MARINE MICROALGAE IN THE EEZ OF INDIA

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By

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Certificate

This is to certify that the thesis entitled **Marine Microalgae in the EEZ of India** is an authentic record of the research work carried out by Mr. Harikrishnan E., under my supervision and guidance in the Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Marine Biology of Cochin University of Science and Technology and no part of this has been presented for the award of any other degree, diploma or associateship in any university.

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Declaration

I hereby declare that the thesis entitled **Marine Microalgae in the EEZ of India** is an authentic record of research work done by me under the supervision of Prof. (Retd.) Dr. K.J. Joseph, Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology and no part of this has been presented for any other degree or diploma earlier.

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Harikrishnan E.

CONTENTS

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Abbreviations

ANS	Andaman Sea
ARS	Arabian Sea
ARSC	Arabian Sea Coastal
ARSO	Arabian Sea Oceanic
BOB	Bay of Bengal
BOBC	Bay of Bengal Coastal
BOBO	Bay of Bengal Oceanic
C	Carbon
CB	Control bottle
chl	chlorophyll
Diss.O_2	Dissolved Oxygen
DO	Dissolved Oxygen
EEZ	Exclusive Economic Zone
FORV	Fisheries Oceanographic Research Vessel
g	Gram
GPP	Gross Primary Productivity
IB	Initial Bottle
l	litre
lat	Latitude
LB	Light Bottle
long	Longitude
m	Micron
mg	Milligram
ml	Milliliter
NO2	Nitrite
NO3	Nitrate
NPP	Net Primary Productivity
PO4	Phosphate
SiO4	Silicate
temp	Temperature
SWM	South west monsoon
NEM	Northeast Monsoon
PRM	Premonsoon

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Chapter 1

GENERAL INTRODUCTION

Contents

The sustainability of biosphere is on the small fraction of solar irradiance that is absorbed and subsequently stored within the photosynthetic organisms – including algae, mosses, ferns and seed bearing plants along with some bacteria. Algae are heterogenous photoautotrophic organisms with either prokaryotic or eukaryotic cells having an array of habit, structure, metabolism and reproduction with a strong affinity to water. The cosmopolitan distribution of the algae at different geographic latitudes, on all continents, covering entire biosphere -atmosphere, hydrosphere and lithosphere, is the result of wide adaptive variations. Their occurrence at different degrees of salinity, temperature, trophicity, mineral ions and organic matter along with a size range, from less than 2µm to more than 60m, creates pressure on nature lovers and conservationists to study the diversity among algae. An autotrophic ancestor with an age of 400 billion years, with energy funnelling chlorophyll '*a*' and other accessory pigments, inhabiting in an upper water column upto a depth of 150-200m gives the outline of a very significant role in phylogeny and ecology of the biosphere. The contribution of these ancestors in the making of the present biosphere, makes the phycological studies more meaningful.

The community structure of the ecosystem is effectively controlled by algae through their critical role as a primary producer in the marine and freshwater food chains. Ecological practices such as adsorption and abatement of pollutants -heavy metals, pesticides and insecticides, leading a way to the purification of polluted waters and sewage; application as an indicator organism for the monitoring of ecosystems and as organisms for biotechnology are the new horizons in algal research. Algae are unique model organisms in evolutionary biology and are also used in various genetic, physiological, biochemical, cytological and biotechnological investigations.

The classification of algae may be based upon size, habit and habitat, motility, pigment composition, reserve food, and reproduction. They belong to monera - prokaryotic unicellular/colonial forms; or protista - eukaryotic unicellular/colonial forms or plantae - eukaryotic multicellular forms (Fritsch, 1935; Whittaker, 1969; Sieburth, 1978; Van den Hoek *et al.*, 1995). Their phylogenetic relationship is given in Figure1.1.

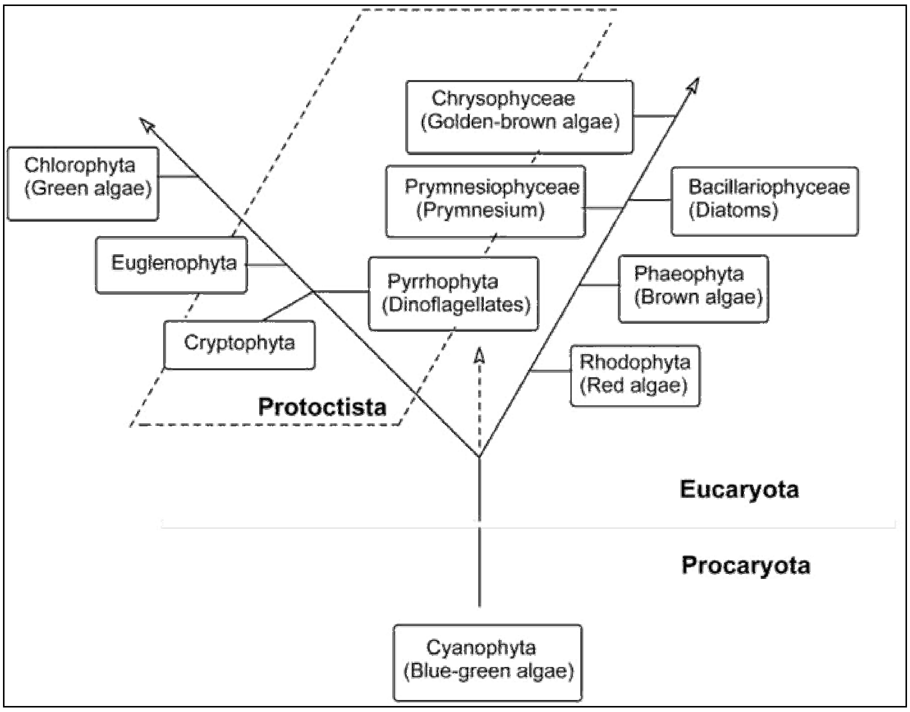

Fig. 1.1 Phylogenetic relationship of classes of microalgae (Lee, 2008)

These simple aquatic plants are microscopic or macroscopic, unicellular or multicellular, mobile or immobile, attached or free-living. Bold and Wynne (1985) and Stevenson (1996) concluded that there are about 26, 000 species of algae all over the world and Norton *et al.*, (1996) reported 37, 300 species. Mann and Droop (1996) estimated the number of diatom itself comes to more than 2, 00, 000 with planktonic, periphytonic and benthic forms. According to UNEP (1995), 10 x 10^5 algae are present in the biosphere, out of which only 40, 000 are described. There are several studies on macroalgae of the marine environment, the larger ones with a common name 'seaweeds', belonging to the algal divisions Chlorophyta, Phaeophyta and Rhodophyta; although they have a lesser diversity in comparison with the microscopic ones, microalgae.

1.1 Microalgae

Microalgae are the microscopic single celled algae, distributed in freshwater, estuarine and marine ecosystems. They comprise a vast group of lower plants which may be photosynthetic, symbiotic, mixotrophic and even parasitic (Lee, 2008). These microflora are unicellular, colonial, or filamentous microalgae having a great range of shape, colour and size; with or without a cellulosic or non cellulosic cell-wall, having mucilage, encrustations, ornamentations and several other modifications which serve as a taxonomic tool for identification of each class, family, genus and species. The size may range from a few micrometers (µm) to a few hundreds of micrometers. Microalgae, capable of performing photosynthesis, are important for life on earth; they produce approximately half of the atmospheric oxygen and use simultaneously the green house gas carbon dioxide to grow photoautotrophically.

Studies on biodiversity of microalgae in the marine environment are very limited compared to that of terrestrial flora. The biodiversity of microalgae is enormous and they represent an almost untapped resource. The sum total of species, belonging to any taxonomic class in varied habitats, would naturally be higher than the described number.

Microalgae play an important role in ocean and coastal ecology by the ability to produce 23.7 x 10^9 tonnes C/year, estimated as half of the annual productivity in the biosphere (Falkowski and Raven, 1997), while accounting for almost half of total production, oceanic autotrophs only account for about 0.2% of the total biomass. Microalgae constitute the basic foodstuff for numerous aquatic species, especially filtering bivalves, fishes, larvae or juveniles of almost all aquatic fauna. They provide them with vitamins and polyunsaturated fatty acids, necessary for the growth of the bivalves which are unable to synthesize it by themselves. Most of these microalgal species produce unique products like carotenoids, antioxidants, fatty acids, enzymes, polymers, peptides, toxins and sterols. Certain microalgae are effective in the production of hydrogen and oxygen through the process of biophotolysis. Others naturally manufacture hydrocarbons which are suitable for direct use as high-energy liquid fuels. Approximately fifty percent of the body of the algae is comprised of oil, called "oilage" which in its crude form can become diesel fuel. They are of particular interest in the development of future renewable energy scenarios because of their ability to produce by-products such as fats, oils, sugars and functional bioactive compounds (Dragone et al, 2010). Microalgae are able to produce 15–300 times more oil for biodiesel production than traditional crops on an area basis. Furthermore compared with conventional crop plants which are usually harvested once or twice a year, microalgae have a very short harvesting cycle (≈1– 10 days depending on the process), allowing multiple or continuous harvests with significantly increased yields (Schenk et al , 2008). The advantages of microalgae in greenhouse gas mitigation are that they can utilize CO_2 from power plant and other flue gases directly, that they can produce high value liquid and gaseous fuels (biodiesel, hydrocarbons, ethanol, methane, hydrogen), that they could potentially exhibit very high biomass productivities approaching the theoretical limits of photosynthesis (about 10% solar conversion efficiency), and that they are able to use waste water and nutrients, allowing for integration of such processes with waste treatment (Huesemann et al, 2003). Over 15,000 novel compounds originating from algal biomass have been chemically determined.

The microscopic species are distributed as planktonic, which remain suspended in the water column and as benthic, which live in association with some substrata, seen in pelagic and benthic environments of the aquatic ecosystem. Any individual alga may be benthic or planktonic at one time or another, but many species are characteristically adapted for either benthic or pelagic environments. Some are mobile, swimming by means of flagella or gliding over the substrata. Others are non-motile-drifting in the plankton, fixing to a substratum or lying free. Several microalgae, in spite of their characteristic adaptations to the specific habitat, have been found both in benthic and pelagic environments.

1.2 Planktonic Microalgae

Most of the planktonic microalgae are distributed throughout the euphotic zone, which is defined by its optical properties and extends to a depth where the incident radiation is attenuated to 1%. Many planktonic microalgae in the oceans are motile, and can undergo substantial vertical migrations in the water column to optimize their position with respect to the incident irradiance (Burns and Rosa, 1980, Tyler and Seliger, 1981). Since light intensity changes during the day and is modulated by a vetting cloud cover, aquatic organisms need to readjust constantly their positions in the water column to achieve optimal rates of photosynthesis. Microalgae suspended in the pelagic environments are of various taxonomic groups such as diatoms, dinoflagellates, green algae, blue green algae, silicoflagellates and coccolithophorids. Depending on the size, microalgae can be grouped into macroplankton

(>1mm), microplankton (<1mm), nanoplankton (5-50μm), ultraplankton (5μm) and picoplankton (>Iμm)(Gopinathan, 2004).

