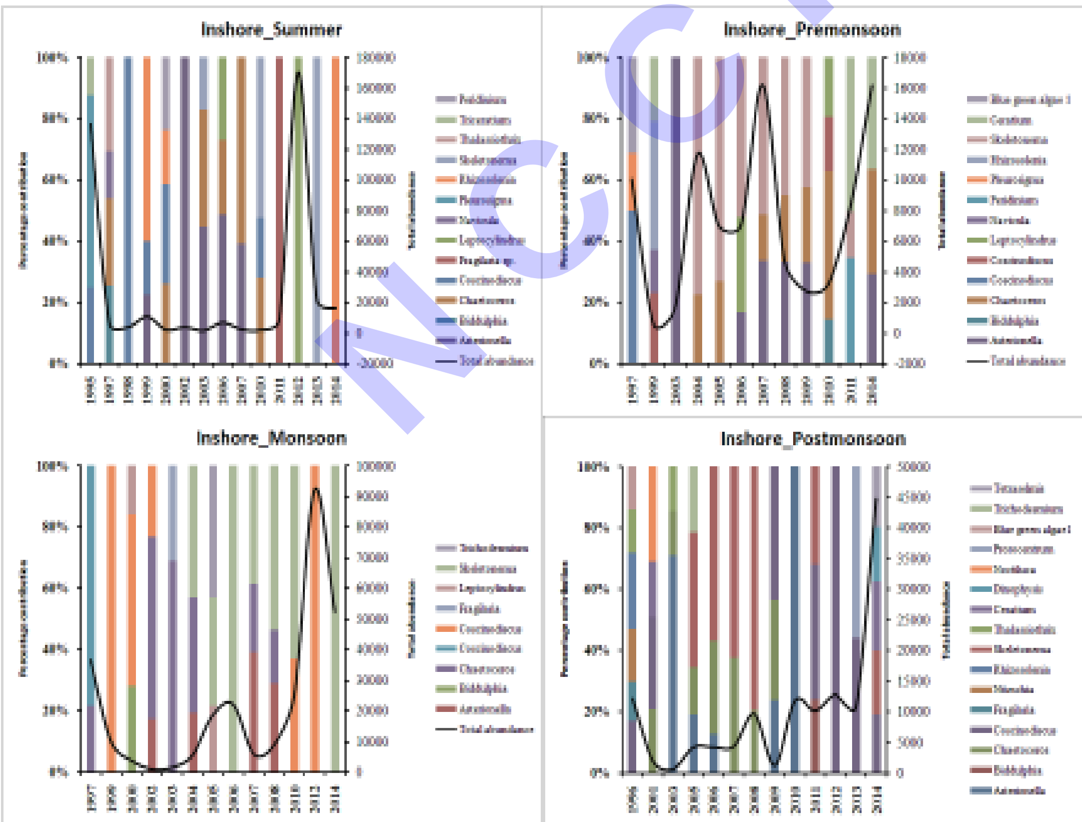


Fig. 3.5.2.5. Year-wise phytoplankton species composition in shore region along Kochi coastal waters

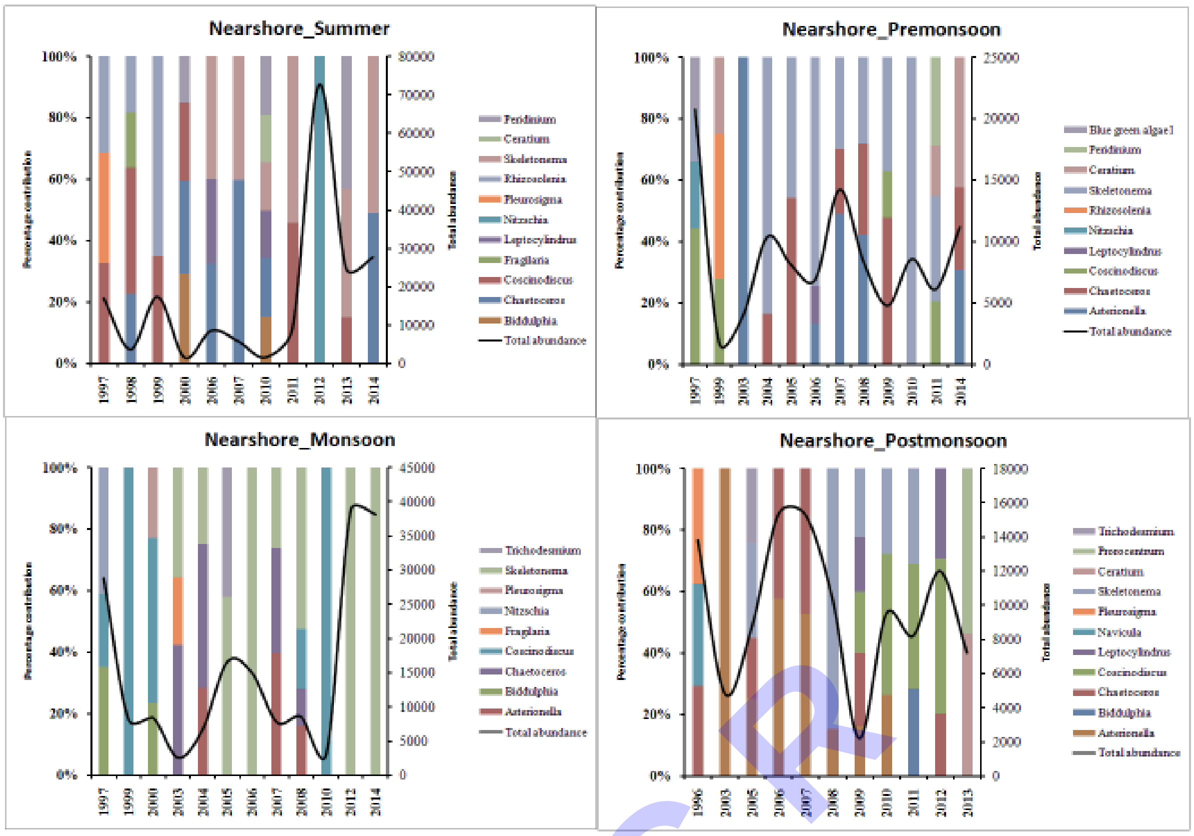


Fig. 3.5.2.6. Year-wise phytoplankton species composition in nearshore region along Kochi coastal waters

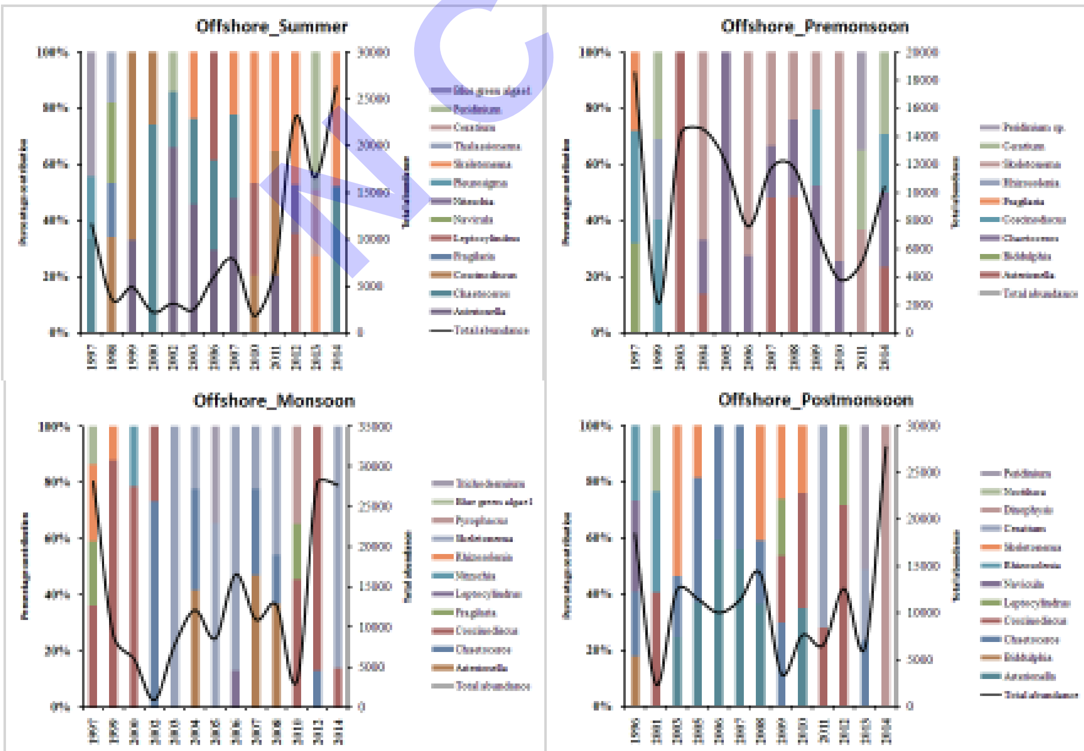


Fig. 3.5.2. Year-wise phytoplankton species composition in offshore region along Kochi coastal waters

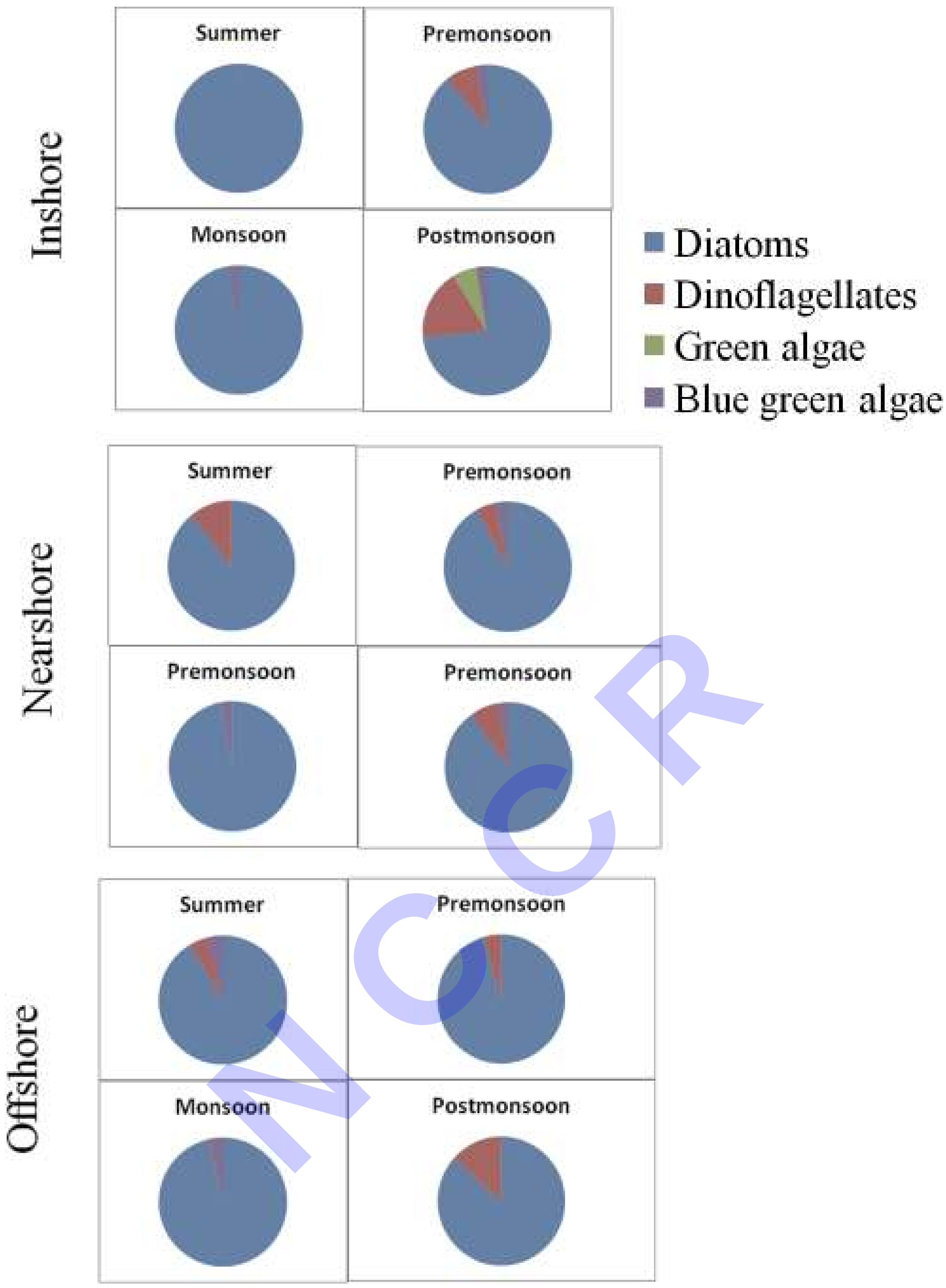


Fig. 3.5.2.8. Phytoplankton groups distribution along Kochi coastal waters

The contribution of different genera of zooplankton to the total abundance varied with time and space. Copepods dominated throughout the study period. Within the copepods, calanoids, cyclopoids, harpacticoids, and poecilostomatoids were dominant groups during the study period. High abundance of fish eggs was mostly noticed during monsoon and post-monsoon period along Kochi coastal waters (Fig.3.5.2.9-11).

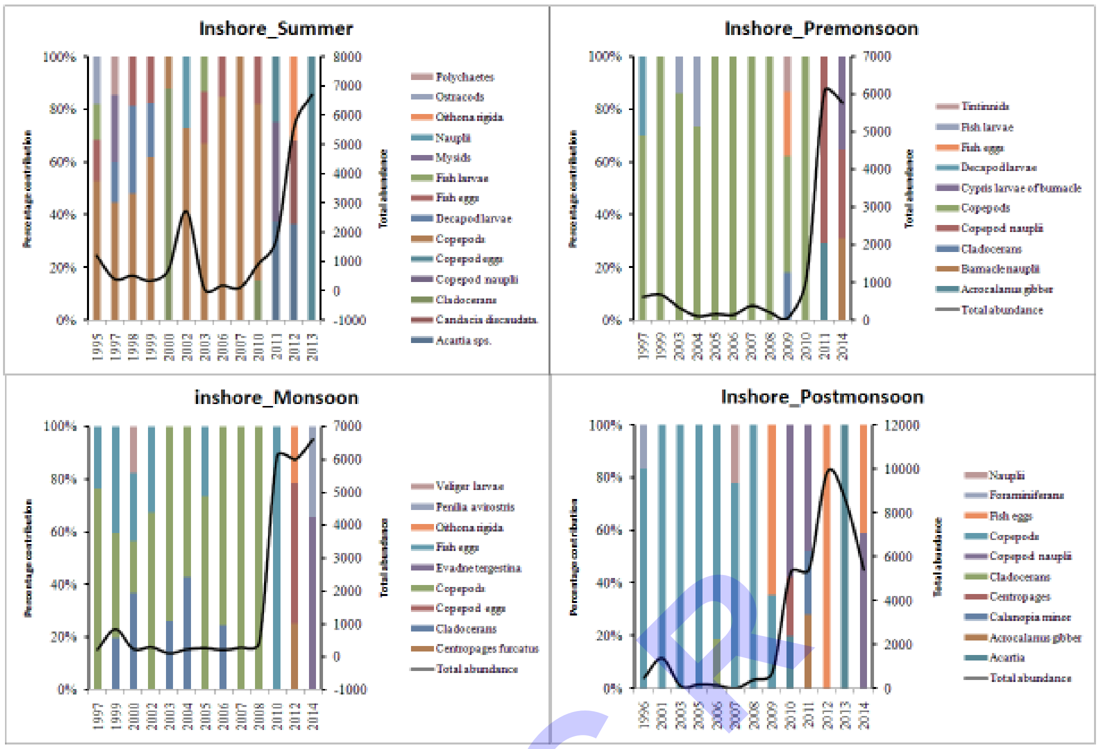


Fig. 3.5.2.9. Year-wise zooplankton species composition in shore region along Kochi coastal waters

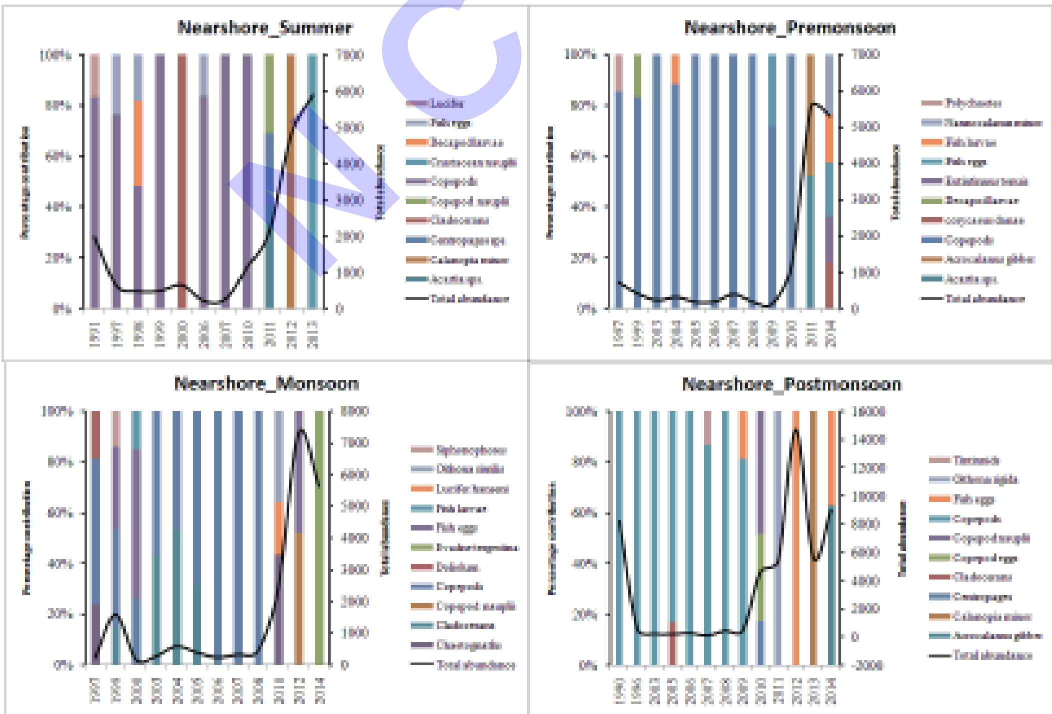


Fig. 3.5.2.10. Year-wise zooplankton species composition in nearshore region along Kochi coastal waters

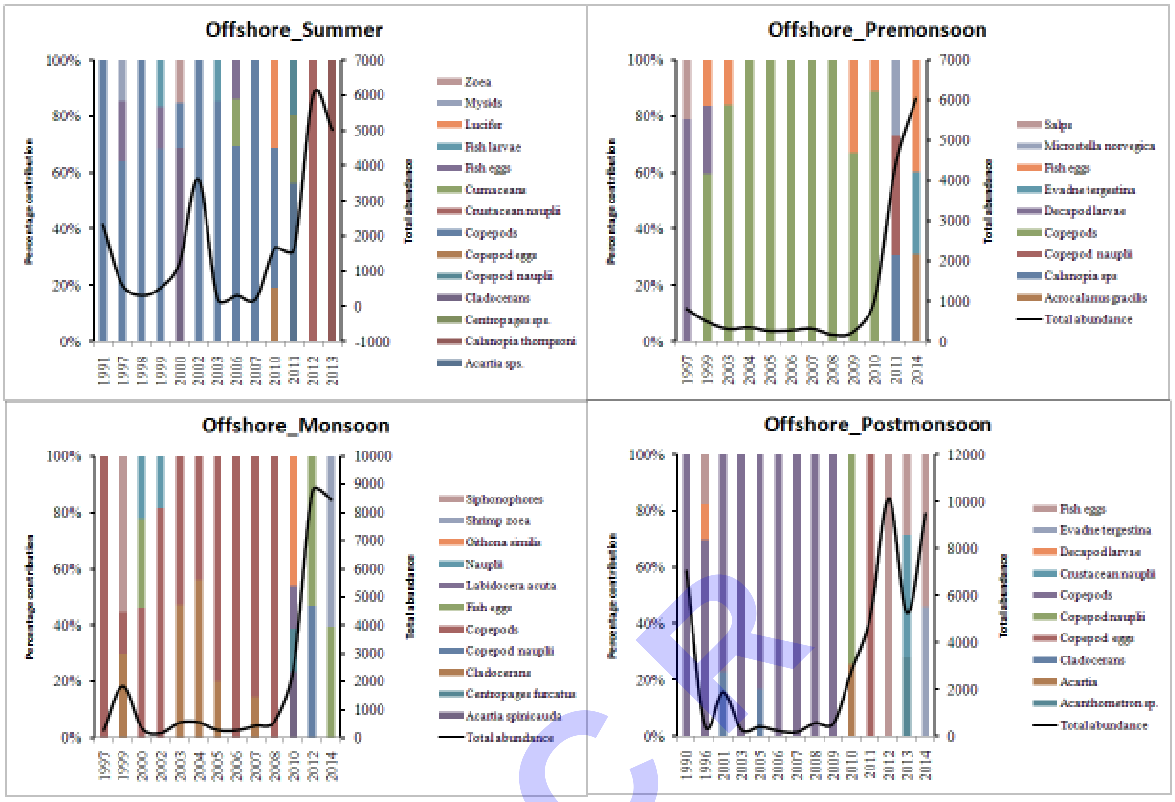


Fig. 3.5.2.11. Year-wise zooplankton species composition in offshore region along Kochi coastal waters

3.5.3. Sediment variables and Macrobenthos

Sediment Organic Matter

The amount of OM in the shore sediment ranged from 1.1 — 36.5 mg g^{-1}(Tables 3.5.3.1 and 2). Although OM values showed variation, it did not show significant change over the time (Fig. 3.5.3.1). An increase in OM was observed in the nearshore (2.8 — 47.36 mg g^{-1}) and offshore zones (2.62 — 44.83 mg g^{-1}) from 2006. The changes observed in OM in the offshore was significant (Chi-Square= 29.33; df = 17; p = .032). The variation in sediment OM was closely related to the changes in the sediment texture with high values of OM recorded in the fine sediment. The nearshore zone was dominated by silt and clay content; however, after 2012 an increase in sand content during the pre-monsoon and post-monsoon period was observed, (Fig. 3.5.3.2). Mud content (silt and clay) dominated the nearshore and offshore sediment (Fig. 3.5.3.3).

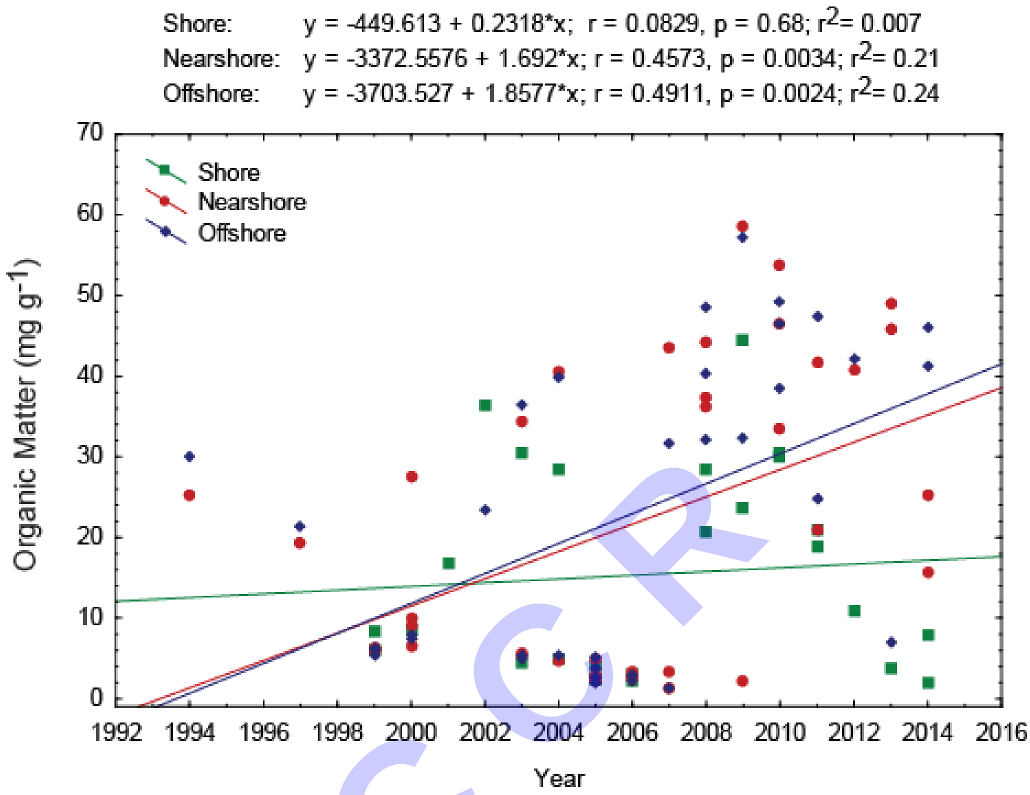


Fig.3.5.3.1. Inter-annual trend in sediment organic matter at Kochi.

Table 3.5.3.1. Range values of sediment OM (mg g^{-1}), macrofaunal abundance (ind. m^{-2}) and biomass (g m^{-2}) at Kochi.

Zone	Season	Organic Carbon	Abundance	Biomass
Shore	*Summer*	3.8-8.71	31-5598	3.01-35.88
	Pre-monsoon	1.1-30.51	19-3666	0.146-32.18
	Monsoon	4.6-36.5	32-4031	0.98-32.08
	Post-monsoon	1.99-28.34	39-5253	2.36-34.05
Nearshore	*Summer*	3.4-25.2	48-6740	3.78-23.7
	Pre-monsoon	1.2-40.56	29-2729	1.88-67.01
	Monsoon	4.8-40.705	67-4968	1.27-43.1
	Post-monsoon	2.3-37.32	78-2664	4.68-22.13
Offshore	*Summer*	2.8-30.1	47-3708	4.1-25.8
	Pre-monsoon	1.4-39.8	38-2448	5.86-48.34
	Monsoon	5.36-7.46	48-7378	1.48-52.26
	Post-monsoon	1.9-40.32	75-4498	3.57-46.4

Table 3.5.3.2. Annual range in values of sediment OM (mg g^{-1}), macrofaunal abundance (ind m^{-2}) and biomass (g m^{2}) at Kochi.

Year	Organic Carbon			Abundance			Biomass		
	Shore	*Nearshore*	*Offshore*	*Shore*	*Nearshore*	*Offshore*	*Shore*	*Nearshore*	*Offshore*
1990	-	-	-	-	60	745	-	6.67	20.71
1994	-	25.2	30.10	-	-	-	-	-	-
1997	-	19.32	21.39	72-98	125-315	89-2671	0.98-1.8	2.8-18.29	1.9-4.52
1998	-	-	-	5598	-	1471	16.8-16.8	-	22.8
1999	6.15-8.32	5.81-6.22	5.31-6.24	180-512	160-1200	160-618	2.8-16.9	5.17-20	1.48-12.8
2000	8.61-8.71	6.48-27.6	7.46-7.94	224-740	86-2096	102-280	8.6-28.4	4.2-43.1	6.5-46.4
2001	16.8-16.8	-	-	730	-	711	-	-	-
2002	36.5-36.5	-	23.51	960-1107	-	1127-1439	-	-	-
2003	4.6-30.51	5.41-34.5	4.9-36.5	918-1441	1231-1585	1501-1981	-	-	-
2004	4.85-28.5	4.8-40.56	5.4-39.8	24-1251	29-1415	38-1085	-	-	-
2005	2.42-4.1	2.3-4.98	1.9-5.1	19-1061	39-2729	48-1875	21.56	8.36-67.01	6.71-48.34
2006	2.1-3.16	2.4-3.4	2.13-2.95	31-940	48-1311	471-709	2.36-6.31	1.27-6.19	2.94-7.11
2007	1.1	1.2-3.42	1.4-31.7	877-1334	1065-1428	979-1575	4.2-5.13	5.48-11.08	4.78-8.14
2008	20.6-28.36	36.25-37.3	32.2-40.32	89-1512	83-1642	62-1686	4.26-8.02	5.48-12.8	6.15-10.14
2009	23.56	2.3	32.42	415-1186	893-956	1121-1206	2.13-11.78	1.88-11.64	6.95-8.57
2010	30.15-30.5	33.51	38.57	395-2183	810-2536	978-2766	3.05-12.58	3.78-16.21	4.29-21.17
2011	18.9-21.03	20.90	24.72	2871-5365	375-6740	333-2683	15.46-18.3	8.25-13.95	5.86
2012	10.90	40.71	-	3168-5253	2232-4968	2448-7378	26.32-35.8	19.57-35.2	18.63-52.3
2013	3.80	-	6.94	1486-4336	1570	2716	21.63-35.2	23.7	25.8
2014	1.99-7.9	15.6-25.27	-	1268-3666	1182-1330	1790-3146	20.95-32.2	12.5-20.05	16.4-31.6

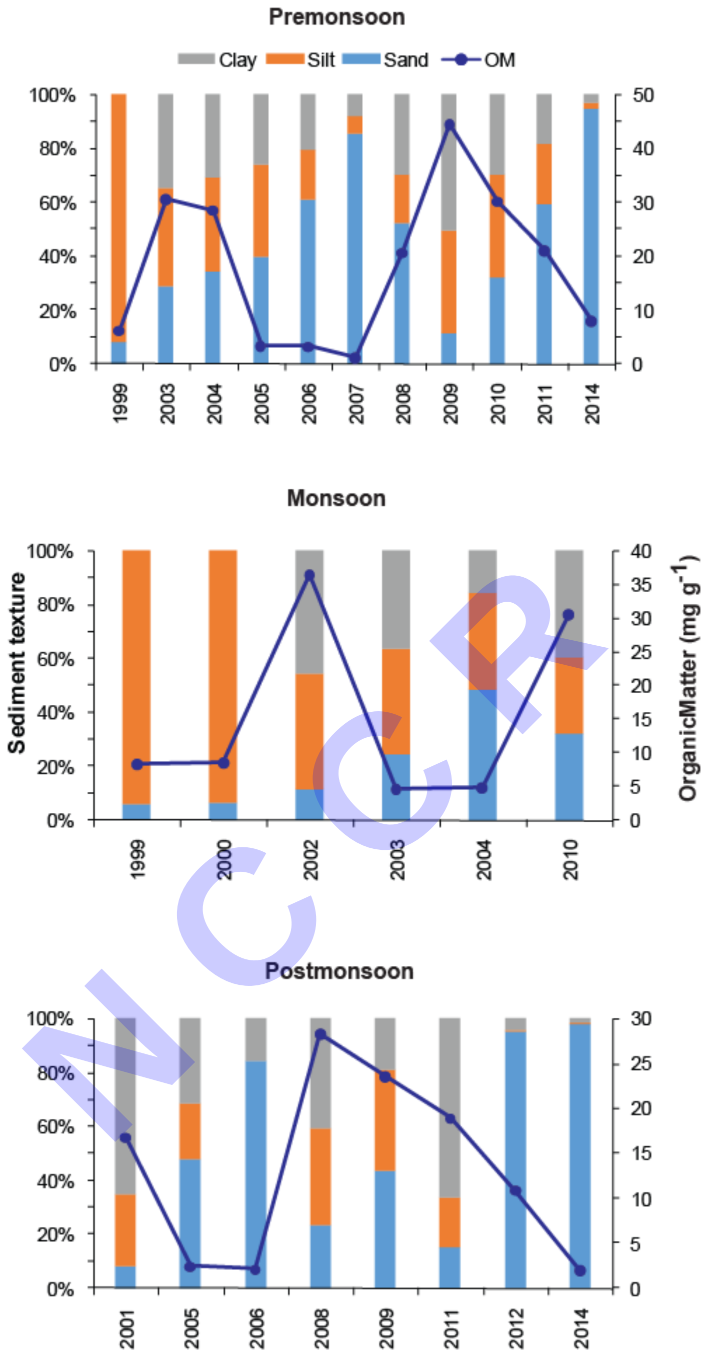


Fig. 3.5.3.2. Seasonal variation in sediment texture and OM in the shore zone of Kochi.

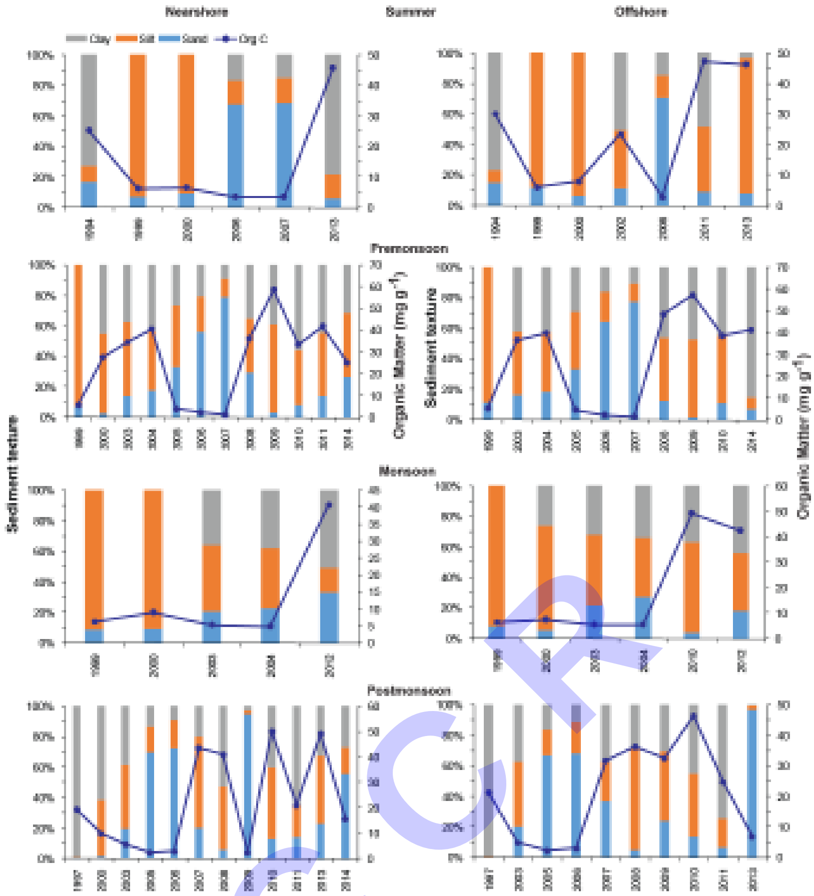


Fig. 3.5.3.3 Seasonal variation in sediment texture and OM in the nearshore and offshore zones of Kochi.

Macrofaunal abundance

The macrofaunal abundance in the sampling point at Kochi from 1990 – 2009 showed an increase from 2010 to2012, but declined thereafter (Fig. 3.5.3.4). The macrofaunal abundance ranged from 85 – 5598 ind. m^{-2}; 60 – 3273 ind. m^{-2} and 166 – 4168 ind. m^{-2} in the shore, nearshore and offshore zones, respectively (Tables 3.5.3.1 and 3.5.3.2). In general, macrofaunal abundance showed a marginal increase from shore to offshore zone. The macrofaunal biomass showed variability over time with two peaks values during, 2000 and 2013 – 14. Biomass showed a marginal decline from shore (1.83 – 30.22 g m^{-2}) to offshore (3.21 – 29.69g m^{-2}) zone (Fig. 3.5.3.4). The biomass in the nearshore ranged from 4.4 – 26.67 g m^{-2}. Seasonal variation in macrofaunal abundance and biomass in all the three zones is represented in Fig. 3.5.3.5. Macrofaunal abundance and biomass range values are given in (Tables 3.5.3.1 and 3.5.3.2).

At Kochi genera/species level data was available only from 2011 onwards. The dominant species in the different zones of Kochi are given in Table 3.5.3.3. The shore location was dominated by molluscs (Bivalvia and Gastropoda) and polychaetes (Fig. 3.5.3.6). The dominant Bivalvia were *Anadara granosa*, *A. rhombea*, *Katelysia* sp., *Musculista senhousia* and *Donax* sp. during different seasons of the year. An unidentified gastropod belonging to the family Trochidae was the most dominant species observed in the Kochi shore zone. The polychaetes were dominated by *Dendronereis aestuarina* and *Capitella* sp. Polychaetes (Chi-Square= 25.82; df = 13; p= 0.018), bivalves (Chi-Square = 29.19; df = 13 p = 0.006) and gastropods abundance (Chi-Square = 30.29; df = 13; p = 0.004) showed a significant increase over the years.

The numerically dominant groups in the nearshore were polychaetes, molluscs and other macrofaunal groups. The abundance of all the groups was variable from 2003 to 2012. However, the values peaked in the year 2012 and declined thereafter. The polychaete abundance in the nearshore also showed a significant increase (Chi-Square = 21.33; df = 11; p = 0.03) over time. Similarly, the abundance of bivalves (Chi-Square = 28.80; df = 11; p = 0.002), gastropods (Chi-Square = 23.13; df = 11 p = 0.02) and other macrofaunal groups (Chi-Square = 21.88; df = 11; p = 0.02) also showed a significant increase. The dominant molluscan taxa were *A. granosa, A. rhombea, Cardium setosum, Donax* sp., Trochidae sp., *Natica sp. Nassarius variegates, Dentalium sp.* and unidentified bivalves. Polychaetes were dominated by *Capitella sp. Ancistrosyllis parva, Lumbrineries sp., Nephthys oligobranchiata, Prionospio cirrifera* and *Notomastus sp.* A nematode *Gonionchus* sp. and the isopod *Sphaeroma serratum* were also other dominant species in the nearshore zones. The macrofaunal group abundance in the offshore showed a similar pattern as that of nearshore, peak values in 2012 and variation during rest of the years. Polychaetes (Chi-Square =

22.89; df = 13; p = 0.04), gastropods (Chi-Square = 32.13; df = 13; p = 0.002) and crustaceans (Chi-Square = 25.29; df = 13 p = 0.02) showed a significant increase over time. In the offshore, nine species of polychaete dominated the macorfaunal community (Table 3.5.3.3). Molluscs were represented by *A. granosa, A. rhombea*, *Donax* sp., *Meretrix meretrix*, *Cardium setosum, Dentalium* sp.and Trochidae sp. The nematode *Astomonema* sp. was also dominant in the offshore zone during 2011.