As microalgae are exposed to ever-fluctuating physico-chemical parameters, they exhibit wide diversity in species and abundance. Similar to terrestrial vegetation, marine phytoplankton diversity is a unimodal function of phytoplankton biomass with maximum diversity at intermediate levels of phytoplankton biomass and minimum diversity during massive blooms (Irigoien *et al.*, 2004). Large biomass standing stocks are generally associated with higher diversity in terrestrial ecosystems, the opposite seems to be the rule in pelagic marine ecosystems, where it is generally reported that increased production is associated with decreased diversity (Krebs, 1994). Changes in species composition and diversity may produce changes in community level parameters, like phytoplankton growth rate and those variables regulating the photosynthetic response to irradiance or other limiting factors. It is important to understand how these changes are reflected in ecosystem functioning and ecosystem services (Duarte *et al.*, 2006). Nutrient levels are important determinants of marine biodiversity, influencing the processes of competition and community structure in the marine environment. In the pelagic waters, concentration levels of inorganic nutrients, such as nitrate, phosphate and silicate in the water dictate population growth of planktonic primary producers. Seasonal variations of nutrient concentrations have been correlated with the abundance of microalgae.

They have several modifications or adaptations; gas vacuoles for cyanophytes; flagellation for the movement from unfavourable chemical, physical and biological conditions; extracellular products to increase the viscosity of surrounding water and wind induced rotation for surface dwelling non flagellates. Several types of cell structure modifications also occur which may be floating life-bladder/needle shape, branching frustules, colony formation, mucilage production, etc. Sometime cell density increases for sinking (Tomaselli, 2004)

1.3 Benthic Microalgae

Benthos (Greek- '*Bevoo*' = bottom) is an assemblage of organisms living in the benthic habitat of various aquatic ecosystems. The primary producers of the benthic habitat, phytobenthos, may be macroscopic seaweeds or microscopic benthic microalgae, the microphytobenthos. Microalgae found attached to any inert material such as rock, coral, sand particles and those attached to detritus or living organisms come under benthic microalgae. The benthic microalgae are very small with an average size of about 62µ (Underwood and Kromkamp, 1999).

Benthic microalgae are always found associated with some kind of substrata in different coastal habitats or within the sediment of intertidal areas. These habitats include estuaries, sand flats, muddy shores, salt marshes and deep soft substrate areas. Based on the substratum affinity, phytobenthos can be classified as epilithon, attached to stones and rocks; epipelon, attached to silt or clay; epipsammon, attached to sand; endopelon, inside the sediment; endolithon, inside rock; epiphyton, attached to macrophytes; epizoan, attached to animals and psychropelon, attached to ice (Round, 1966, 1971, 1991). Epilithic algae grow on hard, relatively inert substrata such as gravel, pebble, cobble and boulder that are bigger than most algae. Epiphytic algae grow on plants and larger algae, which provide relatively firm substrata those, are bigger than the epiphytic algae, but can be highly active metabolically and can be a great source of nutrients (Hynes, 1970).

Benthic microalgae or microphytobenthos are, in fact, the dominant flora in the littoral zone and estuaries. Benthic microalgae are recognized as important primary producers in shallow aquatic ecosystems (MacIntyre et al., 1996). Benthic microalgal species serve as the food of prawns and other crustaceans and oysters and they have a significant role in the bio productivity of benthic environment. In fact, the contribution of benthic algae is more than that of any other type of algae in shallow water. On tidal flats benthic macro-organisms receive their nutritional needs by feeding on benthic microalgae and labile organic matter settling out of the overlying water. Surface-algal covers are food sources for surface deposit feeders and act as interceptors for nutrients that are regenerated in sediments.

While extensive studies have been carried out on planktonic species, very little has been done on the taxonomy, distribution, abundance and productivity of benthic microalgae which contribute about one sixth of the total primary production in the world Oceans (Cahoon, 1999). In the absence of comprehensive studies on the microalgae in benthic habitats, a realistic estimate of the biodiversity, biotic interactions, potential fishery resources, etc., becomes difficult.

1.4 Microalgal Blooms

A rapid temporary increase in the population of microalgae may result in the formation of discoloured water, generally known as ‘algal blooms’ or ‘red tides’or even simply ‘tides’. Algal blooms are easily identified by the rapid change in water colour - green, white, olive, brown, red, yellow, golden, or even black colour in the water and may produce unpleasant odour and taste. On the surface of the viscous water, there will be thick slicks, scums or mats and may leave behind coloured deposits on rocks and substrates around the edges of aquatic ecosystem. When a bloom happen, naturally the diversity would decrease and the abundance of a particular species or two would increase. At the end of the bloom event or bloom crash, the species diversity may further go up and abundance will fall.

Planktonic blooms in the marine system can be broadly classified into two types, `spring blooms' and `red tides'. Seasonal blooms occur annually, mainly as a result of changes in temperature and nutrient availability whereas red tides are localized outbreaks and occur due to a variety of reasons which are characteristic of each species and locality (Richardson, 1997).

Most of the blooming algae are vitally important to marine and fresh-water ecosystems, and serve as the energy producers at the base of the food web; but some are harmful by toxin-production, or gill clogging; and it is termed as harmful algal bloom (HAB), which may harm the health of the environment, plants, or animals. Of the 5000+ species of marine phytoplankton that exist worldwide, about 2% are known to be harmful or toxic (Landsberg, 2002). HABs occur in many regions of the world. Most harmful algal blooms are caused by plants that form the "base" of the food chain that referred to as phytoplankton. Other HABs are caused by accumulation of non-chlorophyll containing cells that are similar in form to microscopic algae. HABs can deplete oxygen and block sunlight that are required for the survival of other organism, and some HAB-causing algae release toxins that are dangerous to animals and humans. HABs can occur in marine, estuarine, and fresh waters, and HABs appear to be increasing along the coastlines and in the surface waters of the oceanic biome.

1.5 Significance of Microalgae

The marine environment provides many different niches for microalgae. The presence of microalgae, both phytoplankton and autotrophic microphytobenthos, have significant role as primary producers. Millions of years of effort of prokaryotic oxygenic autotrophs, blue green algae, was the force behind the shift of atmosphere from primitive anoxygenic condition to an oxygenic environment.

The microalgal species within each niche has specific combination of requirements to the external environment, as any other species in any ecosystem. Microalgae exhibit seasonal fluctuations, many species are found at certain periods of the year, others are present for much of the time but their numbers may fluctuate, with massive abundance interspersed by periods of relative scarcity. Planktonic species are more seasonal and their seasons may last only a week or two in each year, with a succession of species waxing and waning throughout the year. The relative composition, distribution pattern, and community dynamics of microalgae becomes the index card of ecosystem health in both pelagic and benthic environment.

The marine pelagic ecosystem has the greatest size of all ecosystems on earth. The Oceans comprise 71% and contain more than 97% of all water on the planet (Riley and Chester 1971). There are 5 major – Pacific, Atlantic, Indian, Arctic and Southern Oceans and 20 minor ocean basins (Dawes, 1998). The marine pelagic environment comprises all ocean waters from the surface to the sediments with an average depth of 3.8 km, approximate volume coming to 14 billion km^3, or 99% of the earth's biosphere volume (Norse, 1994). The extreme heterogeneity, a characteristic of the coastal zone, which harbours more than 50% of the human population, influences the carbon cycling and carbon storage at global scale (Dileepkumar, 2006). India is the largest country having a wider EEZ, with coastal line of 8000 km that occupy 400 million human beings in the coastal area (Venkataraman, 2003). Increasing population along with the expansion of human activities build the potential to diminish the ocean's productivity in various ways. The Ocean's living resources and the benefits derived from them are threatened by fisheries operation, chemical pollution and eutrophication, alteration of physical habitat and invasion of exotic species (Choudhury et al., 2002). Both natural and anthropogenic activities that affect the coastal area in turn may influence these microscopic photosynthetic organisms. The microalgae of the oceanic environment, both pelagic and benthic, have a direct or indirect influence over the dynamicity of coastal as well as Open Ocean.

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Chapter 2

MATERIALS AND METHODS

Contents

2.1 Study Area

India is the most diverse country having high species richness not only in the terrestrial ecosystem, but also in the oceanic ecosystem of an Exclusive Economic Zone of 2.02 million km^2 area. The Exclusive Economic Zone of India comprises of three zones, Arabian Sea (ARS), Bay of Bengal (BOB) and Andaman Sea (ANS) of Indian Ocean, having 0.86 million sq km on the west coast, 0.56 million sq km on the east coast and 0.6 million sq km around the Andaman and Nicobar islands (Fig. 2.1). The coastline is having a length of 7,516 km; out of which 5, 422 km is the margin of 3.3 million km^2 land area in the Indian subcontinent. Lakshadweep coast is having a length of 132 km whereas Andaman and Nicobar islands have a coastal line of 1962 km. Nearly 250 million people are residing in the coastal belt upto 50km (Venkataraman, 2008).

This research work was initiated as a Junior Research Fellow of a project sponsored by Ministry of Earth Sciences (Formerly, Department of Ocean Development), Government of India- "Investigations on the toxic algal blooms in the EEZ of India". The surface water samples collected during the cruises (cruise nos. 189, 193, 195, 196, 203, 204, 205, 207 and 209) of Fisheries and Oceanographic Research Vessel (FORV) Sagar Sampada (Fig.2.2), conducted during the period from November 2000 to November 2002, are used as samples for microalgal estimation in the EEZ of India. The present research work includes the identification and distributional pattern of planktonic microalgae in the EEZ of India. The blooms encountered during the above mentioned cruises of FORV Sagar Sampada and the blooms of Kerala coast during the period from 2001-2005 were also studied.

2.2 Objectives of the Research Work

The objectives of the research work are as follows.

1) Quantitative and qualitative estimation of microalgae from EEZ of India

2) Study of the correlation of nutrients- NO_3, NO_2, PO_4, SiO_4 with the standing crop of phytoplankton, chlorophyll and primary productivity.

3) Study of the spatial and temporal distribution pattern of planktonic microalgae in the EEZ of India with an emphasis on algal blooms.

4) Assessment of the factors influencing microalgal bloom formation and the impact of algal bloom on other microflora and fauna.

5) Qualitative and quantitative estimation of microalgae present in the algal blooms observed on the Kerala coast during November 2001 to November 2005.

2.3 Sampling and Analysis of Microalgae

Samples were taken for qualitative and quantitative analysis of phytoplankton from the Indian EEZ, including oceanic and coastal areas. Several cruises, cruise nos. 193, 195, 196, 203, 204, 205, 207 and 209 of FORV Sagar Sampada during November 2000 to November 2002 have been used for the microalgal sampling and the measurement of physico-chemical variables. Inorder to study the seasonal variation in physico-chemical and biological parameters the data collected is divided into three, Pre-Monsoon (PRM: March-May), South West Monsoon (SWM: June-August) and North East Monsoon (NEM: September-November). The details of the cruises are given in Table2. 1; Fig. 2.3 and Fig. 2.4.

Table 2.1. Details of Cruises

Sl. No	Cruise No	No. of samples collected	Period	Season	Area of EEZ
1	189	28	Nov-00	NEM	West Coast
2	193	34	Apr-01	PRM	East coast
3	195	8	Jun-01	SWM	North West Coast
4	196	11	Jul-01	SWM	West Coast
5	203	39	May-02	PRM	West Coast
6	204	14	Jun-Jul 02	SWM	South West Coast
7	205	25	Jul-Aug 02	SWM	East Coast
8	207	16	Sept-Oct 02	NEM	Andaman Sea
9	209	16	Nov ‘02	NEM	East Coast

Collection and preservation of planktonic microalgae

50 litres of surface water (collected using a scientific deck-water pump attached with the vessel) was filtered through 20 µm bolting silk, 1% Lugol’s Iodine solution was added as a fixative and the filtrate was preserved in 3% formaldehyde solution. 25 litres of water was filtered in the case of local collections. In case of blooms, two samples were taken, 250 ml of was as such and another one by the filtration of 10 litres. The preservation and fixation procedures were the same for all filtrates. All the samples were stored in 300 ml polyethylene containers having double lids. Microscopic analysis was carried out both, *in situ* and laboratory conditions; the former one is preliminary whereas the latter was elaborate and laborious.