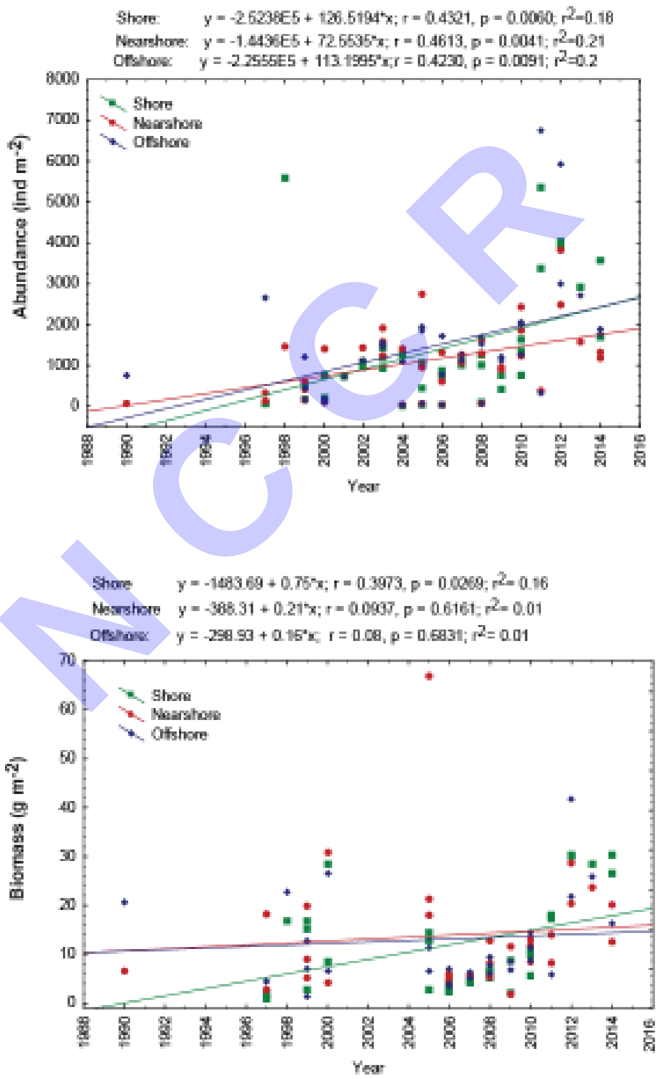


Fig.3.5.3.4. Inter-annual trend in macrofaunal abundance and biomass at Kochi.

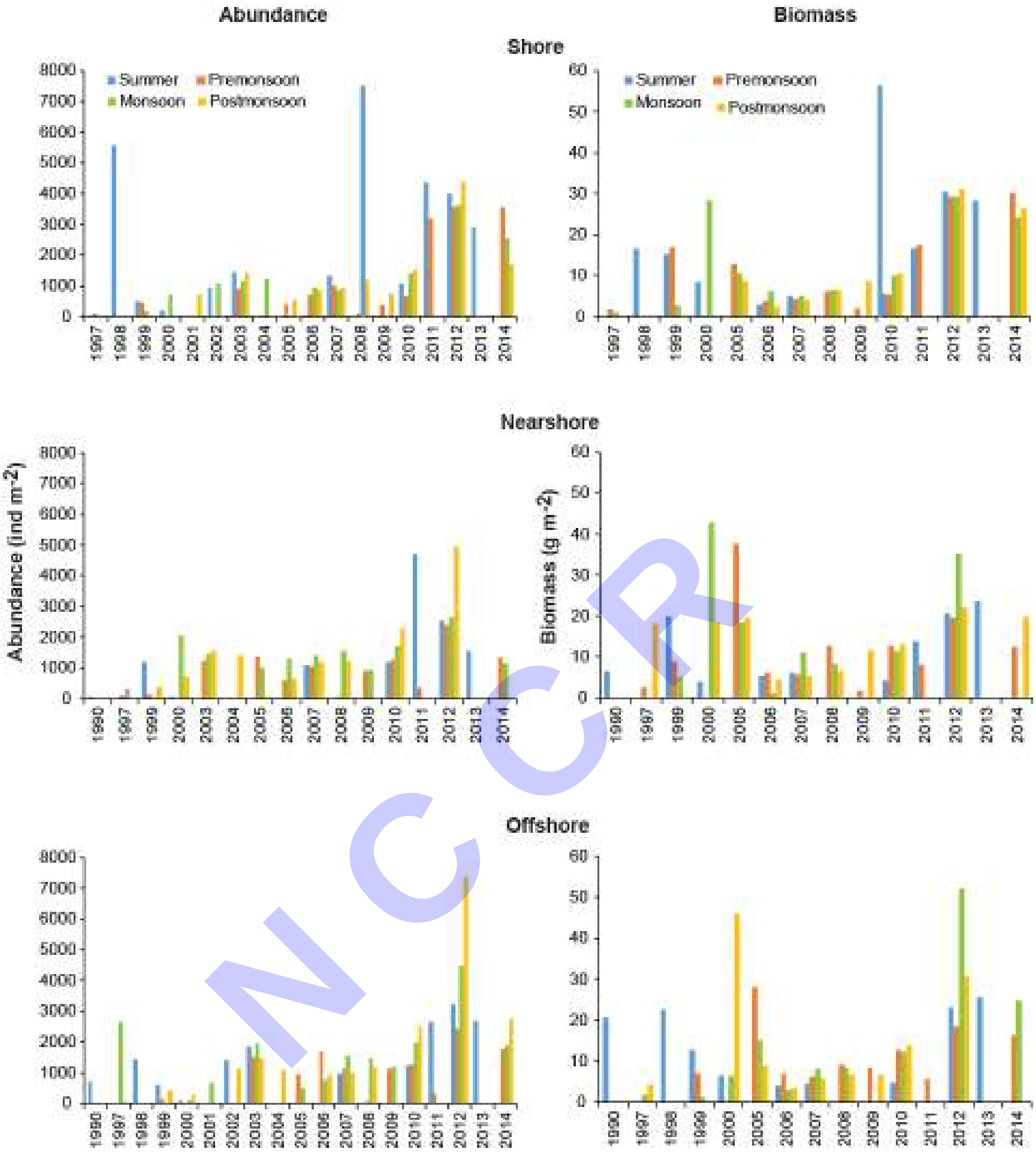


Fig.3.5.3.5. Seasonal variation in macrofaunal abundance and biomass in the different zones of Kochi.

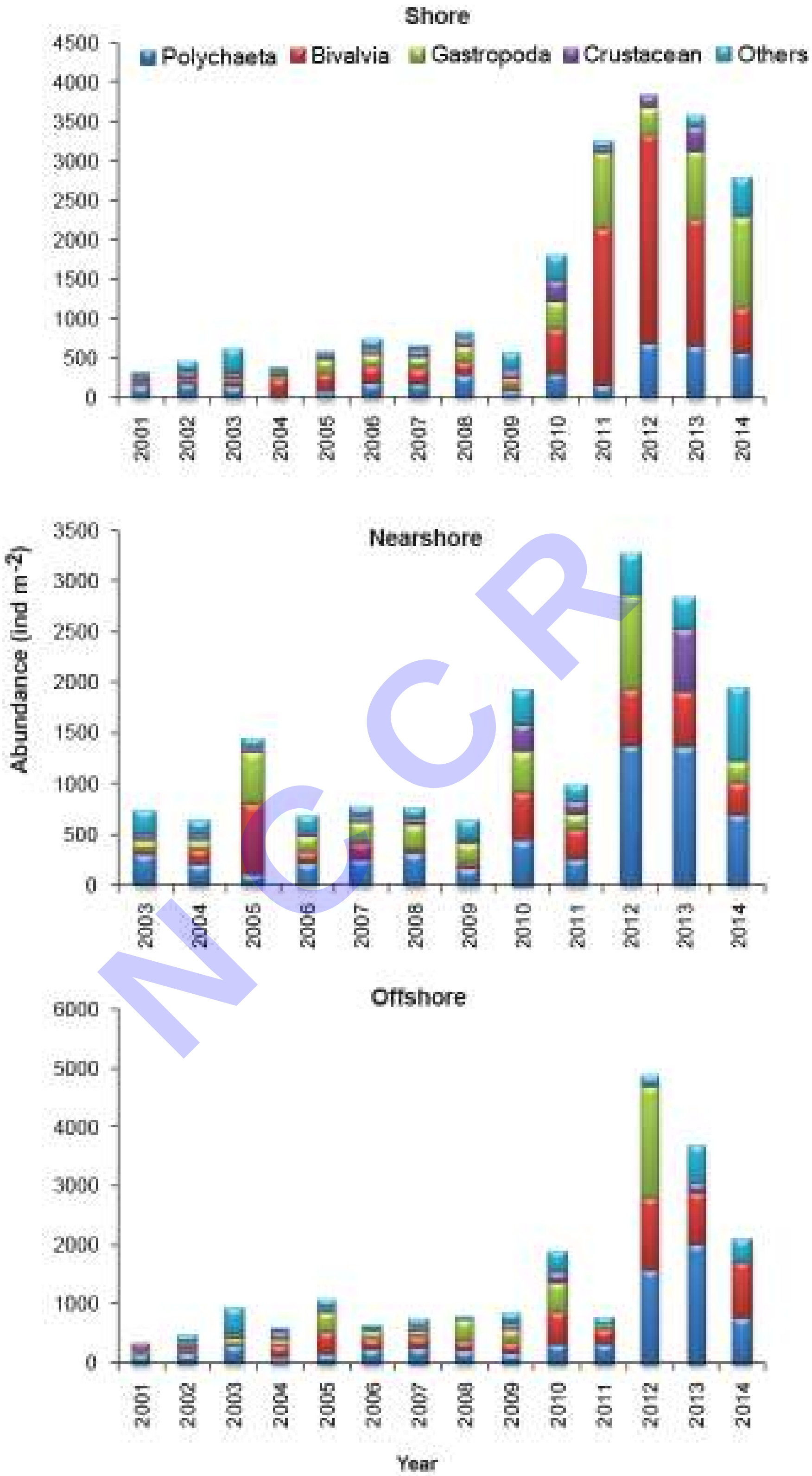


Fig.3.5.3.6. Inter-annual trend in macrofaunal group abundance in the different zones of Kochi.

Table 3.5.3.3 Dominant taxa (>10% of the total abundance) at Kochi

	2011	2012	2013	2014
Shore	**Bivalvia** *Anadara granosa* *A. rhombea* **Gastropoda** Trochidae sp. **Polychaeta** *Capitella* sp.	**Bivalvia** *A. granosa* *A. rhombea* Meretrix veliger *Musculista senhousia* *Donax* sp. *Katelysia* sp**Polychaeta** *Dendronereis aestuarina,*	**Polychaeta** *Katelysia* sp **Gastropoda** Trochidae sp.	NA
Nearshore	**Bivalvia** *A. granosa* *Cardium setosum* **Scaphopoda** *Dentalium* sp. **Gastropoda** Trochidae sp. **Polychaeta** *Capitella* sp. *Glycera alba* **Isopoda** *Sphaeroma serratum* **Nematoda** *Gonionchus* sp.	**Bivalvia** *A. granosa,* Bivalvia **Gastropoda** Trochidae sp. **Scaphopoda** *Dentalium* sp. **Polychaeta** *Ancistrosyllis parva* *Lumbrineries* sp. *Capitella* sp	**Bivalvia** *A. granosa* *A. rhombea* **Scaphopoda** *Dentalium* sp. **Polychaeta** *Nephthys oligobranchiata* *Prionospio cirrifera*	**Bivalvia** *A. granosa* *Donax* sp. **Scaphopoda** *Dentalium* sp. **Gastropoda** *Bullia vitata* *Natica* sp. *Nassarius variegatus* **Polychaeta** *A. parva* *Capitella* sp.*N.oligobranchia* *Notomastus* sp. *Prionospio cirrifera*
Offshore	**Bivalvia** *A. granosa* *A. rhombea* Trochidae sp. **Gastropoda** *Dentalium* sp. **Polychaeta** *Capitella* sp. *Chaetopterus* sp. *Cirratulus africanus* *Phyllodoce castanea* **Nematoda** *Astomonema* sp.	**Bivalvia** *A. granosa,* *Donax* sp. **Scaphopoda** *Dentalium sp.* **Gastropoda** Trochidae sp *Natica sp.* **Polychaeta** *Ancistrosyllis constricta* *Capitella sp* *Diopatra neapolitana* *Nereis sp.* *Prionospio polybranchiata*	**Bivalvia** *Cardium setosum* *Donax* sp. **Scaphopoda** *Dentalium* sp. *Neries* sp.	**Bivalvia** *Donax* sp. *Meretrix meretrix.* **Scaphopoda** *Dentalium* sp. **Polychaeta** *Capitella* sp *Lumbrineries* sp.

3.5.4. Status of microbial quality at Kochi

Total viable count of bacteria in Kochi coastal waters increased over the years. The TVC recorded from 1992 to 2014 is shown in the box plot (Fig. 3.5.4.1). The counts of total viable bacteria in coastal waters were between 5 and 4.8×10^4 cfu/ml. Further, the counts in sediment were between 36 and 9×10^5 cfu/g. The bacterial counts were found to be high in sediment than in waters. Inter-annual variation of TVC showed an increasing trend with high values in 2002. Monitoring of*E. coli* from 1992 to 2014, shows that counts increased from 2005 and high levels of *E. coli* were observed in 2010 (Fig. 3.5.4.1). The counts of *E. coli* in coastal waters were between 0 and 2.9×10^3 cfu/ml. Alarmingly, the counts of *S. faecalis* have increased over the years, particularly from the year 2010 (Fig. 3.5.4.1). The prominent increase in *E. coli* and *S. faecalis*indicates that the quantum of discharge of untreated domestic sewage may have been increased in the Kochi coast.

Insights into seasonal variations show that the TVC were steadily increasing in all the four seasons (Fig. 3.5.4.2). Further, TVC were high during summer and the highest values were recorded in 2010. The *E. coli* counts showed increasing trend in pre-monsoon and the highest values were recorded in 2010 (Fig. 3.5.4.3). Further, counts of *S. faecalis* showed an increasing trend in all the seasons (Fig. 3.5.4.4). The levels of *S. faecalis* were extremely high in post-monsoon of 2013 and summer of 2014. The highest values were observed in post-monsoon of 2013 (i.e., 2.4×10^4 cfu/ml.).

Spatial pattern based on the data recorded from 1992 to 2014 in the microbial counts is represented in Fig. 3.5.4.5. Like most west coast transects, the TVC, *E. coli* and *S. faecalis* showed a decrease towards offshore.

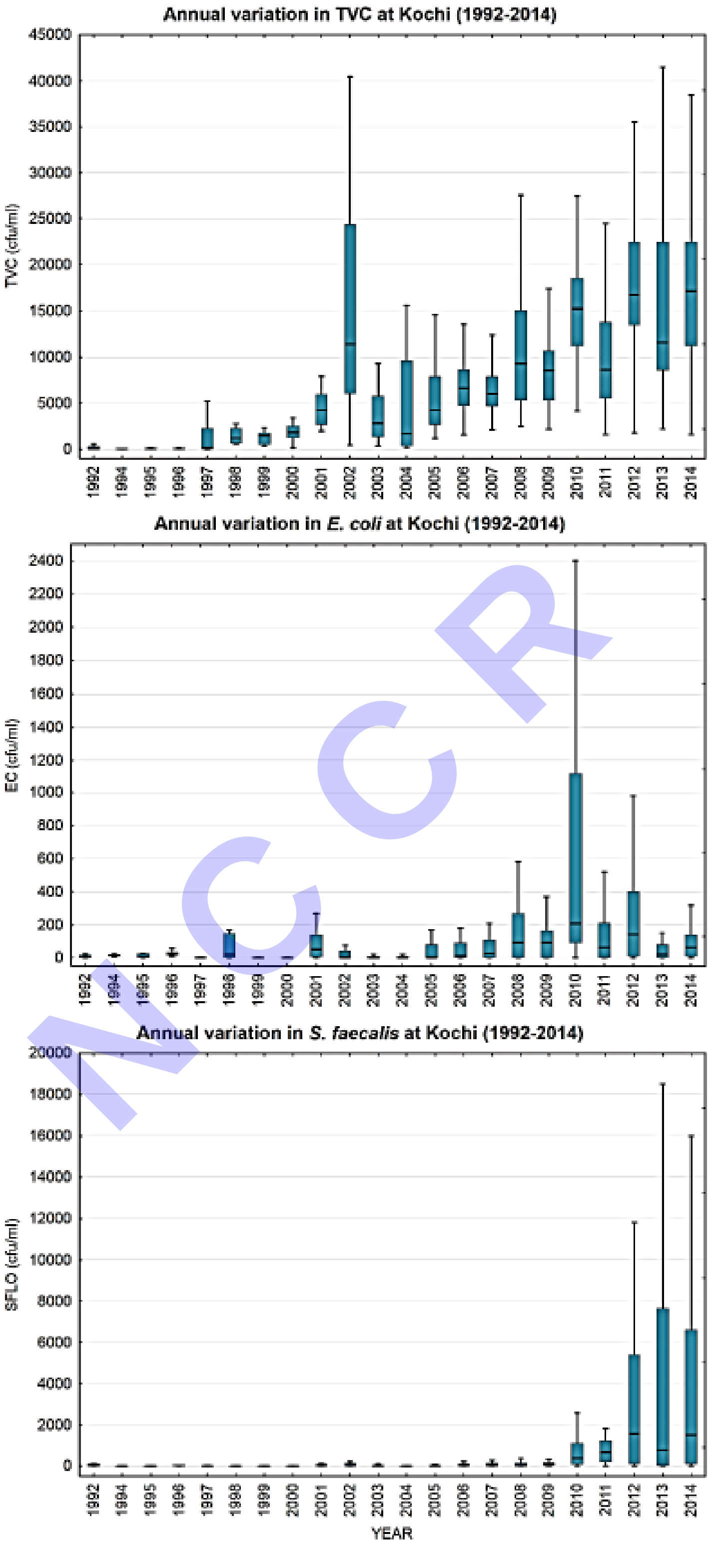


Fig. 3.5.4.1. Box plot showing inter-annual variation (1992-2014) in TVC, EC and SFLO at Kochi.

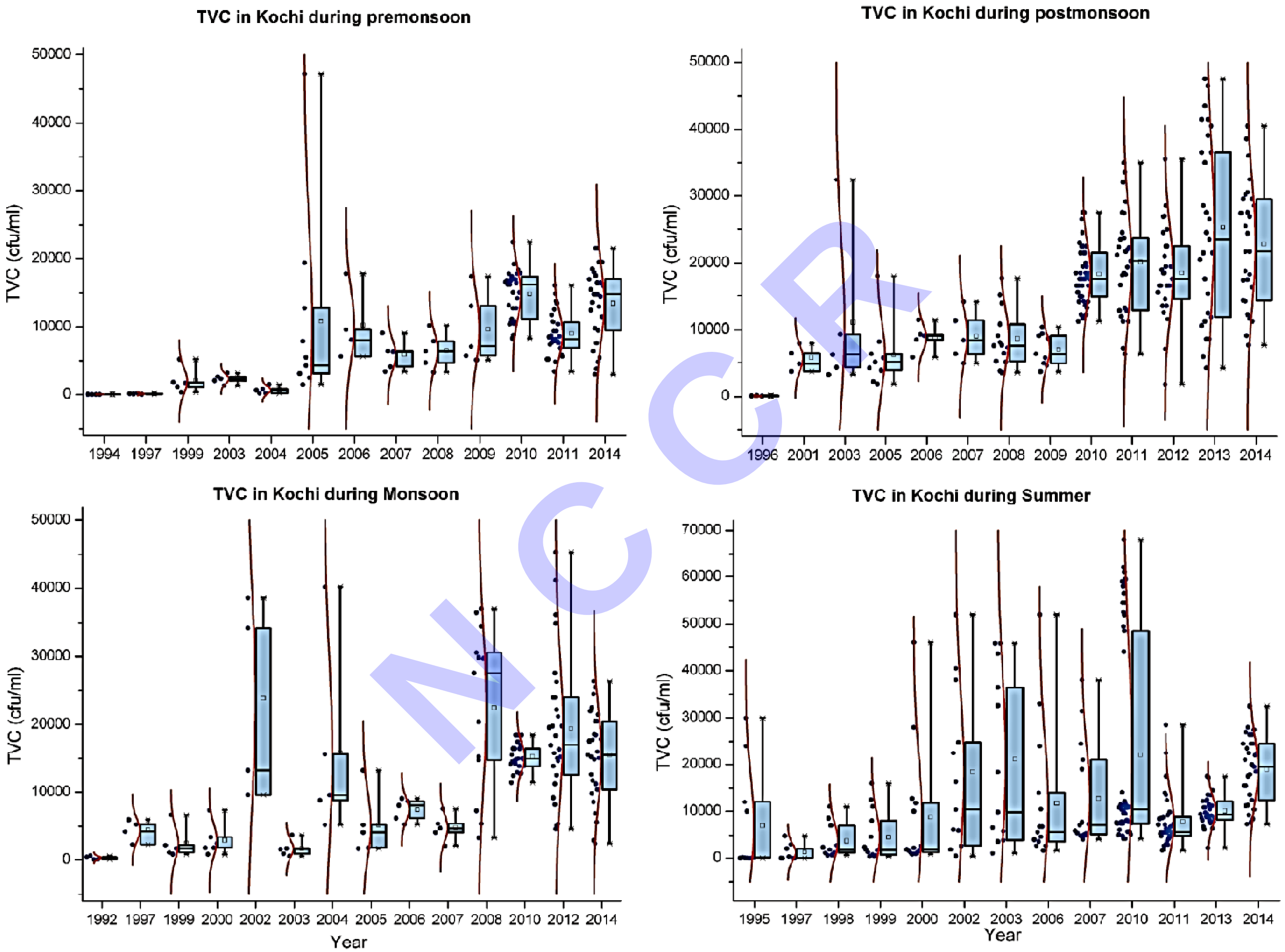


Fig. 3.5.4.2. Box plot shows seasonal variation in TVC at Kochi. Blue dots: data points; Red lines: distribution curve.

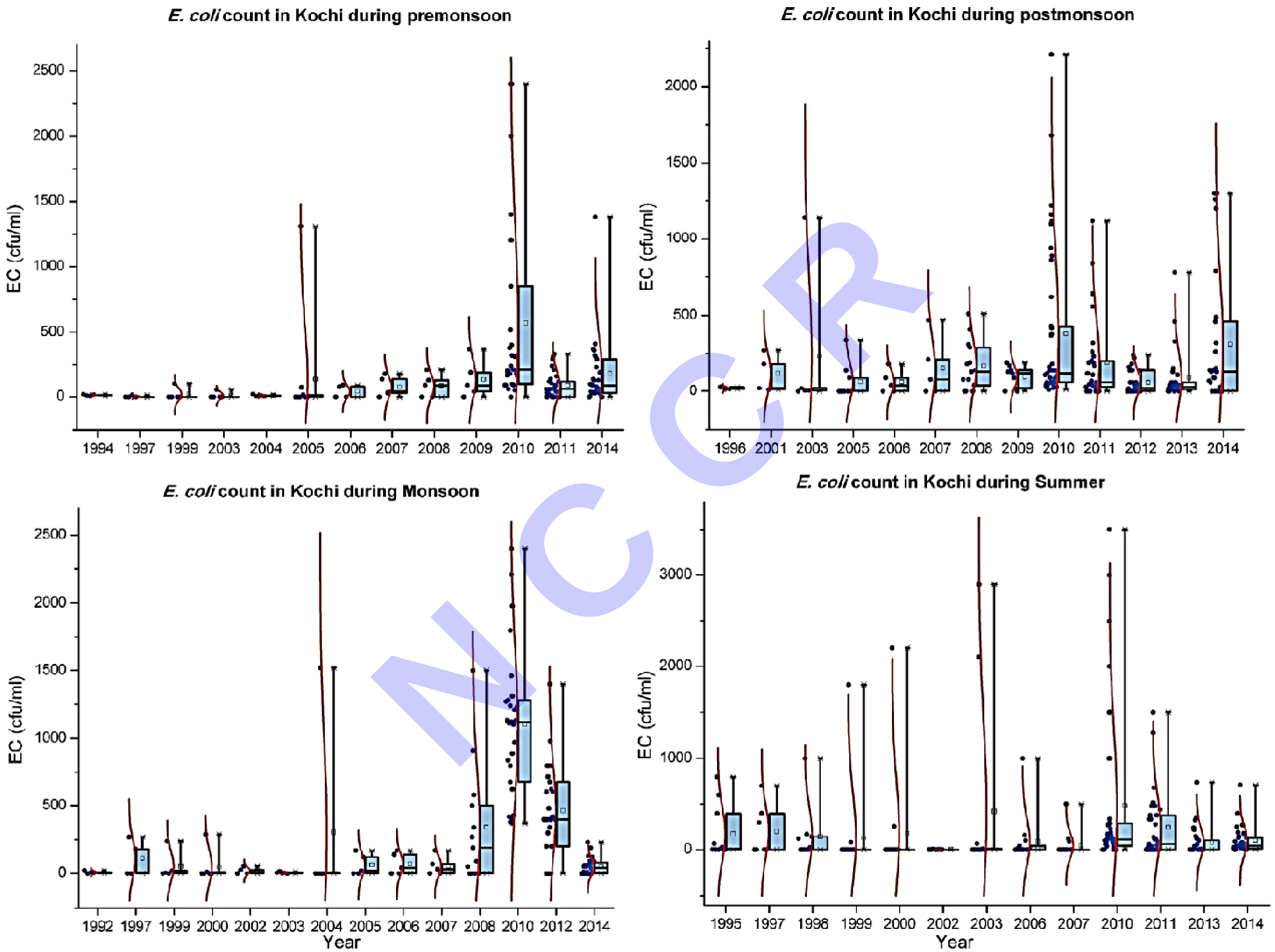


Fig. 3.5.4.3. Box plot shows seasonal variation in *E. coli* count at Kochi. Blue dots: data points; Red lines: distribution curve.

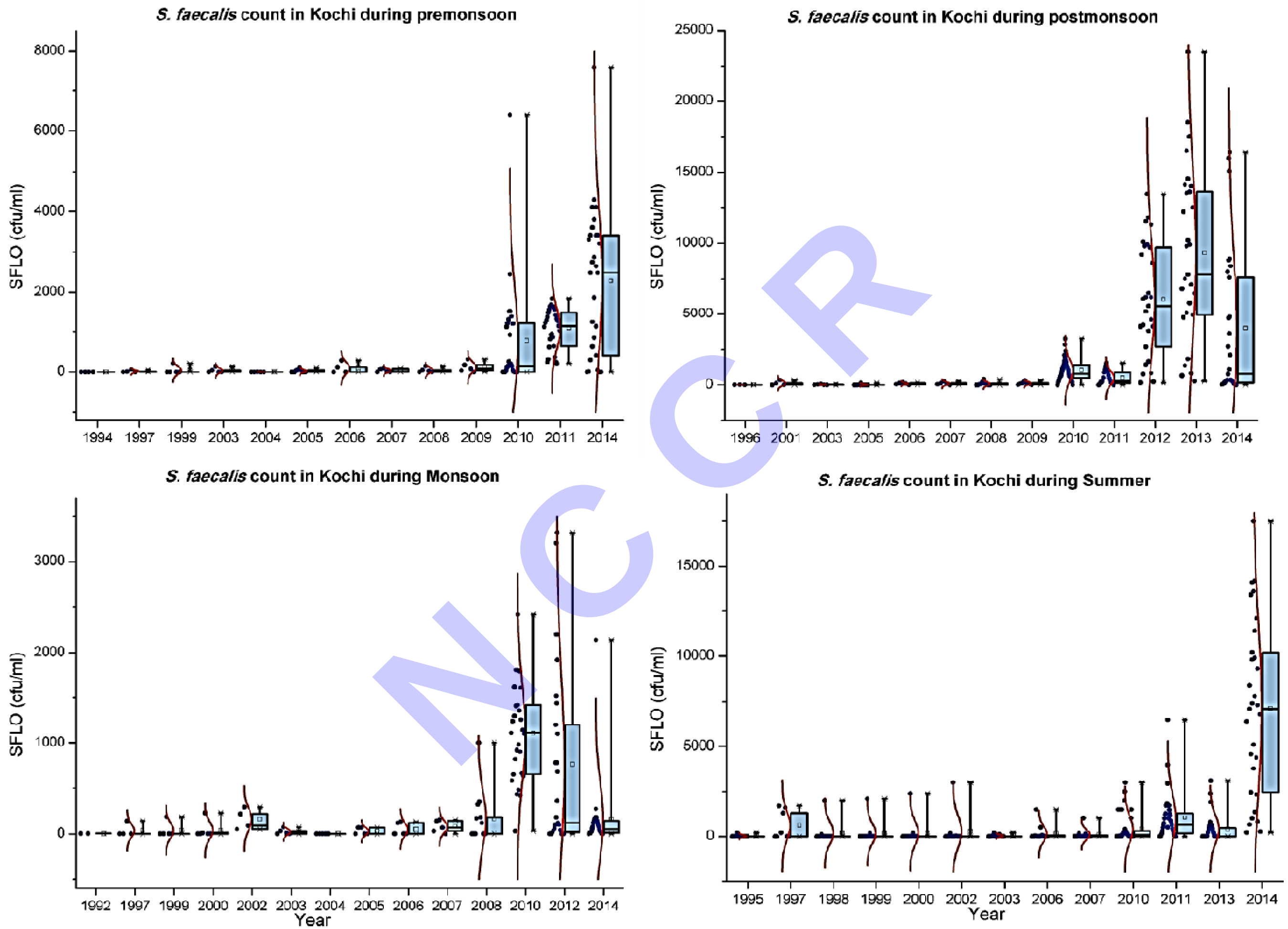


Fig. 3.5.4.4. Box plot showing seasonal variation in *S. faecalis* count at Kochi. Blue dots: data points; Red lines: distribution curve.

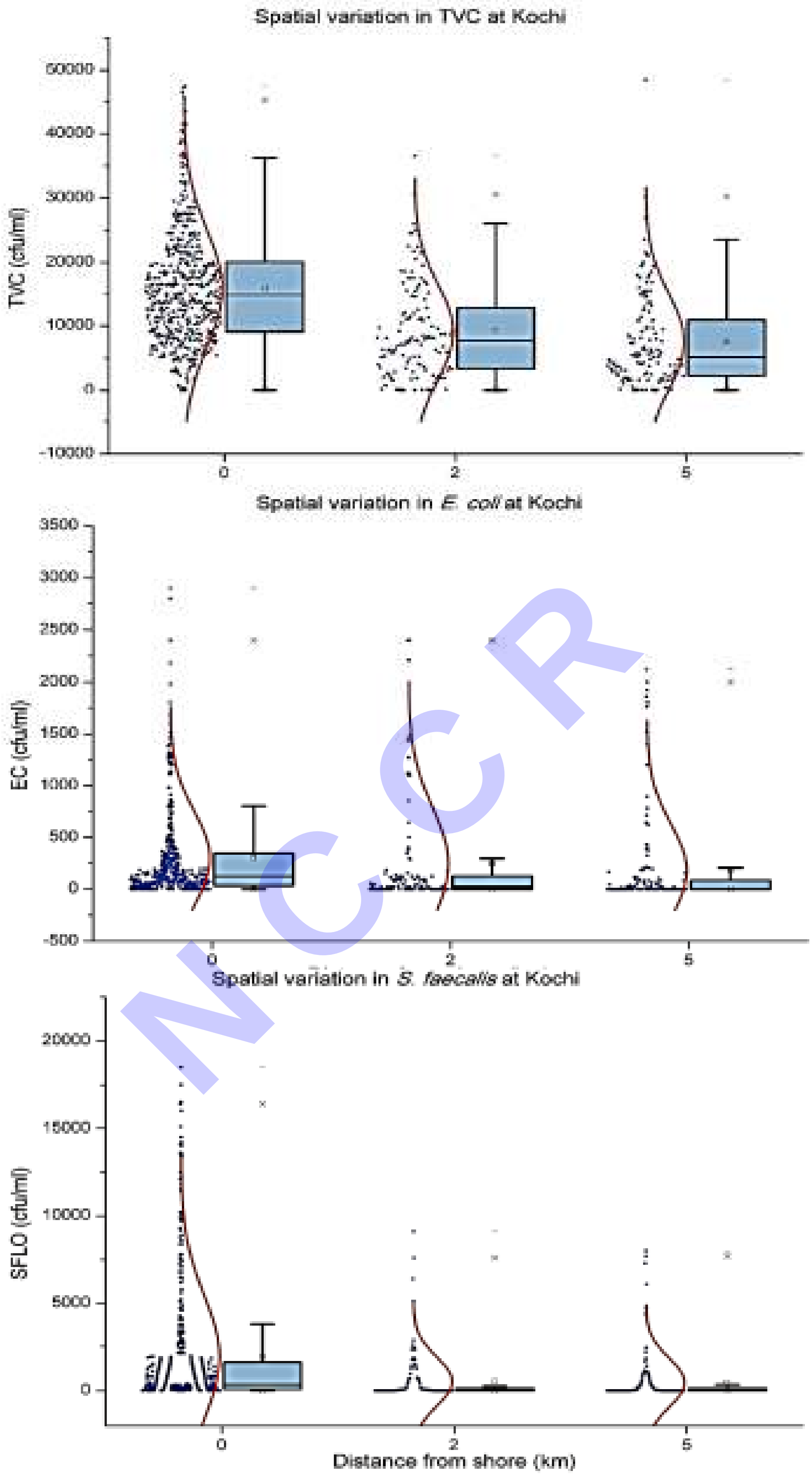


Fig. 3.5.4.5. Box plot showing spatial variation in TVC, EC and SFLO at Kochi. Blue dots: data points; Red lines: distribution curve.

3.6. Ennore

3.6.1. Physicochemical variations

Temperature ranged between 25 – 36 ºC, 23 – 36 ºC and 25 – 33 ºC, in the shore, nearshore and offshore zonesof Ennore, respectively (Fig. 3.6.1.1). Seasonally, the highest median values of temperature were recorded during pre-monsoon in the shore and nearshore zones while in the offshore, high values were observed during summer (Fig. 3.6.1.2). The seasonal pattern of salinity was typical of tropical coastal regions, with the lowest values during monsoon (Fig. 3.6.1.4). All the zones showed similar seasonal patterns in surface water *p*H, with the lowest values during monsoon (Fig. 3.6.1.7). In the shore zone, the lowest DO was recorded in 2006, the values increased thereafter, with a second decline during recent years (Fig. 3.6.1.7). The lowest DO in the nearshore was reported during 2001, with values fluctuating thereafter. Compared to the 1990s, lower DO values were recorded during 2014 – 2015 in the offshore zone (Fig. 3.6.1.8). Seasonally, the lowest DO was observed during the pre-monsoon in the shore and nearshore zones, while a reverse trend of the highest DO during this period was observed in the offshore (Fig. 3.6.1.8). The SSC showed high variability in the nearshore, compared to the shore and offshore zones (Fig. 3.6.1.9). In the nearshore, SSC declined from 2006, with minimum values during 2013 and increased during 2014 – 2015. Surprisingly, the SSC was the lowest during the monsoon period in all the three zones (Fig. 3.6.1.10).

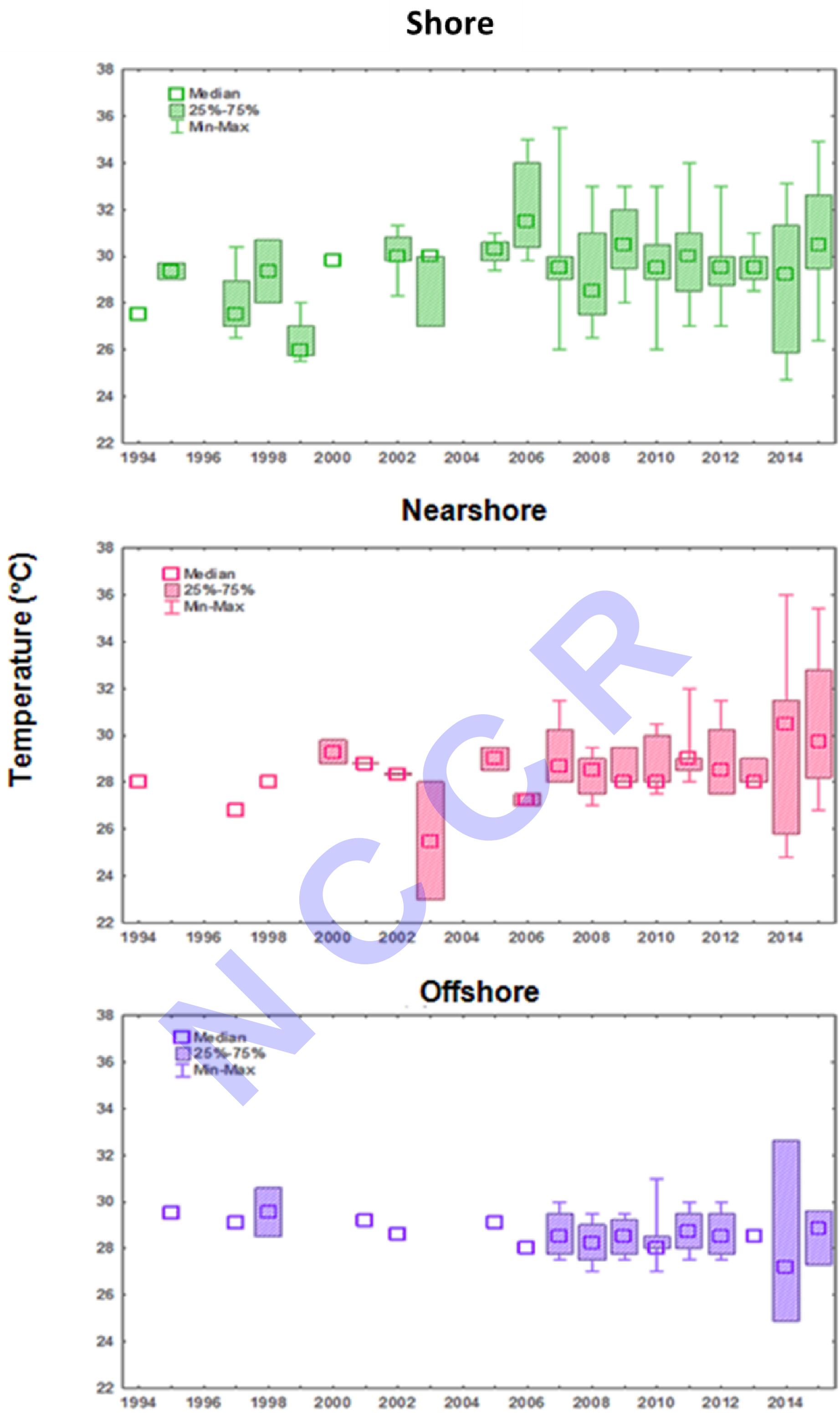


Fig. 3.6.1.1. Inter-annual trend in surface water temperature at Ennore.

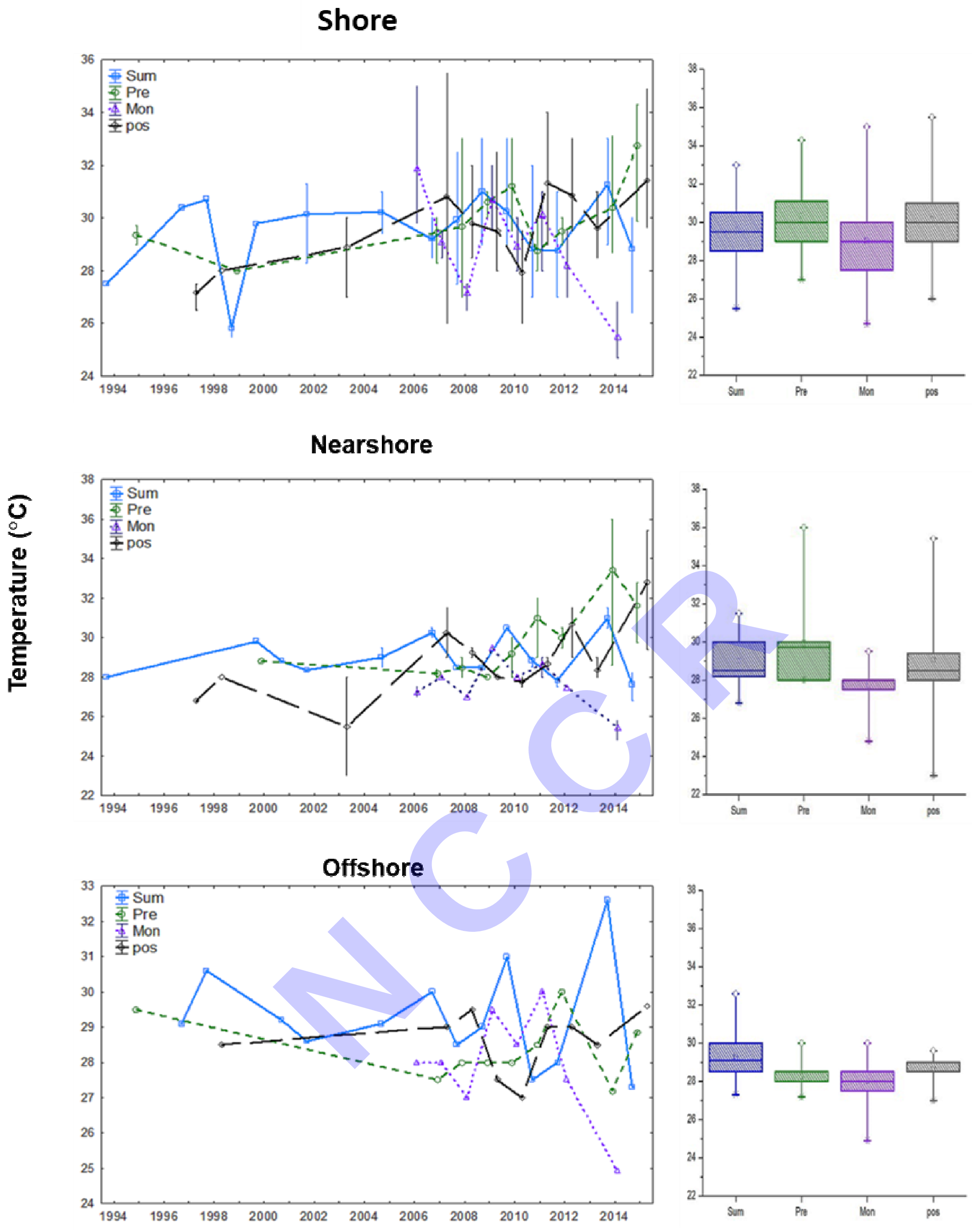


Fig. 3.6.1.2. Seasonal trend in surface water temperature at Ennore.

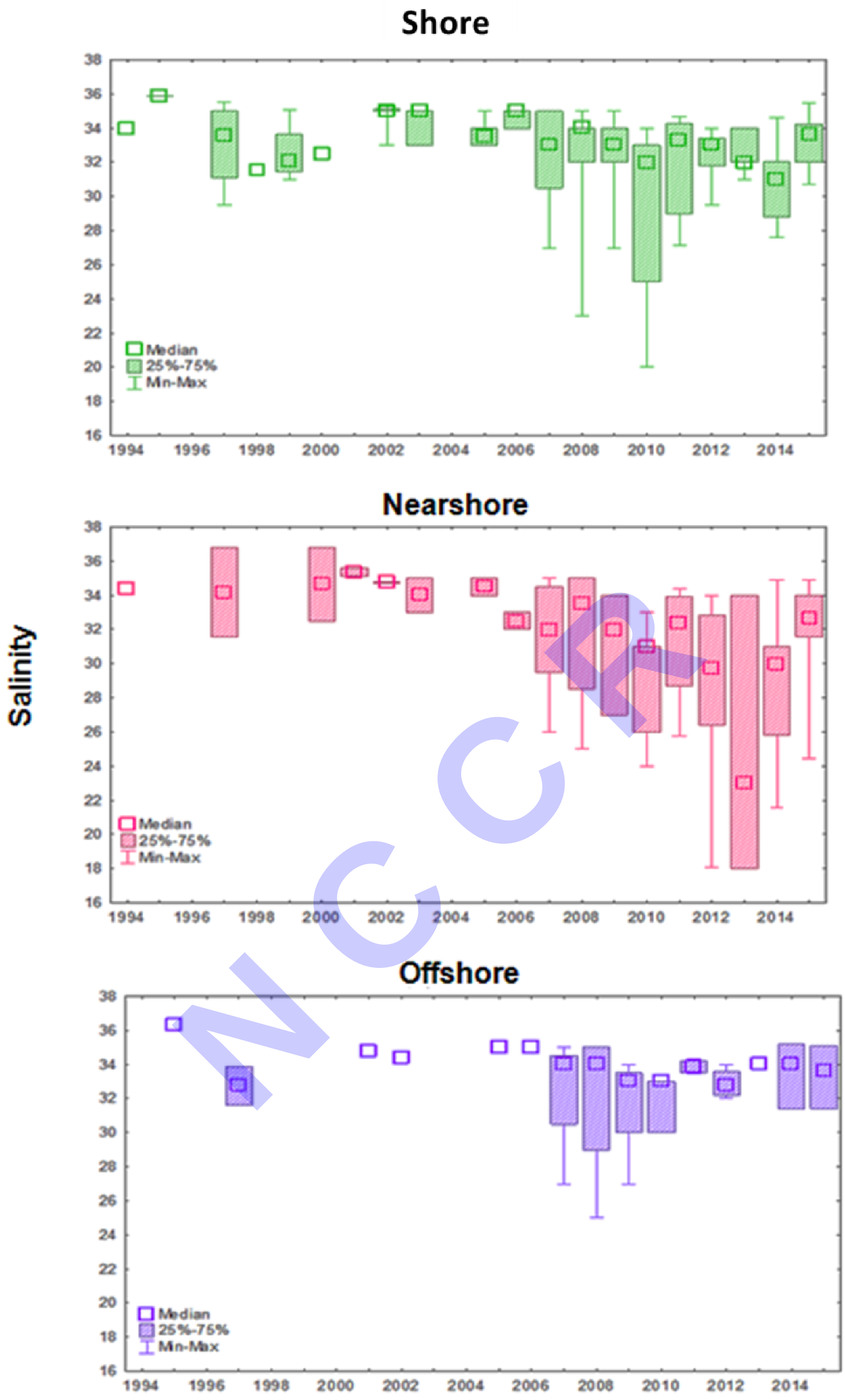


Fig. 3.6.1.3. Inter-annual trend in surface water salinity at Ennore.

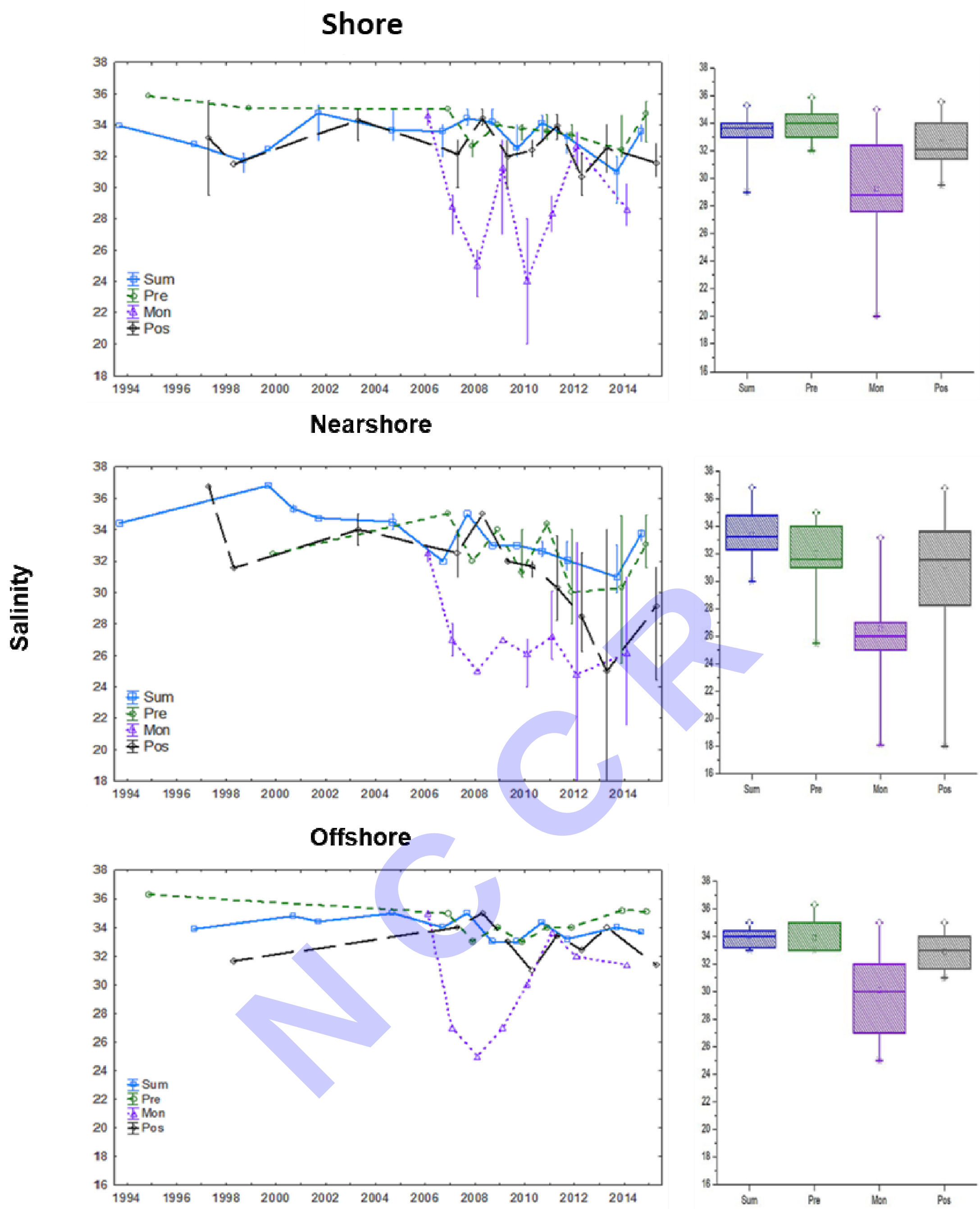


Fig. 3.6.1.4. Seasonal trend in surface water salinity at Ennore.

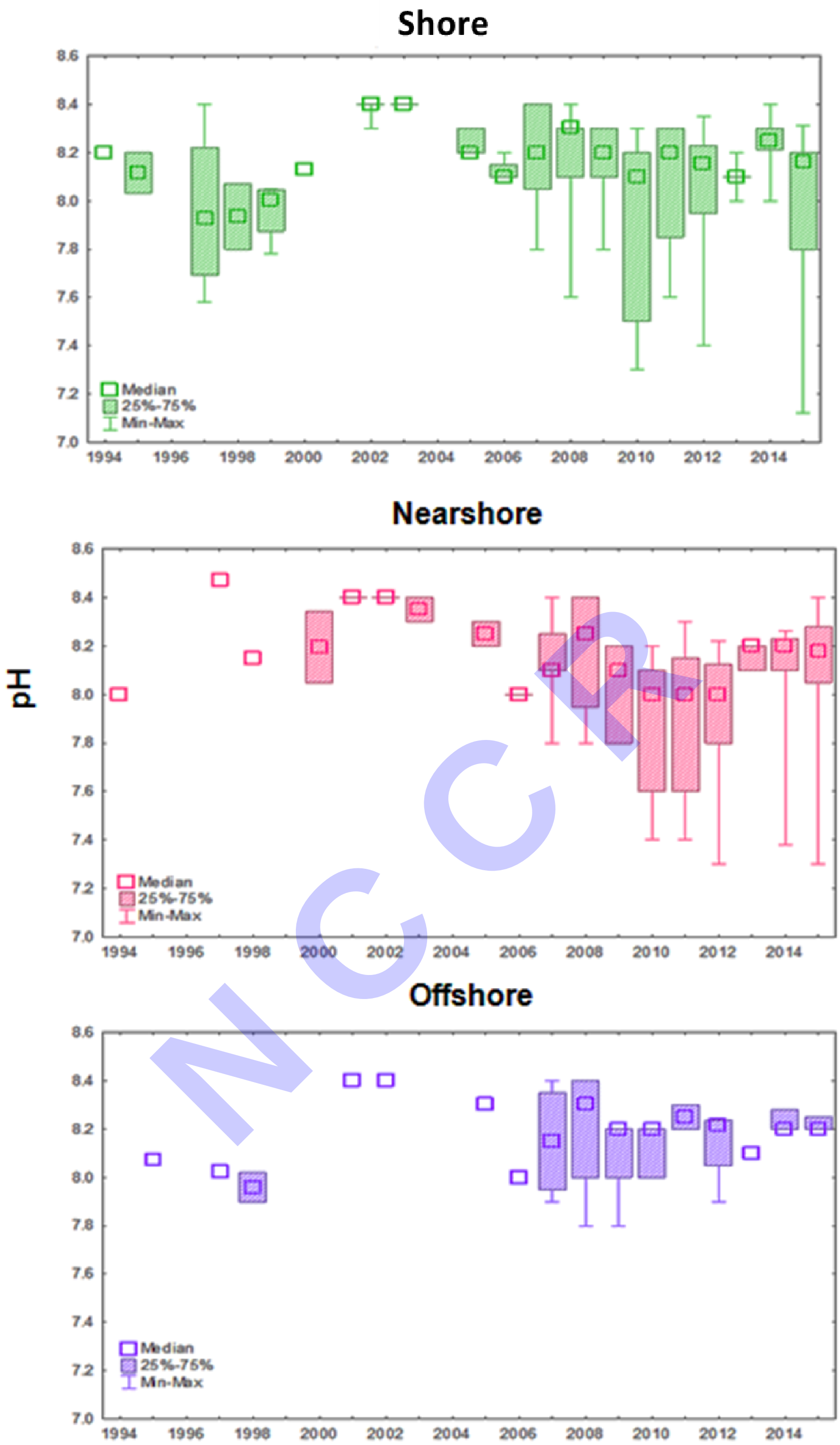


Fig.3.6.1.5. Inter-annual trend in surface water *p*H at Ennore.

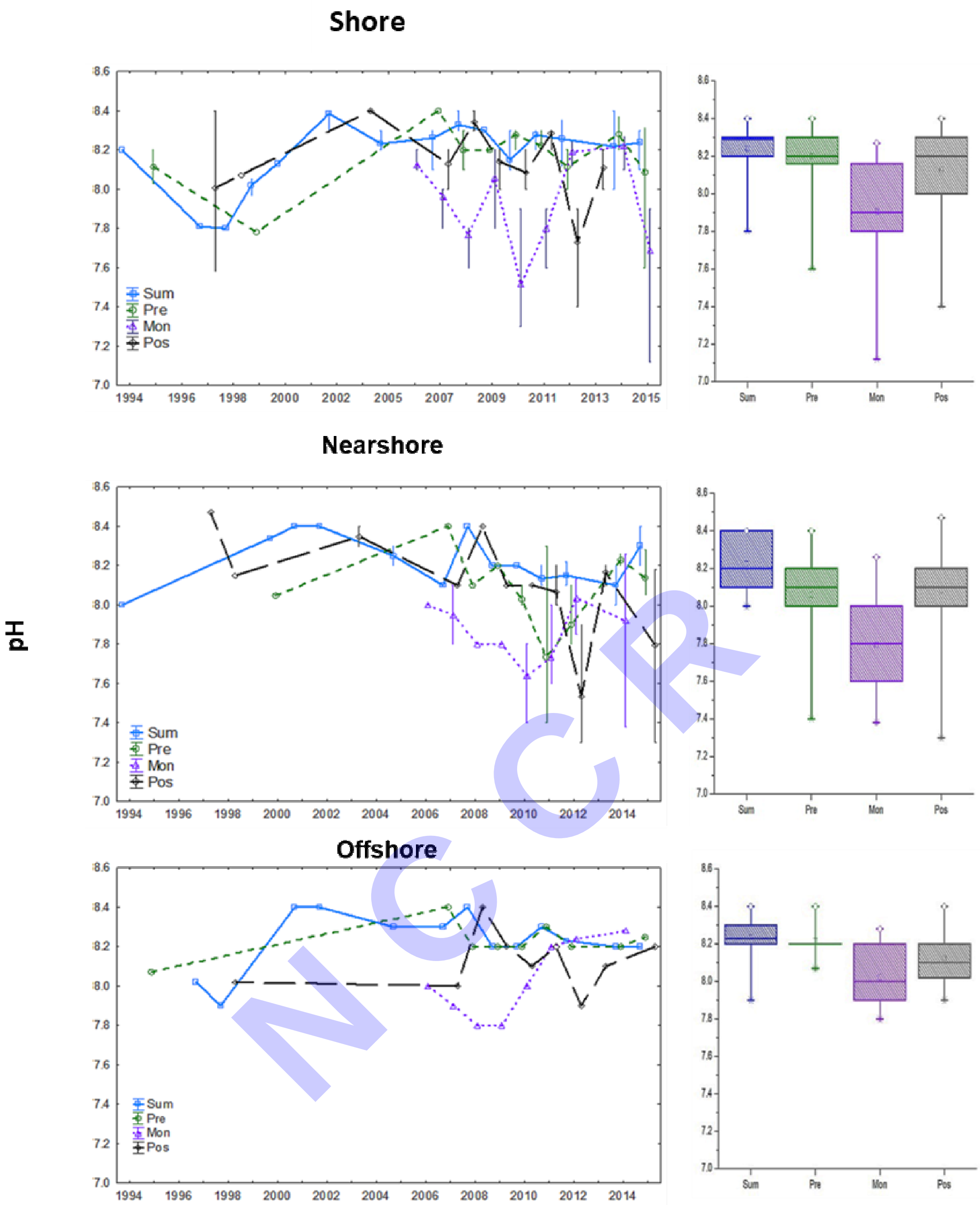


Fig.3.6.1.6. Seasonal trend in surface water *p*H at Ennore.

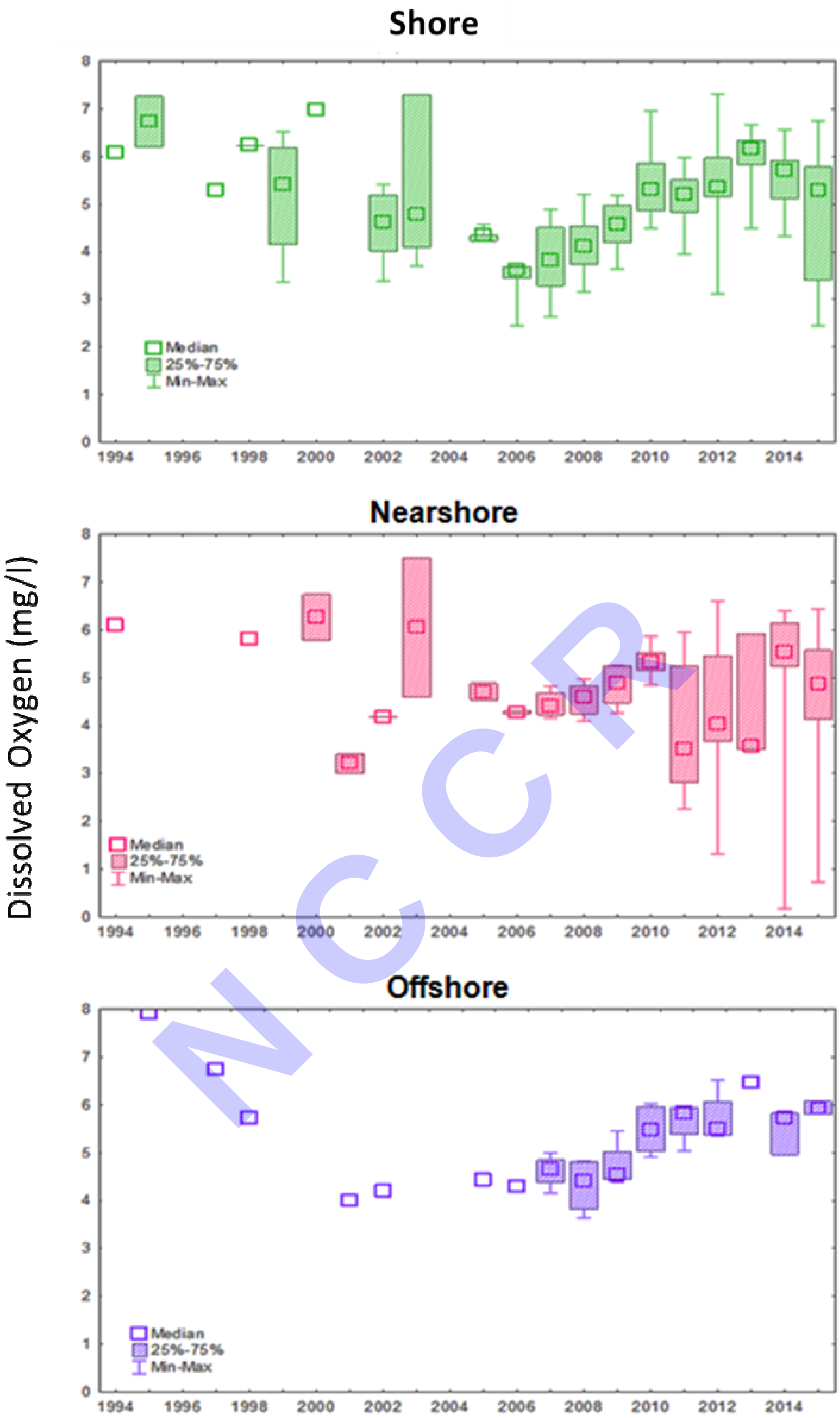


Fig. 3.6.1.7. Inter-annual trend in surface water DO at Ennore.

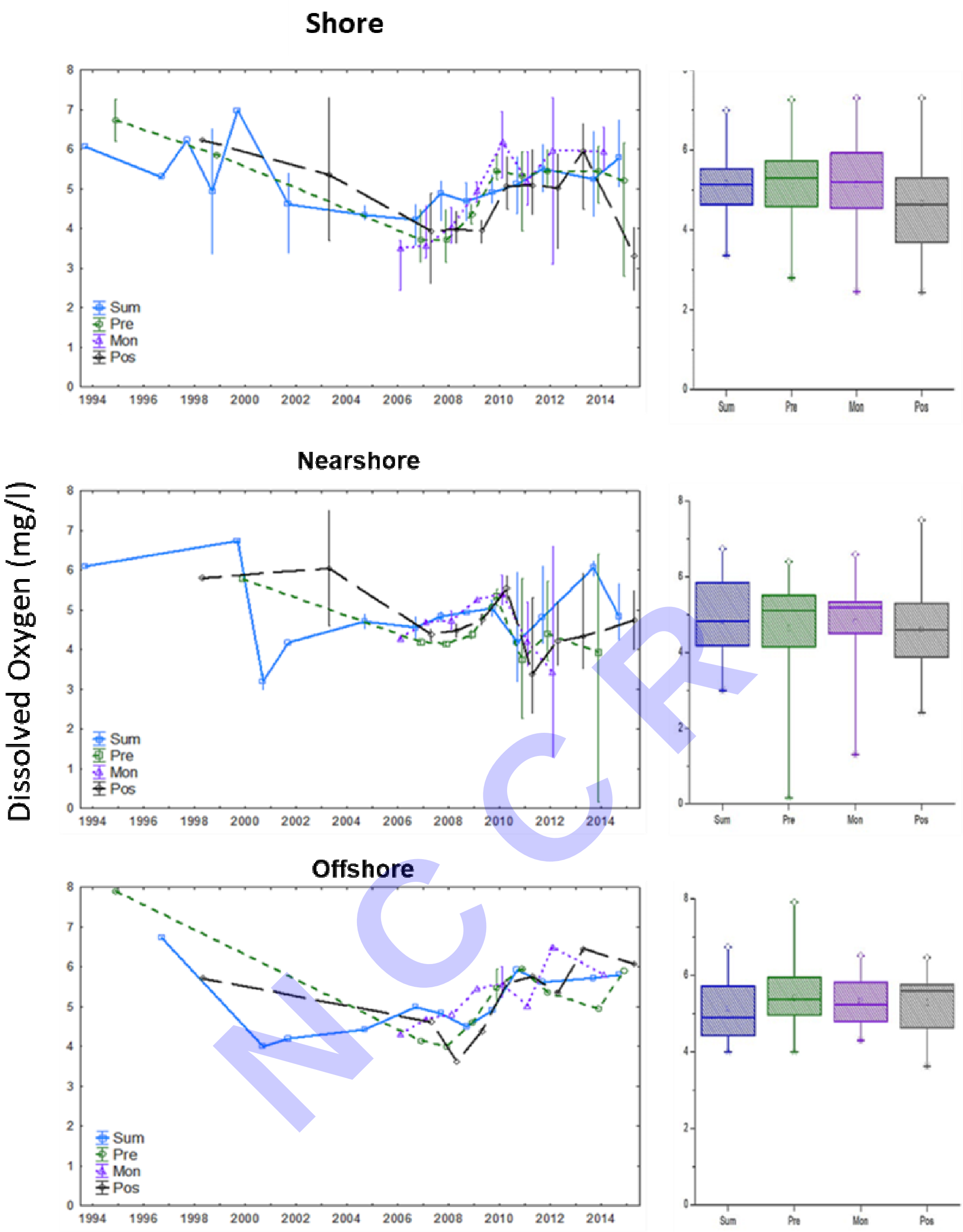


Fig. 3.6.1.8. Seasonal trend in surface water DO at Ennore.

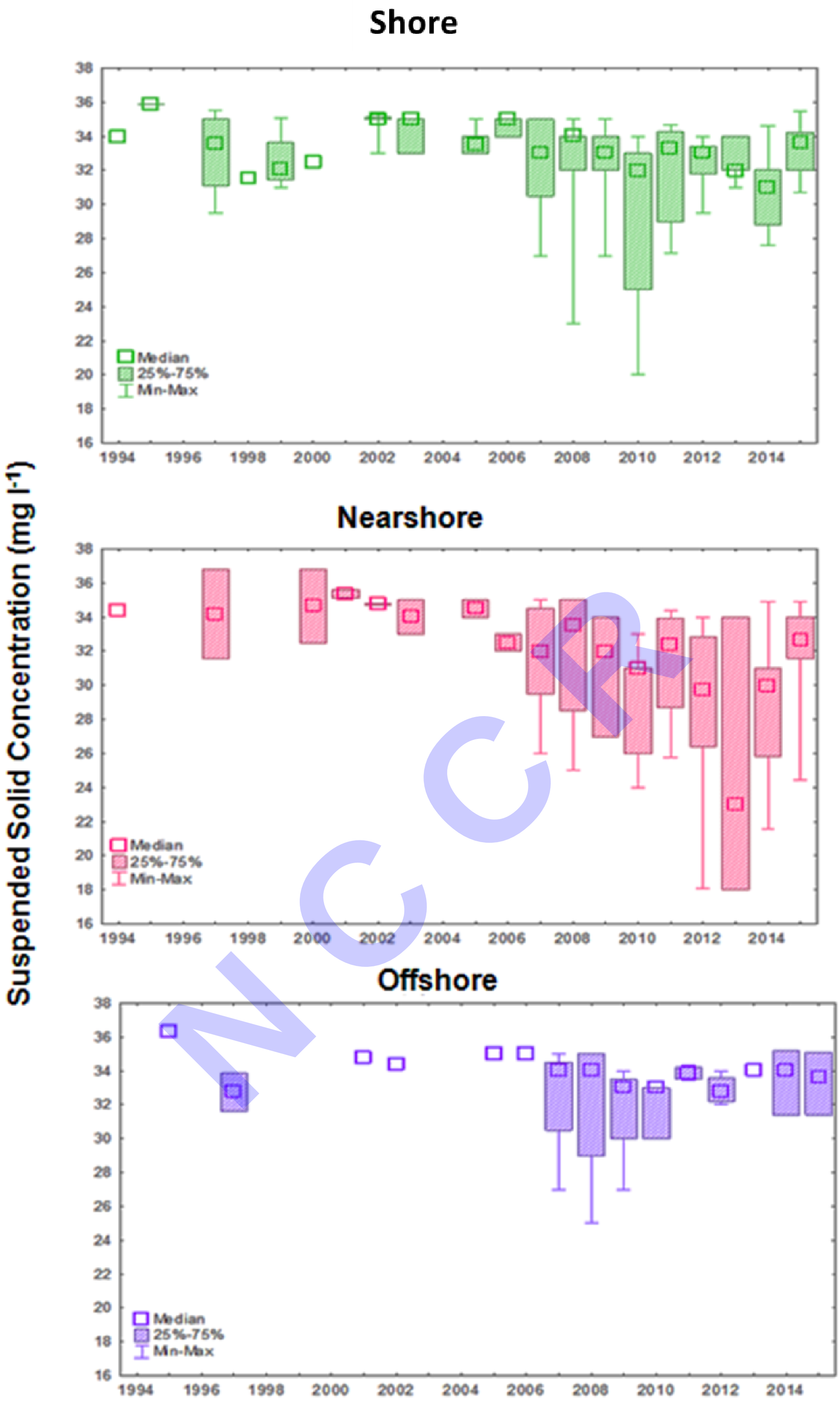


Fig. 3.6.1.9. Inter-annaul trend in SSC at Ennore.

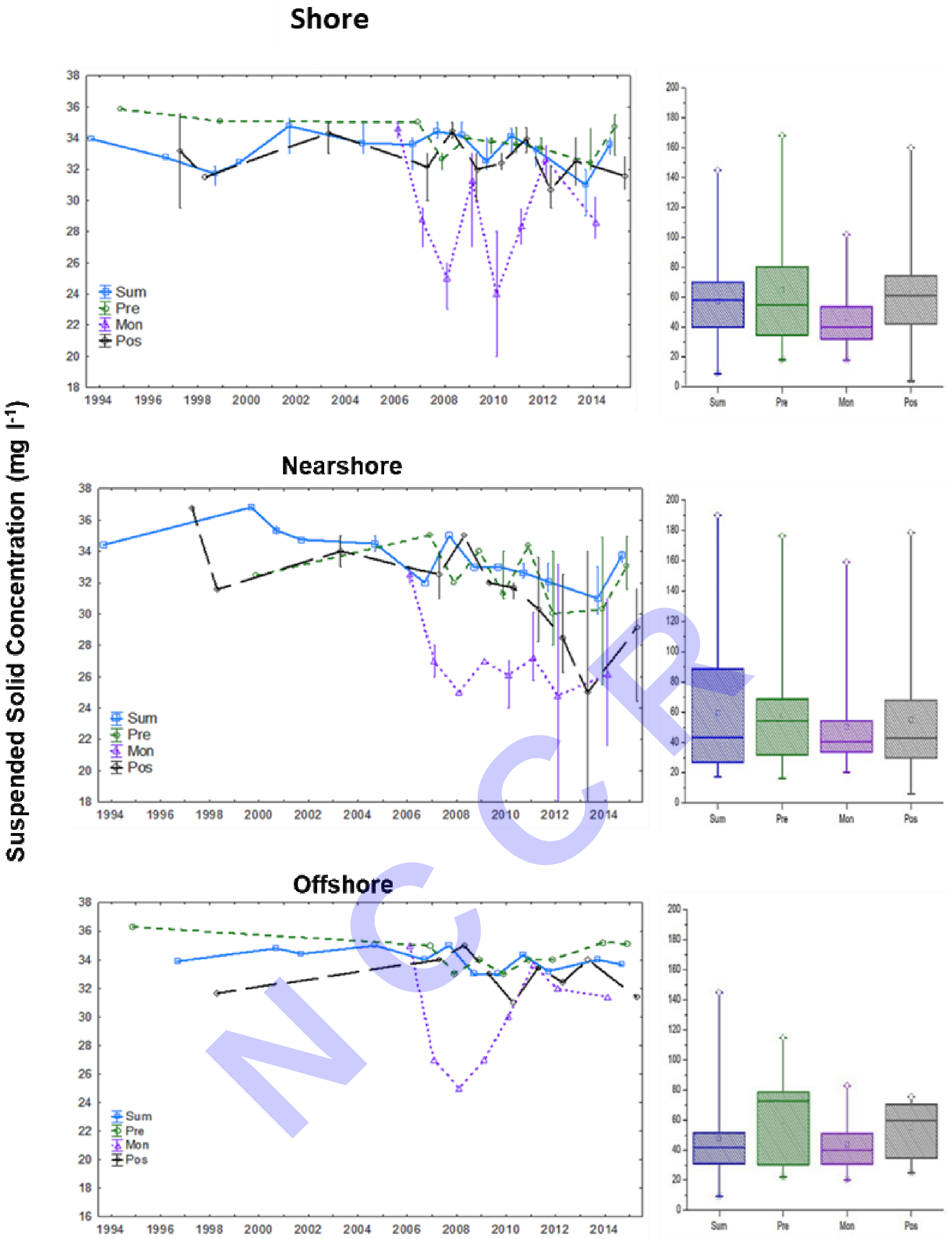


Fig. 3.6.1.10. Seasonaltrend in SSC at Ennore.

Nutrients:

Number of data points (N), minimum (Min), maximum (Max), mean and standard deviation (SD) are presented in Table 3.6.1.1. to 3.6.1.4. Nitrate concentration in the coastal waters of Ennore ranged from 0.2 μM – 50.3 μM (Table 3.6.1.1). As seen in Fig. 3.6.1.11, nitrate showed two low value periods, the first was from 2004 – 2008 and second during the recent years (2014 – 2015). As shown in the table 3.6.1.2, the ammonium concentration ranged from 0.004 μM – 162.3 μM. Except for high values during some years, ammonium concentration was <2μM throughout the study period with the highest value recorded in the nearshore zone during 2014 (Fig. 3.6.1.11). Phosphate ranged from 0.02 μM – 13.8 μM (table 3.6.1.3) with an increasing trend from 2007 – 2010 (Fig. 3.6.1.12). However, the values declined from 2011 to 2013, but showed an increase from 2014 onwards (Fig. 3.6.1.12). Silicate showed a decreasing trend, particularly from 2007 – 2015 (Fig. 3.6.1.12) and, the values ranged from 0.4 – 95.9 μM. The frequency distribution of nutrient data is given in Fig. 3.6.1.13.

Further, nutrient concentrations did not show any spatial variability within 5 km zone of the coastal region of Ennore. Spatially, median nutrient (nitrate, ammonium, phosphate and silicate) values were found more or less similar from shore to offshore. However, maximum variability in nutrient concentration was observed in the shore zone, compared to nearshore and offshore. The hydrodynamic features of Ennore may be immediately dispersing the nutrients into the coastal water as a result the impact of anthropogenic activities is seen observed beyond 2 km.

Table 3.6.1.1. Statistical summary of nitrate (µM), Ennore

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	145	0.2	50.3	8.6	10.2
	Nearshore	11	0.5	36.7	6.9	10.6
	Offshore	13	0.3	35.7	6.5	9.5
Pre-monsoon	*Shore*	119	1.4	13.6	6.1	3.2
	Nearshore	15	1.3	13.7	4.9	3.2
	Offshore	13	0.8	12.1	6.4	3.1
Monsoon	*Shore*	112	1.5	13.5	6.3	3.0
	Nearshore	12	2.3	12.2	7.6	3.4
	Offshore	13	1.4	7.4	5.1	1.8
Post-monsoon	*Shore*	142	0.3	46.5	4.9	4.3
	Nearshore	15	0.2	21.2	4.3	5.1
	Offshore	11	0.5	14.8	4.0	3.9

Table 3.6.1.2. Statistical summary of Ammonium, Ennore.

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	146	0.005	162.3	5.8	17.4
	Nearshore	11	0.025	7.9	1.0	2.4
	Offshore	13	0.036	3.8	0.6	1.1
Pre-monsoon	*Shore*	119	0.006	97.2	3.8	12.0
	Nearshore	16	0.004	11.6	1.3	3.1
	Offshore	12	0.025	9.2	0.9	2.6
Monsoon	*Shore*	113	0.025	93.1	4.6	13.3
	Nearshore	12	0.050	2.9	0.7	0.8
	Offshore	13	0.040	1.7	0.6	0.5
Post-monsoon	*Shore*	143	0.008	55.3	3.9	10.5
	Nearshore	15	0.030	10.5	1.8	3.4
	Offshore	13	0.033	12.7	1.4	3.5

Table 3.6.1.3. Statistical summary of phosphate, Ennore.

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	147	0.11	13.8	1.6	2.0
	Nearshore	14	0.13	9.4	1.4	2.4
	Offshore	16	0.13	1.7	0.7	0.5
Pre-monsoon	*Shore*	118	0.07	5.1	1.1	0.8
	Nearshore	16	0.11	2.8	0.8	0.8
	Offshore	13	0.04	1.3	0.6	0.4
Monsoon	*Shore*	112	0.11	4.9	1.4	0.9
	Nearshore	12	0.15	1.7	1.1	0.6
	Offshore	13	0.27	2.0	1.3	0.6
Post-monsoon	*Shore*	142	0.02	6.2	1.3	1.1
	Nearshore	12	0.19	1.3	0.7	0.4
	Offshore	12	0.12	1.9	0.7	0.6

Table 3.6.1.4. Statistical summary of silicate, Ennore.

Season	*Zone*	N	Min	Max	Mean	SD
Summer	*Shore*	144	2.6	63.6	14.3	8.9
	Nearshore	11	2.8	43.3	14.7	13.2
	Offshore	14	2.2	42.1	11.4	9.9
Pre-monsoon	*Shore*	118	3.1	54.3	14.2	8.2
	Nearshore	15	2.9	22.7	11.7	5.5
	Offshore	12	2.8	28.0	14.0	6.6
Monsoon	*Shore*	112	0.4	95.9	30.7	24.1
	Nearshore	13	3.7	46.9	26.7	15.2
	Offshore	13	1.9	48.1	31.1	16.7
Post-monsoon	*Shore*	139	0.4	59.7	12.9	12.2
	Nearshore	11	2.4	45.2	12.1	12.2
	Offshore	11	0.8	38.7	10.4	11.1

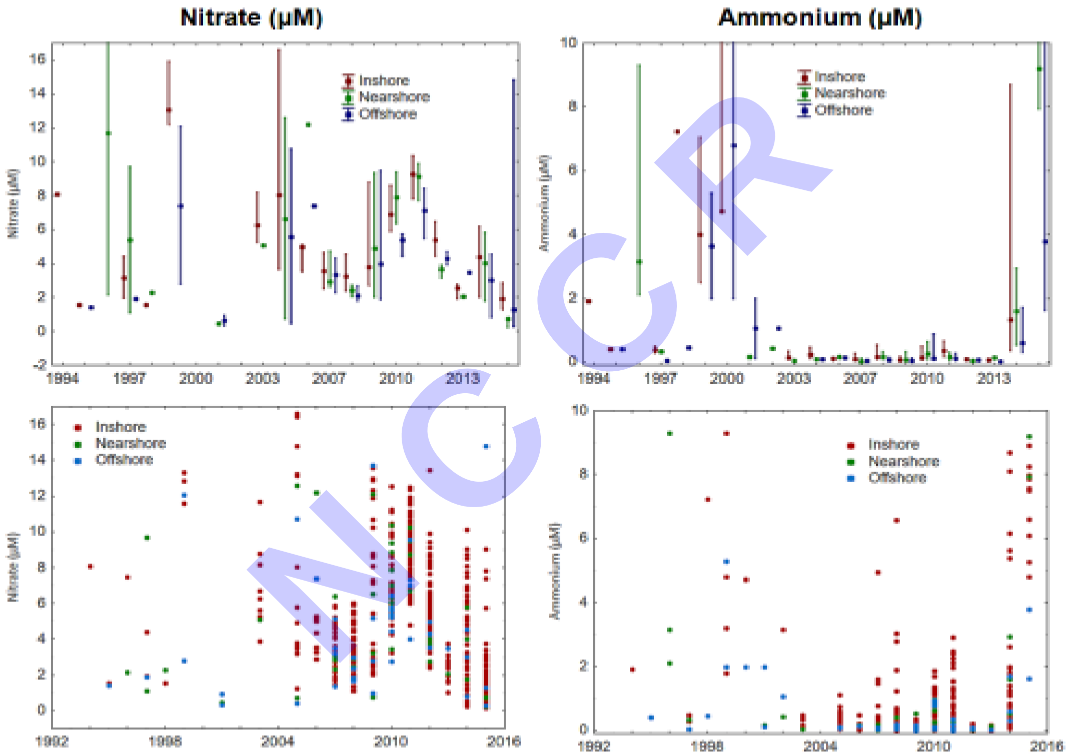


Fig.3.6.1.11. Inter-annual variation of nitrate and ammonium at Ennore.