Quantitative and qualitative analysis

1 ml of the preserved sample was taken in Sedgewick-Rafter counting chamber and the species wise and total phytoplankton in the sample was estimated with the help of Nikon and Biolux Binocular Research Microscopes having 5x, 10x, 20x, 40x and 100x objectives and 10x eyepiece. The size of the cell was measured by micrometer. Nikon Eclipse E200 microscope with Epifluorescence and Phase Contrast facilities were used for photography. From fresh sample, movement of algal cells was also observed under microscope.

Enumeration by Sedgewick-Rafter counting cell

The planktonic microalgae filtered from 50 L of surface water was made up to a fixed volume concentrate. One ml of this sample was transferred to the Sedgewick-Rafter counting cell (the volume of this chamber is 1 ml.). The number of microalgae present in the all thousand grids was calculated. Counting was reported for three times and average was taken. The total number of planktonic algal species present in one litre of water sample was calculated using the formula,

$N = nv/V$

Where,

N = no. of planktonic algae per litre of water filtered

n = average no. of planktonic algae in one ml. of sample

v = volume of plankton concentrate in ml.

V = total volume of water filtered in litre

Identification of microalgae

The major identification features of the microalgae described by Allen and Cupp, 1935; Venkataraman, 1939; Cupp, 1943; Subrahmanyan, 1946; Hustedt, 1955; Hendey, 1964; Simonsen, 1974; Gopinathan, 1975 and 1984; Gopinathan and Pillai, 1975; Jin Dexiang *et al.*, 1985, Desikachary, 1959, Desikachary et al., 1987a and 1987b; and 1988; Desikachary and Sreelatha, 1989; Hallegraeff *et al.*, 1995 and Tomas, 1997 are observed under Binocular Research Microscope and identified upto species level. The salient features observed for identification include cell structure, cell complexity, branching and movement pattern, flagellation, nature of colony, mucilage, encrustation, ornamentation, colour and size of individual cells and colony, etc.

2.4 Estimation of Hydrographic Parameters

Physical variables

From all stations covered by Cruises of FORV Sagar Sampada the data on temperature salinity and dissolved oxygen was measured collected by the Conductivity Temperature Depth (CTD) profiler (*SBE Model 911 PLUS*, Sea-Bird Inc. USA). Surface meteorological parameters were recorded in the Automated Weather System. Mechanized canoes (Out board engine boats) were used for the collection of samples from the coastal areas. Hydrographic parameters such as temperature, salinity, pH and dissolved oxygen were measured from the coastal stations as given below.

Temperature

Temperature was measured using a precision mercury thermometer with an accuracy of $\pm 0.01^{o}$ C.

Salinity

Salinity was measured using a hand-held refractometer (Atago, S/Mill – E, Japan)

pH

pH measurements were made using a portable pH meter (Perkin Elmer, accuracy, ± 0. 01).

Dissolved oxygen (DO)

Samples were collected in 50 ml ground stoppered BOD bottles (bottles generally used for measure as Biological Oxygen Demand) and fixed using Winkler's A and B solutions. DO was determined by Winkler's method (Gaarder and Gran, 1927).

Chemical Variables

The sampled water was anlaysed for the quantitative estimation of NO_2, NO_3, SiO_4 and PO_4 using AUTOSAL in onboard analysis, and the data was given by the research team of National Institute of Oceanography. Strickland and Parson's (1972) standard water analysis methodology in the laboratory analysis was used for the coastal water samples.

Biological Variables

Primary productivity (PP)

Photo-autotrophic organisms are able to synthesize organic compounds from simple inorganic compounds utilizing the energy derived from solar radiation. This photosynthetic process is termed as primary production or it can be defined as the total amount of organic materials synthesized in unit time per unit volume of water.

Light and dark bottle method (Gaarder and Gran, 1927) was used for the estimation of primary productivity. The "Winkler" method of determining dissolved oxygen is normally used in the 'light and dark bottle' technique for studying production rates.

Procedure

A set of three ground stoppered oxygen bottles of 50 ml capacity was used in the experiment. Out of these, one was treated as light bottle (LB), one as control bottle (initial bottle, IB) and the third one served as dark bottle (DB).

Water samples from the surface were collected using clean plastic buckets. Water was siphoned into the sampling bottles using a siphon tube; the end of which was fitted with nylon net/bolting silk of 200-300 pore size in order to remove the zooplankton, if present; which may otherwise interfere with the oxygen content in the experiment bottles. Care was taken to avoid agitation of water. All the bottles were simultaneously filled with water samples using polythene tube, which touched the bottom of the bottle while filling to avoid the formation of air bubbles. The bottles were properly stoppered without trapping air bubbles inside.

The control bottle (initial bottle) containing water sample was immediately fixed with 0.5 ml. of Manganese sulphate and 0.5 ml of alkaline Potassium iodide (fixatives normally used in determination of oxygen by Winkler's method). The dark bottle was wrapped with aluminium foil and kept in a black polythene bag so as to be protected completely from sunlight. The light and dark bottles were kept suspended in a transparent acrylic chamber. These bottles were incubated for a period of 3 hours in the chamber by keeping the exact light penetration and temperature as in the sampling area.

After the period of incubation, the bottles were taken out and were fixed as in the same manner as control bottle was incubated. The oxygen content of the different bottles was determined by Winkler's chemical titration method. The oxygen content of the light bottle relates the amount of oxygen evolved during photosynthesis minus the amount of oxygen consumed in respiration by the entrapped phytoplankton. The amount of oxygen utilized by the phytoplankton for the respiration can be estimated by using measurements of oxygen changes concurrently in control/initial and light bottles. The decrease in O_2 content of dark bottle (compared to that of control bottle) was only due to respiration. Hence to get the estimate of total amount of photosynthesis (gross production), negative change in O_2 content of the dark bottle has to be added with the positive change in the O_2 content of the light bottle.

The Light and Dark bottle method assumes a fixed photosynthetic quotient (PQ) It is B Collected by dividing the number of molecules of CO_2 liberated during photosynthesis with the molecular of CO_2 assimilated during photosynthesis. Theoretically PQ is considered to be one, assuming the product of photosynthesis as starch (hexose sugars). Since it was not possible to determine the nature of photosynthetic product, a PQ value of 1.25 is invariably applied for fieldwork.

Calculations

Gross production =	O_2 content of LB – O_2 content of DB...............A
Net production =	O_2 content of LB – O_2 content of IB................B
Respiration =	O_2 content of CB - O_2 content of DB................C

The period of incubation is 3 hours, then

Gross production (mgC/l/hr) = A x 0.375 / PQ x 3 ------------------------D

Net Production (mgC/l/hr) = B x 0.375/PQ x 3 --------------------------E

Generally, aquatic productivity is measured in (gC/m^3/day), for the conversion of which values of D and E should be multiplied with 12 x 10^6. Gross production (GPP) and Net production (NPP) represented in the thesis in terms of gC/m^3/day.

Chlorophyll estimation

On both Sagar Sampada and local collections, one litre of surface water was filtered through Whatman GF/C filter papers using Millipore filtration unit and pigment was measured as per Strickland and Parson (1972). During onboard FORV Sagar Sampada sampling, the filter paper containing pigments were kept in 10ml capped test tubes containing 90% Acetone solution. The test tubes were covered by black paper and stored in the deep freezer. During local collections, the filtration was carried out *in-situ* and the filter paper was placed in an acid free test tube containing 10 ml of 90% acetone and kept in a refrigerator for 24 hours. The filter paper, containing the pigments, was ground well in a mortar and transferred to a centrifuge tube. The samples were centrifuged for at least five minutes in 4000 rpm. Make up the clear supernatant extract to 10ml. with 90% acetone. Thus chlorophyll and carotenoid pigments were extracted from the phytoplankton, resulting in coloured acetone extract. The pigment composition of this acetone extract was estimated with the help of a spectrophotometer (Hitachi U-2001, UV-visible spectrophotometer) using 90 % acetone as blank and wavelengths of 750, 665, 645, 630 and 450 nm, ie., the maximum absorption wavelengths of the pigments (Strickland and Parsons 1972).

The following equations are used to find out the chlorophyll contents.

Chlorophyll a (Ca) = 11.85 E665 - 1.54 E645 - 0.08 E630

Chlorophyll b (Cb) = 21.03 E645 - 5.43 E665 - 2.66 E630

Chlorophyll c (Cc) = 24.52 E630 - 1.67 E665 – 7.60 E645

where ‘E’ is the absorbance at different wavelengths in the respective wavelengths.

Chlorophyll a µg/lit. = (Ca X v)/ (V× l)

Chlorophyll b µg/lit. = (Cb X v)/ (V× l)

Chlorophyll c µg/lit. = (Cc X v)/ (V× l)

where ‘v’ is volume of acetone (ml.), ‘V’ is volume of water (lit.) filtered for extraction and ‘I’ is the path length (cm) of cuvette used in spectrophotometer. The unit of chlorophyll estimated will be µg/l in the thesis.

2.5 Statistical Analysis

For the storage, sorting and analysis of data, Microsoft Excel of MS Windows 2007 was used. Arithmetic Mean, Range and Standard Deviation were the statistical tools used for basic statistics. SPSS 11(1999) was used for correlation study on microalgal abundance with different biotic and abiotic parameters. PRIMER 6 (Clarke and Gorley, 2006) was used for the study of the microalgae community, similarity studies and cluster analysis.

2.6 Microalgal Culture

Inorder to study the stimulating factors of algal bloom, several algal cultures were made in the laboratory, using different media. The study of algal bloom dynamics was carried out by maintaining the algal bloom sample in several ways (Gopinathan, 1986). One was maintained as such and the others were maintained in used with different algal culture media. Media like enriched medium (Pantastico, 1977), `f -2' and 'f-10' medium (Guillard and Ryther, 1962) and Conway medium (Walne, 1974) were used for the experiments.