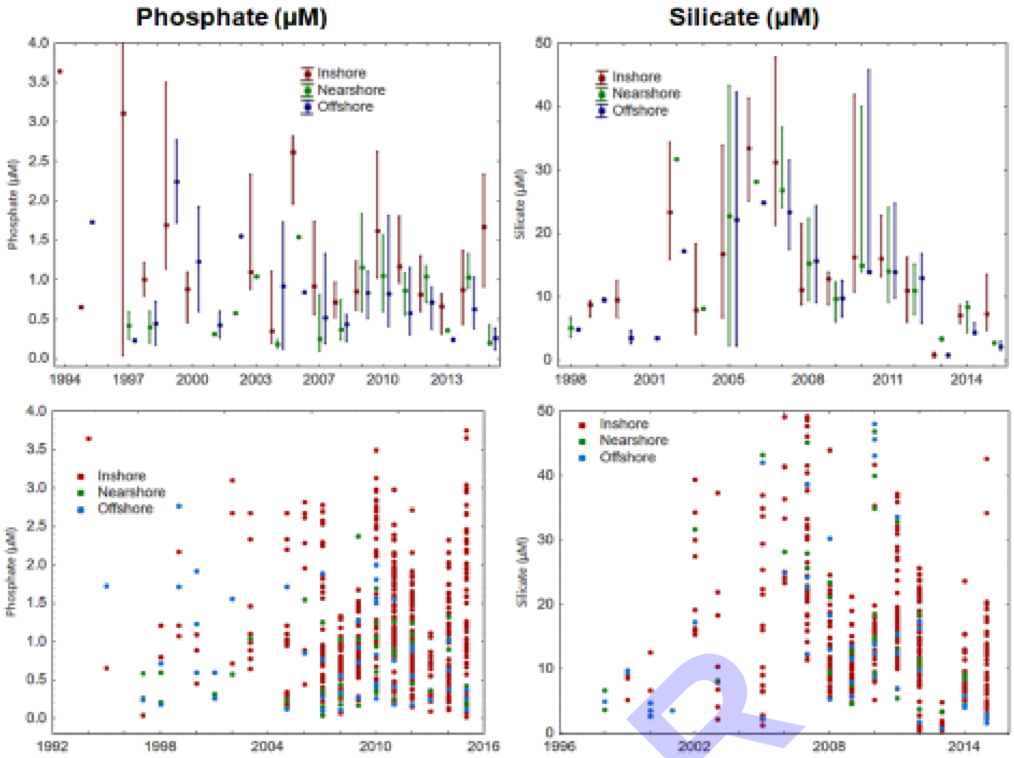


Fig.3.6.1.12. Inter-annual variation of phosphate and silicate at Ennore.

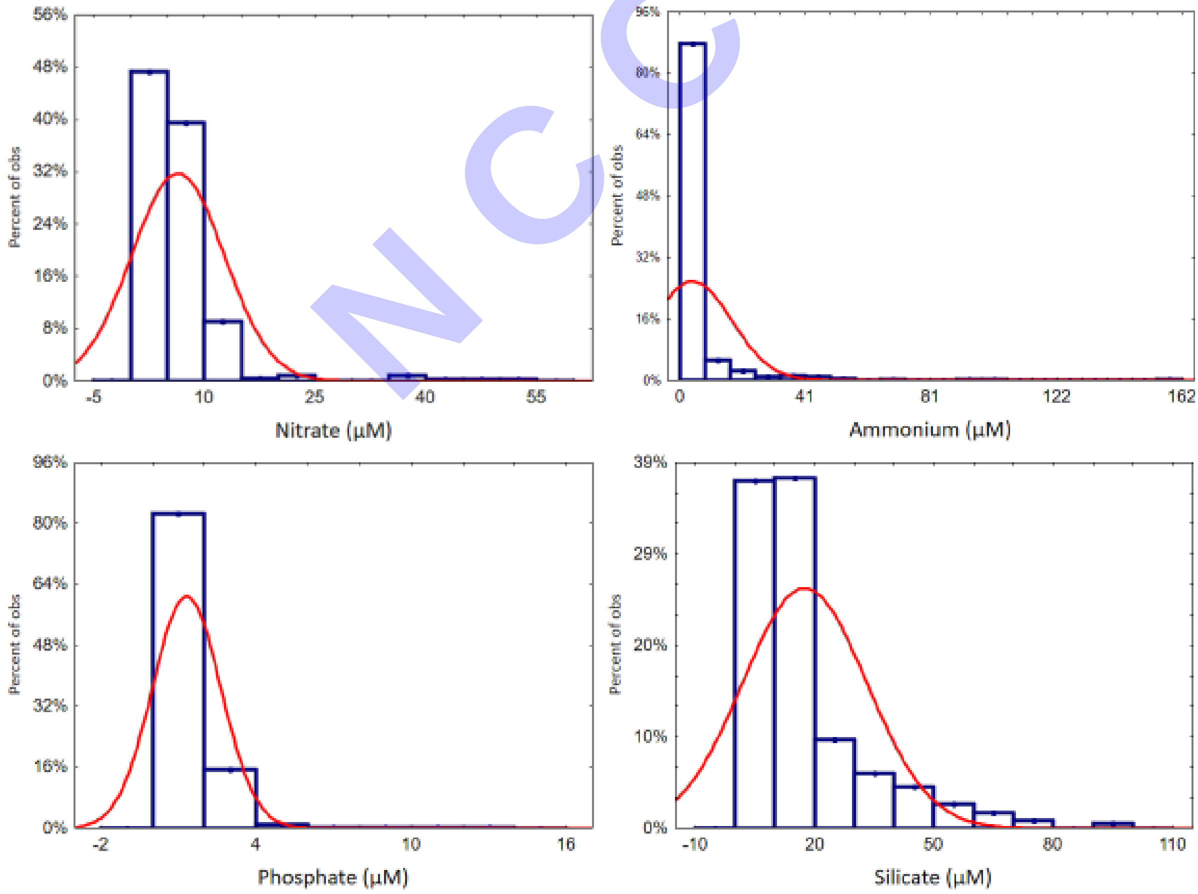


Fig.3.6.1.13. Frequency distribution for nutrient concentrations during 1994–2015.

Seasonal variability

Seasonal variation of nutrients in the surface water of Ennore transect is given in Fig.3.6.1.14 (nitrate and ammonium) and Fig.3.6.1.15 (phosphate and silicate). In the shore zone, nutrient concentrations did not show any seasonal variability, probably due to surplus discharge of sewage (including domestic, industrial effluents and from other sources) throughout the year. The seasonal pattern in the nearshore and offshore zones was influenced by the annual monsoon, with the highest nutrient values observed during this period due to increased runoff. However, compared to all the nutrients, silicate showed clear seasonal variability as land runoff was the major source of silicate to coastal waters; while nutrients enter the system all the year round due to discharge from various sources (Fig.3.6.1.15).

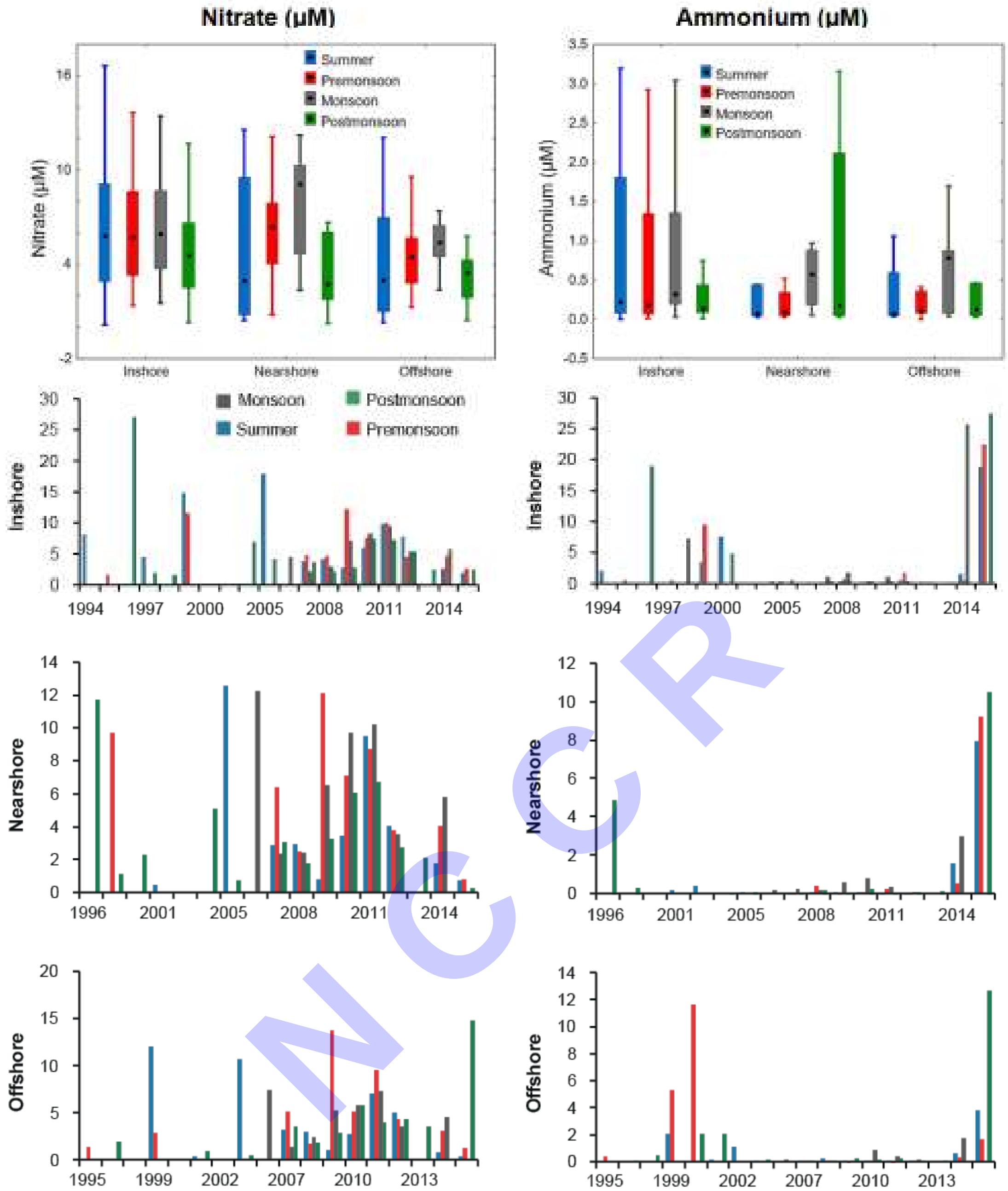


Fig.3.6.1.14. Seasonal variation of nitrate and ammonium at Ennore.

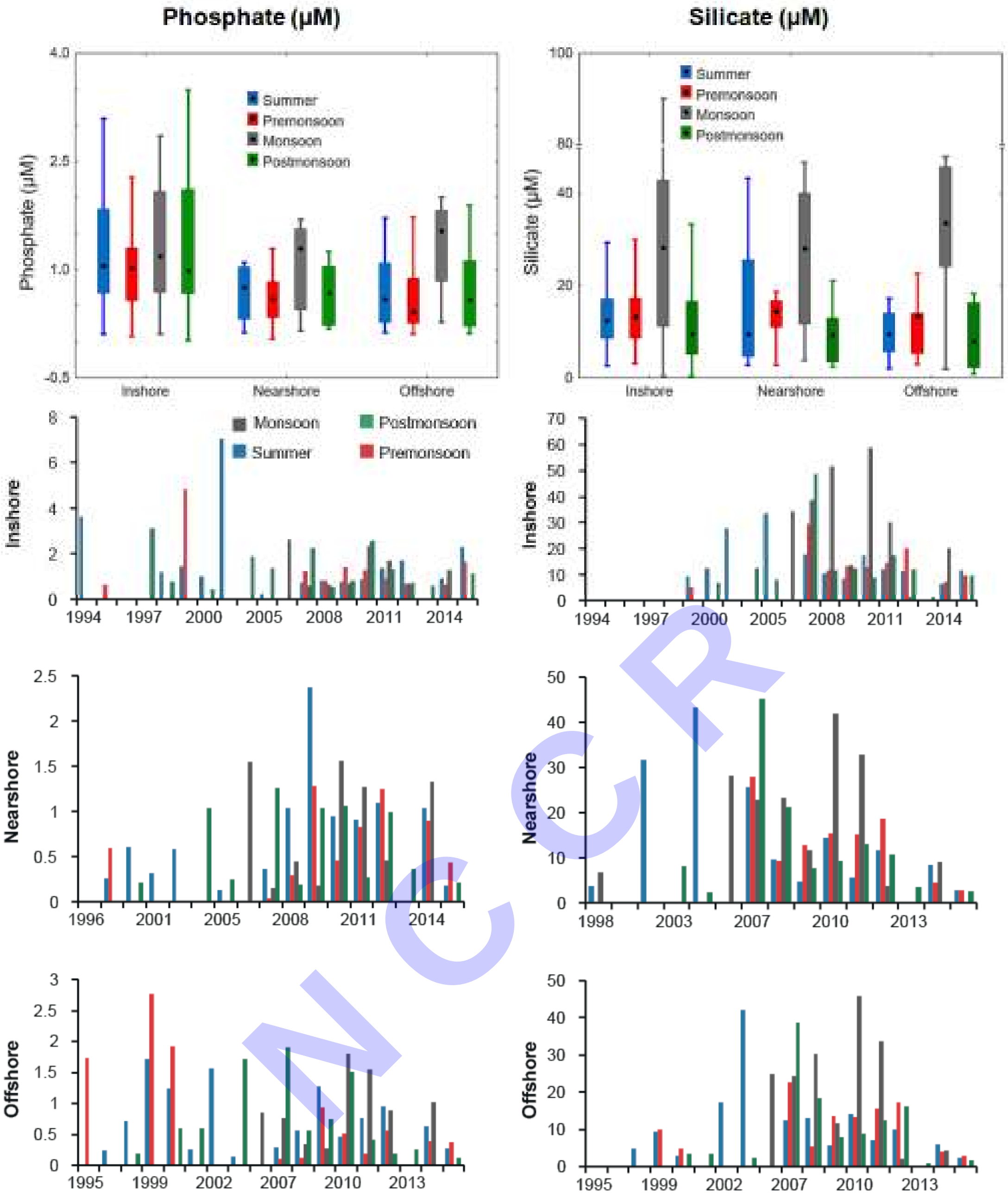


Fig.3.6.1.15. Seasonal variation of phosphate and silicate at Ennore

3.6.2. Status of Plankton at Ennore

Number of data points (N), minimum (Min), maximum (Max), mean and standard deviation (SD) are presented in Table 3.6.2.1. to 3.6.2.4. The phytoplankton biomass ranged from 0.01 – 26.8 mg/m^3, as given in the statistical summary table 3.6.2.1. Phytoplankton biomass showed their highest values during 1994 to 2007 and a declining trend was observed from 2006 to 2015 (Fig. 3.6.2.1). Phytoplankton abundance ranged from 519 – 1778067 cells/l (Table 3.6.2.2). Abundance showed an increase from 2003 to 2007 and decline from 2007 to 2015 (Fig. 3.6.2.1). The intra-annual variability in abundance was higher in the nearshore and offshore zones. Zooplankton biomass and zooplankton abundance ranged from 0.01 to 9.6 ml/m^3 (Table 3.6.2.3) and 31 – 36774 no./m^3 (Table 3.6.2.4), respectively. Zooplankton biomass showed low value during 2002 – 2007, followed by an increase with the highest values during 2014 – 2015 (Fig. 3.6.2.2). Zooplankton abundance showed an increased trend from 2003 to 2008, and again from 2010 to 2015 (Fig. 3.6.2.2). The frequency distribution of plankton data is given in Fig. 3.6.2.3.

Plankton (phytoplankton and zooplankton) biomass and abundances showed variability across the zones. Phytoplankton and zooplankton, although showed a similar variability during most of the years, the values increased from shore to offshore zones. The continued supply of nutrients, their dispersal and light penetration (low suspended solids) may have accounted for the abundance of plankton in the nearshore and offshore zones. Zooplankton community followed the pattern of phytoplankton of increase in values from shore to offshore, probably influenced by the salinity and food availability.

Table. 3.6.2.1. Statistical Summary of Phytoplankton biomass (mg/m^3), Ennore.

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	126	0.06	14.2	2.3	2.4
	Nearshore	15	0.25	24.9	7.0	7.8
	Offshore	16	0.21	9.6	4.5	3.3
Pre-monsoon	*Shore*	103	0.04	26.8	1.8	4.4
	Nearshore	16	0.21	19.5	3.5	4.6
	Offshore	14	0.20	6.1	3.0	1.9
Monsoon	*Shore*	96	0.01	6.2	0.9	1.4
	Nearshore	14	0.04	22.5	3.0	6.1
	Offshore	13	0.12	8.7	2.1	3.0
Post-monsoon	*Shore*	119	0.18	9.8	1.6	1.9
	Nearshore	12	0.22	8.3	3.4	3.0
	Offshore	13	0.33	6.5	2.8	2.3

Table. 3.6.2.2. Statistical Summary of Phytoplankton abundance (cells/l), Ennore.

Season	*Zone*	N	Min	Max	Mean	SD
Summer	*Shore*	124	1200	287945	20378	34076
	Nearshore	13	5027	367637	126899	143998
	Offshore	14	1896	167457	44328	39861
Pre-monsoon	*Shore*	102	1136	231457	15540	36868
	Nearshore	13	2382	887728	177226	317506
	Offshore	14	2079	1778067	332582	618784
Monsoon	*Shore*	96	519	118212	6536	14163
	Nearshore	13	1226	1445880	121976	398397
	Offshore	13	1418	136632	20223	38368
Post-monsoon	*Shore*	116	1249	280538	16617	32478
	Nearshore	12	1467	553447	91717	151909
	Offshore	12	1661	801117	125663	225322

Table. 3.6.2.3. Statistical Summary of zooplankton biomass (ml/m^3), Ennore.

Season	*Zone*	N	Min	Max	Mean	SD
Summer	*Shore*	124	0.01	8.13	1.45	1.93
	Nearshore	14	0.02	5.65	0.99	1.67
	Offshore	15	0.02	5.36	1.21	1.76
Premonsoon	*Shore*	104	0.01	9.58	1.88	2.49
	Nearshore	16	0.03	8.09	1.39	2.17
	Offshore	14	0.02	5.65	1.14	1.79
Monsoon	*Shore*	96	0.01	5.19	0.87	1.14
	Nearshore	13	0.02	3.58	0.67	1.09
	Offshore	13	0.02	4.58	0.81	1.42
Postmonsoon	*Shore*	120	0.02	4.86	1.05	1.40
	Nearshore	14	0.02	3.28	0.75	0.92
	Offshore	13	0.02	3.89	0.98	1.10

Table. 3.6.2.4. Statistical Summary of zooplankton abundance (Nos./m^3), Ennore.

Season	Zone	N	Min	Max	Mean	SD
Summer	*Shore*	125	38	36774	6570	4726
	Nearshore	15	90	28130	10568	8192
	Offshore	16	31	22850	9534	7850
Pre-monsoon	*Shore*	104	72	21353	5367	3347
	Nearshore	16	45	15147	6309	4007
	Offshore	14	597	17260	7186	3941
Monsoon	*Shore*	96	884	12504	4073	2482
	Nearshore	13	2662	9230	5071	2444
	Offshore	13	2635	9132	4964	2254
Post-monsoon	*Shore*	120	76	16405	4968	2961
	Nearshore	14	96	14382	6969	4421
	Offshore	13	40	11571	6164	4063

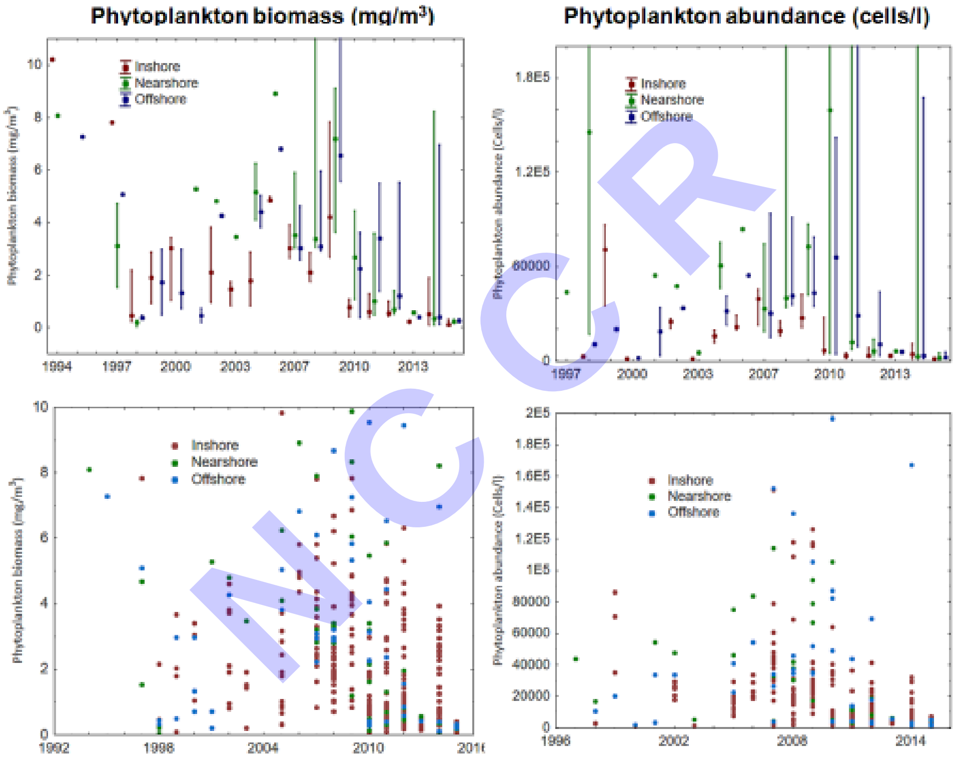


Fig.3.6.2.1. Inter-annual variability in phytoplankton biomass and abundance at Ennore.

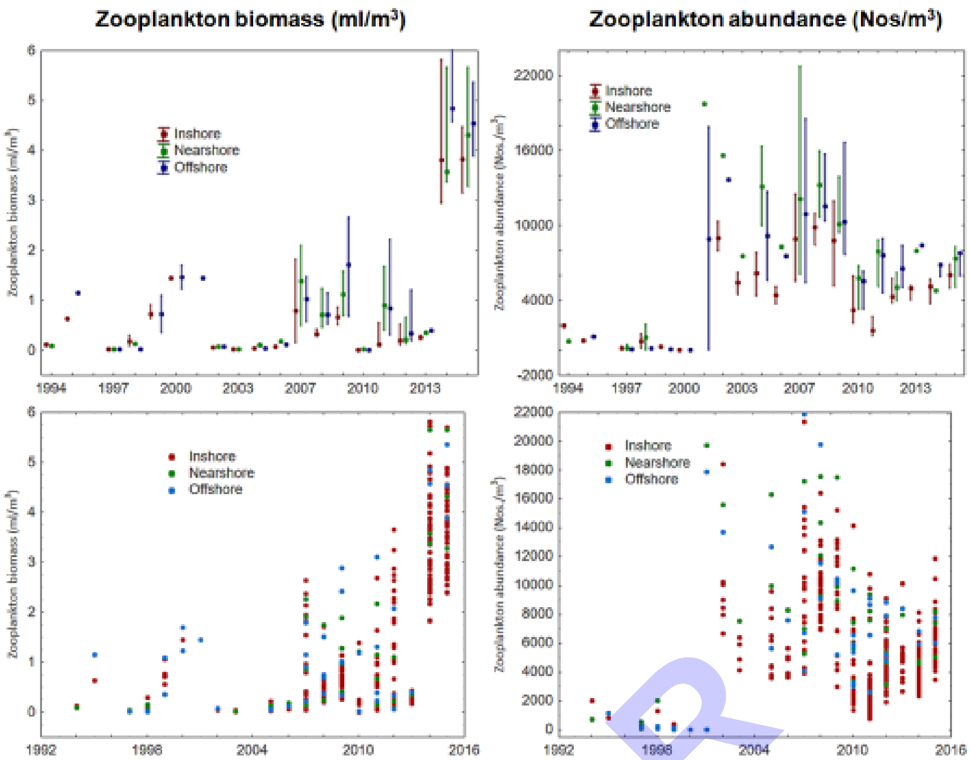


Fig.3.6.2.2. Inter-annual variability in zooplankton biomass and abundance at Ennore.

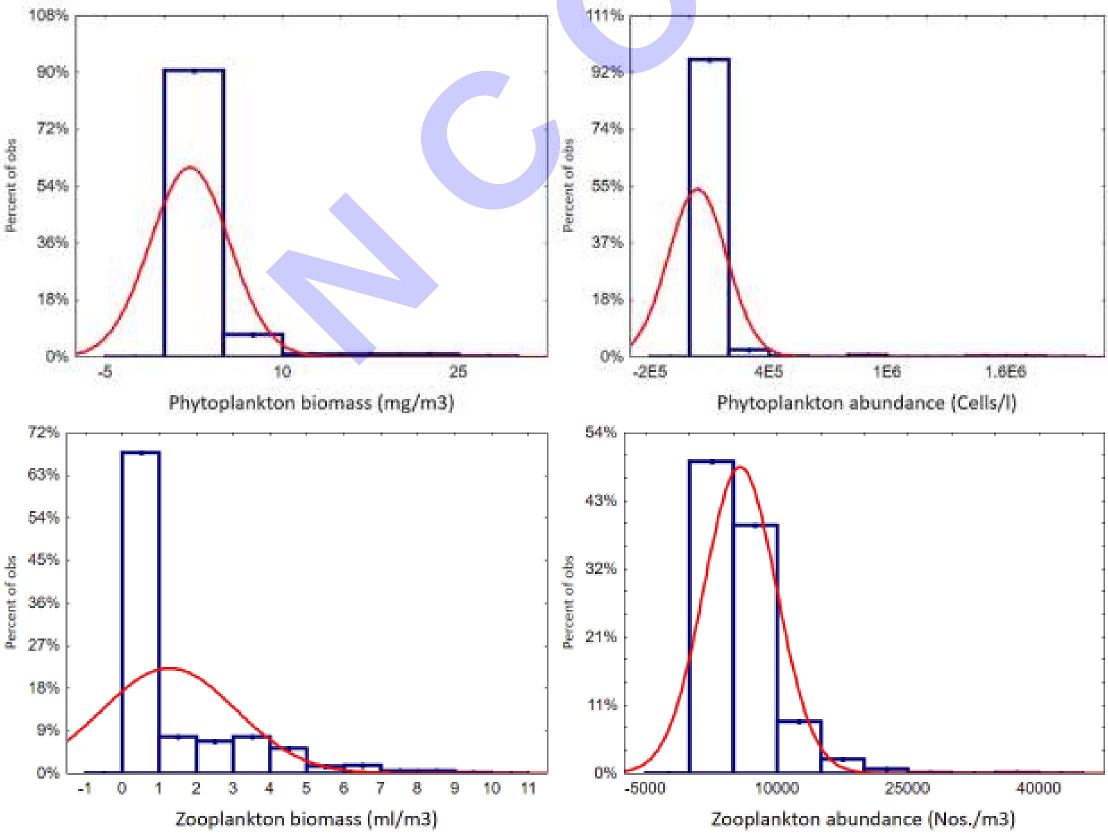


Fig.3.6.2.3. Frequency distribution for plankton during 1994-2015

Seasonal variability

Phytoplankton biomass and abundance in the shore did not show any seasonal variability, probably due enormous supply of nutrients into the shore zone from various sources throughout the year (Fig. 3.6.2.4). The nearshore and offshore zones showed the lowest phytoplankton biomass and abundance during monsoon due to reduced phytoplankton production as a result of low light penetration caused by increased SSC from runoff. Zooplankton biomass in the shore and offshore zones was marginally higher during pre-monsoon, while nearshore recorded high values during post-monsoon (Fig. 3.6.2.5). Less abundance of zooplankton was noticed at nearshore and offshore zones, which may be associated with hydrological changes (salinity and turbidity) during monsoon (Fig. 3.6.2.5). Higher concentrations during non-monsoon season are due to food availability and favourable hydrological conditions.

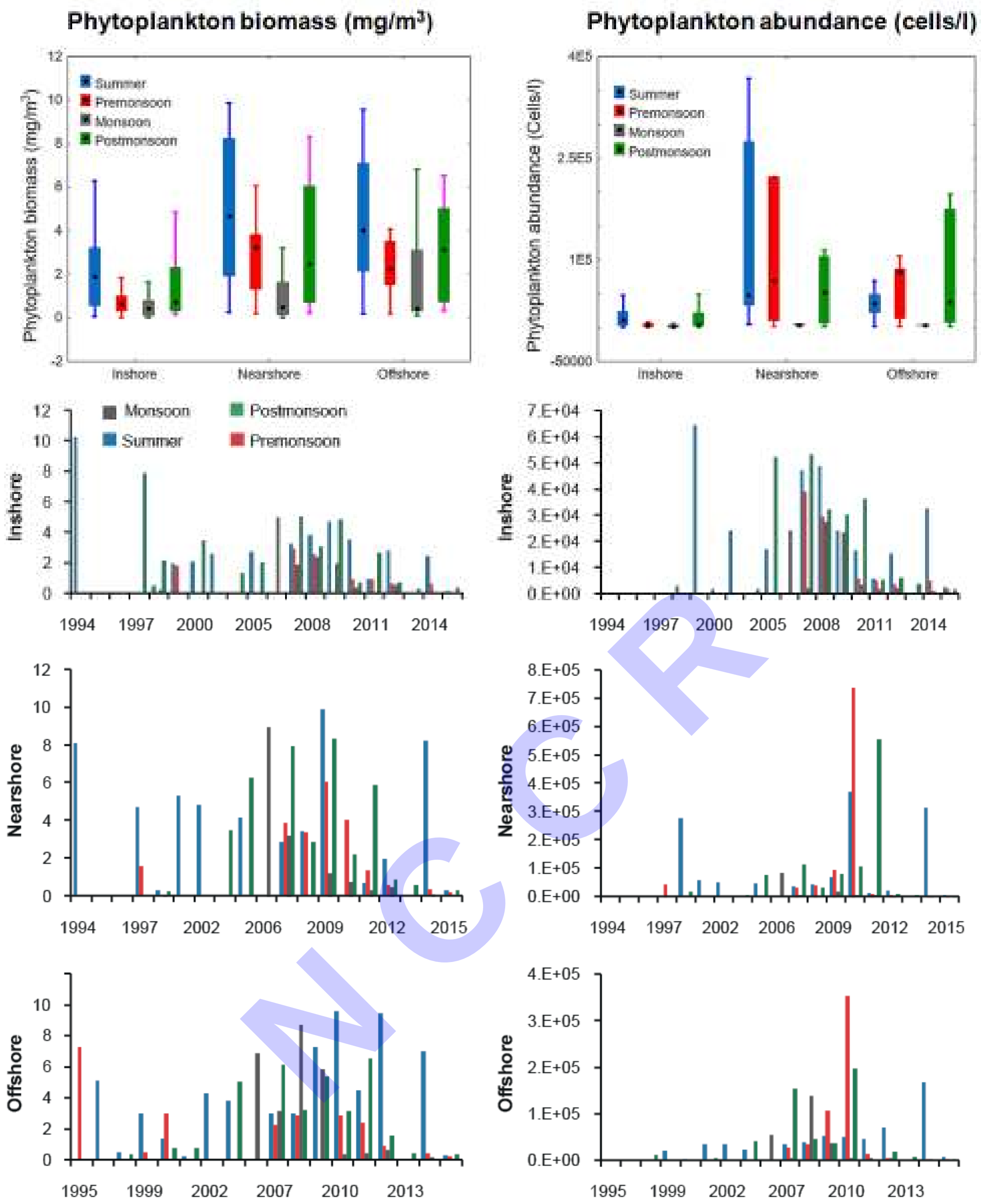


Fig.3.6.2.4. Seasonal variability in phytoplankton biomass and abundance at Ennore.

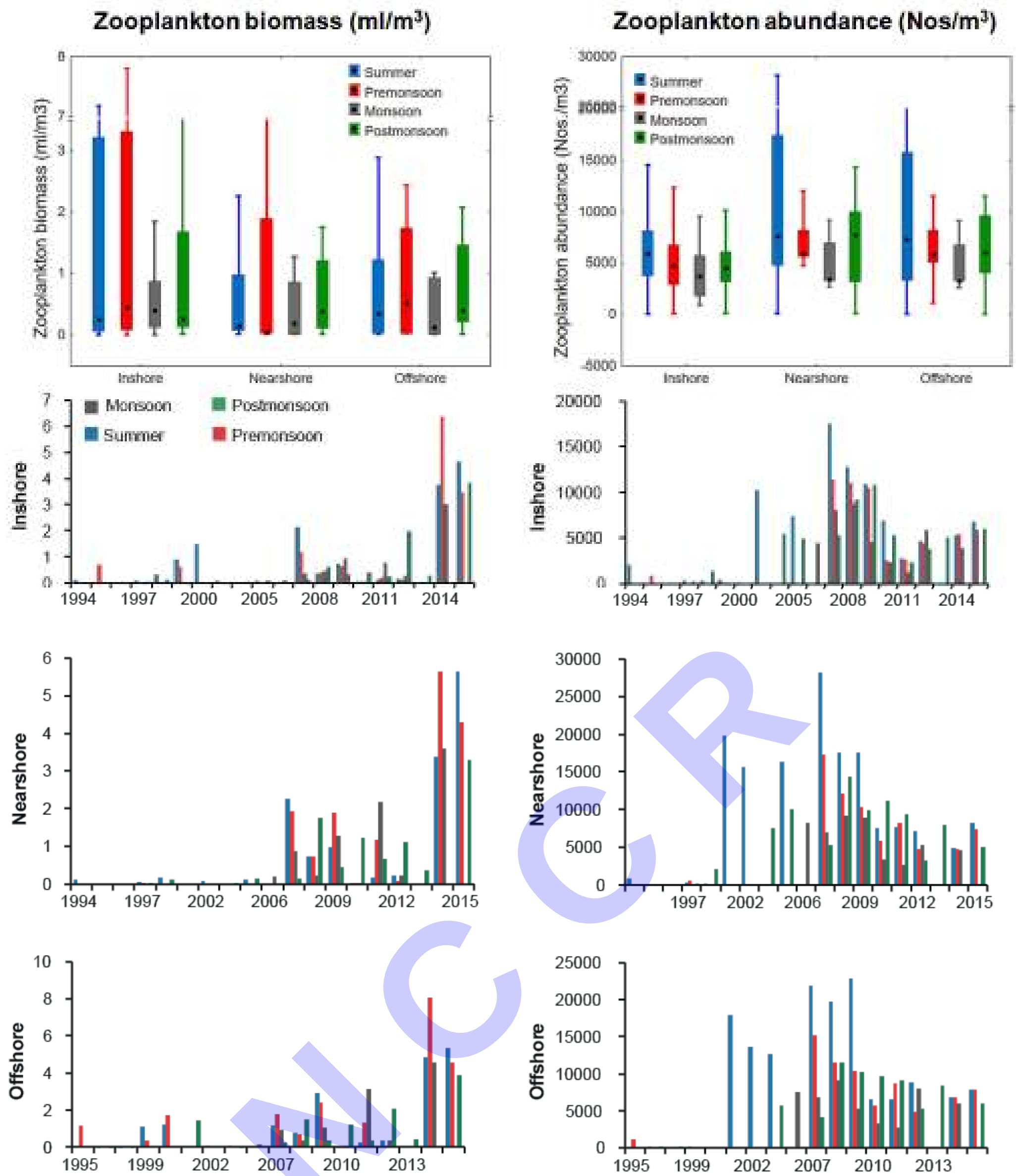


Fig.3.6.2.5. Seasonal variability in zooplankton biomass and abundance at Ennore.

Plankton species composition

The phytoplankton community of Ennore was composed of three major classes, (i) diatoms (19 genera: *Asterionella* spp., *Bacteriastrum* spp., *Bellerochea* spp., *Chaetoceros* spp., *Odentella* spp., *Coscinodiscus* spp., *Ditylum* spp., *Lauderia* spp., *Leptocylindrus* spp., *Nitzschia* spp., *Pleurosigma* spp., *Rhyzosolenia* spp., *Skeletonema* spp., *Streptotheca* spp., *Thalassionema* spp., *Thalassiosira* spp., *Thalassiothrix* spp., and *Triceratium* spp.); (ii) dinoflagellates (3 genera: *Ceratium* spp., *Peridinium* spp. and *Protoperidinium* spp.); and (iii) blue-green algae (3 genera: *Spirulina* spp., *Trochodesmium* spp. and *Phormidium* spp.) (Fig 3.6.2.6-8).

The contribution of different genera of phytoplankton to the total abundance varied with time and space. The species composition showed seasonal variability. In the post-monsoon season, the Ennore coastal waters were dominated by the blue green algae, *Trichodesmium* spp., and the diatoms, *Asterionella* spp. and *Chaetoceros* spp. Although diatoms dominated during summer, pre-monsoon and monsoon, different genera dominated during different seasons. *Skeletonema* spp., *Coscinodiscus* spp., *Asterionella* spp. and *Ceratium* spp were the predominant species during summer. Relatively, phytoplankton was dominated by diversified species composition during summer. *Coscinodiscus* spp. and *Chaetoceros* spp. dominated from shore to offshore during pre-monsoon period. *Chaetoceros* spp. along with *Thalassiothrix* spp. and *Asterionella* spp. dominated during monsoon season. Overall, the Ennore coastal waters were dominated by diatoms, followed by dinoflagellates and blue green algae during summer, pre-monsoon and monsoon, and by the blue green algae during post-monsoon (Fig 3.6.2.9).

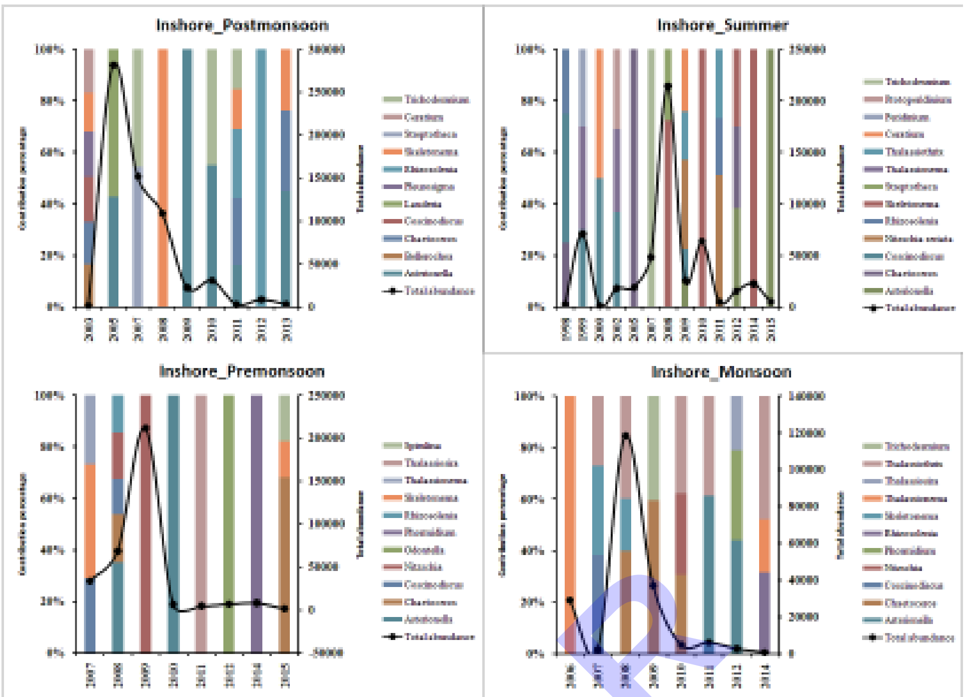


Fig. 3.6.2.6. Year-wise phytoplankton species composition in shoreshore region along Ennore coastal waters

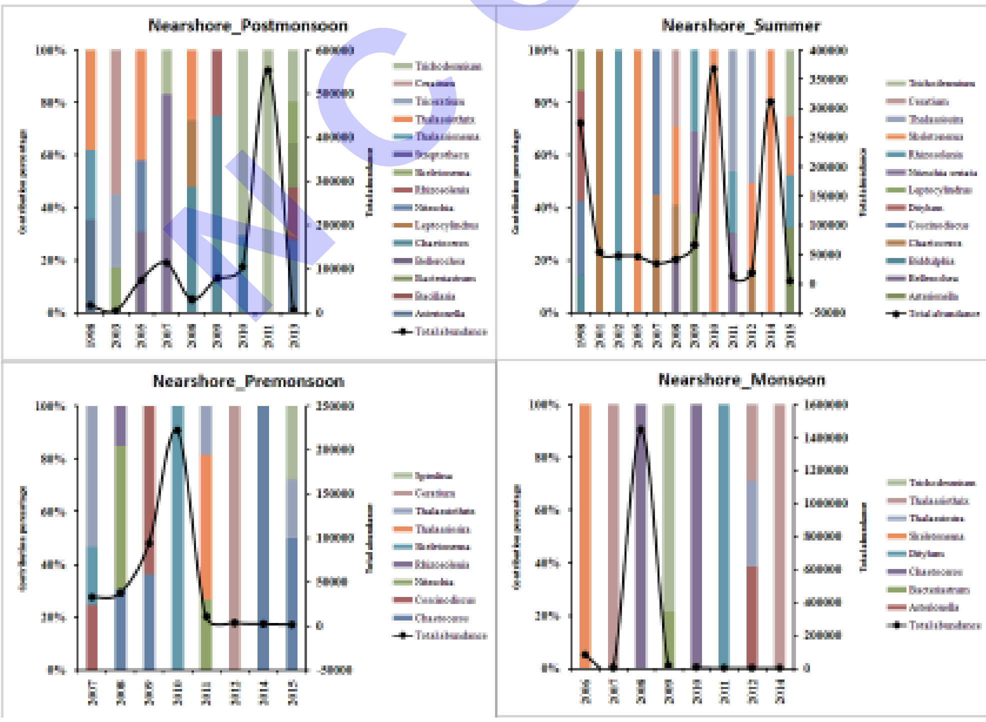


Fig. 3.6.2.7. Year-wise phytoplankton species composition in nearshore region along Ennore coastal waters

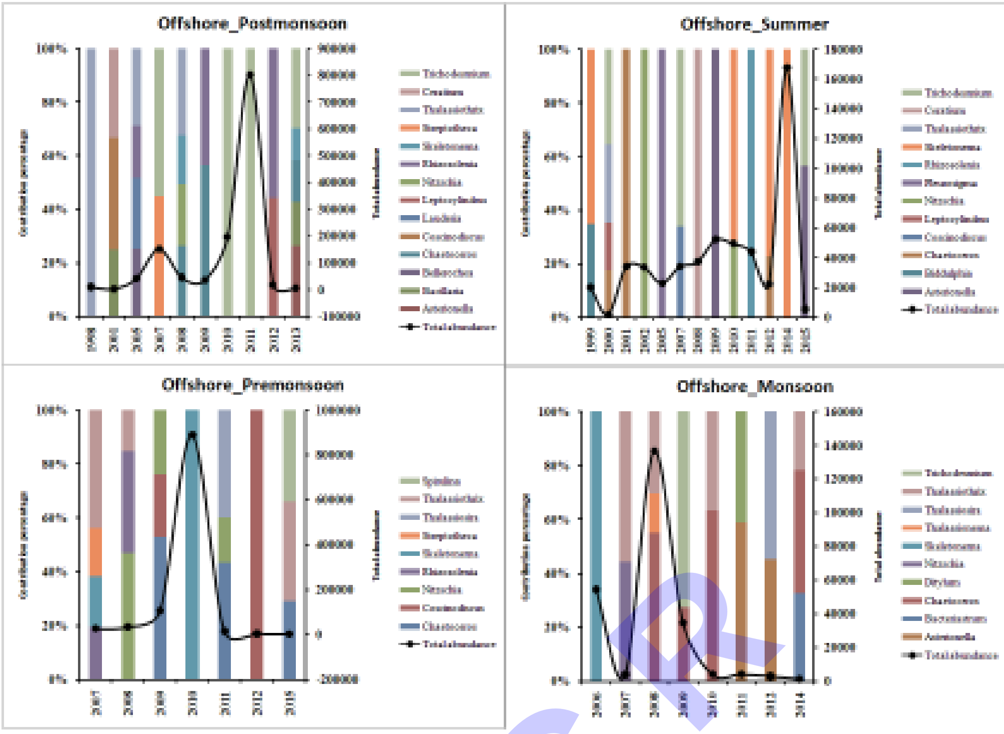


Fig. 3.6.2.8. Year-wise phytoplankton species composition in offshore region along Ennore coastal waters

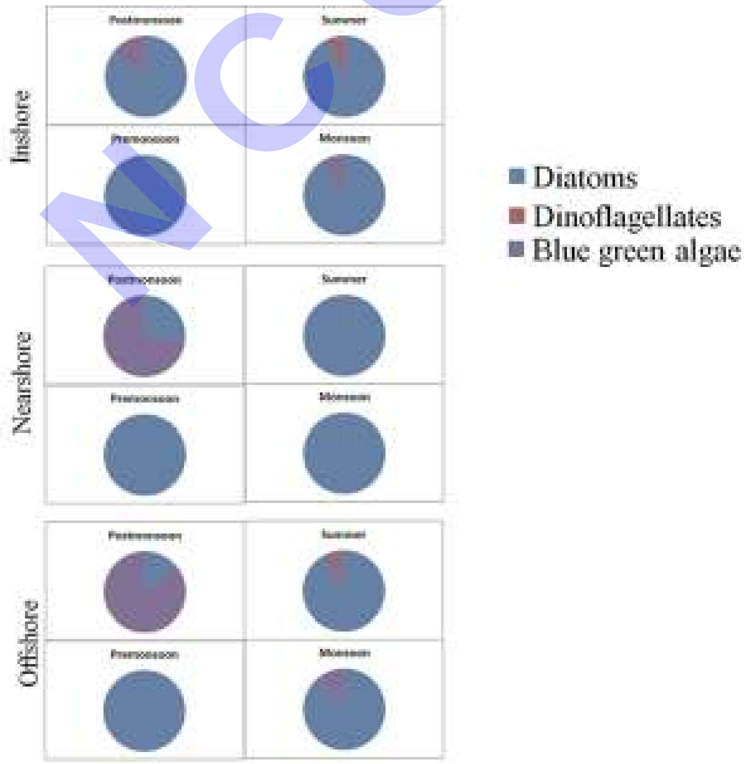


Fig. 3.6.2.9. Contribution of phytoplankton groups along Ennore coastal waters

The contribution of different genera of zooplankton to the total abundance varied with time and space. Copepods dominated throughout the study period. Within the copepods, calanoids, cyclopoids, harpacticoids, and poecilostomatoids were dominant groups in the entire study period. *Acrocalanus* spp. and *Euterpina* spp. were found during the study period irrespective of time and space. In particular, summer was mainly dominated by *Paracalanus* spp., whereas monsoon was dominated by *Acrocalanus* spp. Overall, post-monsoon and summer seasons were mainly contributed by diversified species abundance (Fig 3.6.2.10-12).

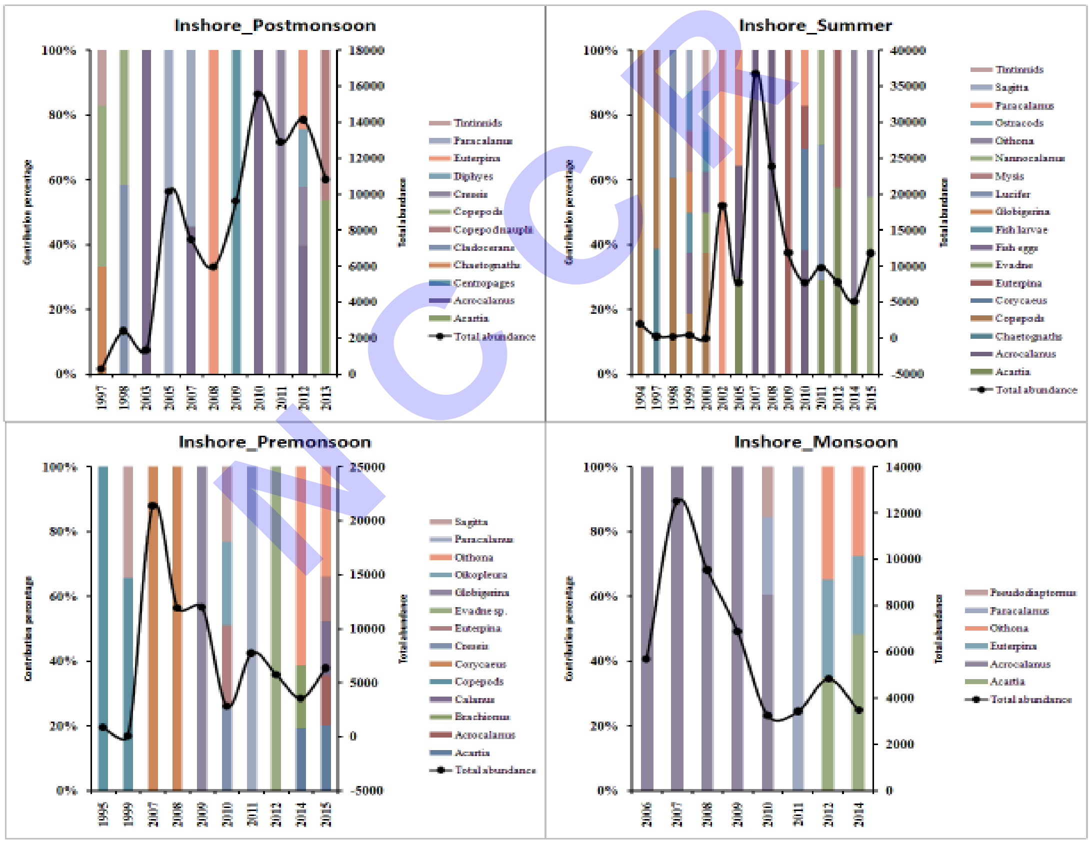


Fig. 3.6.2.10. Year-wise zooplankton species composition in shore region along Ennore coastal waters

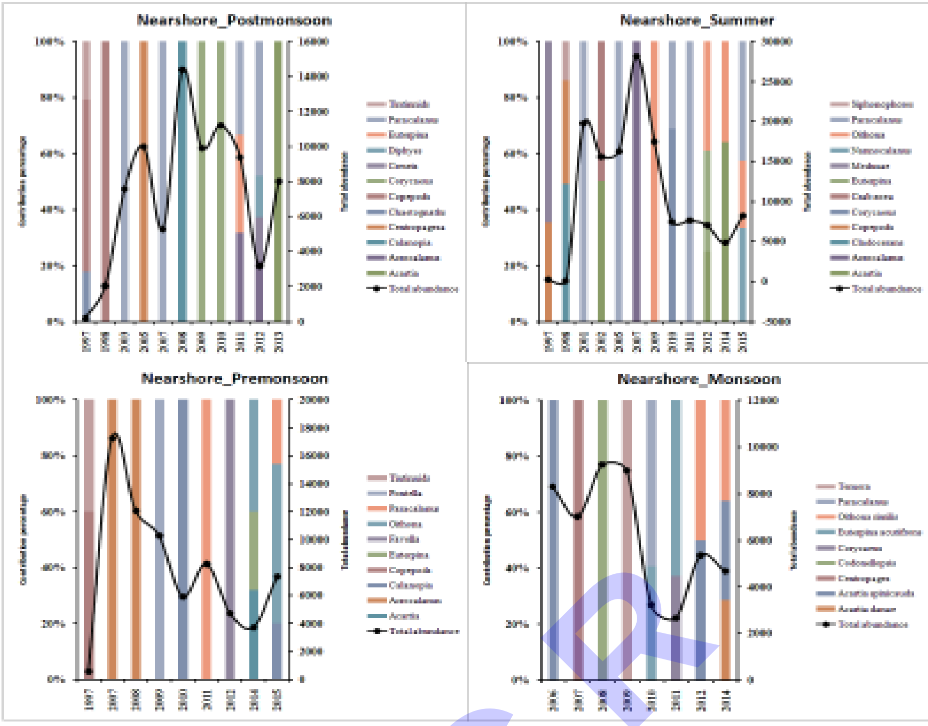


Fig. 3.6.2.11. Year-wise zooplankton species composition in nearshore region along Ennore coastal waters

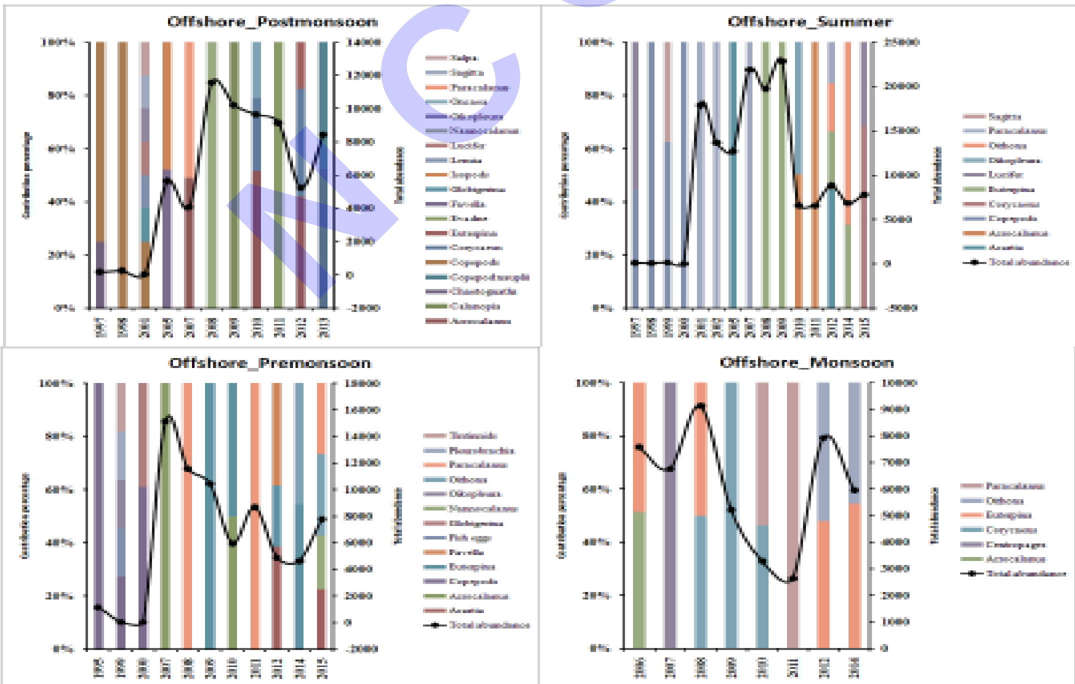


Fig. 3.6.2.12. Year-wise zooplankton species composition in offshore region along Ennore coastal waters

3.6.1. Sediment variablesand Macrobenthos

Sediment Organic Matter

Changes in the OM were observed in Ennore during the two and half decades of monitoring (Fig. 3.6.3.1). In the shore zone, OM showed fluctuation with values > 8 mg g^{-1} (Tables 3.6.3.1 and 3.6.3.2) The OM did not show any significant variation between the zones, except during 2015. In the nearshore and offshore zones, the OC values showed a sudden peak in 2015.

The sediment grain size became finer i.e., increase in silt and clay content in shore zone during the recent years (2013-15) (Fig. 3.6.3.2). A similar shift from sand to silt and clay was observed in the nearshore and offshore zones (Fig. 3.6.3.3).

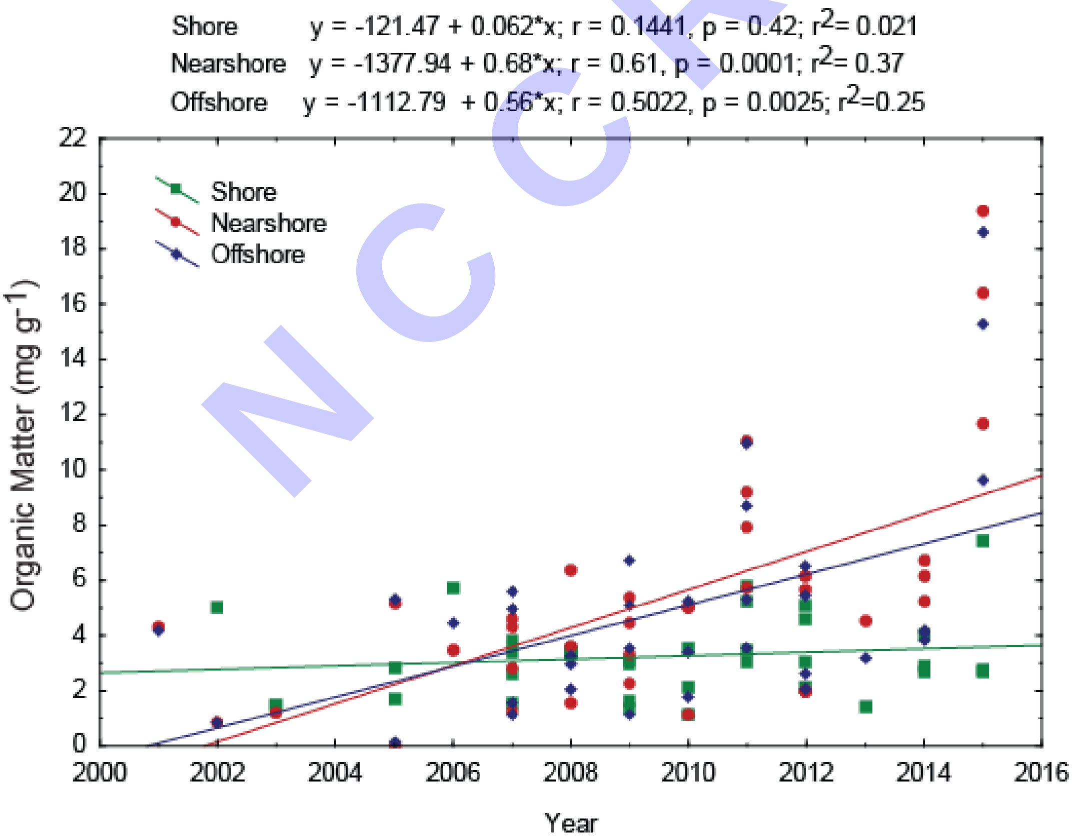


Fig. 3.6.3.1. Inter-annual trend in sediment OC at Ennore.

Table 3.6.3.1. Range values of sediment OM (mg g^{-1}), macrofaunal abundance (ind. m^{-2}) and biomass (g m^{-2}), Ennore.

Zone	Season	OM	Abundance	Biomass
Shore	*Summer*	0.41-9.24	175-11200	0.33-31.4
	Pre-monsoon	0.83-6.76	275-3800	0.28-13.53
	Monsoon	0.27-8.85	350-8800	0.0495-2.5
	Post-monsoon	0.3-12.64	175-12800	0.1-1.53
Nearshore	*Summer*	0.01-19.26	300-3550	0.42-6.23
	Pre-monsoon	1.93-15.84	400-5700	0.314-12.8
	Monsoon	0.73-8.35	400-1625	0.03-2.51
	Post-monsoon	0.87-21.57	225-3275	0.2-5.96
Offshore	*Summer*	0.13-15.26	96-5775	0.95-10.57
	Pre-monsoon	1.45-9.62	550-2300	0.59-14.92
	Monsoon	1.17-8.71	450-2925	0.25-4.91
	Post-monsoon	0.89-18.62	175-5325	0.83-15.89

Table 3.6.3.2. Annual range values of sediment OM (mg g^{-1}), macrofaunal abundance (ind m^{-2}) and biomass (g m^{-2}), Ennore.									
Year	**Organic Matter**			**Abundance**			**Biomass**		
	Shore	*Nearshore*	*Off Shore*	*Shore*	*Nearshore*	*Off Shore*	*Shore*	*Nearshore*	*Off Shore*
1997				200-1275	300-2175		0.1-1.17	0.2-12.8	
1998				175-175	375-375	96-525	0.63	5.96	3.36-15.89
1999				175-200		275	3.1-8.6		7.1
2000				350-375		475-550	11.4-31.4		4.17-10.57
2001	-	4.31	4.21	-	2225	650-5775	-	-	10.8
2002	1.93-7.56	0.84	0.83	725-4800	1175	1025	-	-	-
2003	0.3-3.1	1.24	-	1800-5500	1300		-	-	-
2005	0.34-6.55	0.01-5.14	0.13-5.28	400-8100	225-1450	175-1325	-	-	-
2006	4.07-8.31	3.45	4.49	1000-3800	725-725	750	-	-	-
2007	1.03-6.62	1.27-4.62	1.17-5.62	275-3600	300-5700	325-1525	-	-	-
2008	0.52-6.48	0.87-6.35	2.04-3.84	275-2600	350-800	500-750	-	-	-
2009	0.76-4.81	2.28-5.36	1.17-6.74	1000-11200	325-1375	475-1400	-	-	-
2010	0.41-4.28	0.73-5.79	0.89-6.07	550-7100	575-1300	725-1525	0.33-13.53	0.73-12.53	2.52-14.92
2011	1.54-8.85	5.25-16.90	3.52-10.99	600-9300	575-3550	825-3700	0.24-1.27	0.27-1.672	1.72-3.52
2012	0.69-6.762	0.48-8.35	2.07-6.51	1250-6100	1200-3425	2050-2925	0.33-1.64	0.35-1.44	1.02-2.58
2013	0.63-1.86	4.35-4.69	3.174	3125-12800	2100-3275	5325	0.21-0.96	0.32-0.85	1.763
2014	0.265-5.985	2.69-9.85	3.79-4.17	525-1675	400-2950	1100-2050	0.05-1.9	0.03-3.55	0.25-2.12
2015	0.97-12.63	7.48-21.57	9.62-18.62	475-1400	400-2025	1250-1725	0.28-2.32	0.26-3.22	0.59-1.86

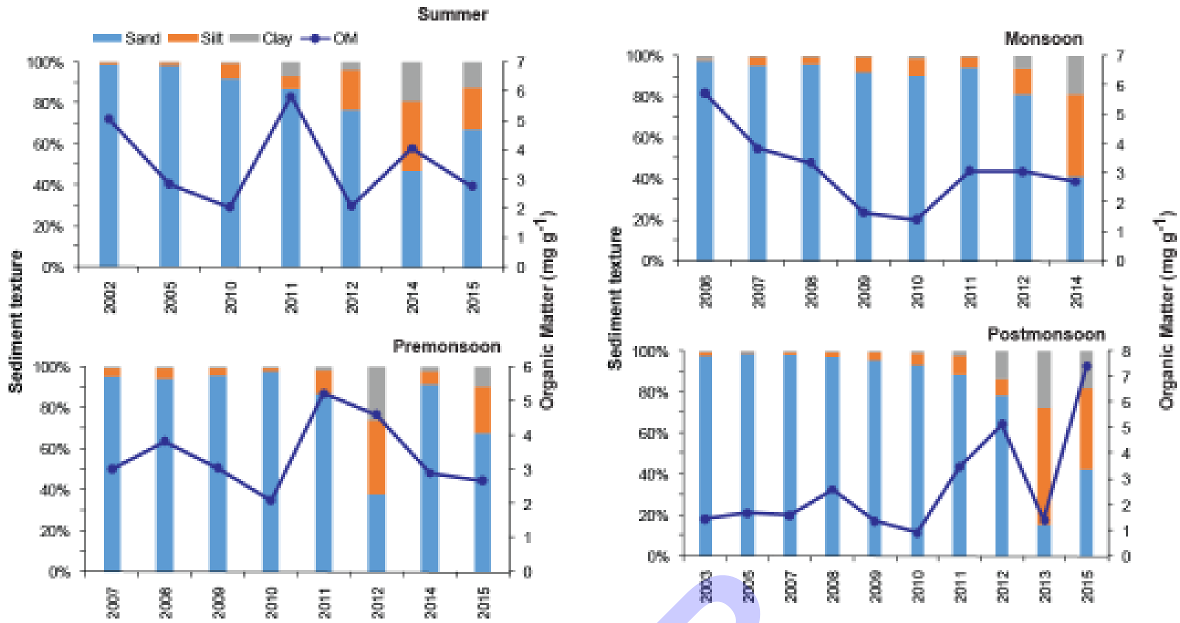


Fig. 3.6.3.2. Seasonal variation in sediment texture and OM in shore zone of Ennore.

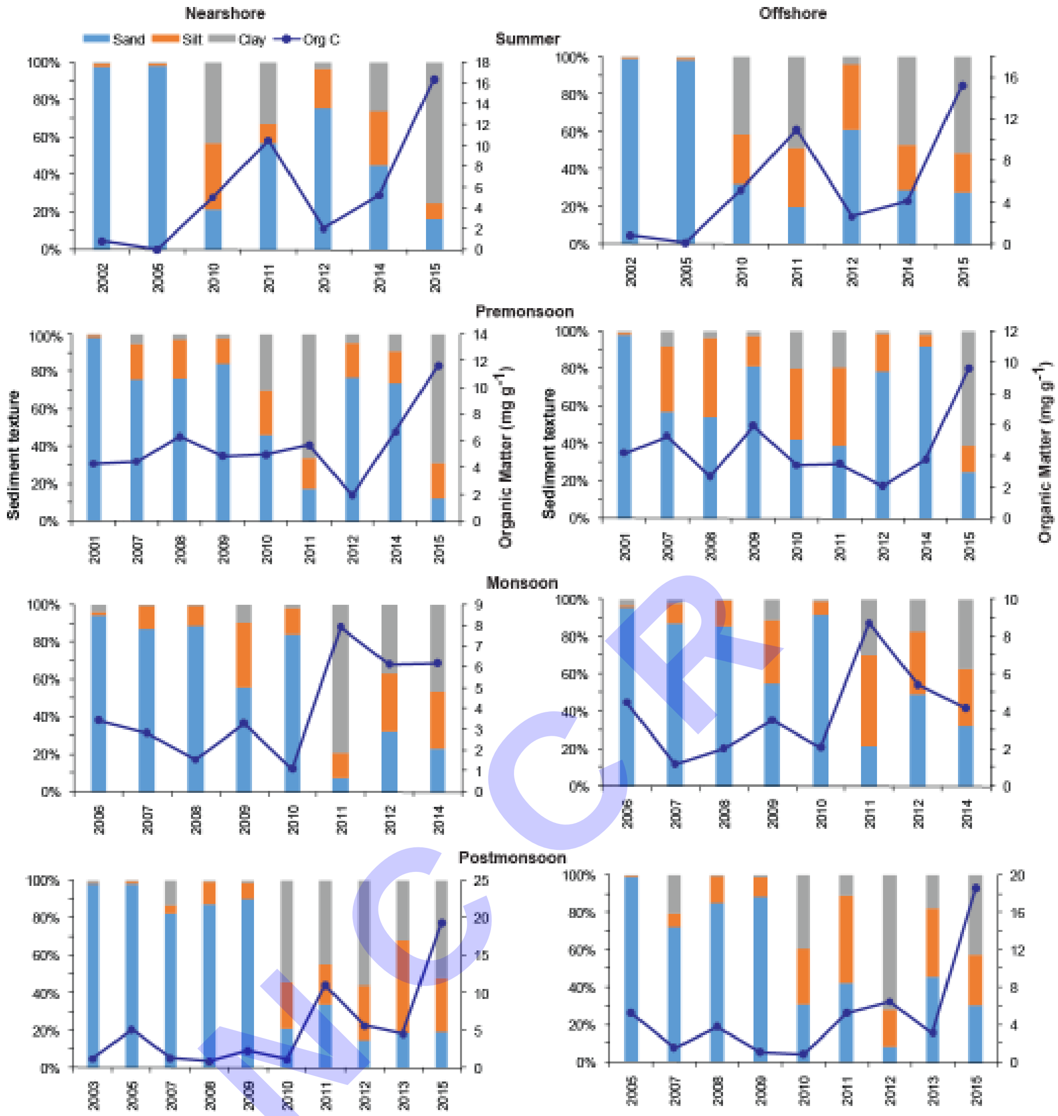


Fig. 3.6.3.3. Seasonal variation in sediment texture and OC in nearshore and offshore zones of Ennore.

Macrofaunal Communities

The inter-annual and seasonal range in macrofaunal abundance and biomass is given in Tables 3.6.3.1 and 3.6.3.2. All the three zones showed variation in the macrofaunal abundance in the last 25 years (Fig. 3.6.3.4). Overall, abundance was higher in the shore, compared to nearshore and offshore zones during the monitoring period, except in the last two years, when a reverse trend was found. Chi-Square test showed that macrofaunal abundance in the shore zone showed significant interannual variability (Chi-Square = 29.99; df

= 17; $p=0.02$). Macrofaunal abundance pattern in the nearshore and offshore zones showed similar pattern to that of the shore, however the interannual variation was not significant ($p>0.05$). In general, the macrofaunal abundance was higher during summer (Fig. 3.6.3.5). Macrofaunal biomass showed an increasing trend from the shore to the offshore zone. However, the values declined in all the three zones from 2010 to 2015. No clear seasonal pattern was observed in the macrofaunal biomass, although low values were observed mostly during monsoon (Fig 3.6.3.5).

The dominant species (>10% of the total abundance) in the Ennore coastal waters is represented in Table 3.6.3.3. In the shore zone, polychaetes completely dominated the macrofaunal abundance with highest values in 2011, after which a decline was observed (Fig. 3.6.3.6). Polychaete was also the dominant group in the nearshore and the values fluctuated throughout the monitoring period. However, though crustacean abundance was low, it showed extremely high values in the year 2007 (Fig. 3.6.3.6). A similar peak in crustacean abundance was also found in the offshore zone. Increase in the abundance of polychaetes, bivalves and other macrofaunal groups was observed from 2011 to 2014 (Fig. 3.6.3.6).

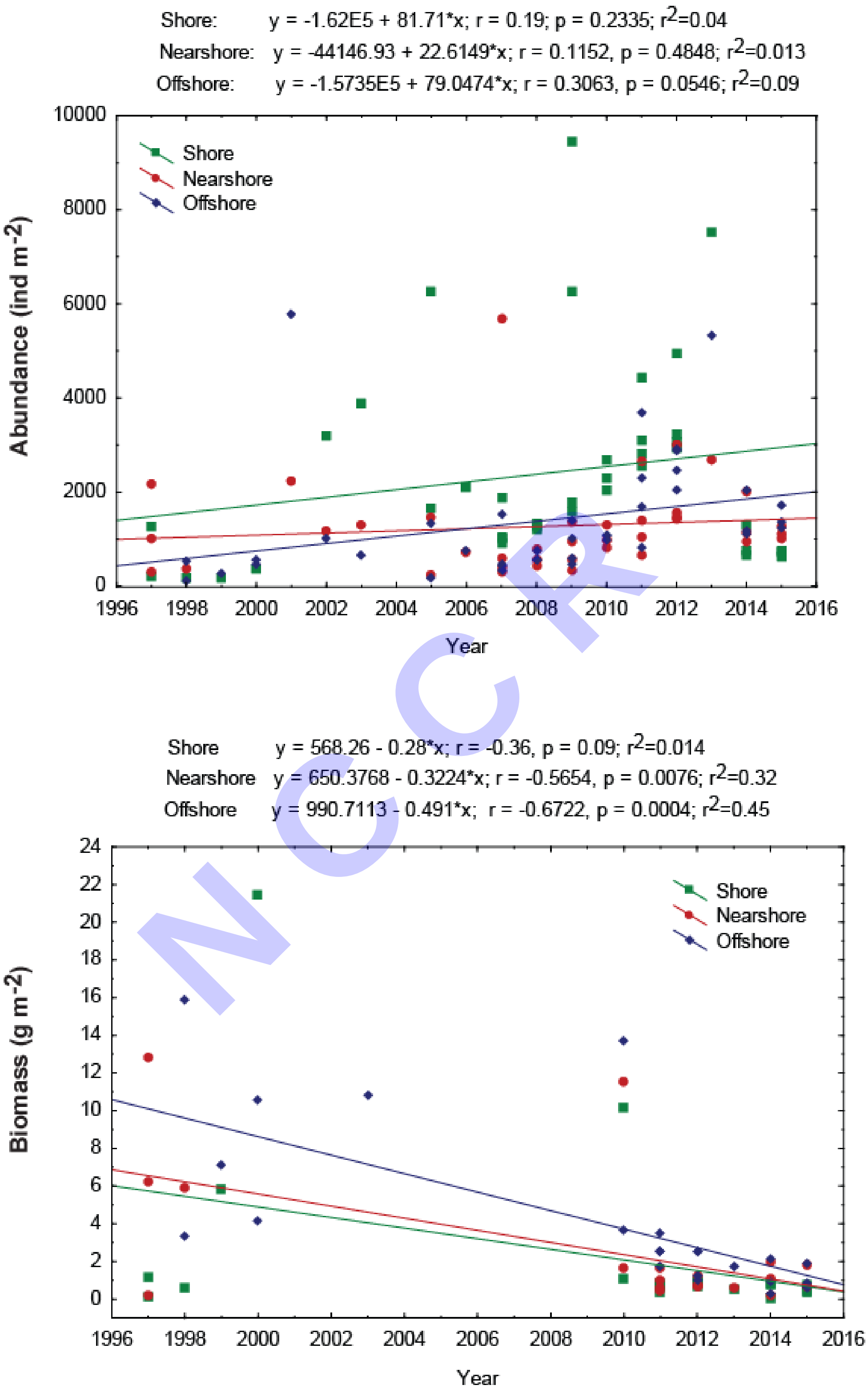


Fig. 3.6.3.4. Inter-annual trend in macrofaunal abundance and biomass at Ennore.

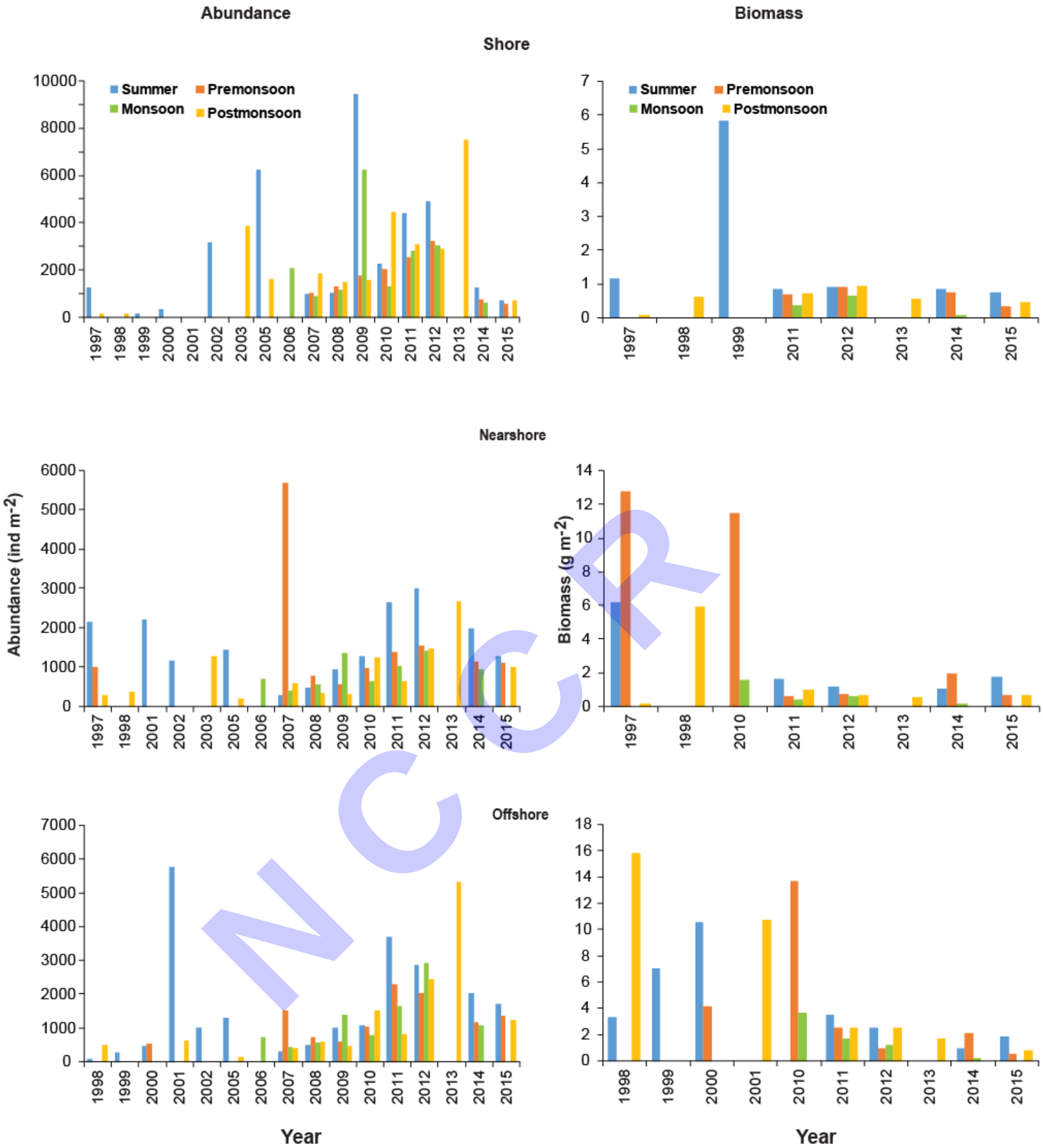


Fig. 3.6.3.5. Seasonal variation in macrofaunal abundance and biomass at Ennore.