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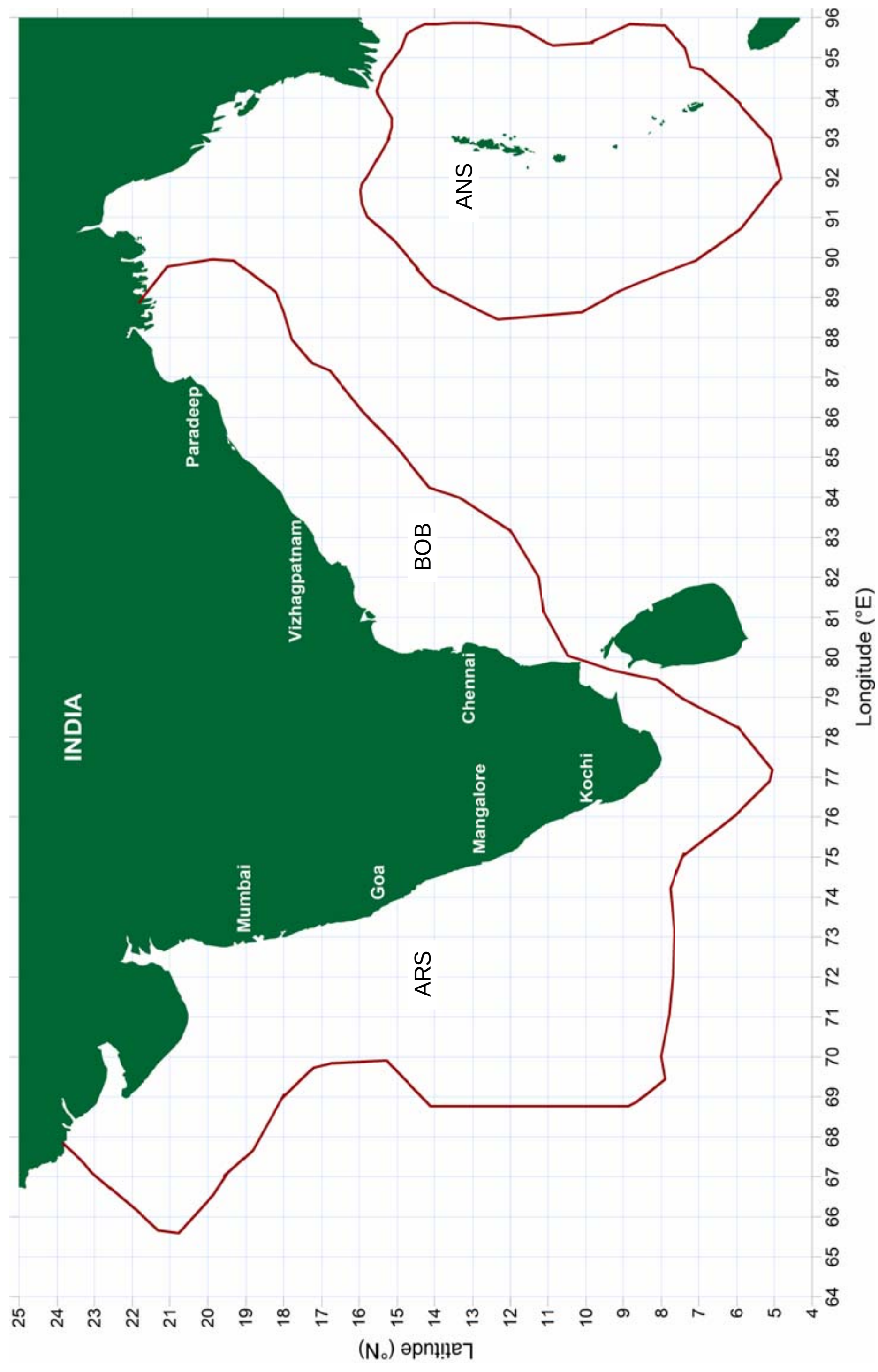

Figure 2.1. EEZ of India, the Study area

Figure 2.2. FORV Sagar Sampada

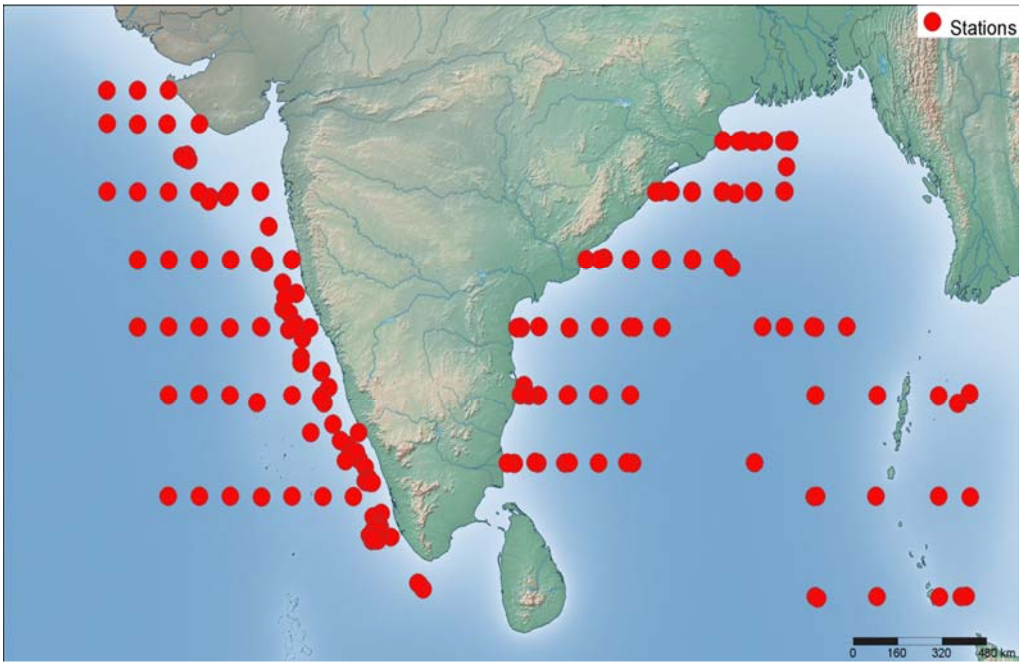

Figure 2.3. Sampling Stations

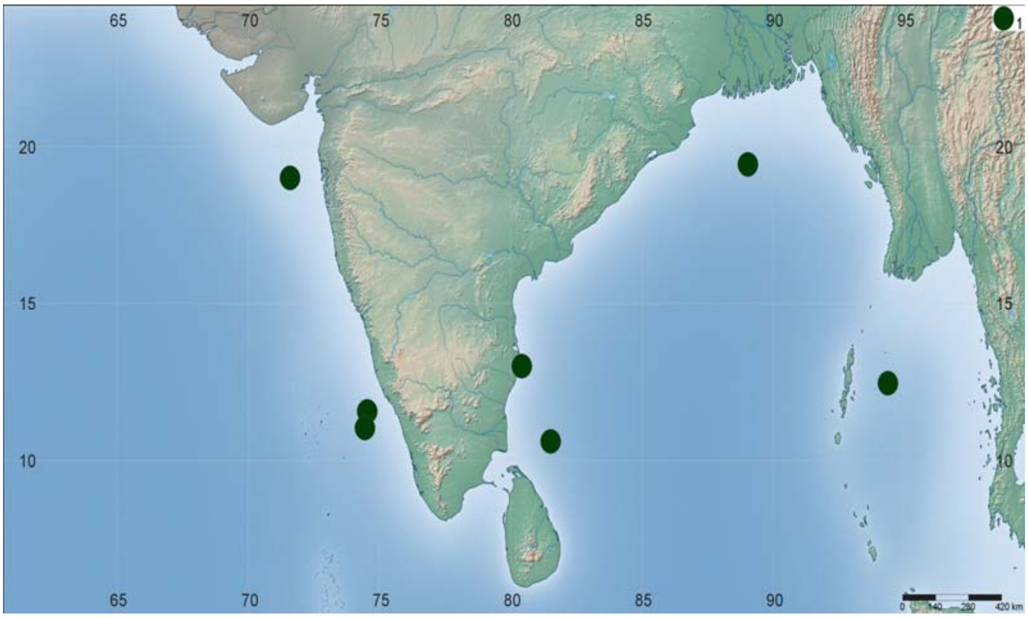

Figure 2.4. Bloom Stations

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Chapter **3**

PLANKTONIC MICROALGAE OF INDIAN EEZ

Contents

3.1 Introduction

'Plankton' is a more general term used to denote the suspended organisms which lack enough mobility and withstanding capacity against local water currents. In most of the cases their distribution is allochthonous, accidental and temporary. According to Reynolds (2006), plankton is imported from one habitat to the other, never grew in a specific habitat and is not suitably and efficiently adapted to the ever-changing conditions. Planktonic microalgae comprise a diverse, polyphyletic group of single-celled and colonial aquatic algae that drift with the currents (Falkowski and Raven, 1997). Being the primary producers of the aquatic environment, several efforts have been made, on the varied aspects of planktonic microalgae, such as primary production, evolution, phytoplankton diversity and their contribution to the system dynamics (Odum, 1971; Hillebrand and Sommer, 2000) in all aquatic ecosystems ponds, lakes, streams, rivers, lagoons and oceans. Knowledge on biodiversity patterns in marine microalgae is still limited compared to the terrestrial plants and planktons of small and closed water bodies.

The community structure and species variability of planktonic microalgae, is reflected in the ecosystem characteristics and regulates the atmosphere, hydrosphere and even climate of the biosphere. The transfer of energy and efficiency of the energy is generally deduced by the estimation of primary productivity and chlorophyll. Planktonic microalgae in the marine ecosystem constitute less than 1% of earth's photosynthetic biomass, yet they are responsible for more than 45% of our planet's annual net primary production (Field *et al*., 1998). They form the base of organic production in all marine food chains and also generate about 70% of the world's atmospheric oxygen supply (Reynolds, 1984). The potential resources can be assessed from the magnitude of primary productivity. Marine and coastal ecosystems provide a wide range of important food products, fish, crustaceans and molluscs. Marine fish provided about 84 million tonnes of human food and live stock supplements (FAO, 2003). Fish accounts for about 16% of the average individual intake of protein at global level and the proportion is much higher in many developing countries.

This chapter analyses the qualitative and quantitative distribution of microalgae collected from the EEZ during the nine *FORV Sagar Sampada* cruises. The seasonal, spatial and regional differences in the microalgal abundance and distribution are discussed along with the primary productivity and chlorophyll concentration estimated *in situ.*

3.2 Review of Literature

The history on the study of planktonic microalgae was started by the invention of light microscope. Scientists engaged in observing, describing and identifying processes from the time of Anton van Leeuwenhoek, father of microbiology. Kutzing in his book, *Species Algarum*, described and contributed several new diatom genera and species in 1844 and 1849. Thwaites, in 1848, have done observations on the Diatomaceae with descriptions on new genera and species. Greville (1857, 1859, 1863), reported several new diatom species from West Indies and California. Brightwell (1858, 1859) described some of the rarer or undescribed species of diatoms and made further observations on the genera *Triceratium* and *Chaetoceros*. Pritchard (1861) made a detailed study along the British coasts, mentioned the history of *Infusoria* including the desmidaceae and diatomaceae. Ralfs (1864) described several new species from marine diatomaceae found in Hong Kong waters. Lewis (1861) evaluated some new and rare species from Diatomaceae along the seabed of United States.

The phytoplankton community of Southern California coast is studied by Kleppel (1980). In 1982, Marshall and Cohn, studied the phytoplankton assemblages of US coastal waters. Rao and Al Yamani (1998) studied the phytoplankton ecology of the Arabian Gulf and projected the importance of the phytoplankton in the food web dynamics of the ecosystem. The South China Sea has been surveyed by several investigators including Boonyapiwat (1999), Canh and Hao (1999) and Ilyash and Matorin (2007) for the phytoplankton composition. The taxonomy and ecology of diatom flora of Albanian coastal wetland waters has been reviewed by Miho and Witkowski (2005). Konzova (2007) studied the spatial and seasonal variation in the phytoplankton composition of salt lagoon of Egypt. The qualitative and quantitative abundance of phytoplankton and zooplankton in the African coastal lagoons was studied by Ramdani et al., 2009.

Indian Scenario

The very beginning of the marine and coastal algal identification, description and study on the phytoplankton distribution was dated back to Subrahmanyan (1958a, 1958b) and Subrahmanyan and Sharma (1960), who made a comprehensive study on the phytoplankton of the west coast of India. Their studies are considered as the pioneer work on quantitative and qualitative fluctuation of total phytoplankton in the marine environment of India. However, a baseline data on the planktonic microalgae in the EEZ of India is not published yet; where an intensive periodical study is required for the study. The present study tries to give an idea about the distributional pattern- spatial, temporal and seasonal- of planktonic microalgae in the EEZ of India.