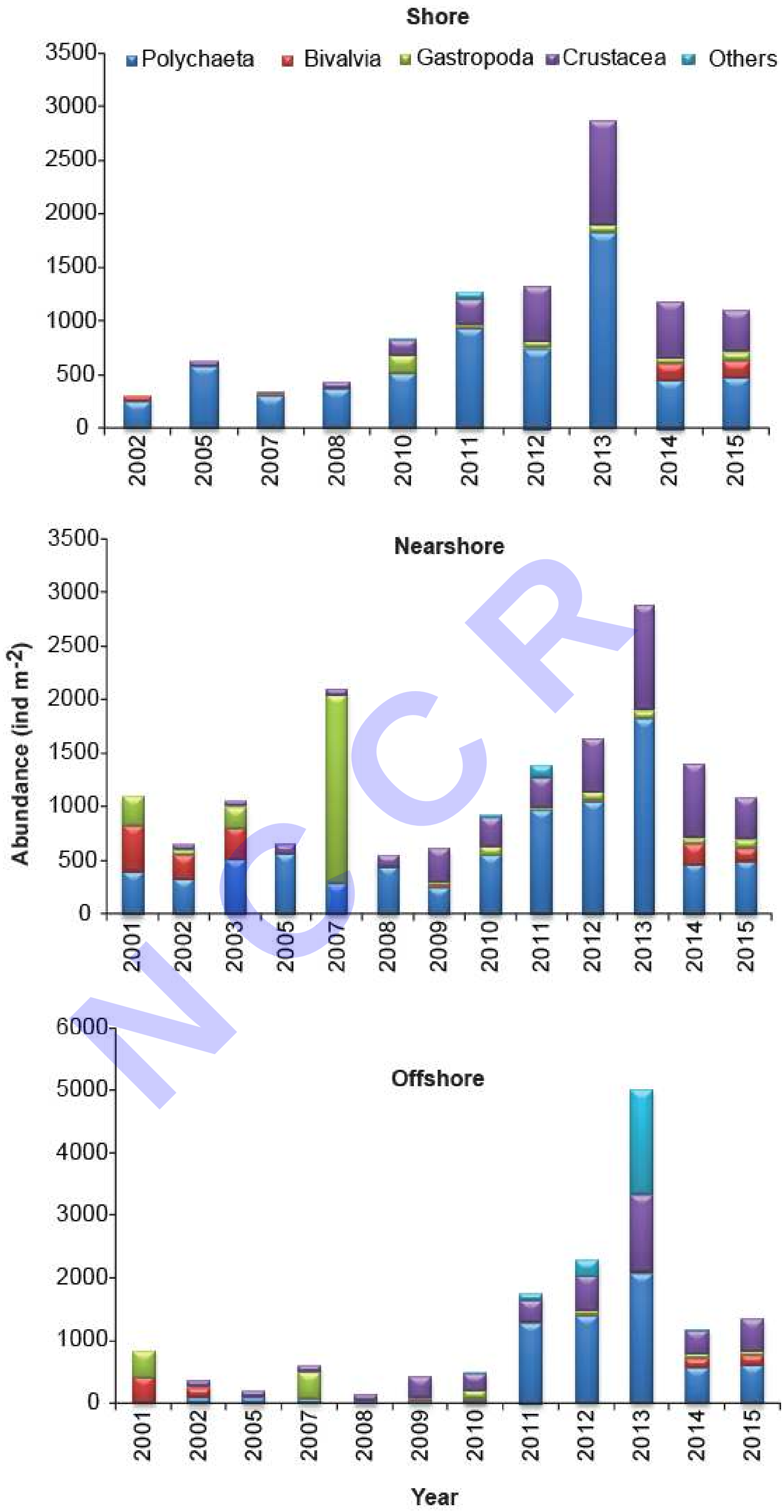


Fig.3.6.3.6. Inter-annual trend in macrofaunal group abundance at Ennore.

Table 3.6.3.3 Dominant taxa (>10% of the total abundance) at Ennore			
Year	**Shore**	**Nearshore**	**Offshore**
2001	**Bivalvia** *Meretrix casta* **Gastropoda** *Cassiella* sp. *Murex* sp. *Rapana* sp.	**Bivalvia** *Pecten* sp.	**Polychaeta** *Capitella* sp. *Nereis* sp.
2002	**Amphipoda** *Ampithoe* sp. **Bivalvia** *Anadara granosa* *Meretrix* sp. **Polychaeta** *Capitella* sp. *Perinereis cultrifera* *Polydora ciliata*	**Bivalvia** *Anadara granosa* *Anadara sp.* *Meretrix* sp. **Polychaeta** *Capitella* sp.	**Amphipoda** *Ampithoe* sp. **Bivalvia** *Anadara granosa* *Anadara* sp. *Meretrix* sp. **Polychaeta** *Capitella* sp. *Perinereis cultrifera* *Polydora ciliata*
2003	**Bivalvia** *Anadara* sp. *Meretrix casta* **Gastropoda** *Cerithidea cingulata* **Polychaeta** *Polydora ciliata*	**Bivalvia** *Anadara sp.* *Meretrix casta* **Polychaeta** *Capitella* sp. *Perinereis cultrifera* *Polydora ciliata*	--
2005	**Amphipoda** *Ampithoe* sp. *Hornellia incerta* **Bivalvia** *Anadara* sp. *Meretrix* sp. **Polychaeta** *Capitella* sp. *Gattyana deludens* *Glycera alba* *Perinereis cultrifera* *Platynereis* sp. *Polydora ciliata*	**Bivalvia** *Anadara sp.* **Polychaeta** *Capitella* spp. *Perinereis cultrifera* *Polydora ciliata* *Platynereis* sp.	**Bivalvia** *Anadara sp.* **Polychaeta** *Capitella* spp. *Perinereis cultrifera* *Platynereis* sp. *Polydora ciliata*
2006	**--**	**Amphipoda** *Ampithoe* sp. *Donax* sp. **Isopoda** Isopoda (Unidentified) **Polychaeta** *Ophelia capensis*	**Isopoda** Isopoda (Unidentified) **Bivalvia** *Donax sp.* **Polychaeta** *Capitella* sp. *Nephtys* sp. *Ophelia capensis*

Contd…

Year	Shore	Nearshore	Offshore
2007	**Amphipoda** *Ampithoe* sp. **Bivalvia** *Anadara granosa*	**Amphipoda** *Ampithoe* sp. **Bivalvia** *Meretrix* sp.	**Amphipoda** *Ampithoe* sp. **Isopoda** Isopoda (Unidentified)
2007	*Meretrix* sp. *Meretrix casta* **Polychaeta** *Capitella* sp. *Nephtys* sp. *Syllis* spp. *Amphinome rostrata* *Magelona* sp.	Bivalvia (Unidentified) **Gastropoda** *Turritella* sp. **Polychaeta** *Amphinome rostrata* *Capitella* sp. *Nephtys* sp. *Ophelia capensis* *Pista* sp. *Syllis* sp.	**Bivalvia** *Meretrixmeretrix* *Donax sp.* **Polychaeta** *Capitella* sp. *Nephtys* sp. *Ophelia capensis* *Polydora ciliata* **Ophiuroidea** *Ophioderma* sp.
2008	**Amphipoda** *Ampithoe* sp. **Bivalvia** Bivalvia (Unidentified) *Meretrix* sp. **Gastropoda** *Bullia* sp. **Polychaeta** *Capitella* sp. *Chone* sp. *Eurythoe* sp. *Nephtys* sp. *Pisionidens indica* *Polydora ciliata* *Prionospio* sp. *Syllis* sp.	**Amphipoda** *Ampithoe* sp. **Polychaeta** *Chone* sp. *Dorvillea* sp. *Glycera alba* *Nephtys* sp. *Ophelia* sp. *Pisionidens indica* *Platynereis* sp. *Polydora ciliata* *Prionospio* sp. *Scolelepis squamata* *Syllis* sp.	**Amphipoda** *Ampithoe* sp. **Polychaeta** *Ancistrosyllis* sp. *Nephtys* sp. *Pisionidens indica* *Prionospio* sp. *Polydora ciliata* *Pista* sp.
2009	**Amphipoda** *Ampithoe* sp. **Isopoda** Isopoda (Unidentified) **Bivalvia** *Anadara* sp. **Polychaeta** *Cirratulus* sp. *Nephtys* sp. *Prionospio* sp. *Syllis* spp.	**Amphipoda** *Ampithoe* sp. **Isopoda** Isopoda (Unidentified) **Bivalvia** *Cardium* sp. *Donax* sp. *Meretrix* sp. **Gastropoda** *Turritella* sp. **Polychaeta** *Armandia* sp. *Nephtys* sp. *Prionospio* sp. *Syllis* spp.	**Amphipoda** *Ampithoe* sp. **Isopoda** Isopoda (Unidentified) **Decapoda** Penaeid shrimp larvae **Bivalvia** *Cardium* sp. *Donax* sp. **Gastropoda** *Oliva nebulosa* **Polychaeta** *Onuphis eremita* *Nephtys* sp. *Nereis* sp.

			Prionospio sp.

Contd…

Year	**Shore**	**Nearshore**	**Offshore**
2010	**Isopoda** *Calabozoa* sp. **Amphipoda** *Hornellia incerta* **Gastropoda** *Cerithidea cingulata* *Littorina scabra*	**Amphipoda** *Ampithoe* sp. *Ampithoe* sp. *Gammarus* sp. **Isopoda** *Microcerberus* sp. *Paragnathia* sp.	**Bivalvia** *Anadara* sp. *Donax* sp. **Gastropoda** *Oliva nebulosa* **Polychaeta** *Capitella* sp.
2010	*Oliva nebulosa* *Turritella* sp. **Polychaeta** *Armandia intermedia* *Capitella* sp. *Scoloplella capensis* *Sphaerosyllis* sp.	**Bivalvia** *Cardium* sp. *Meretrix* sp. **Gastropoda** *Turritella* sp. **Polychaeta** *Boccardia polybranchia* *Cossura* sp. *Goniadides falcigera* *Onuphis* sp. *Polydora ciliata* *Prionospio cirrifera*	*Exogone* sp. *Glycinde capensis* *Myrianida pulchella*
2011	**Amphipoda** *Ampithoe* sp. *Urothoe* sp. **Bivalvia** *Anadara* sp. *Donax* sp. *Modiolus metcalfei* *Perna viridis* **Gastropoda** *Bullia* sp. *Littorina scabra* *Natica* sp. *Nassarius* spp. **Oligochaeta** *Limnodriloides* sp. **Polychaeta** *Boccardia polybranchia* *Nepthys*sp.*Onuphis*sp. *Drilonereis falcata* *Exogone* sp. *Euclymene annandalei*	**Amphipoda** *Ampithoe* sp. **Bivalvia** *Modiolus metcalfei* *Perna viridis* *Donax* sp. *Meretrix* sp. **Gastropoda** *Littorina* sp. *Natica* sp. *Nassarius* spp. **Oligochaeta** *Limnodriloides* sp. **Polychaeta** *Onuphis* sp. *Scoloplos johnstonei*	**Oligochaeta** *Limnodriloides* sp. **Polychaeta** *Euclymene annandalei* *Euclymene* sp. *Maldane sarsi* *Notomastus aberans* *Goniada emerita*

Contd…

Year	Shore	Nearshore	Offshore
2012	**Amphipoda** *Ampithoe* spp. **Polychaeta** *Boccardia polybranchia* *Capitella* sp.	**Amphipoda** *Ampithoe* sp. *Gammarus* sp. *Grandidierella* sp. **Isopoda** *Joeropsis* sp. *Sphaeroma serratum* *Paragnathia* sp. **Bivalvia** *Donax* sp. **Gastropoda** *Nassarius* spp. **Polychaeta** *Anguillosyllis* sp. *Boccardia polybranchia* *Capitella* sp.	**Amphipoda** *Gammarus* sp. **Isopoda** *Anthura gracilis* **Gastropoda** *Littorina* sp. **Polychaeta** *Prionospio cirrifera* **Sipuncula** *Sipunculus* sp.
2012		*Cossura* sp. *Exogone* sp. *Nephtys* sp. *Polydora ciliata* *Prionospio cirrifera* *Polyodontes melanonotus*	
2013	**--**	**Decapoda** Penaeid shrimp larvae **Polychaeta** *Capitella* sp. *Goniadides falcigera*	**Cephalochordata** *Branchiostoma* sp.
2014	**Amphipoda** *Urothoe* sp. **Isopoda** *Paragnathia* sp. **Bivalvia** *Donax* sp. *Meretrix meretrix* **Polychaeta** *Capitella* sp. *Cirratulus* sp. Nereidae(Unidentified) Spionidae (Unidentified) Terebellidae (Unidentified)	**Amphipoda** *Cheiriphotis* sp. **Decapoda** *Emerita* sp.**Bivalvia** *Anadara* sp. *Meretrix meretrix* *Perna indica* **Gastropoda** *Cerithidea cingulata* *Umbonium* sp. **Polychaeta** *Capitella* sp. *Cirratulus* sp. *Prionospio capensis* *Polyodontes melanonotus* Nereidae(Unidentified) Terebellidae (Unidentified) **Sipuncula** Sipuncula (Unidentified)	**Decapoda** *Emerita* sp. **Bivalvia** *Anadara granosa* *Meretrix meretrix* *Perna indica* **Polychaeta** *Cirratulus* sp. *Prionospio* sp.

Contd…

Year	Shore	Nearshore	Offshore
2015	**Amphipoda** *Gammarus* sp. **Bivalvia** *Donax* sp. **Polychaeta** *Capitella* sp. *Cossura coasta* *Nereis capensis* *Prionospio capensis* *Syllidia armata* Terebellidae (Unidentified)	**Gastropoda** *Littorina variegata* *Harpinia* sp. **Isopoda** *Microcerberus* sp. **Polychaeta** *Capitella* sp. *Cirratulus* sp. *Prionospio* sp. *Goniada emerita* *Nereis capensis* *Syllidia armata* Spionidae (Unidentified)	**Amphipoda** *Ampithoe* sp. *Grandidierella* sp. *Natarajphotis manieni* **Harpacticoida** *Phyllopodopsyllus bradyi* **Bivalvia** *Scapharca inaequivalvis* *Donax* sp. *Meretrix meretrix* **Polychaeta** *Cirratulus concinnus* *Chone collaris*

3.6.3. Status of microbial quality at Ennore

Total viable count of bacteria in Ennore coastal waters increased over the years. The TVC recorded from 1994 to 2014 is represented in the box-whisker plot (Fig. 3.6.4.1). The counts of total viable bacteria in coastal waters were between 6 and $5.5x10^7$ cfu/ml. Further, the counts in sediment were between $1x10^2$ and $2.8x10^8$ cfu/g. The bacterial counts were found to be high in sediment than in waters. Annual variation of TVC showed an increasing trend throughout the course. The *E. coli* showed low counts till 2006 with two extremely high values in 2008 and 2010 and low counts were reported till 2006 (Fig. 3.6.4.1). The counts of *E. coli* in coastal waters were between 1 and $5.5x10^5$ cfu/ml. The counts of *S. faecalis* increased from 2007 to 2013 (Fig. 3.6.4.1).

Seasonal variations indicated the following: TVC showed increasing trend in all the four seasons. High levels of TVC were observed in post-monsoon of 2010 (Fig. 3.6.4.2). The *E. coli* counts did not show any trends at Ennore coast. However, extremely high counts were observed during 2008, 2009 and 2010 in all the seasons (Fig. 3.6.4.3). Further, counts of *S. faecalis* did not exhibit any trends. The levels of *S. faecalis* were extremely high during the period of 2009 –

12. The highest values were observed in summer of 2007. Further, *S. faecalis* counts decreased in 2014 and 2015 (Fig. 3.6.4.4).

Spatial variation in microbial counts at Ennore is shown in the Fig. 3.6.4.5. The data recorded from 1994 to 2014 were used to study the variations in microbial counts at various distances from shore. Like other locations, TVC, *E. coli* and *S. faecalis* showed a decreasing trend from the shore to the offshore zone.

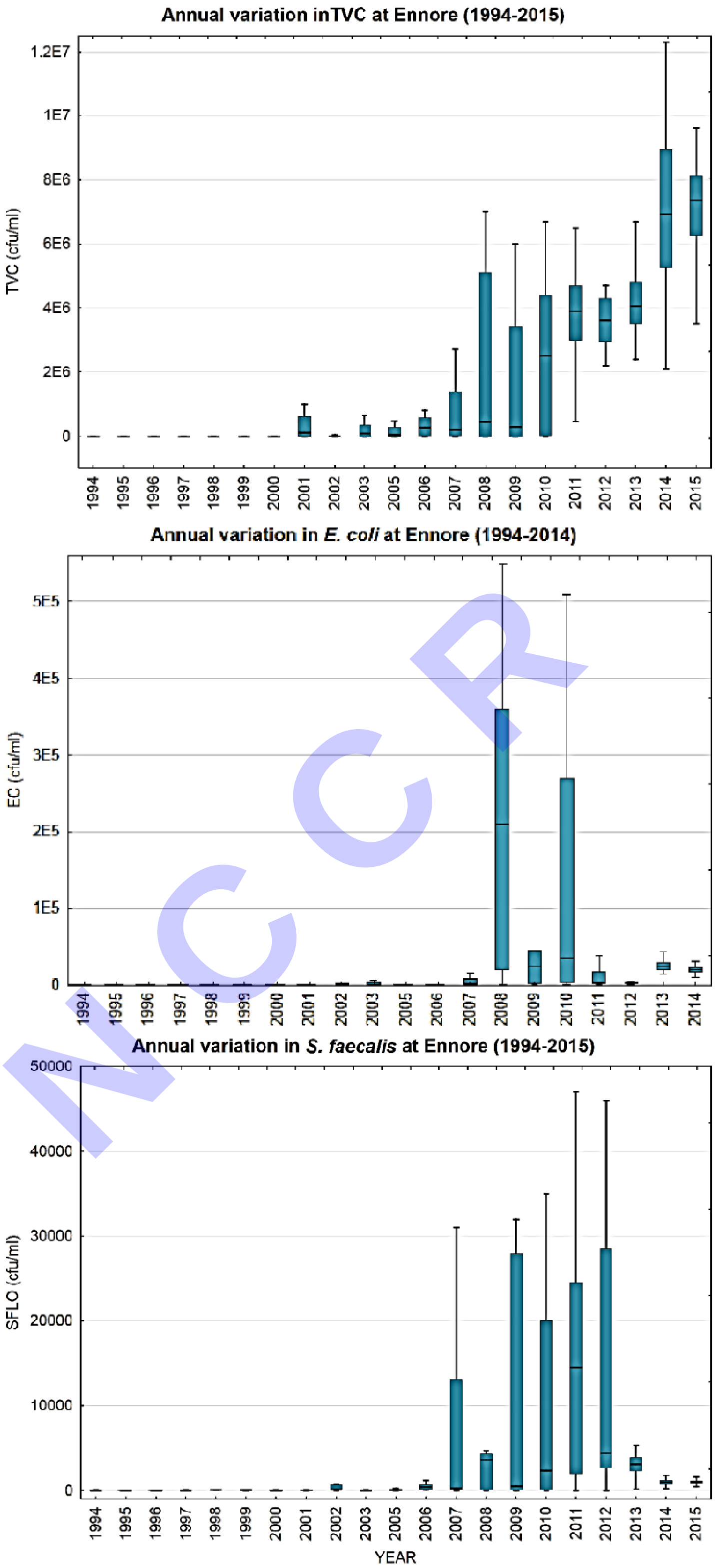


Fig.3.6.4.1. Box plot showing inter-annual variation (1994-2015) in TVC, EC and SFLO at Ennore.

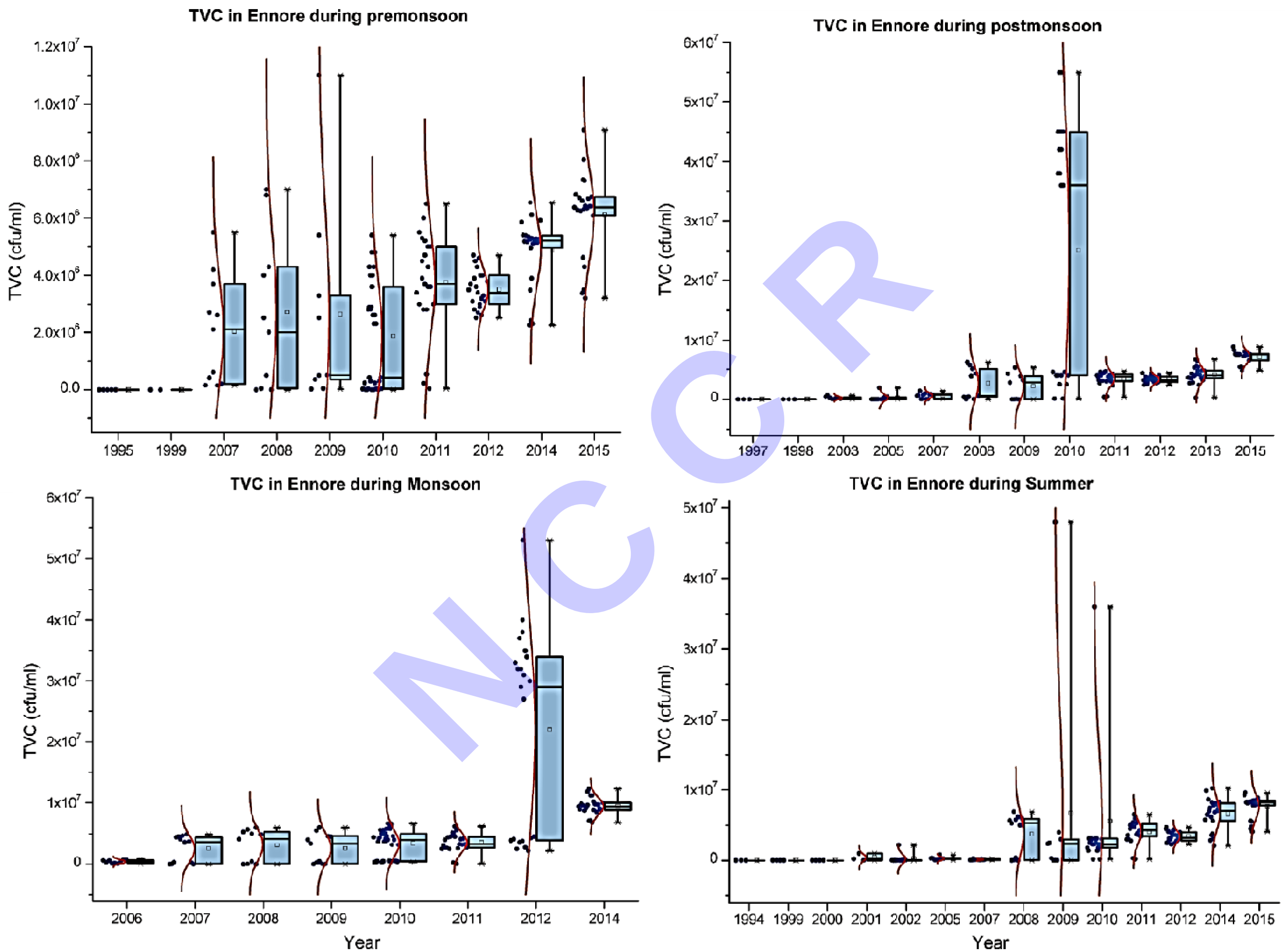


Fig.3.6.4.2. Box plot shows seasonal variation in TVC at Ennore. Blue dots: data points; Red lines: distribution curve.

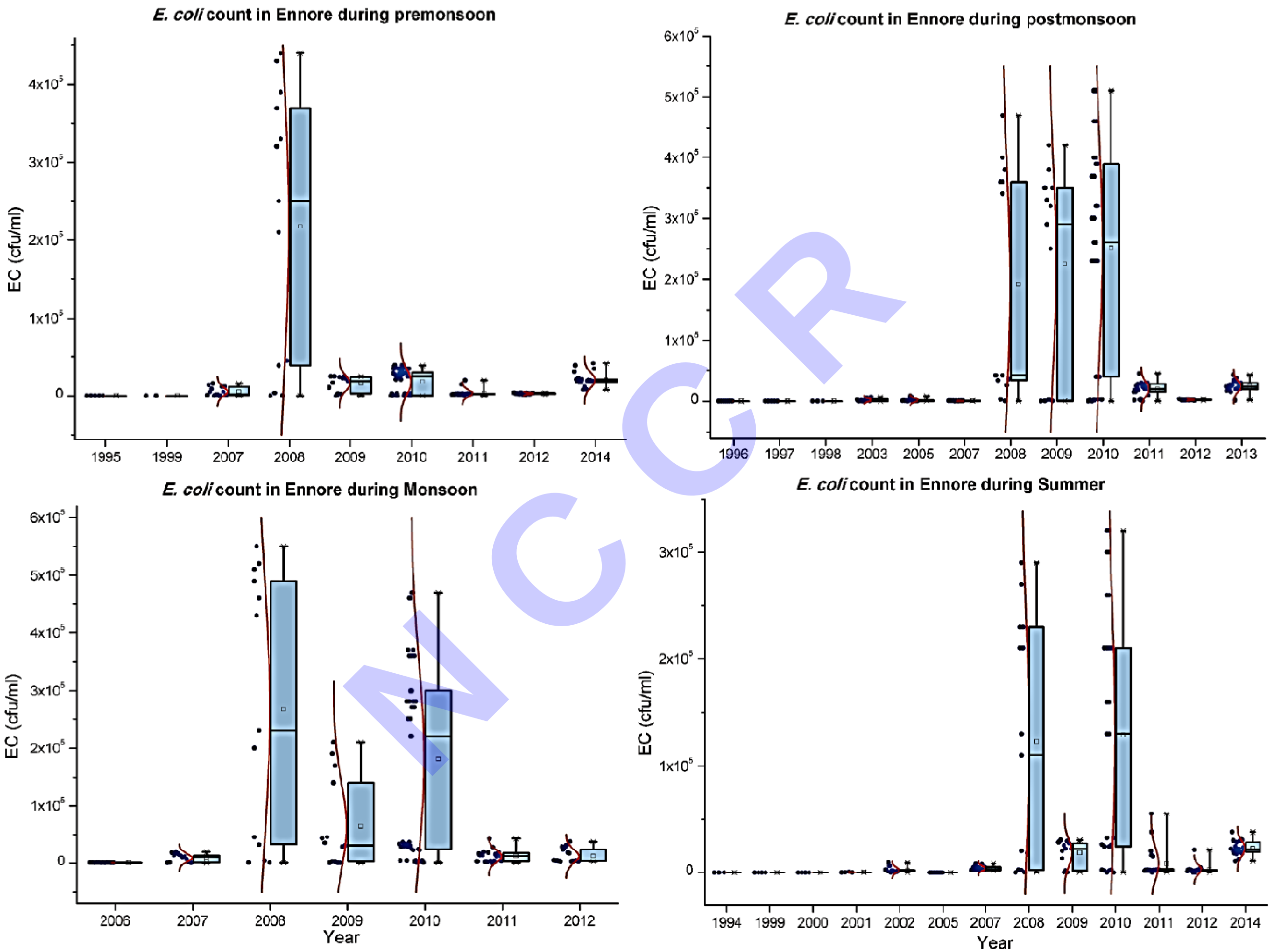


Fig.3.6.4.3. Box plot shows seasonal variation in *E. coli* count at Ennore. Blue dots: data points; Red lines: distribution curve.

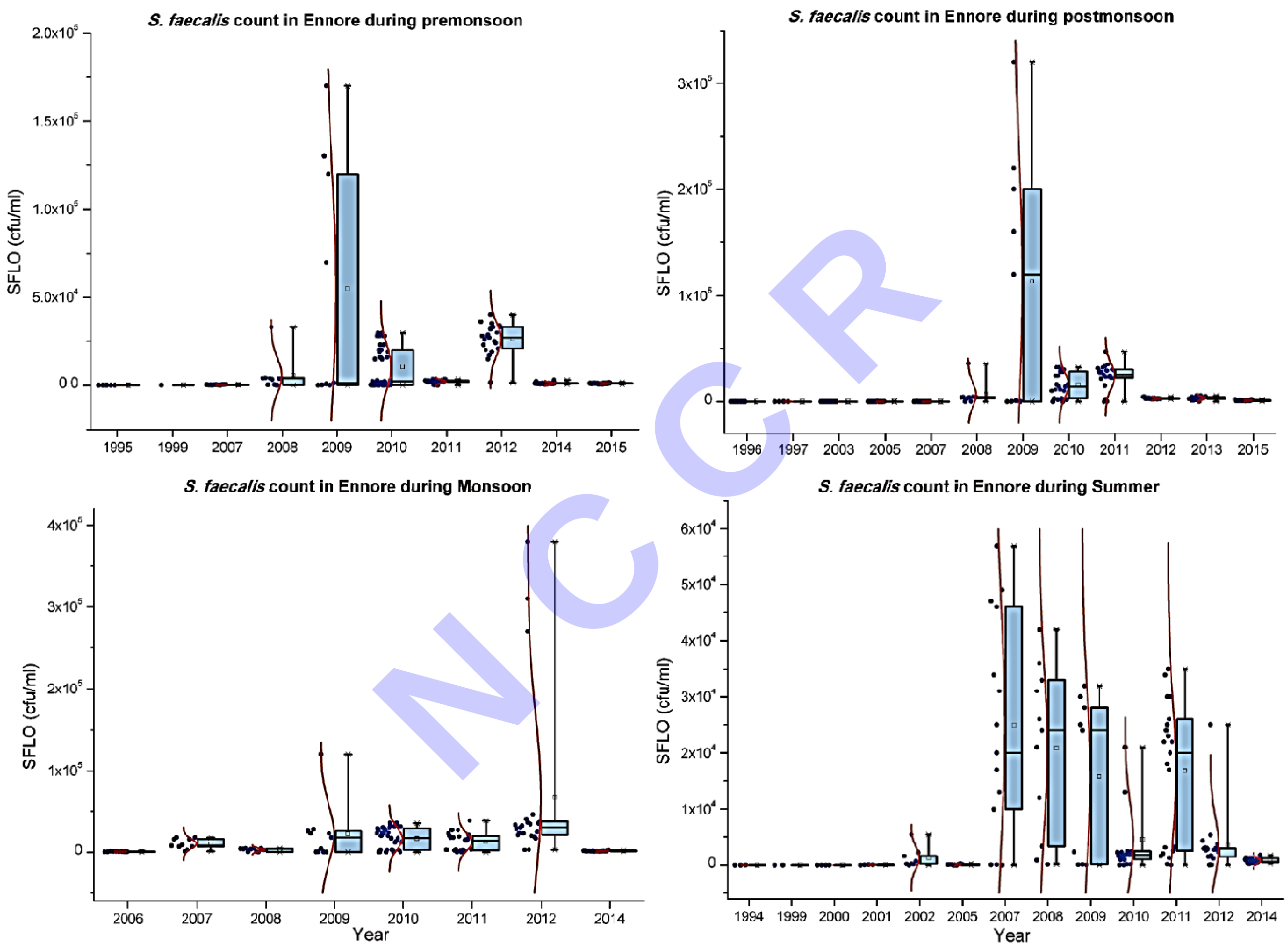


Fig.3.6.4.4. Box plot showing seasonal variation in *S. faecalis* count at Ennore. Blue dots: data points; Red lines: distribution curve.

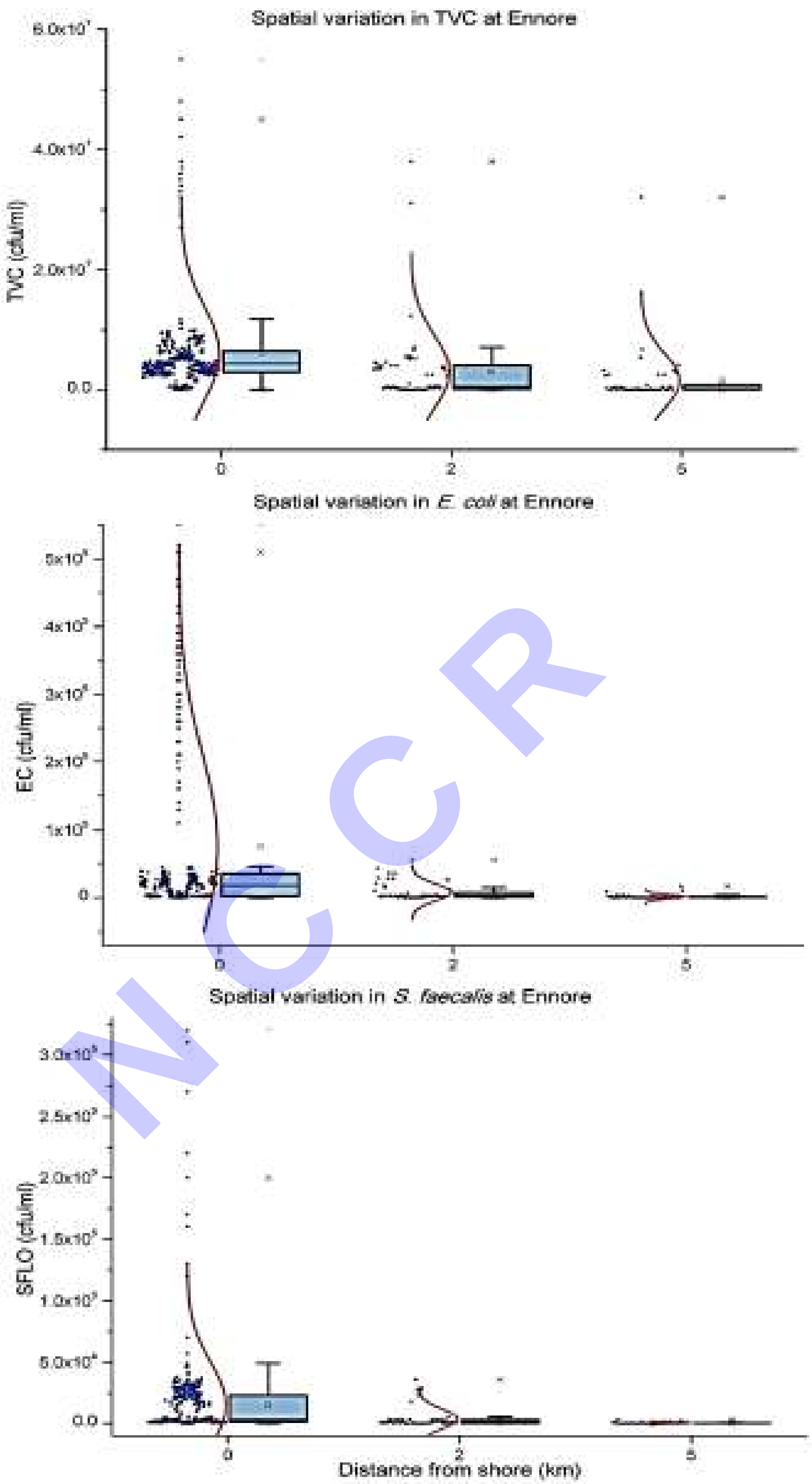


Fig.3.6.4.5. Box plot showing spatial variation in TVC, EC and SFLO at Ennore. Blue dots: data points; Red lines: distribution curve

3.7. Discussion

The figure 3.7.1 represents the overall trend of the primary parameters in the last 25 years along the monitored locations. The nutrients showed an increase in most of the locations during the monitoring period. Ammonia and phosphate dominated the nutrients in most of the locations. Dominance of phosphate in the nutrients indicates that untreated sewage continuous to be dumped into the coastal waters of India. Increase in ammonia and phosphate concentration in coastal waters is indicator of sewage discharge (Xu et al. 2008). The population of India increased from 870.610 million in 1990 to 1.311 billion today. In addition, riverine runoff loaded with agriculture wastes further contributes to the nutrient input into the coastal system (Seitzinger et al. 2010). The upward trend of the measured nutrients every year in most of the locations is of major concern as this will increase the incidences of eutrophication, fueling phytoplankton blooms causing increasing hypoxia and anoxia in the coastal waters.

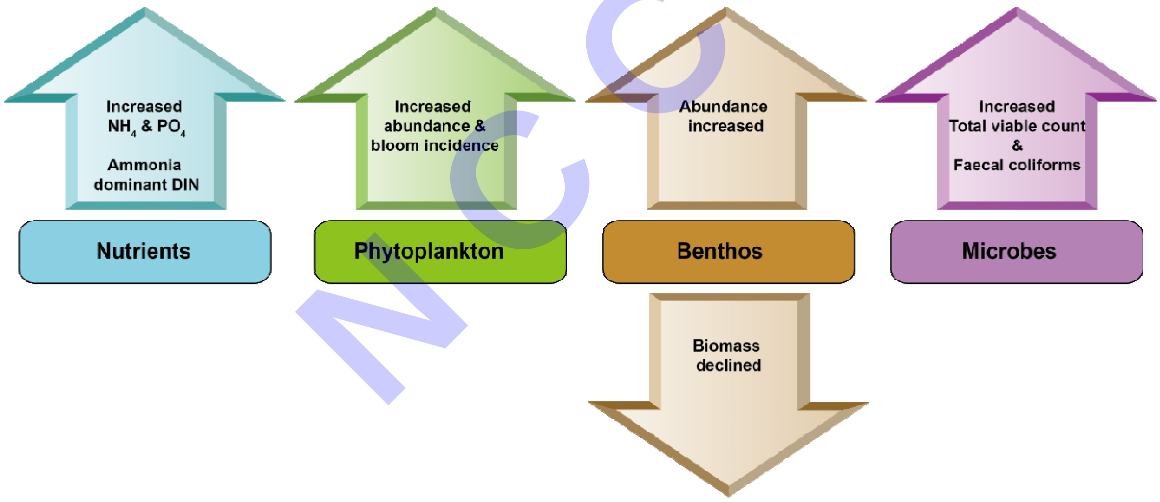


Fig. 3.7.1. Schematic diagram of status of Indian coastal waters.

Large loadings of nutrients in the coastal system will have significant impact on the primary production and phytoplankton species composition. Although the nutrient increased, phytoplankton did not show any significant variation over the years. In addition to nutrients, phytoplankton growth are influenced by suspended load and grazers community in the region.The high suspended in the most of the monitored locations could have resulted in the observed trend of phytoplankton in the monitored locations. Another possible reason of why phytoplankton biomass and abundance did not show any relation with nutrients could be due to the dominance of ammonia in the nutrients.Ammonia are known to inhibit the uptake of NO_3, a pattern observed in a number of coastal regions worldwide (Dugdale et al. 2012). Although the biological implications of nutrient load and in turn on the N:P ratios are still being debated, one of the consequences is that N and P rich waters favours growth of harmful algal blooms (O'Boyle et al 2016). This could explain for the increase in the incidences of harmful algal blooms along the Indian coast (Padmakumar et al. 2012). Harmful algal blooms cause economic losses through their negative impacts on human uses of ecosystem services (Anderson et al.2002, Davidson et al. 2011 and Hallegraeff, 1993). The occurrence of blooms in Indian waters is a matter of concern as most of the bloom cases reported, had direct or indirect effects on the coastal waters and affected fisheries, other marine organisms and humans (D'Silva et al. 2012). Further, high nutrients will result in ecological disturbances affecting the coastal ecosystem processes and services.

Sediment OM was highest at the shore zones of Veraval, Mumbai and Port Blair. In the nearshore and offshore zones, high sediment OM was observed at Veraval, Ratnagiri, Mangaluru and Kochi. One possible reason for the high values in these shore zones of these locations is that dominance of fine sediment (silt and clay). Veraval is one of the oldest fishing harbour in the country and a total of 60 registered fisheries units are located in the region. As per the 2011 census, the total population of the region is 2,20,115. The major sources of pollutant in this region are from industries, fishing harbours and fish processing activities and domestic waste water discharge into the coastal waters. Therefore, along with fine sediment organic loading from the various sources could have accounted for the high OM at Veraval. The Mumbai coastal regions have diversified industries including chemical, textile, pharmaceutical, engineering and major fertilizer complex that release their effluents into the coastal waters. Moreover, discharges of wastewater from the nearby sewage treatment facilities and non-point sources could have resulted in the high sediment OM in the shore zones of Mumbai. In addition, clearing of mangroves vegetation for coastal constructions are further affecting the coastal waters of Mumbai. The sources of high sediment OM in the shore of Port Blair are from the land-based runoff during the monsoon, and human activities including sewage disposal, boat, cargo, ferries, tourism and hotel (Sahu et al., 2013; Equbal et al 2017). In the coastal waters of Ratnagiri, Mangaluru and Kochi, in addition to anthropogenic sources and river runoff, the seasonal upwelling influenced increased primary productivity also contribute to the high organic matter. In fact, significant increase in OM was observed in the nearshore and offshore zones of Kochi (Fig. 3.5.3.1) and Ennore (Fig. 3.6.3.1). Therefore, the high sediment organic matter and increase in the values over the years at some of the locations are due to anthropogenic sources and natural factors like river runoff, upwelling and dominance of silty sediment that retains higher organic matter. However, as only the total organic matter in the sediment was analysed during the present monitoring, isotopic studies may give a clearer picture of the different sources of organic matter in the coastal waters of India.

In general, macrofaunal abundance showed an increasing trend from the north to the southern locations along the east and west coast. Moreover, macrofaunal abundance and biomass did not show any significant variation among the locations. The high biomass recorded at Thoothukudi, Kochi and Puducherry are due the presence of bivalves and gastropods. In Kochi, macrofaunal abundance showed an increase over the time at all the three zones, while biomass showed a significant increase only in the shore zone (Fig. 3.5.3.4). The increase in biomass in the shore zones is due to the increase in the bivalve and gastropod taxa (Table 3.5.3.3). The nearshore and offshore was dominated by polychaetes species belonging to the family Spionidae, Pilargidae, Nepythidae and Capitellidae. Species belonging to this family are *r*-selected species (small-size and fast reproducer) and opportunistic species that dominate under increasing organic matter load. Organic matter also showed an increase in the Kochi coastal that may have influenced the increase in the macrofaunal community dominated by *r*-selected species. The correlation between the macrofaunal abundance and biomass and all the measured variables did not show any significant relation in any of the zones. In Ennore, although abundance showed non-significant increase, biomass showed a significant decline in all the three zones (Fig. 3.6.3.4). The dominance of polychaete (Fig. 3.6.3.6 and Table 3.6.3.3) may have attributed to this trend. Macrofaunal abundance and biomass showed weak negative relation with nutrient (NH_4, total nitrogen, total phoshphate) and organic carbon and positive realtion with sand and DO. In the last few years silt content has shown an increase in all the three zones of Ennore (Fig

3.6.3.2 and 3.6.3.3). The identification of macrofauna to the species level and use of functional trait approach can provide a better understanding of the effect of anthropogenic activities on the distribution and diversity pattern and in turn the ecosystem functioning.

The SWQM programme currently employs only the culture-based method and focused on total coliform (TC), faecal coliform (FC), *Escherichia coli* (EC) and *Streptococcus faecalis* (SF). The continuous monitoring of indicator bacteria from 1991, showed that the bacterial abundance showed an increasing trend in the coastal waters. At nearly all spatial scales, annual mean of TVC showed an increase (Malvan, Mumbai, Ratnagiri, Veraval and Worli). Further, TC, FC and EC exhibited increasing trend at Malvan, Ratnagiri, Veraval and Worli. However, EC values decreased at Ennore, Puducherry and Thoothukudi. In general, bacterial population (TVC) tend to decrease towards offshore in all monitored locations except Worli where bacterial counts increased towards the offshore. Further, other microbial parameters such as, TC, FC, EC, and SF also decreased towards offshore. Among all the monitored stations, TVC values were found to be low at Mangalore; however, SFLO values were high in this area.

The microbial indicators suggest that overall water quality of the Indian coast is deteriorated. Especially, stations from Tamil Nadu coast (Ennore, Puducherry and Thoothukudi) showed extremely high number of TC, FC, EC and SF when compared to the other locations. The increase in faecal bacteria could be associated with the increasing nutrient load (e.g. Nogales et al. 2010; Paerl et al. 2003). This alarming level of microbial load necessitates immediate action to control direct discharge of domestic sewage which is the main source of faecal contamination. Further, stringent regulations should be implemented and followed in order to manage coastal water quality of India.

Given the potential threat to the coastal waters of India, there is an urgent need to reduce the nutrient loads in order to restore the stoichiometric nutrient balance of our coastal waters. Many countries through effective management measures have reduced the nutrient load to their coastal regions by > 70% (O'Boyle et al 2016, OSPAR 2010). The mitigation measures included improvement in the waste water treatment, changes in agricultural practices and licensing of industrial discharge (O’Boyle et al 2016).

4. Water Quality Index

4.1 Introduction

Coastal areas have some of the most productive habitats on Earth and hence form an essential component of the global life-support system. However, the coastal area is also one of the most overexploited ecosystems. In view of the awareness on the long-term sustainability of this important area, countries are regularly monitoring to assess the quality of coastal waters. Such monitoring plans, including the SWQM programme generate large datasets for several coastal variables.

Success of such monitoring programmes depends on the transfer of knowledge gathered or generated to the policy makers, non-technical water managers and the public in an easily understandable format (Fig 4.1). This will also allow them to take decisions on sound scientific basis. However, the task of simplifying the enormous abiotic and biotic data is not straight forward. The Water Quality Index (WQI) concept offers a useful framework to transform complex datasets into comprehensive form that allows assessing the environmental health of the coastal waters.

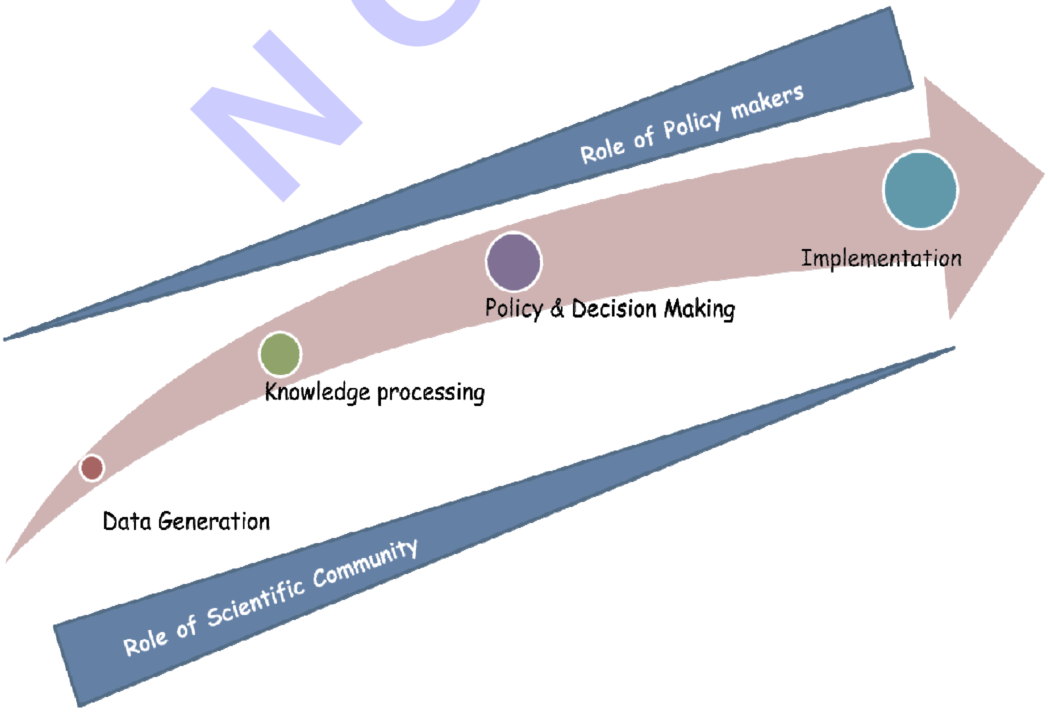


Fig.4.1.1. Schematic diagram of a monitoring programme

Indices like WQI are becoming useful tools to approximate the water quality and facilitate to design specific pollution prevention programmes by grouping and analysing numerous parameters into a simple numerical classification system (Fig. 4.1.2). Further, it also allows determining whether goals such as compliance with pollution regulations or implementation of effective pollution control actions are being met.

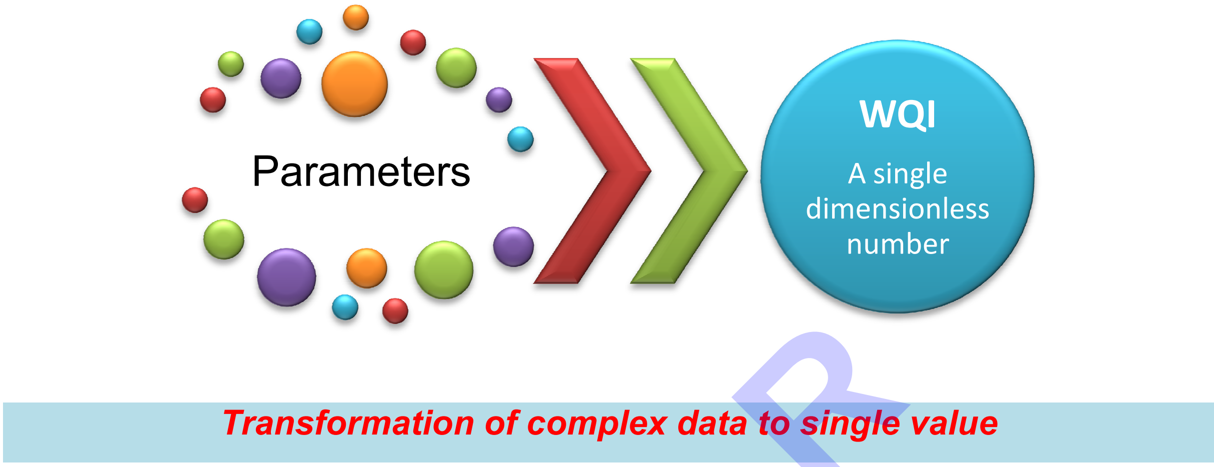


Fig.4.1.2. Schematic diagram of an index calculation

4.2. Methodology

Today, it is widely accepted that nutrient enrichment and toxic wastes are some of the prominent anthropogenic vectors that change the state of most aquatic systems including the coastal areas. Nutrients largely added through domestic wastewater and agricultural runoff to the coastal waters threaten the delicate balance of this important ecosystem. This does not mean that the other pollutants such as trace metals, pesticides, petroleum hydrocarbons and phenols are of less consequence, but their impacts are localised requiring site-specific actions. Generally, coastal monitoring programme developed indices using several parameters based on the following categories ((OSPAR, 2003), (US EPA, NCCR 2012); (Rho et al., 2012); (Kim et al., 2014).

Category I: degree of nutrient enrichment;

Category II: direct effects of nutrient enrichment; and

Category III: indirect effects of nutrient enrichment

Developing a simple water quality index requires selecting one or two parameters from each category as indicators. Globally, Dissolved Inorganic Nitrogen (DIN) and Dissolved Inorganic Phosphorus (DIP) were the potential parameters identified for the assessment of eutrophication from Category I, surface Chlorophyll-a (Chl-a) as an indicator from Category II as it reflects the immediate response for enrichment of nutrients and bottom DO as an indicator from Category III because it is a critical parameter for sustenance of ecosystem diversity (OSPAR, 2003); (OSPAR Procedure, 2005); (US EPA, NCCR, 2005; 2008; 2012).

In the Indian context, disposal of sewage is the major threat to the coastal waters. The major fraction of sewage in India is released untreated or with minimal treatment (CPCB 2016), consequently bringing enormous loads of organic matter along with pathogenic microbial population to the coastal waters. In the recent years, organic forms of nutrients were found to contribute more than 70% of total nutrient pools in the coastal waters. Hence, pollution monitoring programmes provide wide attention to total or organic form of nutrients rather than the inorganic forms i.e. DIN & DIP. #

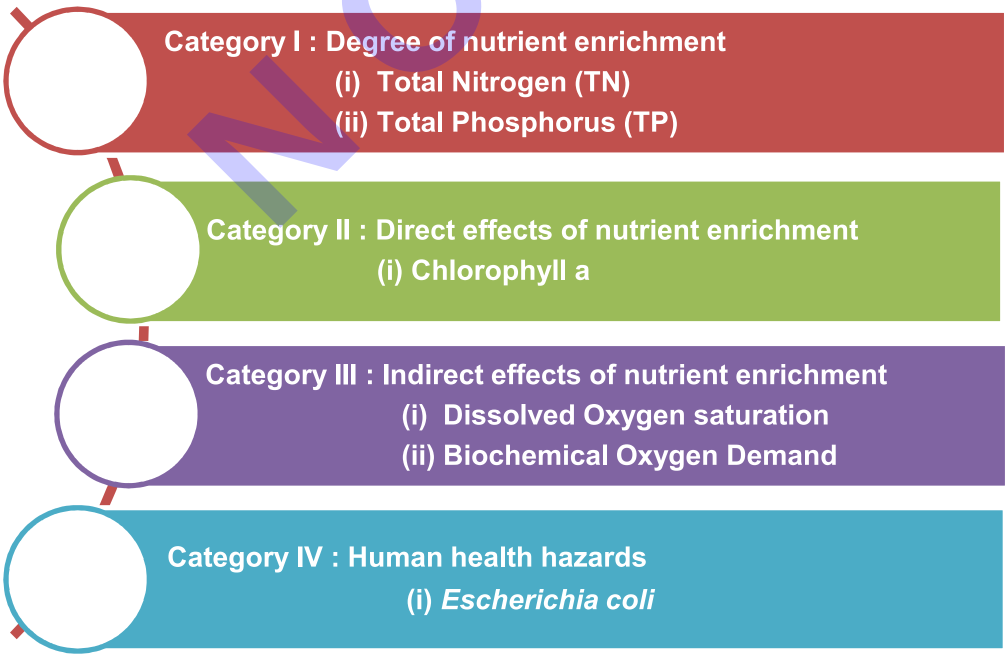


Fig.4.2.1. Parameters considered for the calculation of WQI

An index developed for the Indian coastal waters without considering total nitrogen (TN), total phosphorus (TP) and bacterial loads (in particular faecal coliforms) would be an underestimation of the water quality. For this reason, along with the above listed categories, faecal coliforms were considered as an indicator under Category IV: Human health hazards to the index calculation (Fig. 4.2.1).

The quality or accuracy of any WQI method relies on the definition of thresholds for selected indicators. Thus, the establishment of thresholds for each indicator should be robust and logical. We adopted the methodologies of Integration and Application Network, Center for Environmental Science, University of Maryland (http://ian.umces.edu/) used for the development of Eco Health Report Cards (https://ecoreportcard.org/) to derive the thresholds and development of WQI.

The main objective for deriving the WQI using the SWQM data was to find out the spatial extent of anthropogenic impacts (i.e. sewage and domestic discharges) on the coastal water quality, hence SWQM/COMAPS dataset of all the stations (ranging from hotspots, 0.5 km, 2.0 km & 5.0 km) from each monitoring location collected during the recent years (2011-2015) were considered to derive thresholds for each indicator. Multiple thresholds were used to score indicators based on a gradient of healthy to unhealthy conditions by diving the data in equal percentiles (EcoCheck, 2011). Cumulative scores for each parameter were converted to 0-100% grading scale and reported as WQI. WQI were developed for each station and five-years average index for each station were used for the preparation of location wise WQI maps.

Table 4.1. WQI grades based on 0- 100 % scale

WQI value (%)	Final Grades
81 - 100	Very Good
61 - 80	Good
41 - 60	Moderate
21 - 40	Poor
01 - 20	Very Poor

4.3. Results

WQI were developed for 21 monitoring locations. Based on the threshold values each parameter was assessed and grades assigned. The faecal coliform which was found to be a critical indicator obtained 'Very Poor' condition in all the monitoring locations (Fig.4.3.1), followed by TN ('Very Poor' in 4 and 'Poor' in 7 locations), BOD ('Poor' in 9 locations), TP, Chl and DO saturation (Each indicator was found 'Poor' in 8 locations). Veraval obtained 'Very Poor' or 'Poor' for all the six indicators and Hazira, Worli, Ratnagiri, Malvan and Dhamra obtained 'Poor' for at least four indicators. Kavaratti was the only location to receive a 'Very Good' condition for the indicator TN and 'Good' for TP and Chlorophyll indicators. Port Blair obtained 'Good' condition for TN and TP indicators.

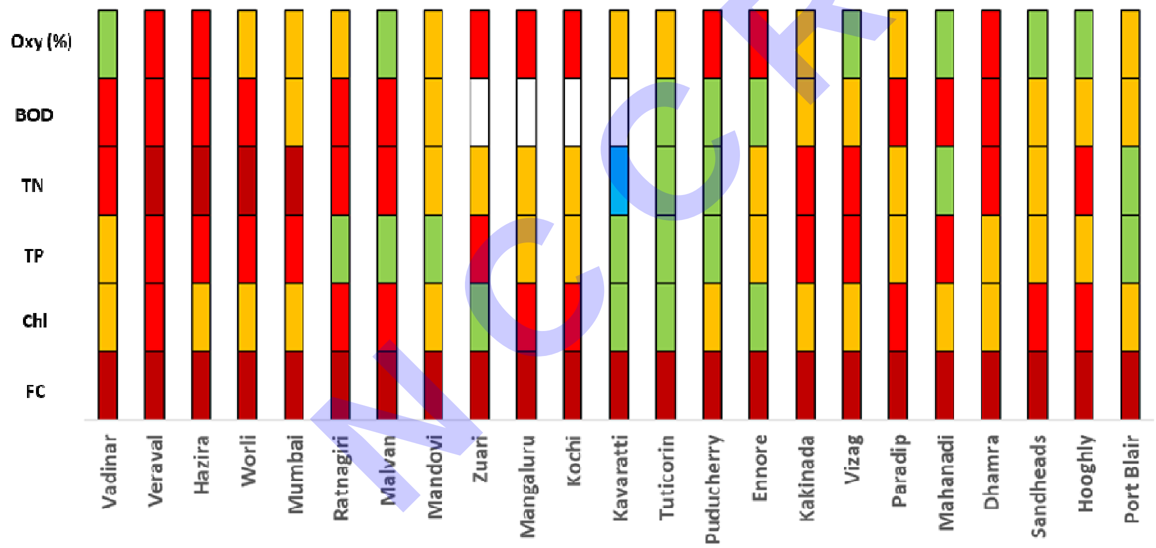


Fig. 4.3.1. Grades of indicators in all the monitoring locations

The WQI at Vadinar, Veraval, Hazira, Worli, Mumbai, Malvan, Mangaluru and Kochi along west coast; Kakinada, Paradip and Dhamra along the east coast obtained 'Poor' status (Fig. 4.3.2). Stations viz. Zuari, Tuticorin, Puducherry, Ennore were found to be in 'Moderate' condition. In general, based on the WQI, 11 out of 21 locations were found to be in 'Poor' condition, and the remaining locations were in 'Moderate' condition. Locations at Port Blair and Kavaratti were found to be in 'Moderate' and 'Good' condition (Figure 4.3.2).

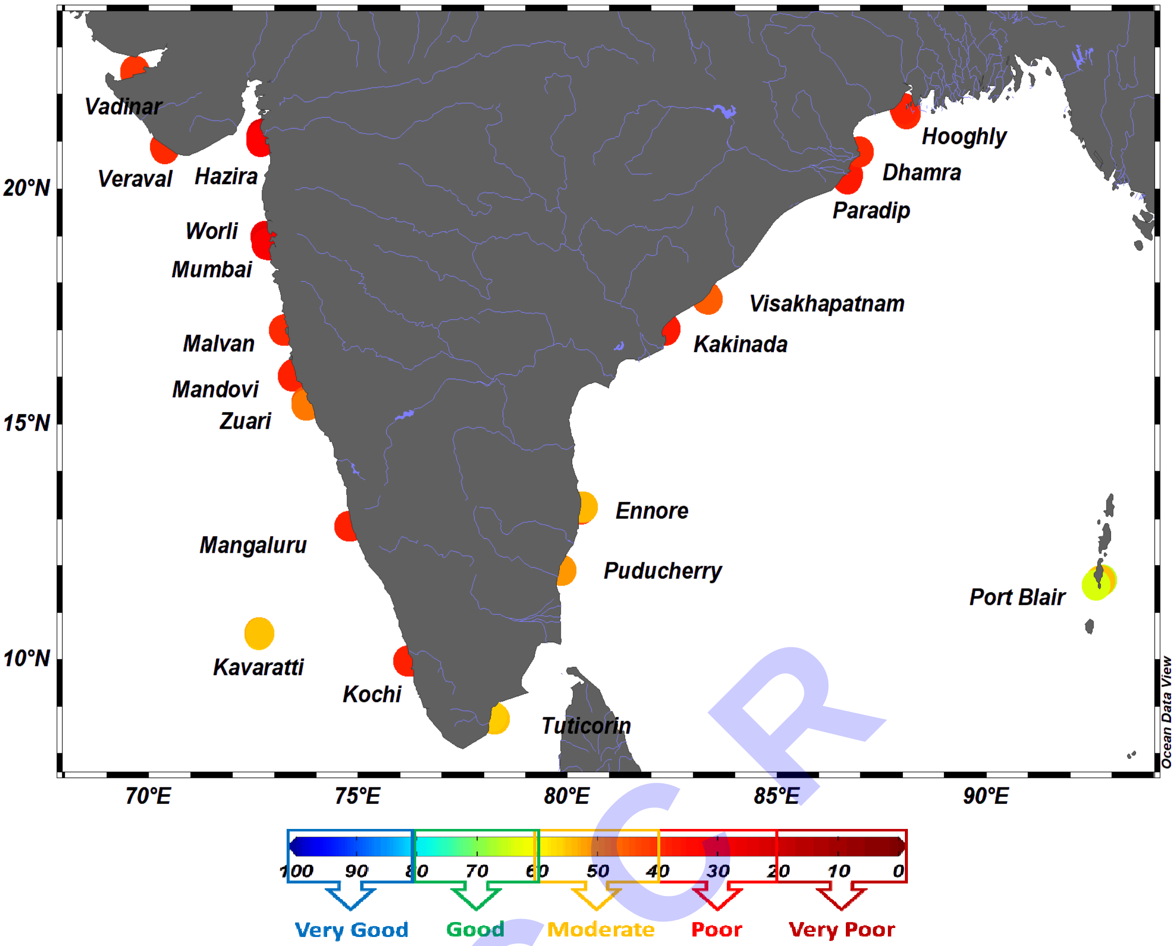
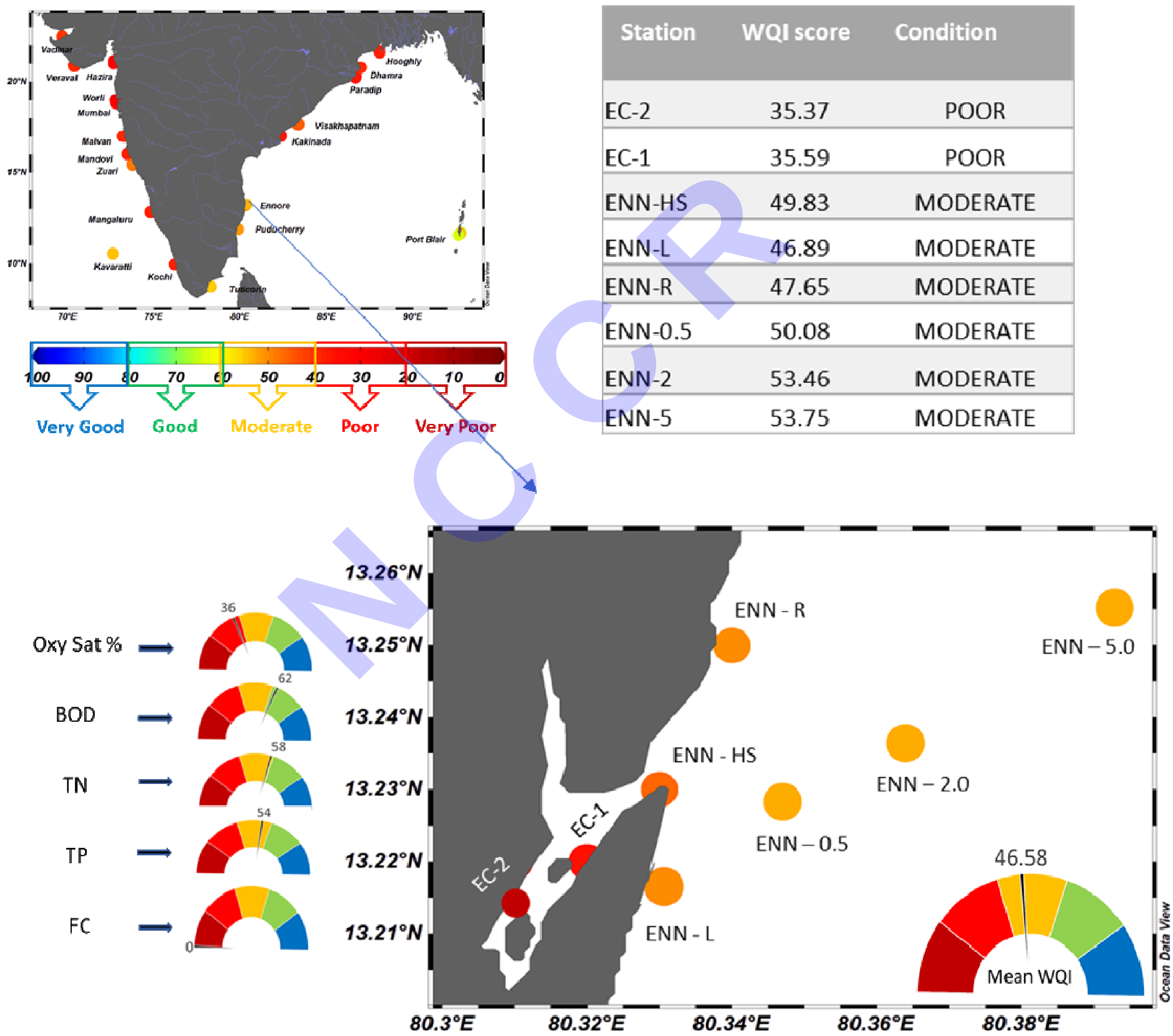


Fig. 4.3.2. Water Quality Index map for the period 2011-2015

Location wise WQI maps were prepared to access the spatial water quality condition from shore to offshore zones. WQI maps for Ennore and Kochi are given in this Volume I and the WQI maps for the other locations are available in Volume II of the report.

4.3.1. Ennore:

The indicators faecal coliform and dissolved oxygen saturation remained as the threat to water quality in Ennore. TN, TP and Chl-a were in 'Moderate' condition (Fig.4.3.3). The sampling stations located inside the Ennore creek revealed 'Poor' condition. Stations located in the shore, near shore and offshore zones were found to be in 'Moderate' condition.



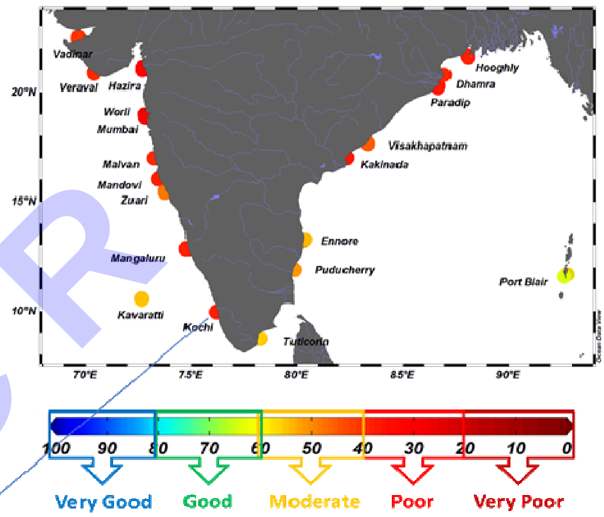
Station	WQI score	Condition
EC-2	35.37	POOR
EC-1	35.59	POOR
ENN-HS	49.83	MODERATE
ENN-L	46.89	MODERATE
ENN-R	47.65	MODERATE
ENN-0.5	50.08	MODERATE
ENN-2	53.46	MODERATE
ENN-5	53.75	MODERATE

Fig. 4.3.3. Water Quality Index map for Ennore

4.3.2. Kochi:

The indicators faecal coliform, dissolved oxygen saturation and chlorophyll-a were in ‘Poor’ condition at Kochi. TN, TP obtained ‘Moderate’ condition. All the stations at Kochi were in ‘Poor’ condition. Fishing and harbour activities may be extending the anthropogenic influences up to the offshore station (5 Km), leading to worsening of the water quality condition as ‘Poor’.

Station	WQI score	Condition
Kochi 00	31.39	POOR
Kochi HS	32.88	POOR
Kochi 02	39.40	POOR
Kochi 05	38.74	POOR



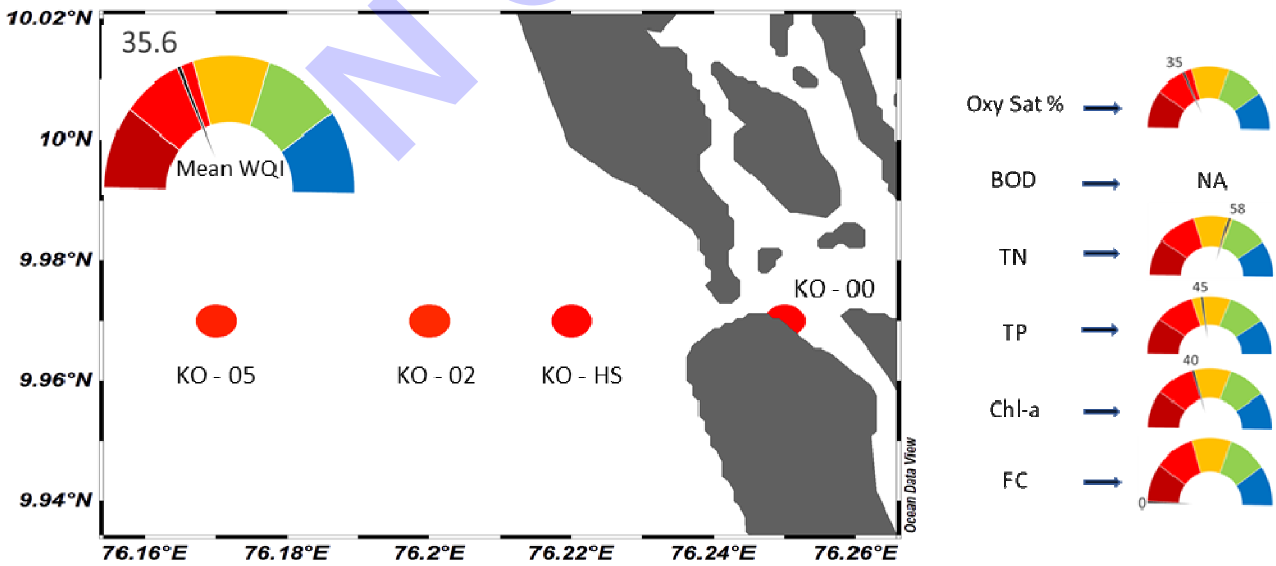


Fig. 4.3.3. Water Quality Index map for Kochi

4.4. Summary and Recommendations:

Water quality index was developed for SWQM monitored locations to understand and characterise the seawater quality. Parameters used for deriving WQI were selected based on the international practices with additional parameters based on local identified problems. Statistical approaches were adopted for deriving the threshold levels for each parameter at the monitoring locations.

The indicator faecal coliform was found to be higher than the reference values even in the offshore zone (5 km) at all the locations, which clearly indicates the impact of anthropogenic activities, particularly domestic wastewater, extending to long distances than expected. TN and TP pose threats in most of the monitoring locations, clearly indicating the impact of sewage and domestic discharges remaining as major threats. The indicator TN appears to have serious deleterious impacts on the stations Veraval, Hazira, Worli and Mumbai. Based on WQI maps, 11 out of 21 locations were found to be 'Poor' in condition. 'Good' condition was visible only at selected sampling stations of Port Blair and Kavaratti.

The use of WQI allowed transforming the complex information into a simple classification that can be easily understood by non-scientific communities and layman. In future, the threshold values derived for each parameter need to be put forth for a national debate with experts, to come up with regional reference values. WQI maps are needed to be generated periodically to support the decision makers for effecting suitable changes in the prevailing legislations aimed at protecting the coastal water quality of India.

5. Accomplishment and Capacity Building

5.1. Introduction

The management of coastal system requires information on how the coast changes through time in response to natural variability and anthropogenic stressors. Such information allow environmental managers and policy makers, to make decisions and develop effective management plans, which can have an impact on the coastal systems and its services. The SWQM has made important achievements in the past 25 years to ensure availability of quality data and its usage for coastal monitoring of the country. The present chapter discusses the some of the major achievements of the SWQM programme.

5.2. Major Accomplishments

5.2.1. Baseline Coatal envrionmnetal data

The SWQM has made important achievements in the past 25 years to ensure availability of quality data and its usage for coastal monitoring of the country.The SWQM team disseminate the processed physical, chemical and biological data to the end user through Indian National Centre for Ocean Information System (INCOIS) web server (http://www.incois.gov.in/portal/comaps/home.jsp). Certified data for 25 parameters from 24 locations and data for 83 locations collected before 2010 are also available at the INCOIS website. The data has been regularly provided to centrala and state government to take necessary actions.

5.2.2. *Follow-up action taken by the Pollution Control Boards based on SWQM information*

The Central Pollution Control Board (CPCB) is the entrusted with the power and function to prevention and control of water and air pollution in the country. There is regular interaction between the Pollution Control Boards and the COMAPS/SWQM institutions. If the environmental parameters data collected under the programme indicates stress to the environment, it was brought to the notice of the Central Pollution Control Board and the concerned State Pollution Control Boards for remedial action. The COMAPS/SWQM institutions also helped the Pollution Control Boards in tracing the sources of pollution from the coastal waters by conducting joint sampling programmes. Since a substantial amount of pollutants flow through the rivers, CPCN has indicated that the National River Action Plan, will now to a great extent, help in preventing the flow of untreated pollutants in the coastal waters.

Based on the information provided, the Gujarat Pollution Control Board has issued directions under the provisions of the Water Act, 1974 to all industries located along the coast to treat the waste water and the treated water should conform to the standards specified the board. The Board has also taken up the matter with the Gujarat Industrial Development Corporation (GIDC) for providing common effluent treatment plants from where effluent is flowing into rivers like Damanganga, Kolak, Mindhola, Amlakhadi, Khari, Mini and ultimately into the sea.

The Maharashtra State Pollution Control Board has informed that measures have been taken to stop supply of water to industries that do not install pollution control systems. Monitoring of industrial effluents is being carried out at Tarapur, Saravali, Thaneand other industrial estates. However, small and medium industries face problems in complying with pollution containment measures due to cost intensiveness of pollution control equipment. Steps have been taken for establishment of common treatment plants at several industrial estates.

The Goa State Pollution Control Board has decided not to allow the discharge of untreated effluent in coastal waters, exercise utmost care, while selecting new industrial proposals on the basis of their pollution potential, and take due care in monitoring both the pesticide and fertilizer industries, presently operating in Goa.

The Karnataka State Pollution Control Board is regularly monitoring the discharge of effluents by Ballarpur Industries Ltd., Karwar, Mangalore Chemicals and Fertilizers, Mangalore and Kudremukh Iron Ore Company Limited, Mangalore. These three industries are generally meeting the standards prescribed by the Board. The Mangalore Municipality discharges untreated sewage effluents into the Gurpur River that ultimately flows into the adjacent sea. Notice has been issued to the Municipality for taking further action as per law. Similar action has been taken for other towns located along the coast.

The water quality data along inshore waters of the Kerala coast were found to be within the acceptable limits. Efforts are being made by the Kerala State Pollution

Control Board to further curtail the industrial waste discharge. The SWQM/COMPAS during its monitoring noticed that the discharge of acidic waste water by an industry at Veli resulted in low pH which was brought to the notice of Kerala Government and State Pollution Control Board. The Government and the Board have taken actions to control the discharge of acidic waste water by the industry. Efforts are also underway to promote sewerage system and sewage treatment system in place of on-site sanitation facilities in urban areas and to extend such facilities to rural areas; to promote bio-fertilizers and bio-pesticides in place of their chemical fertilizers and to control hospital and municipal waste disposal.

The Tamil Nadu Pollution Control Board has initiated appropriate measures to the prevention and control of marine pollution along the Tamil Nadu Coast especially at the discharge points of river such as Cooum, Adyar, Buckingham Canal, Palar, Pazhayar and other outfalls into the sea.

Safety standards have been prescribed by the Andhra Pradesh Pollution Control Board for discharging effluents from aquaculture farms that are more than 40 hectares.

5.2.3. Consultancy Services

The COMAPS programme is being monitored by a Steering Committee chaired by the Chairman, Central Pollution Control Board and represented by all the State Pollution Control Boards. The COMAPS laboratories using the experience gained under the COMAPS programme, undertake consultancy services for the industries to investigate the pollution problems in the industrial areas, for locating waste disposal points and also the Environmental Impact Assessment studies. Further, the National Marine Data Centre on Marine Pollution has been established at Regional Centre, National Institute of Oceanography, RC Mumbai to disseminate the information on status of marine pollution in the country.

5.2.4. GIS Database for Marine Pollution

Any monitoring programme that collects long-term data at regular intervals using consistent methods can generated valuable knowledge about the ecosystem processes. Such scientific information can help environmental managers to develop effective management plans. Geographical Information System (GIS) is an excellent tool to combine many types of information concerning the environment and convert the data into a value-added information product. The SWQM programme also initiated a GIS based marine pollution database for efficient utilization of the data. In this programme, spatial data derived from the satellite images and the water and sediment quality data stored in an external database were integrated in GIS and the results were graphically presented. All the data are stored in Oracle database. A query development system was generated for 5 sites that enable the user to assess the trend of various parameters.