The ecology and taxonomy of phytoplankton in the estuarine and near shore waters of west coast of India has also been studied by Rajagopal, 1981; Joseph, 1982; Tiwari and Vijayalakshmi, 1998 and Gowda et al., 2001.The major works on the phytoplankton in and around Kerala coast include those of Nair (1959); Gopinathan et al., 1974; Devassy and Bhattathiri, 1974; Joseph and Pillai, 1975; Kumaran and Rao, 1975. Such qualitative and taxonomic works also have been referred for the identification of microalgae. Jugnu (2006) studied about the phytoplankton blooms of Kerala Coast with an emphasis on the impact on fisheries and in 2007, Bindhu carried out a study on diatoms of Kerala Coast. Nair (1959), Joseph (1989), Sreekumar and Joseph (1997), Sivadasan and Joseph (1997), Sanilkumar (2009) and Sanilkumar et al. (2009, 2011) have also contributed to the study of phytoplankton and benthic microalgae, their identification in and around the coastal and marine ecosystems of India, especially Kerala coast.

Similar studies have also been conducted along the east coast. The phytoplankton characteristics along the east coast have been studied very early by Ganapati and Rao (1953, 1958). Phani and Raman (1992) studied the diversity and species assemblage patterns in the northwest Bay of Bengal. Qualitative and quantitative distribution of phytoplankton and its seasonal and regional variation in the coastal waters of the east coast was done by Geethamadhav and Kondalarao (2004). Jyothibabu (2004) worked on the microzooplankton, including some of the dinoflagellates, of the east coast. Rahaman (2006) studied the plankton communities in the hypersaline waters of solar saltworks of Tamilnadu coast.

The pioneer work on the ecology and seasonal succession of diatom flora of estuarine waters of India was that of Iyengar and Venkataraman (1951) for the Cooum estuary in Madras. Since then biological investigations were carried out by various works on the planktonic algae of Chilka Lake (Roy, 1954;

Devasundaram and Roy, 1954; Patnaik, 1973) and in the Hoogly estuary (Dutta et al., 1954; Gopalakrishnan, 1971). On the south east coast of India, the inshore waters of Mandapam and Gulf of Mannar studied for its phytoplankton and productivity by Prasad (1954, 1958) and Prasad and Nair (1960 and 1963). Radhakrishna et al. (1978 a) studied some qualitative aspects of phytoplankton productivity in the coastal areas of east coast including some stations in the Bay of Bengal. Ecology of phytoplankton in Cuddalore and Uppanar estuary was studied by Murugan and Ayyakkannu (1993) and species diversity in Hughly estuary by De et al. (1994).

Studies on primary productivity of the coastal waters have also been carried out extensively. Subrahmanyan and Sharma, 1960, found that the production on the west coast of India is of a high order comparable to some of the most productive areas in the temperate regions. The productivity of the Indian waters and the potential fishery resources they can support was estimated by Nair et al. (1968). Radhakrishna (1969) made a study of primary productivity in the shelf waters of Alleppy on the south west coast of India during the post monsoon period. Qasim et al. (1978) have discussed the biological productivity of coastal waters of India upto 50m depth and stated that the larger phytoplankton organisms (macroplankton) contributed greater spatial variation in primary production than the smaller forms (nannoplankton). Radhakrishna et al. (1978 b, c) studied the primary productivity, chlorophyll *a* and related parameters from the shelf and oceanic regions in North eastern Arabian Sea and Northern Arabian Sea. Later Rani and Vasantha (1984); Krishnakumari *et al.* (2000); Gowda *et al.* (2001, 2002); Selvaraj *et al.* (2003) studied the primary productivity and variation in phytoplankton composition of estuarine and near shore waters of Indian coast.

In East coast, Marichamy *et al.* (1985) studied the primary and secondary production in relation to hydrography in the inshore waters of Tuticorin for a period from 1983 to 1984. Primary production of the same region in relation to hydrographic parameters for the period from 1985 to 1987 was done by Gopinathan and Rodrigo (1991).

Earlier works on phytoplankton distribution in Indian waters was confined to the coastal waters. Studies on the biology and ecology of the phytoplankton of various estuarine systems of India received much attention in comparison with the marine environment, because of the feasibility of the study.

3.3 Results

Planktonic Microalgae

191 stations in the entire EEZ of India extending over both Arabian Sea and Bay of Bengal (Fig.2.3) were analysed for the qualitative and quantitative distribution of planktonic microalgae. The surface water samples were collected and the analysis was carried out in the laboratory and the results obtained are given below.

MICROALGAE- Species composition:

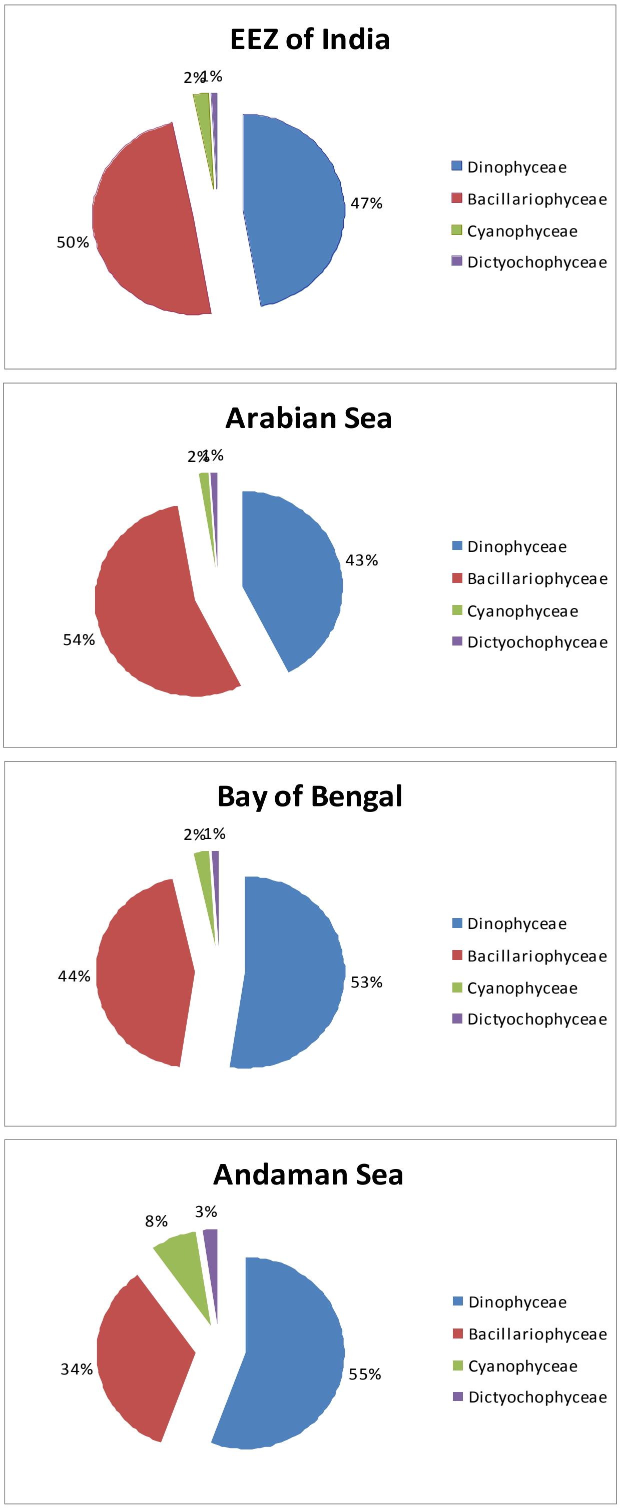
The diversity of microalgae in the EEZ is revealed by the present analysis of 191 samples from the EEZ. 245 species of microalgae belonging to the classes Dinophyceae, Bacillariophyceae, Dictyochophyceae and Cyanophyceae (See Table No. 3.1 and Annexure I, II & V) were identified. They exhibited seasonal and spatial variation. 116 species of dinoflagellates identified belong to 25 genera and 19 families (Table. 3.1). The most abundant genera was *Ceratium* with 31 species and the other major genera being *Peridinium* (24 spp.), *Gonyaulax* (8 spp.), *Gymnodinium* (6 spp.) *Ornithocercus* (6 spp.) and *Prorocentrum* (6 spp.). 121 species of diatoms were found in the EEZ samples. They belong to 36 genera of 25 families of diatoms. The most abundant genera was *Chaetoceros* with 28 species others being 12 species of *Coscinodiscus* 9 species each of *Navicula* and *Rhizosolenia* and 7 species of *Biddulphia*. Six species of blue green algae belonging to 3 genera were identified, namely *Oscillatoria* (3 spp.), *Trichodesmium* (2 spp.) and *Lyngbya* (1 sp.). Both of the dictyophycean species belong to one genus, *Dictyocha* (*Dictyocha fibula* and *Dictyocha staurdone*) (Table.3.1 and Graph.3.1).

Table.3.1: No. of species of microalgae in the EEZ, showing class-wise distribution.

	Class Dinophyceae			**Class Bacillariophyceae**			**Class Cyanophyceae**			**Class Dictyochophyceae**		
	species	**genera**	**family**	**species**	**genera**	**family**	**species**	**genera**	**family**	**species**	**genera**	**family**
Arabian Sea (ARS)	74	19	14	95	30	22	3	2	1	2	1	1
Bay of Bengal (BOB)	88	22	18	71	30	22	4	3	1	2	1	1
Andaman Sea (ANS)	44	18	16	27	14	12	6	3	1	2	1	1
EEZ	**116**	**25**	**19**	**121**	**36**	**25**	**6**	**3**	**1**	**2**	**1**	**1**
	Abundant genera- *Ceratium* and *Peridinium*			Abundant genera- *Chaetoceros and Coscinodiscus*			Abundant genera- *Oscillatoria* and *Trichodesmium*			One genera- *Dictyocha*		

MICROALGAE- standing crop

The concentration of microalgae varied from 21 cells/l at Station no. 1149 of cruise no.204 (Latitude 8.7^{o}N and 75.8^{o}E in the Arabian Sea) to 11.5 x 10^{7} cells/ l in a *Trichodesmium erythraeum* bloom station (Station no. 874 of cruise no. 193), of latitude 13.0^{o}N and longitude 80.7^{o}E in Bay of Bengal. Seven blooms were observed, three each in Arabian Sea and Bay of Bengal and one in Andaman waters. The microalgal standing crops of discoloured areas were from 4390 to 11.5 x10^{7} cells/l. Diatoms varied from 10 cells per litre to 9480 cells per litre where as dinoflagellate varied from 5 cells to 380 cells in a litre.



Graph 3.1. Species Number wise contribution of microalgae

Biological Variables

The results of primary productivity studies and chlorophyll estimation are given below.

Primary Productivity

The gross primary productivity (GPP) of the EEZ varied from 0.057 gC/m^3/ day to 1.99 gC/m^3/day (Table.3.2 and Graph.3.1). The average value of GPP was found to be 0.618gC/m^3/day. The range of gross primary productivity in Arabian Sea is found to be the same as that of EEZ with a higher average of 1.082gC/m^3/day. Bay of Bengal with 0.066 to 0s.435 and Andaman waters of the EEZ with 0.260 to 0.800. The average of the GPP in the EEZ is 0.618 gC/m^3/day. The average GPP of the Arabian Sea, Bay of Bengal and Andaman Sea estimated are 1.082, 0.213 and 0.417gC/m^3/day respectively and their magnitude may be expressed as ARS > ANS > BOB. The ratio between the average GPP is 1:2:5 in BOB, ANS and ARS (Table. 3.2).

Table.3.2 Variation in biological parameters- primary productivity and pigment composition in the EEZ

	GPP gC/m^3/day		**NPP** gC/m^3/day		**Chl. *a*** µg/l		**Chl. *b*** µg/l		**Chl. *c*** µg/l	
	Range	**Average**	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**	**Range**	**Average**
Arabian Sea (ARS)	0.057 to 1.990	*1.082*	0.030 to 1.930	*0.463*	0.003 to 5.360	*0.862*	0.010 to 0.330	*0.125*	0.030 to 0.170	*0.106*
Bay of Bengal (BOB)	0.066 to 0.435	*0.213*	0.020 to 0.227	*0.094*	0.101 to 0.107	*0.103*	0.083 to 0.095	*0.086*	0.108 to 0.116	*0.112*
Andaman Sea (ANS)	0.260 to 0.800	*0.417*	0.120 to 0.390	*0.224*	0.020 to 6.99	*0.435*	0.050 to 0.310	*0.156*	0.080 to 0.960	*0.348*
EEZ	0.057 to 1.990	**0.618**	0.020 to 1.930	**0.266**	0.003 to 6.690	**0.689**	0.010 to 0.330	**0.131**	0.030 to 0.960	**0.226**

The average net primary productivity (NPP) of EEZ is 0.266 $gC/m^3/day$ and the range of which is from 0.020 to 1.93. The wide range of NPP in the Arabian Sea is found to have a higher average of 0.463 $gC/m^3/day$ than the other two regions BOB and ARS. The pattern in NPP is the same as that of GPP, i. e., ARS>ANS>BOB in both range and average. The ratio between the NPP of AR, AS and BB is similar to that in GPP. The relationship of the GPP and NPP is found very near to 2:1 in all the three regions (Table 3.2).

Chlorophyll

Chlorophyll *a* is also found to exhibit variation in the three regions and have an EEZ average of 0.689 µg/l within a range of 0.0036 to 6.93 µg/l (Table.3.2). The maximum value was contributed by the bloom area of Andaman waters during the cruise no. 207. The average chlorophyll *a* value ranged from 0.103 of Bay of Bengal to 0.862 of Arabian Sea, having a value of 0.435 in Andaman waters. The other accessory pigments, chlorophyll *b* and c were also estimated to indirectly give an idea on the relative contribution of prochlorophytes, diatoms and dinoflagellates. Those pigments were also varied from region to region and the average value of chlorophyll *b* is 0.131 µg/l and chlorophyll *c* is 0.226 µg/l in the EEZ revealed through the present study. The variation of these pigments is also presented in the Table. 3. 2.

Statistical Analysis

The resultant data of qualitative and quantitative analysis of microalgae is used for the cluster analysis and also for the test of taxonomic distinctiveness at each station. The values of primary productivity and chlorophyll pigments are correlated with the abundance of total microalgae, diatoms and dinoflagellates. The k- dominance curve, Funnel Plot, MDS plot and Diversity indices of microalgae of all stations were carried out. Shannon - Wiener index (H'), Simpson index (D), Pielou's evenness index (J') and Margalef richness index (d) are calculated using PRIMER 6. Inorder to analyse the data regionally, data is divided into Arabian Sea (ARS), Bay of Bengal (BOB) and Andaman Sea (ANS); in relation to the geography of the study area. The averaging is done by dividing the data into several groups (Table. 3. 3). This grouping is used for the graphical representation, statistical analysis, discussion and conclusion.

Table. 3.3. Grouping of data for data analysis

Region wise groups	ARS-Arabian Sea	BOB-Bay of Bengal	ANS-Andaman Sea
Latitude wise groups (Latitudinal Clusters LC)	LC **I**- 07°N to 10°N LC **II**- 10°N to 13°N LC **III**- 13°N to 16°N LC **IV**- 16°N to 19°N LC **V**- 19°N to 22°N	LC **I**- 10°N to 13°N LC **II**- 13°N to 16°N LC **III**- 16°N to 19°N LC **IV**- 19°N to 22°N	LC **I**- 06°N to 09°N LC **II**- 09°N to 12°N LC **III**- 12°N to 15°N
Season wise groups*	**SWM-** June-August : **NEM-** September-November : **PRM-** March- May		
Station depth wise groups*	**C**-Coastal - upto 200 m **O**-Oceanic- above 200 m		
Time of sampling*	**N** –Night (19.00 -4.00); **D** - Day (4.00 – 19.00) DSR – Sun rise (4.00-8.00) DMO- Morning (8.00-11.00) DMN- Mid noon (11.00-14.00) DAN- After noon (14.00-16.00) DEV- Evening (16.00-19.00)		

*grouping is the same for ARS, BOB and ANS

The station wise diversity indices are given as Annexure III, for Arabian Sea, Bay of Bengal and Andaman Sea.

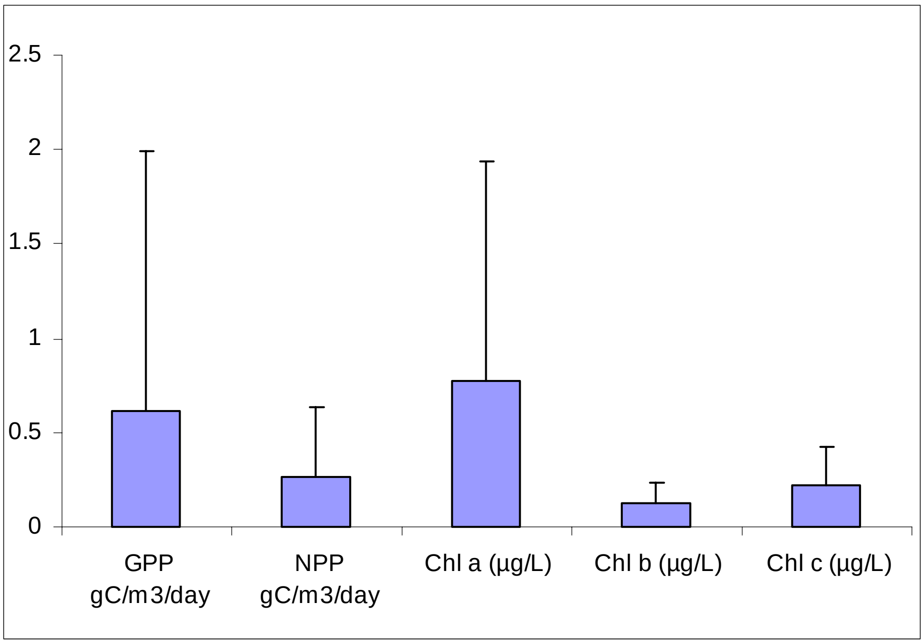
Correlation Analysis

The relationship of the standing crop, productivity and chlorophyll concentration is assessed, using the correlation analysis using SPSS 11. Table is given below (Table.3.4).

Table. 3.4. The table showing correlation coefficients of standing crop of microalgae with biological parameters - productivity and pigments

	Total microalgae	Total Diatom	Total Dinoflagellata
GPP gC/m^3/day	-0.124	0.010	-0.158
NPP gC/m^3/day	-0.218	0.003	-0.255*
chl *a* µg/l	-0.077	-0.064	-0.265*
chl *b* µg/l	-0.151	-0.142	-0.211
chl *c* µg/l	-0.138	-0.121	-0.392*

(*Correlation is significant at 5% level)



Graph 3.2. Mean and Standard deviation of biological variables in the EEZ

3.4 Discussion

Microalgae- Species composition

The results of the present study reveal that two classes of algae, Bacillariophyceae and Dinophyceae outnumber any other class of algae, although cyanophyceae and dictyochophyceae are present sporadically. Diatoms and dinoflagellates are present in all the stations investigated with a wide range in the numerical abundance and species composition. Number of diatom species was found to be higher than dinoflagellates in the EEZ and it was true at genera and family level also (Table. 3.1).

The regional wise microalgal distribution also showed more or less the same pattern; except at Bay of Bengal. 95 diatoms, 74 dinoflagellates, 3 cyanophytes and 2 dictyochophyceae were present in the Arabian Sea. In Andaman waters, a dominance of dinoflagellates (44) over diatoms (27) along with 4 cynophytes and 2 dictyochophytes is observed. From Bay of Bengal samples, 74 diatoms, 88 dinoflagellates, 4 cyanophytes and 2 *Dictyocha* spp. were identified (Annexure IV). Thus, the microalgal community structure of EEZ is having a difference in the three regions, Arabian Sea, Bay of Bengal and Andaman Sea. 49% of the planktonic microalgae in the EEZ are found to be diatoms, 47% dinoflagellates, 3% cyanophytes and 1% dictyochophyte. In Arabian Sea, the species composition is different with 55% diatoms, 42% dinoflagellates 2% cyanophytes and 1% dictyochophytes. Eastern part of EEZ is having a dominance of dinoflagellates (52 and 56% in Bay of Bengal and Andaman waters respectively). The contribution of diatom is limited to 44 and 34 in the Bay of Bengal and Andaman parts of EEZ. The contribution of cyanophyte and dictyochophyte is similar to that of EEZ average. Andaman waters had a relatively greater contribution of cyanophytes and dictyochophytes (8% and 2% respectively).

This type of microalgal composition was also reported by several others. The present investigation unravelled that the open sea waters of Bay of Bengal had a dominance of dinoflagellates. However, Madhu *et al.*, (2006) described that a pronounced seasonal variation couldn't find in the phytoplankton standing stock in western Bay of Bengal during summer, winter and spring inter monsoon.

In Arabian Gulf, Rao and Al-Yamani (1998) reviewed the same trend of microalgal composition with a dominance of diatoms and dinoflagellates. A dominance of diatoms over dinoflagellates were also presented in the work of Al-Saadi and Hadi (1987) at Arabian Gulf. Vijayaraghavan and Krishnakumari (1989) along the West coast of India also described that dominance of Diatom. The coastal south east Arabian Sea provided a dominance of diatoms over dinoflagellates. However, the open sea waters of the same area comprise more dinoflagellates than diatoms (Sanilkumar, 2009).

Geethamadhav and Kondalarao (2004) studied the coastal waters of East coast during 1999 to 2002 and 249 species of microalgae have been identified with 131 species of dinoflagellates and 111 species of diatoms and 7 species of cyanophytes. Similar result is obtained in the present investigation not only in the coastal regions of east coast but also in the oceanic waters of Bay of Bengal and Andaman Sea with a variation in species diversity and standing crop (Table. 3.1 and 3.2). Geethamadhav and Kondalarao (2004) also observed that at genera level diatom is more diverse (43 genera) than dinoflagellate (30 genera). The diversity of microalgae at generic level at Bay of Bengal is found to be similar but with a lesser species diversity (30 genera of diatoms and 22 of dinoflagellates). Generally coastal regions are more diverse than the oceanic region. But the present study observed a variation at Bay of Bengal, the diversity of microalgae lesser in the coastal region (Table 3.6).

Some species had a wide occurrence where as some others had sporadic occurrence. 28 species of dinoflagellates and 13 diatoms were present in all the three regions of the EEZ. 27 dinoflagellates and 36 diatoms were commonly present in Arabian Sea and Bay of Bengal. The presence of 9 dinoflagellates and 6 diatoms were present only in the Eastern part of the EEZ. There were no dinoflagellate and diatom species showing a common occurrence at Arabian Sea and Andaman Sea with absence in Bay of Bengal.

The species composition showed much variation in quality and quantity without any correlation with the season or time or region. In Arabian Sea, out of 93 analysed samples the most frequently occurred microalgae were *Ceratium fusus* and *Dictyocha fibula* with 54 where as *Oscillatoria agardhii* occured 53 times. Among the dinoflagellates the most frequently observed microalgae were *Ceratium furca* (45), *Peridinium depressum* (32) *Ceratium trichoceros* (29) *Amphisolenia bidentata* (28) and diatoms were *Planktoniella sol* (39) *Rhizosolenia hebetata* (33) *Thalassionema nitzschioides* (30) and *Asterionella japonica* (28). Four dinoflagellates, namely *Dinophysis miles*, *Gonyaulax polygramma*, *Pyrocystis lunula* and *Pyrocystis pseudonoctiluca* and six diatoms, *viz, Bacteriastrum delicatulum*, *Chaetoceros lorenzianus*, *Chaetoceros seriacanthus*, *Guinardia striata*, *Pleurosigma directum* and *Rhizosolenia setigura* occured in a single station during the analysis of 191 stations.