5.2.5. Oil spill trajectory modeling and sensitivity mapping

The oceans remain in the frontier of intercontinental trade. Large number of countries, including India, is increasingly dependent on the Indian Ocean for their foreign trade. The future is expected to make the sea-lanes of the Indian Ocean highly important not only to India, but also to the littoral states of the Indian Ocean. Study shows that about ~70% of the total sea transport is ferried through the Indian coastal waters (Anon 2003). Oil pollution is a major environmental problem and is important, in particular to the Indian coastline as two main oil tanker routes pass through the Arabian Sea. This is evident from the number of accidental oil spills have increased along the Indian coast (Sivadas et al., 2008). Moreover, Alang, the largest ship breaking yard is also located along the Gujarat coast. In an attempt to mitigate or avoid future damage to the vulnerable marine and coastal ecosystem of India caused by oil pollution, research has been undertaken in the COMAPS/SWQM programme to (1) study the impact of oil spills on the environment; (2) to strengthen the capabilities for oil spill trajectories; (3) predict and develop habitat specific models for control and management of oil spill; and (4) develop sensitivity map for the Indian coast. A few case studies are presented below.

The Oil Spill off Car Nicobar Islands

A Danish tanker 'Maersk' carrying 300,000 tonnes of light crude oil collided with an empty Japanese tanker 'Sanko Honour' outside India's Exclusive Economic Zone (EEZ) about 110 km south-east of the Indira Point off Greater Nicobar Islands on 23 January 1993, resulting in the leakage of oil into the sea. The tanker drifted 56 nautical miles off west / north-west directions due to wind action, causing pollution in the marine environment. Subsequently, a fire broke out, which continued till26th January 1993, when it was put out by the salvagers. As the collision of vessels and the resultant oil spill posed a threat to marine environment in the vicinity of the Nicobar Islands, the Indian Coast Guard (ICG), commissioned the Coast Guard Vessel at Port Blair along with the vessel 'Vikram ' to prevent further damaged to the environment. The Oceanographic Research Vessel,*Sagar Kanya* (ORV Sagar Kanya) was sent to the site with 12 scientists for collecting samples of water and marine life in the affected area. On the basis of the investigations, a preliminary assessment of the damage caused to the marine environment was completed. A long-term survey was conducted to study the impact of oil spill on the benthic community.

The MV Rak Carrier spill, Mumbai

On 7th August 2011, a bulk cargo ship MV Rak Carrier oil sank off Mumbai harbor. The ship was headed towards Dahej in Gujarat from Lubuk Tutung (Indonesia) with 30 crew, 60054 MT of Coal, 290 tons of fuel oil and 50 tons of diesel. Based on the available data and experience, a trajectory model was developed and used in the forecast mode to predict the likely path of spilled oil from the sunken ship "MV Rak Carrier". The model predicted that the spilled patch of oil reach the shore near Juhu and Colaba areas in 24-48 hour. This critical information was provided to the Indian Coast Guard (ICG) for combating the oil spill and preparedness purposes. Based on the feedback received from ICG, it was confirmed that the model trajectories were nearly accurate. The MIKE-21 generated currents and forecasted wind data obtained from National Centre for Medium Range Weather Forecasting (NCMRWF) was used as input in the NOAA model and Regional Ocean Modeling System (ROMS) model of Indian National Centre for Ocean Information Services (INCOIS) for Indian Ocean.

Collection of Input data for developing oil spill model

A success of a model is dependent on both the algorithms and the accuracy of the input data. In the construction of oil spill models, primary oceanographic and hydrodynamic data are some of the important input required. Further, since the Indian coast is very dynamic, it is necessary to develop habitat specific models and sensitivity mapping. The oil spill trajectory modeling and sensitivity mapping are aimed to understand the local habitat specific issues related to oil spill risks, to identify potential resources /areas that are at risk and for priory identification of the sensitive coastal resources.

In this regard, essential data required for modeling has been collected from the coastal areas of Chennai, Kakinada, Visakhapatnam, Dahanu-Mumbai, Goa, Neendakara and Kanyakumari. Based on the collected information, an oil spill models were developed for Chennai, Goa, Dahanu and Kochi. Local hydrodynamic models were set up for Chennai, Kakinada, Visakhapatnam, Kanyakumari, Kochi, Kavaratti, Goa, Mumbai, Dahanu and Hazira, to generate oil spill trajectory scenarios. Performance of local hydrodynamic models was compared with field measured data. The model outputs showed very good comparison of measured and simulated results. After successful validation of hydrodynamic models, the same was coupled with the MIKE 21/3 oil spill model to compute oil spill trajectories for different environmental conditions including oil characteristics, bathymetry, oceanographic, meteorological parameters. The model was run for predicting fate and trajectory of oil spilled with the actual wind data and simulation was carried out for 48 hour after an oil of about 100 m^3 of Crude oil off Chennai.

A GIS-based information system with two scenarios for three seasons set in General NOAA oil modeling environment (GNOME) was used for risk assessment of coastal resources. Model output from GNOME was imported into GIS and over- laid on the resource information and the risk was calculated based on the proximity of oil from the coast. The oil transport, weathering and oil thickness computation provide a way to analyze the environmental risks to the marine as well as coastal ecosystems due to spill. The oil slick movement and areal coverage (km^2) of the slick was calculated in GIS to analyze possible impact under different scenarios. Oil Spill Sensitivity and Risk Assessment maps of the study areas, have been prepared. As for now, oil spill sensitivity mapping and risk assessment has been completed for Chennai coast. Presently, INCOIS provides the advisories on oil spill trajectories for the Indian coast.

5.3. Capacity Building

5.3.1. Marine Microbial Reference Facility (MMRF), MoES

Recent research relating ocean and human health is addressing a range of issues in environmental microbiology along with continuous monitoring of water quality, which includes source of pathogen, human exposure and the expression of disease.

Understanding the national importance of monitoring, isolating and maintaining pathogenic bacteria population in marine environment, MoES took the initiative to start a Marine Microbial Reference Facility (MMRF) under the COMAPS programme. The MMRF started functioning in 2003 at CSIR-National Institute of Oceanography, RC Kochi. The major objectives of the Centre were to: (1) support the nodal agencies involved in COMAPS programme for identification and preservation of health indicator bacteria; (2) conduct training programmes on basic techniques involved in monitoring health indicator bacteria; and (3) maintaining the library of health indicator bacteria isolated from the coastal waters. The major activities and achievements of MMRF since its inception are given below.

Infrastructure facility augmented/ created

A full-fledged facility for studying the various aspects of microbial ecology, specifically for culture dependent and independent approach for distribution of health indicator bacteria have been created as part of MMRF programme at CSIR-NIO regional centre Kochi. This includes: a) a microbiology lab for isolation, identification and preservation of health indicator bacteria; and b) Molecular biology lab for the identification of organisms based on 16S rRNA gene studies. Major equipment procured for creating the facility are: Ultra Low temperature Cabinet, High Speed Refrigerated Centrifuge, Gel Documentation & anlaysis system “Biovisgel-2000M” , Orbital Shaker, Micro Modulyo 230 Freeze drying System, Master Cycler, Network GC system, PowerPac 3000 power supply, Micro Log 1 System, Trinocular Microscope, Liquid Nitrogen Storage system, Stainless steel water bath, Water Purification System, Ice Flaker, Sampling Manifold unit, Master cycler Gradient, Laboratory Autoclave, Water Bath, LN2 supply tank, Ultra Low temperature Freezer, Ultrasonic water bath, Mini Hybridization Oven, UV-VIS Spectrophotometer, Electronic Analytical Balance, Freeze Dryer, Ultra low temperature Upright Freezer, Multi purpose Cooling centrifuge, etc.

Supporting nodal agencies for identification of bacteria

MMRF support nodal agencies for confirmation of identity of health indicator bacteria by fatty acid profile analysis and 16S rRNA gene sequencing. A total of nearly 4000 analyses were done during the period, out of which, only 1177 were submitted by participating centres under COMAPS/SWQM programme (Table 5.1) and the remaining isolates were received from 28 other agencies including academic institutions/Universities, CSIR and ICAR Research Institutes, private educational and research institutes.

Table 5.1.Total number of samples analysed using fatty acid profile analysis during 2003 – 17.

Nodal agency	No. of isolates received		
	2003- 07	200 –12	2013 –17
National Institute of Ocean Technology (NIOT) Chennai	28	86	211
CSIR- Institute of Minerals and Materials Technology, Odisha	9	46	54
National Centre for Earth Science Studies (NCESS, Thiruvanathapuram.	Nil	7	10
CAS Marine Biology, Annamalai University	Nil	244	267
CSIR- National Institute of Ocenography, RC Mumbai	Nil	56	89
CSIR- National Institute of Ocenography, Goa	64	6	Nil
Other agencies	583	1400	748

Maintenance of Marine Microbial Reference Facility (MMRF)

MMRF functioned as a nodal agency for the identification and storage of representative health indicator bacteria from Indian coast. Here the health indicator bacteria received from nodal agencies as well as those isolated by CSIR-NIO RC Kochi through different research programmes were deposited to the library. Presently, the library contains 1055 number of isolates, among which 556 are health indicators. Figure 1 shows the distribution of different groups of microorganisms in the library. 52.7% of MMRF library includes health indicators, which include *Vibrio* spp (34.9%), Staphylococcus sp. (6.16%), Pseudomonas spp. (3.6 %), *Escherichia coli* (3.98%), *Klebsiella* spp (1.8 %), *Shigella* spp (0.85 %), *Enterococcus* spp (0.5%) and Salmonella spp. (0.95% %). These isolates were retrieved from coastal regions of Kerala, Tamil Nadu, Andhra Pradesh, Maharashtra, Goa, Gujarat, Odisha, Andaman and Lakshadweep.

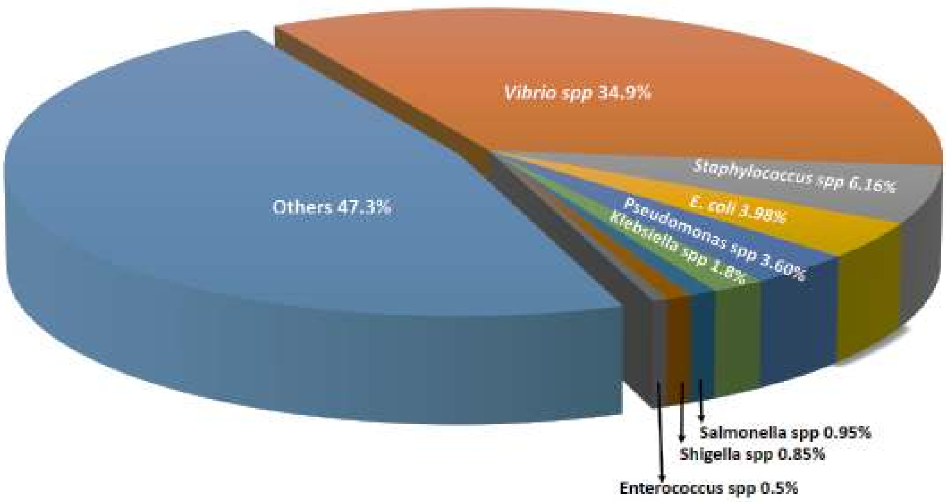


Fig. 5.1. Different groups of health indicator bacteria available in MMRF

Conducting training programmes/workshops

As part of the programme, MMRF also organized regular hands on training programmes/workshops on isolation and identification of health indicator bacteria to project assistants recruited to COMAPS/SWQM programme. The purpose of the programme was to reduce the level of error in data generated from different nodal agencies by ensuring that all the project assistants follow the same procedure and medium and inter-laboratory calibration of techniques used in different nodal agencies for monitoring health indicator bacteria. Technical manuals were prepared and distributed to all participants for further implementation in their laboratories. In all, seven training programmes were conducted during 2004 – 2016 (Table 5. 2).

Table 5.2. List of training programmes/workshops conducted during 2003 to 2017

Year	Training programmes/workshops
July 2004	Application of biochemical and molecular techniques for enumeration and identification of coastal health indicator bacteria
March 2007	An inter-calibration workshop: Enumeration, Identification and Preservation of Health Indicator.
March 2009	Polyphasic taxonomic approach for identification of coastal health indicator bacteria

July 2010	Basic techniques for isolation and identification of health indicator bacteria from marine environment.
December 2011	Applications of fluorescent techniques in microbial ecology
August 2014	Basic techniques for coastal health indicator bacteria
August 2016	Basic Techniques for the isolation and Identification of Health Indicator Bacteria from Marine Environment

Human resource development

Generation of trained manpower in microbiology is a major achievement of MMRF during the past decade. Apart from organising training programmes, MMRF also supported the dissertation programmes of post graduate students and project assistants. During the past decade 38 postgraduate dissertations and six doctoral thesis were produced and awarded and 34 project assistants were trained.

Initiation of new research programmes

Apart from contributing to strengthening of MMRF, research programmes on antibiotic and heavy metal response of microorganisms isolated from coastal waters, response of health indicators to novel antibacterial agents like silver nanoparticles, standardisation of new tools like fluorescent *in-situ* hybridisation for easy detection of health indicators, etc., were initiated. The outcomes of these programmes were published in the form of 29 papers in different international peer reviewed journals.

5.4. Reports and Publications

The primary objective for the collection of the data is to provide a baseline to understand the impact of disturbance along the Indian coast. The data were used by the participating institutes and NCCR for publications and production of ecosystem models. The details of the publication and studenst warded Ph.D duringXIIth Five Year Plan is given in Table 5.3.The present report that will be published as two volumes, Part I (consolidated report) and Part II (detailed report) provides the detailed information of the programme have progressed in the last 25 years, the current status of the coastl waters of India and way forward.

Table 5.3. Details of the publications and PhD warded under the SWQM/COMAPS programme				
Year	**Institute**	**No. of Papers**	**Impact Factor**	**No. of PhD**
2012-13	CSIR-NIO, RC Mumbai	2	1.06	
	CASMB, Annamalai University	2	3.24	2
	ANCOST-NIOT	1	1.092	
2013-14	CSIR-NIO, RC Mumbai	1	0.56	
	CASMB, Annamalai University	4	12.6	2
	ANCOST-NIOT	3	5.767	
2014-15	CSIR-NIO, RC Mumbai	2	2.736	
	CASMB, Annamalai University	3	8.8	3
	ANCOST-NIOT	3	8.907	
	CSIR-NIO, RC	1	3.1	1
	Visakhapatnam	1	3.1	1
2015-16	CSIR-NIO, RC Mumbai	1	0.9	
	CASMB, Annamalai University	4	9.1	2
	ANCOST-NIOT	5	4.833	
2016-17	CSIR-NIO, RC Mumbai	4	6.89	
	CASMB, Annamalai University	2	7.6	2
	ANCOST-NIOT	1	4.839	
2017-18	CSIR-NIO, RC Mumbai	2	4.715	
	CASMB, Annamalai University	3	5.9	1
	ANCOST-NIOT	4	4.905	
	TOTAL	**49**	**94.244**	**13**

6. WAY FORWARD

6.1. Introduction

The SWQM Programme provides the foundation for monitoring water quality of coastal waters of India. In the past 25 years of its implementation, the SWQM / COMAPS programme has continuously generated data that support planners and decision makers for developing strategies for management of coastal ecosystem and its resources. One of the lessons learnt by implementing this programme was that monitoring seawater quality on long-term basis should be based on regular evaluation of the results, the quality and gaps in data collection and interpretation through a critical review of the programme periodically. This will help in taking remedial actions for systematic monitoring of the status of pollution, its impact on the coastal ecosystem and its resources and introducing mitigation measures for abatement of pollution and its impacts on the coastal and marine environments. This Chapter focuses on the attributes of the monitoring programme and presents the future plans for deliverance of comprehensive marine ecology related information in addition to improved data quality.

6.2. Future Plans of SWQM

Based on the lessons learned from implementing the SWQM programme during the last 25 years, a number of issues that remained unanswered have been identified and a few of immediate importance are suggested below for inclusion in the future plan of action for implementation under the SWQM Programme. Moreover, it is acknowledged that networking between Indian and International institutes is required for enhancing the effectiveness of the coastal monitoring programme of India.

Improved / Revised Monitoring Schedule

Through a combination of consultations with regional experts and local communities, literature review, and analysis of the two and a-half decadal data, it has been decided to improve the coastal and marine pollution monitoring programme. Under regular monitoring, the SWQM has proposed to increase the coverage of the monitoring to 26 locations along the east and west coasts during the years 2018 – 22 (Fig. 6.1). Further, all the four seasons (summer, pre-monsoon, monsoon, and post-monsoon) will be sampled at all the sites. The number of parameters is also proposed to be increased and details are given in Table 6.1 and 6.2.

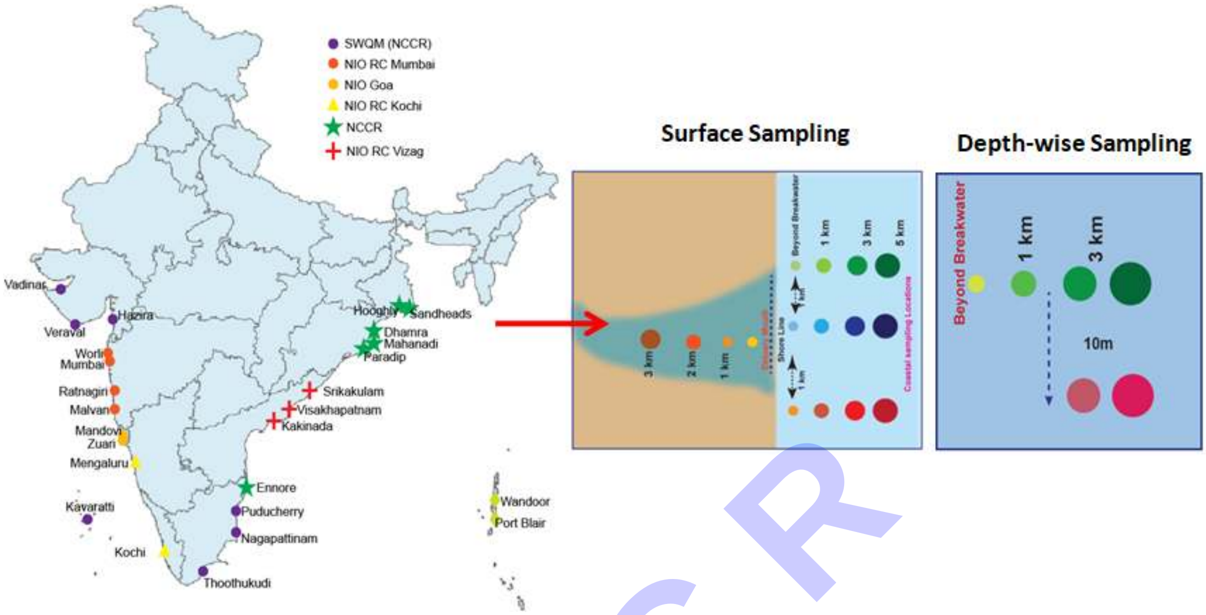


Fig.6.1. Map of the proposed monitoring locations during 2018-2022.

Table 6.1 Physico-chemical parameters to be monitored during 2018-2022

Parameters	Summer	Premonsoon	Monsoon	Postmonsoon
All four Season				
Temperature, Salinity, pH, SSC, DO, Nutrients (NO_2, NO_3, NH_4, PO_4, SiO_4)	✓	✓	✓	✓
CO_3 , HCO_3 , Total Alkalinity	✓	✓	✓	✓
*DOC and POC ($\delta^{13}C$ and $\delta^{15}N$)	✓	✓	✓	✓
Sediment: Chl-a, TC, TOC,	✓	✓	✓	✓
Metals (water and sediment) (Al, Cd, Cu, Cr,Fe, Hg, Mn, Ni, Pb, Zn)	✓	-	-	-
PAH and PHC (water and sediment)	✓	-	-	-
Once in a year		-	-	-
*Pharmaceutical waste	✓	-	-	-
*Pesticides Residues	✓	-	-	-
*Radionuclide	✓	-	-	-
Every 2 year		-	-	-
*Stable Isotopes: ($\delta^{13}C$, $\delta^{2}H$, $\delta^{18}O$ & $\delta^{15}N$)	✓	-	-	-

Table 6.2 Biological parameters to be monitored during 2018-2022				
Parameters	Summer	Premonsoon	Monsoon	Postmonsoon
All four Season (All sites)				
Microbiology (water and sediment)	✔	✔	✔	✔
Chl-a (Total and *size fractionated)	✔	✔	✔	✔
Phytoplankton	✔	✔	✔	✔
Zooplankton	✔	✔	✔	✔
Benthos (Macro and Meiobenthos)	✔	-	-	✔
Once in a year				
Primary Productivity	✔	-	-	-
Metals in tissue (Molluscs, Crustacean and Fish)	✔	-	-	-
*Pesticides residuals tissues	✔	-	-	-
Pilot-study		-	-	-
*Small Sub Unit sequencing and detailed diversity study of Microbes	✔	-	-	-
*Molecular study of dominant plankton and benthic organism	✔	-	-	-
*Ecosystem based approach	✔	-	-	-

Functional trait approach to monitoring

Each component of the marine food web is important for transfer of energy and controls variability in fluxes of biologically important elements in the global ocean. As the marine communities affect the biogeochemical cycles, they in turn, are affected by changes in its environment (natural or human-induced). Therefore, any disturbance in the trophic level has the potential to cause a cascading effect on the entire ecosystem through the functional interaction. Examples of these changes are the cascading effects of the loss of top predator, and the concomitant population shift to small-sized opportunistic species which have low functionality.

Most of the monitoring programmes presently, use a single ecosystem component approach to assess the ecological status e.g., the use of species abundance and composition. The ecosystem process, e.g., the nutrient recycling, is the result of networking among the physical, chemical and biological components of an ecosystem. There are evidences that modification of environmental variables due to human-activities can alter the ecosystem functionality; however this aspect has not been explored in detail in most of the monitoring programmes, including SWQM. Thus, in addition to ecosystem state changes, understanding the ecological processes and how anthropogenic activities will alter these processes is fundamental to the monitoring programme. Assessment based on physical and chemical variables, which was the focus of the SWQM programme, though being comparatively inexpensive and simpler to link to anthropogenic stressor, cannot reflect the holistic impact on the ecosystem processes. Thus, dedicated effort to analyse the ecosystem process is a prerequisite for successful implementation of monitoring objectives. The SWQM during its future programme, in addition to the regular monitoring, will conduct a pilot-study on the functional-trait based approach to monitoring at selected hotspots. Moreover, there is a need to combine data obtained from very diverse types of approaches (*in situ* data and experimental observations) to build a rational picture of the ecosystem process in the coastal habitats.

Documentation of biodiversity

A number of R&D and academic institutions are involved in the SWQM programme, which are following different methodologies and standards for identification of marine flora and fauna. This has resulted in some cases erroneous identification of some of the organisms at species level and also some gaps in the information on the biodiversity in some sampling points. This has prompted us to introduce in the future SWQM programme an uniform procedure and standardised methodologies for collection, preservation, identification and use of the taxonomic nomenclature for undertaking comparative studies between the regions that will help in better understanding of the interaction between the biodiversity and ecosystem functioning. This could be improved in future as proposed below: -

(i) Detail sample collection for taxonomic work

(ii) Voucher sample to be kept at host institute and participating institutes. Maintaining the reference collection of benthic species in particular is a major step forward to facilitate quality control in taxonomy. Specimens archived will be used, for (i) future reference, (ii) consistency of the data (iii) standardising the taxonomy, and (iv) training and verification purposes.

(iii) Documenting the species in the form of photographs, line diagrams, key for their identification including the information on their morphometric and meristic characters, their distribution pattern, functional traits, reproduction behaviour, molecular data and abundance. Such information will provide a baseline against which the ecological health/integrity of coastal waters can be evaluated and will also help the participating institutes to interact with other institutions and assist them in improving their identification skills.

(iv) Involve different Taxonomists who are experts in identification of various groups of marine flora and fauna, at regular intervals to assist the institutions / Scientists for precise identification of the organisms so as to ensure consistency in the biodiversity data.

(v) Through national and international collaboration, and training of the researchers of the participating institutions on standardising the taxonomic procedures, taxonomic nomenclature and classification, stimulate interest among them for improving the overall accuracy of India’s marine biological taxonomy.

(vi) Updated taxonomic monographs of marine organisms of India need to be produced by involving national and international experts of repute to serve as the guide for identification and cataloguing of marine organisms collected from the sampling points up to generic or species level.

Development of an Index for assessing Coastal Water Quality

Given the increasing threat to the coastal environment, over the last decade several countries worldwide have developed many indices and enforced legislative measures to assess the ecological quality of estuarine and coastal waters. However, most of these indices have been developed in the temperate region and all these developed indices have advantages and disadvantages.

Despite the considerable importance of the coastal system and threats imposed by increasing pollution, no attempt has so far been made to develop an index to assess the ecological status of the coastal waters of India. India, therefore, needs to develop its own cost-effective ecological status indices for application in assessment of coastal and marine water quality. Development of new indices, testing of approaches and discussion will lead to further insights and improvements in the selection of indices for evaluating environmental status. Therefore, there is an urgent need for initiating and accelerating scientific research under the Indian coastal research programmes in general and the SWQM programme in particular to develop indices that are comparable across the heterogeneous coastal environment.

Application of new and improved scientific technology

Genomics in coastal monitoring

In the last few decades, advances in scientific technology have reduced the processing time and accuracy of data that have considerably improved the management of environmental resources. Therefore, efforts are made to develop cost-effective methods to assess and monitor marine ecosystem (Frolov et al., 2013). Classical monitoring programme was limited to the observation of specific groups of marine organisms (e.g. Plankton, zooplankton, macrobenthos, and fish) in limited regular sampling sites. Further, many of the data are incomparable due to unverifiable taxonomic precision (Bourlat et al., 2013) and inconsistency in the level of identification. In addition, lack of Taxonomists for identifying the marine invertebrates in many countries makes their identification a daunting task. An ideal monitoring programme should consider all the marine taxa (from virus to mammals) and all the life stages (Bourlat et al., 2013). Genomics techniques are rapidly improving and yield faster, easier and more reliable taxonomic identification allowing for quicker and better assessment of the ecological status of marine waters (Bourlat et al., 2013) and are therefore being employed in ecosystem management (Sagarin et al., 2009; Bourlat et al., 2013).

In particular, the micro-organisms are emerging as crucial components of ecosystem functioning and providing critical information on the ecological state. However, *in situ* study of the micro-organisms is a challenging task. The culture based Faecal Bacteria Indicators (FBI) are used worldwide for assessing the health and quality of aquatic system. However, the relevance of indicator bacteria has been highly debated. The FBI, like *E. coli* (Byappanahalli et al., 2003; Solo-Gabriele, et al., 2000; Whitman and Nevers, 2003) and enterococci (Byappanahalli et al., 1998; Fish and Pettibone, 1995; Fujioka et al., 1999) can take residence in the environment and multiply under certain conditions, hence confounding the connection between indicator organism and risk to human health (Anderson et al., 2005). This is of particular concern for the tropical and subtropical waters, as *E. coli* and enterococci are known to multiply in warm waters (Byappanahalli et al., 1998; Desmarais et al., 2002; Solo-Gabriele, et al., 2000). Another problem in the tropical and subtropical environments is that the bacterial indicators are consistently present and in high concentrations (rev. Stewart et al., 2007).

Yet another concern is that the differential survival of indicator bacteria from different sources of pollution jeopardises the determination of the source of faecal pollution in the environment (Anderson et al., 2005). The simple method of identifying FIB does not often correlate with health risk, since not all strains of infectious bacteria are equally pathogenic, but there is always the potential for the emergence of more infectious strains (Stewart et al., 2007). Additional issues include longer processing time, (culture based method require 24 hr for sample processing and considered slow), since majority of the contamination events dissipate by the time results are available (Bourlat et al., 2013). In certain situations, the management decisions are needed quickly as delayed data will not be fit for the purpose (Borja and Elliot, 2013).Currently, water quality criteria for faecal coliforms and other bacteria in Indian coastal waters are expressed in the MPN/ml unit, which should be changed to CFU/ml as plate count method is currently being used in our monitoring programme.

Molecular techniques allow rapid and specific identification of pathogenic bacteria in the environment, for example, use of molecular technique (quantitative PCR) in the California Beach Water Quality Monitoring, reduced the processing time from 24 to 2 hr and allowed immediate notifications to the public about the water quality(Griffith and Weisberg, 2011). Currently, the other global monitoring programmes that focus on using genomics approaches and continuous collection of metadata to understand the microbial community include, the Global Ocean Survey, Tara Oceans, the Hawaiian Ocean Time Series, the Bermudan Ocean Time Series, the Western Channel Observatory, and the National Ecological Observatory Network (NEON). At present, we are only monitoring a few health indicator bacteria. However, detailed studies on microbial communities may provide early warning signals on the impacts of anthropogenic and natural disturbances on the environment (Aylagas et al., 2017; Borja, 2018). Further, it will provide useful information on the link between the microbial assemblage composition and the putative source of contamination in polluted marine environments (Aylagas et al., 2017). Advancements in high throughput sequencing technologies provide unprecedented opportunities to study the microbial communities easily in a cost-effective manner. The use of genomic techniques for characterisation of the bacterial community has many advantages over traditional methods including (1) evaluating the loading, transport and fate of pathogens in coastal ecosystems, (2) identifying sources of contamination, (3) rapid and specific information about the ecosystem functioning and identification of pathogenic bacteria, and (4) better understanding of the relationship between microbial community and coastal environment, which could lead to more robust health risk indication at a lower cost than the routine approaches (Stewart et al., 2008; Bourlat et al., 2013; Ininbergs et al., 2015). In the future, under the SWQM programme the aforesaid molecular methods for characterisation of the bacterial community in the coastal waters of India will be introduced and followed.

Remote sensing, geographic information system and network of observation platforms

There is often a need to increase the coverage and frequency of data collection for improvement of monitoring programmes. However, conventional monitoring methods are limited by spatial coverage, temporal frequency and logistics involved in the collection and analyses of such large samples. Remote sensing, geographic information system (GIS) and *in situ* observatory platforms have emerged as powerful tools to provide an invaluable complementary source of data at local to global scales and in uninterrupted frequency. Continuous improvement in sensor design, data analyses and cost-effectiveness is making these tools practical and attractive for use in regular monitoring of coastal systems. Therefore, data obtained from such tools have wide applications in marine habitat and shoreline mapping, water quality monitoring, oil spill detection, primary production and phytoplankton bloom monitoring, and biogeochemical cycles. For e.g. in recent years, increased availability of remote sensing data has greatly facilitated marine ecosystem mapping (Spalding et al., 2012; Fendereski et al., 2014). In the future, under the SWQM programme the data obtained through remote sensing, GIS and in *situ* observatory platforms shall be used for monitoring the health and quality of coastal waters of India.

Networking with regional marine programmes

The MoES is funding a number of Institutes for developing and conducting scientific programmes on coastal and marine ecosystems of India (http:// www.moes.gov.in/ programmes). However, there is a critical need to develop and strengthen the interplay between the research programmes for improving the conservation programme and sustainable use of coastal and marine resources. In future, the participating agencies / institutions under SWQM programme should take part in the Inter-laboratory Calibration Exercises (ILCE) conducted by Scientific Committee on Oceanic Research (SCOR) International Council for the Exploration of the Sea (ICES) and others to improve the data quality and to get a global recognition.

Risks from Climate change in coastal zones

The available evidence from the last few years, suggests that climate-change will have significant impact on the biodiversity, particularly among the marine communities. For countries like India, with a large coastline and which depends on this ecosystem for its major economy, understanding the potential impacts of climate change is a critical issue. Additionally, climate change scenario has been predicted to increase the frequency or intensity of extreme events in India (Sudha Rani et al., 2015). Such an outcome may adversely affect the coastal ecosystem. Furthermore, coastal habitats in most part of the world are already degrading due to anthropogenic activities. When these changes in the coastal regions combine with the projected climate change scenarios, an increased risk on this important ecosystem could be foreseen. Therefore, understanding the impact of climate change has now become one of the key issues for environmental managers.

Monitoring is one of the effective ways of understanding, predicting the consequence of climate change and planning for the management of any ecosystem. However, most monitoring programmes including the SWQM programme were based on the presumption of stable climate. Numerous marine and coastal monitoring programmes around the world have developed and are in the process of developing strategies for climate change and priorities for climate change adaptation. Therefore, SWQM programme needs to consider the '*Shifting baselines*' and '*unbounded boundaries'* caused by climate-change as suggested by Elliot et al., 2015. The 25 year SWQM data can form the baseline to conduct systematic research to provide an in-depth knowledge and understanding and adapt to the challenges of climate change.

Beach Monitoring: Interstitial fauna

Sandy beaches comprise approximately three-quarters of the world's shorelines (Bascom, 1980). They harbour a diverse and abundant fauna (Brown and McLachlan, 1990). Based on the naval hydrographic charts, sandy beaches account for 43% the Indian mainland and are highly-valued for its socio-economic reasons. Less known are the values of biological diversity in the sandy beaches. Most of the species living in the sandy beaches have relatively low abundance, the bean clams, mole crabs, and some species of isopods can attain density of > 5,000 ind/m^2.

Beaches are not ecological deserts, but an important ecosystem that needs scientifically-based management, as this ecosystem is threatened by natural and anthropogenic perturbations. SWQM presently does not include the study of the intertidal habitat, which needs to be addressed as one of the issues in the future action plan.

An important fauna in the sandy beaches is the interstitial fauna. This sandy microfauna or interstitial fauna are found in sand and similar sediments of most aquatic systems. This community is represented by most invertebrate classes, some groups that are exclusively found in the interstitial environment and particularly the Phylum Tardigrada, considered to be the toughest creature on Earth. These organisms have contributed significantly to systematic zoology, development, evolution and ecology.

The interstitial fauna of sandy beaches of India was extensively studied by KH Alikunhi, R.G. Aiyar, AG Govindankutty, NB Nair, and GC Rao resulting in the discovery of several new species from the region. Most of these studies were carried out along the coasts of Kerala, Tamil Nadu and Andaman and Nicobar Islands. However, the study of the fauna has been neglected in recent years due to several reasons including, lack of Taxonomists. Despite their importance in the ecology of sandy beaches and vulnerability to disturbances, the interstitial fauna have been relatively neglected by most marine researchers in India. Difficulties in collection and analysis, want of taxonomists for precise identification of the organisms up to generic or species level and their apparent lack of economic importance to humans are some of the reasons why the group has been overlooked in ecological studies. However, their importance in elucidating the phylogeny of Metazoans, and the uniqueness of some groups like Tardigrades that are capable of withstanding some of the most severe environmental conditions, has recently evinced interest in the study of interstitial fauna. India with vast sandy beaches is a potential area to study this community and contribute to understanding the role of these organisms in the sandy beach ecosystem functioning. Some of the aspects given below could be addressed under the future programmes of SWQM that may help answering some of the basic questions and issues related to sandy beach management.

- Documenting the biodiversity of interstitial fauna

- Trophic ecology
- Habitat destruction
- Interaction with adjacent ecosystem

Infrastructure requirements

A comprehensive research infrastructure is a pre-requisite for successful monitoring of any environment and to meet the growing demands of scientific studies. Despite the significance of the coastal monitoring programme, the NCCR does not have the requisite research infrastructure with wide range of modern facilities for implementing its various ongoing programmes as well as the proposed future plans under SWQM. Marine research depends on a broad range of infrastructure assets including, ships, sensors and samplers, analytical instruments, computational and data systems, supporting facilities and trained scientific personnel. Such barriers have hindered detailed scientific studies on the subject and coordination and collaboration with national and international research organisations involved in similar studies. Establishing the modern infrastructure facilites are basic need to address the current research plans to cater the demands in coming years, such as climate change and sustainable development and utilization of coastal ecosystem.

All the monitoring agencies need to equip with the recent sampling gears like CTD, vertical multiple plankton sampler and latest analytical facilities such as High accuracy water Quality Probes, Autoanalyzer, Autotitrator, Fluorometer, ICPMS HPLC, Flow cytometer, Fluorescent and light microscope with advanced image processing software, Advanced sequencers like Illumina-NextSeq 550 or Oxford Nanopore-PromethION for the better-quality data generation. NCCR needs a well furnished national and centralised laboratory facility for the analysis of all parameters, including trace metals and trace organics, which should be accessible by all the monitoring agencies.

Requirement of Coastal Research Vessels

Another critical requirement for successful monitoring of coastal water quality is immediate analysis of samples as soon as it was collected. Coastal Research Vessels (CRV) serves as platforms for sample collection, analytical work, and coastal observations. When the COMAPS programme was initiated, sites were selected based on the location of the ports, due to easy accessibility. The MoES had built two CRVs, viz. Sagar Purvi and Sagar Paschmi, mainly intended for coastal oceanographic work. These vessels were initially dedicated for the SWQM programme. In the long-run, poor maintenance and utilisation of these vessels for other programmes resulted in non-availability for SWQM programme. Moreover, the draft of those vessels was high and hence could be operated only at > 10 m depth and lacked stability in adverse weather conditions and rough sea conditions hampering the sampling schedule. Moreover, India's oceanographic research fleet mainly consists of large research vessels of 100-120 Overall Length (OAL), which cannot be operated at <10 m water depth, expensive to run/operate and are logistically very demanding. As a result, inshore coastal monitoring and research in India has been limited for want of suitable coastal research vessels. Subsequently, most participating centres have depended upon fishing boats for collecting samples.

In order to successfully implement the environmental monitoring of India's coastal and marine waters, two inshore research vessels, one for east coast and another for the west coast with state-of-the-art modern facilities, dedicated exclusively for the purpose, are required. The technologically advanced vessels need to be equipped with the advanced analytical instruments for physical, chemical and biological parameters. These well-equipped vessels will serve as ideal platforms to explore areas along the Indian coast that have been hitherto unexplored and facilitate collection and analyses of data on-board. However, for the shore and nearshore sample collection, a small fishing boat for each participating institutes is also recommended. Moreover, a field laboratory close to the sampling site which facilitates the analysis of samples critical parameters (e.g. Ammonium, dissolved oxygen).

Skilled Dedicated Manpower

The SWQM programme is facing a severe shortage/lack of skilled workforce, affecting the monitoring, progress of programme implementation and coordination with the project implementation agencies/institutions. It has been observed that although the SWQM programme allows employing project staff, there are no experienced staffs in most of the institutions, who can train the new recruits. This is of particular concern with respect to collection and analysis of biological samples and precise identification of the marine organisms collected. In India, there are very few Taxonomists, particularly for precise identification of the marine organisms representing different phyla/class. As a result, project staffs are “self-taught” based on published and outdated literature, resulting in following inappropriate methods for collection, analysis and interpretation of data and improper identification of the marine organisms leading to unwanted criticisms from all quarters. Consequently, many participating institutes identify organisms at higher taxonomic level (Group, family or genera) or/ and misidentify the species. Marine research programmes are often prone to shortage of skilled staff because such projects are of shorter duration of 3-4 years and lack job security for the incumbent staff. As result, trained staff often leave the project mid-way, a major risk for the smooth and timely implementation of the project activities and for the poor and unreliable data quality. Implementation of SWQM programme through proper coordination and collaboration with national research laboratories, academia and other stakeholders, therefore, needs recruitment of adequate number of regular and trained scientists and support staff at NCCR exclusively for the programme on priority basis during 2018-19. Trainings and workshops can be conducted at regular intervals for the project staff of the participating institutes by the Scientists of NCCR, who can also improve the quality of the data collection and analysis by actively participating in the sample collection and analysis processes, periodically. In the long-run, the involvement of the regular Scientists of SWQM in NCCR will help in a proper networking/better coordination between NCCR and participating institutions/ centres in improving the coastal and marine water quality data which is equal to international standards and acceptable to one and all.

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