Bay of Bengal had a difference in the frequency of occurrence. *Ceratium contortum* (35) and *Pyrophacus horologium* (34) had the maximum samples of occurrence out of 73 samples analysed. The other microalgae most frequently occurred include *Ornithocercus magnificus*, *Dictyocha staurdone, Nitzschia longissima*, *Ceratium declinatum*, *Ceratium extensum*, *Ceratium gibberum*, *Ceratocorrys horrida* and *Peridinium divergens*.

From Andaman Sea, analysed 16 surface water samples and *Dictyocha staurodone* (12), *Amphisolenia bidentata* (11), *Ceratium gibberum* (8), *Oscillatoria agardhii* (8), *Oscillatoria nigroviridis* (8), *Ceratocorrys horrida (7)*, *Ceratium fusus* (7), *Ornithocercus magnificus* (7) and *Dictyocha fibula* (7) are the most frequently occurred species.

The latitudinal variation in the species composition can be explained by the variation in the species number in the latitudinal clusters of EEZ (Table. 3.5). The southernmost cluster of ARS, BOB and ANS had a total microalgal species no. of 73, 72 and 39. As the latitude increases there found a steady increase in the species diversity, in all the three regions of EEZ. This tendency is repeated in the case of diatoms in ARS, BOB and ANS. The dinoflagellate distribution is found to have the southernmost cluster with a lesser no.of species; but all the other clusters had a consistency in the no. of dinoflagellates. The no.of species, belong to other microalgal classes, cannot be used for the distributional study, because of the lack of enough sample size.

Seasonal variation in the number of species is presented in the Table. 3.6. Based on the number of species Arabian Sea had a SWM>PRM>NEM pattern, very similar to that in the dominating classes, diatom and dinoflagellates. Bay of Bengal exhibited another type of distribution PRM>SWM>NEM. The no of species of microalgae during SWM (with 92 sp.) and NEM (with 88 sp.) are found to be similar but with a shift in the dominance of diatoms to dinoflagellates. 50 species of diatoms and 37 dinoflagellates are present in the SWM season but the NEM experiences the dominance of dinophyceae (51 sp.) over diatoms (31 sp.). The relative contribution of diatom and dinoflagellate was found to have an inverse relationship; as the number of diatom species increases the no. of diatoms decreases. The lack of sufficient previous work on these aspects of microalgae along the EEZ, creates insufficiency in discussion.

Table.3.5. The latitudinal variation in the number of species in the EEZ of India.

	LC I	LC II	LC III	LC IV	LC V
ARS	Dinophyceae: 30 Bacillariophyceae: 39 Cyanophyceae : 2 Dictyochophyceae: 2	Dinophyceae: 54 Bacillariophyceae: 59 Cyanophyceae : 3 Dictyochophyceae: 2	Dinophyceae: 59 Bacillariophyceae: 63 Cyanophyceae : 3 Dictyochophyceae: 2	Dinophyceae: 57 Bacillariophyceae: 81 Cyanophyceae : 1 Dictyochophyceae: 2	Dinophyceae: 53 Bacillariophyceae: 75 Cyanophyceae : 3 Dictyochophyceae: 2
Total	73	118	127	141	133
BOB	Dinophyceae: 44 Bacillariophyceae: 23 Cyanophyceae : 4 Dictyochophyceae: 1	Dinophyceae: 60 Bacillariophyceae: 34 Cyanophyceae : 4 Dictyochophyceae: 1	Dinophyceae: 61 Bacillariophyceae: 49 Cyanophyceae : 4 Dictyochophyceae: 1	Dinophyceae: 65 Bacillariophyceae: 64 Cyanophyceae : 5 Dictyochophyceae: 1	-s
Total	72	99	115	135	
ANS	Dinophyceae: 19 Bacillariophyceae: 15 Cyanophyceae : 3 Dictyochophyceae: 2	Dinophyceae: 28 Bacillariophyceae: 18 Cyanophyceae : 3 Dictyochophyceae: 2	Dinophyceae: 29 Bacillariophyceae: 14 Cyanophyceae : 3 Dictyochophyceae: 2	-	-
Total	39	51	48		

The seasonal variation in species composition is summarised in the table. 3.6. South west monsoon season is found to be more productive to the Arabian Sea

Table. 3. 6. Seasonal variation in the number of species of microalgae in the EEZ

Season	ARS		BOB		ANS	
	Total microalgae	Class wise distribution	Total microalgae	Class wise distribution	Total microalgae	Class wise distribution
PRM	97	Dinophyceae: 37 Bacillariophyceae: 55 Cyanophyceae : 3 Dictyochophyceae: 2	105	Dinophyceae: 62 Bacillariophyceae: 36 Cyanophyceae : 5 Dictyochophyceae: 2	No sampling	
SWM	145	Dinophyceae: 63 Bacillariophyceae: 78 Cyanophyceae : 2 Dictyochophyceae: 2	92	Dinophyceae: 37 Bacillariophyceae: 50 Cyanophyceae : 3 Dictyochophyceae: 2	72	Dinophyceae: 39 Bacillariophyceae: 27 Cyanophyceae : 4 Dictyochophyceae: 2
NEM	69	Dinophyceae: 25 Bacillariophyceae: 40 Cyanophyceae : 2 Dictyochophyceae: 2	88	Dinophyceae: 51 Bacillariophyceae: 31 Cyanophyceae : 4 Dictyochophyceae: 2	36	Dinophyceae: 24 Bacillariophyceae: 10 Cyanophyceae : 0 Dictyochophyceae: 2

There is an evident difference in the species composition and standing crop of the coastal region inshore waters and the oceanic off shore waters in both the parts of Indian EEZ, ARS and BOB. The station depth was more than two hundred meters in all the sampled stations of Andaman Sea (Table 3.7). The coastal regions of Arabian Sea are found to be more productive than the oceanic region but the reversal one is present in Bay of Bengal. Even after excluding three blooms of *Trichodesmium,* the average standing crop as well as the number of species of microalgae is higher in the oceanic environment of Bay of Bengal. The conclusion, open ocean of Arabian Sea have more dinoflagellates than diatoms (Sanilkumar, 2009) on the west coast of India, was not found to be true in the case of EEZ.

Table. 3.7. Spatial variation, between the coastal and oceanic waters, in the number of microalgae in the EEZ

	Total spp.	Class Dinophyceae	Class Bacillariophyceae	Class Cyanophyceae	Class Dictyochophyceae
ARSC	163	67	91	3	2
ARSO	160	70	85	3	2
BOBC	111	55	51	3	2
BOBO	164	85	72	5	2

Coastal upwelling areas will be more dominant with picophytoplankton (less than 2 micrometer size) where as the offshore upwelling areas are dominant with diatoms (Ras et. al., 2007). Studies including the coastal waters were found to have more species diversity than the present study. (Sanilkumar, 2009; Rao and Al-Yamani,1998). The dominance of diatoms in the Arabian Sea can be linked with the high upwelling process during south west monsoon season. The oceanic environment of Bay of Bengal is having more species diversity and both the dominant classes, diatoms and dinoflagellates are more diverse than the coastal waters.

Marra and Barber (2005) argues that in Arabian Sea phytoplankton biomass varies temporally and spatially at all scales from the diurnal to the seasonal, and from fine to large scale. This study also supports the dynamicity of the Arabian Sea along with the Bay of Bengal. The species diversity and abundance varies with the latitude, station depth as well as with all physicochemical parameters; although only some of the physicochemical factors are significantly correlated in the present study.

Microalgae – Standing crop

Table.3.8. Variation in the average concentration of microalgae per litre in the EEZ

	Microalgae (no/l)	Dinophyceae (no/l)	Bacillariophyceae (no/l)	Others (no/l)
Arabian Sea (ARS)	499	41	277	9586
Bay of Bengal (BOB)	9.8×10^5	99	55	2.3×10^7
Andaman Sea (ANS)	670	10	11	8464
EEZ	**3.2×10^5**	**50**	**114**	**7.8×10^6**

The average microalgae per litre in the present study, by the standing crop estimation using 191 samples , 3.2×10^5 in the EEZ, where as Arabian Sea (499), Bay of Bengal, 9.8×10^5 and Andaman with 670 cells/per litre. There is a high fluctuation in the standing crop of individual classes (Table. 3.8). By excluding the bloomed species from the total count it was found that in Arabian Sea the Mean microalgae per litre was 207, and that of others to 1123/l. At Bay of Bengal, the exclusion resulted into 95 for microalgae and 470 for others. In Andaman waters, 20 cells/l, was the average microalgal standing crop and 140 cells/l in the case of other than diatoms and dinoflagellates. The abundance of microalgae showed a high fluctuation because of the high dynamicity of the seas. The latitudinal, spatial, seasonal variation in the standing crop is not mentioned here. The microalgal community structure was varying, with the criterion used for, is evident from the species variability and chlorophyll-productivity studies. The standing crop and the physicochemical variables are correlated.

Marra and Barber (2005) converges to a point that the variations in phytoplankton biomass can be explained from variations in mixing at diurnal to seasonal scales and spatial variations caused by upwelling near the coast and the presence of mesoscale eddies. Vertical mixing regulates the supply of irradiance and nutrients, but vertical mixing is never deep enough to limit phytoplankton productivity and nitrogen does not appear to be a factor limiting phytoplankton growth. Vertical mixing, however, also affects grazing by diluting micro-grazers along with phytoplankton. It is argued here that mixed layer deepening acts as a natural dilution experiment that allows phytoplankton to escape grazing losses and grow and thereby create the observed variability in phytoplankton biomass.

Madhu et al, 2009 observed a high microalgal biomass, primary productivity and species richness in the Western part of the Andaman Sea instead of the Eastern region. There was a higher concentration of zooplankters and fish larvae in the eastern region which may be responsible for the lowering of biomass and productivity in the eastern region. In the present investigation, the average standing crop of the eastern Andaman Sea is found to be more than the western part; which also included a bloom of *Trichodemsium erythraeum* (50094 cells/l). But the average number of diatom and dinoflagellate was found to be more in the eastern region. When the *Trichodesmium erythraeum* was excluded for calculating the average, the trend changed and showed a similar trend as observed by Madhu et al, (2009). This could be due to the comparatively higher averages of hydrographic variables of western region, which was found to be warmer and saline than the eastern region. If the influence of bloom is ignored the productivity and total phytopigments also found to be more in the western region. It is also to be noticed that the amount of chlorophyll *a* was not showing the trend. Besides that the number of species present in the eastern region is more than that of the western region. More frequent and enough sampling, with more facilitated studies are required to understand the phenomenon existing if any in this part of EEZ.

Biological Variables

Primary Productivity

Information on primary productivity is generally essential for the assessment of the potentiality and fertility of a region. In the present study it was found that the GPP and NPP are showing a same pattern of ARS>ANS>BOB in a ration 5:2:1 (table. 3.2). Arabian Sea is considered as more productive than Bay of Bengal. The factors attributed for the phenomenon were composition of microalgae, upwelling, wind and water current pattern, two monsoon seasons.

Latitudinal variation:

The latitudinal variation in primary productivity is also very prominent in the present study. Southern most cluster, LC I was having more GPP and NPP in Arabian Sea. GPP was increasing steadily from LC IV to south ward, but having the second in average for the northern part of Arabian Sea. The lowest NPP, 0.112 gC/m3/day was reported by the LC III with a peak of 0.657gC/m^3/day at LC I. From the central region of the ARS southwards as well as northwards the Net primary productivity was increasing (Table.3.9). In both the primary productivities the southern cluster is followed by the northernmost cluster. The ratio between GPP and NPP was changing irregularly.

Table.3.9. Latitudinal variation in the primary productivity and Chlorophyll, in the clusters of Arabian Sea

ARS cluster	GPP (gC/m^3/day)	NPP (gC/m^3/day)	chl *a* µg/l	chl *b* µg/l	chl *c* µg/l
LC I	0.964	0.657	0.788	-	-
LC II	0.578	0.596	0.519	0.220	0.090
LC III	0.562	0.112	0.324	0.127	0.070
LC IV	0.543	0.255	0.589	0.105	0.113
LC V	0.827	0.475	1.874	0.055	-

There are several reports that southern region (including LC I and II of the present study) is more productive than the others. Bay of Bengal experienced a decrease and increase of GPP as well as NPP, when analyses the average of these two biological variables latitudinally. The ratio between the primary productivity varies considerably (Table.3.10).

Table.3.10. Latitudinal variation in the primary productivity and Chlorophyll, in the clusters of BOB

BOB Cluster	GPP ($gC/m^3/day$)	NPP ($gC/m^3/day$)	chl *a* µg/l	chl *b* µg/l	chl *c* µg/l
LC I	0.206	0.066	0.103	0.085	0.111
LC II	0.178	0.088	0.103	0.085	0.111
LC III	0.273	0.124	0.102	0.084	0.109
LC IV	0.222	0.107	0.108	0.095	0.116

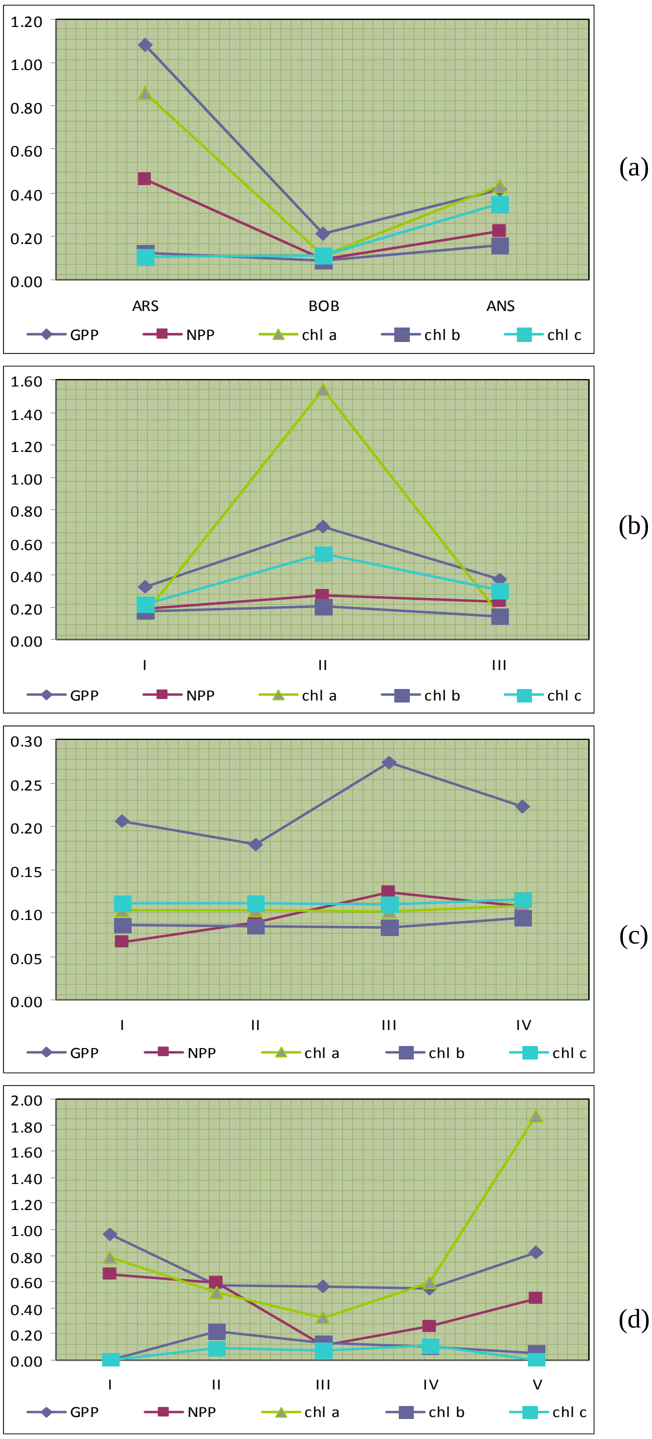
Any geography, riverine input responsible for this zigzag nature of GPP and NPP.

Andaman Sea is having an average value of primary productivity in between that of Arabian Sea and Andaman waters. The central region of Andaman waters is found to be more productive than the northern and southern parts. The ratio between them varies; may be due to the lesser depth of the region and the influence of many small land masses in between (Table. 3.11).

Table.3.11. Latitudinal variation in the primary productivity and Chlorophyll, in the clusters of Andaman Sea Seasonal variation:

ANS cluster	GPP ($gC/m^3/day$)	NPP ($gC/m^3/day$)	chl *a* µg/l	chl *b* µg/l	chl *c* µg/l
LC I	0.326	0.188	0.158	0.175	0.218
LC II	0.698	0.270	1.538	0.202	0.526
LC III	0.368	0.236	0.148	0.143	0.302

The seasonal variation in primary productivity and chlorophyll of Arabian Sea is given in the table. (Table. 3.12)



Graph 3.3 Variation in GPP, NPP, Chl *a*, Chl *b* and Chl *c*

(a) EEZ (b) ANS (c) BOB (d) ARS

GPP and NPP in gC/m^3/day Chl concentration in µg/l

Table.3.12. Seasonal variation in the primary productivity and Chlorophyll, in the clusters of Arabian Sea

ARS	GPP (gC/m^3/day)	NPP (gC/m^3/day)	chl *a* μg/l	chl *b* μg/l	chl *c* μg/l
NEM	0.421	0.260	0.354	-	-
PRM	0.729	0.451	1.704	-	-
SWM	0.761	0.618	0.581	0.126	0.098

The south west monsoon season is having a maximum productivity; the same trend is present for both the GPP and NPP. The difference in GPP and NPP is in the pre-monsoon season and NEM is also having a higher variation between GPP and NPP. The inshore waters are found to have a higher GPP than the oceanic waters but the NPP is having a reverse phenomenon on averaging (Table.3.13).

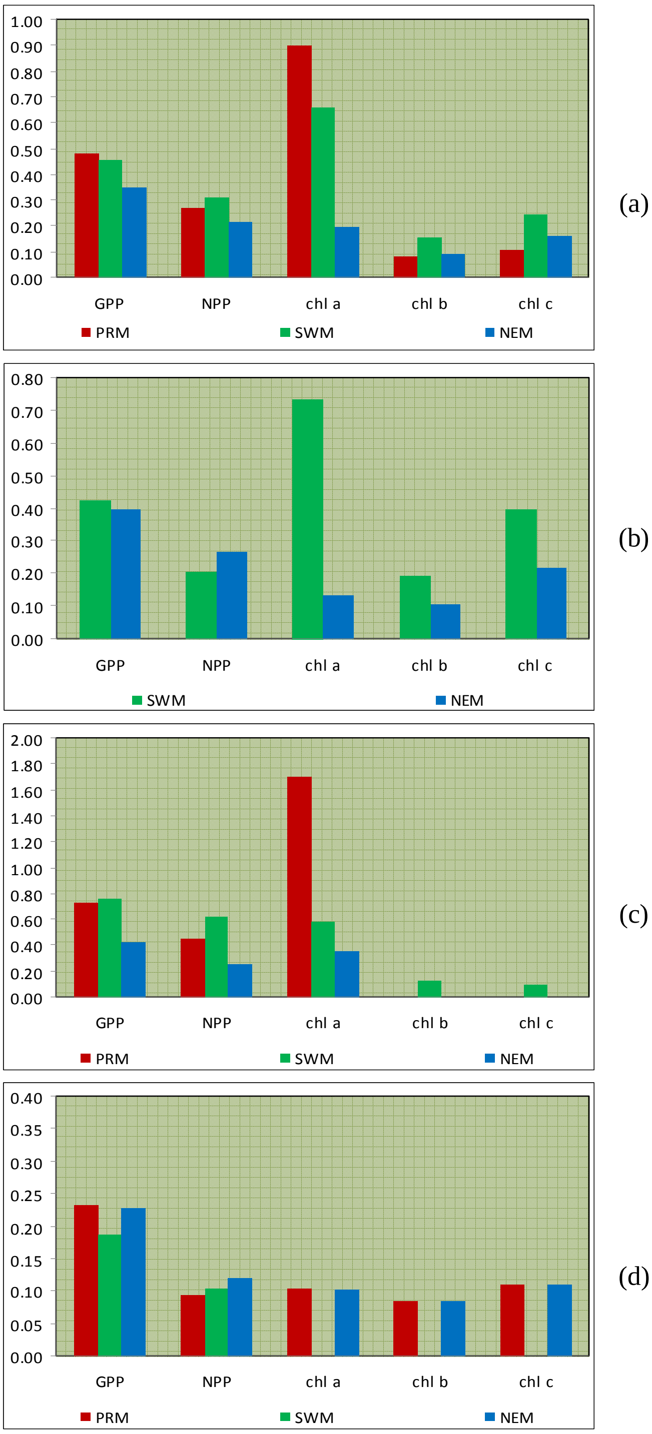
Table. 3.13. Seasonal variation in the biological variables, Primary productivity and chlorophyll in Bay of Bengal

BOB	GPP (gC/m^3/day)	NPP (gC/m^3/day)	chl *a* μg/l	chl *b* μg/l	chl *c* μg/l
PRM	0.233	0.094	0.104	0.084	0.109
SWM	0.188	0.104	--	--	--
NEM	0.228	0.120	0.103	0.085	0.111

The average values of the GPP and NPP are prepared seasonally and concluded that the Bay of Bengal region is having a lower GPP in the south west monsoon where as the PRM is having a lesser productivity. The difference in the value of GPP and NPP is more in the PRM season.

Table 3.14. Seasonal variation in the biological variables, Primary productivity and chlorophyll in Andaman Sea

ANS	GPP (gC/m^3/day)	NPP (gC/m^3/day)	chl *a* μg/l	chl *b* μg/l	chl *c* μg/l
NEM	0.400	0.265	0.132	0.103	0.216
SWM	0.424	0.206	0.736	0.192	0.396



Graph 3.4 Seasonal variation in GPP, NPP, Chl *a*, Chl *b* and Chl *c*

(a) EEZ (b) ANS (c) BOB (d) ARS

GPP and NPP in $gC/m^3/day$ Chl concentration in µg/l

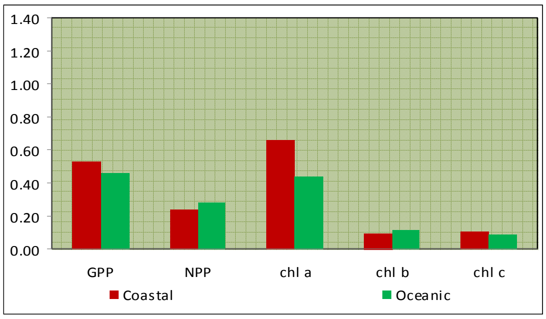
In Andaman Sea, only two seasonal sampling was present. The variation between these two cannot be considered as true values because the sampling was done during the same cruise and moreover the no of stations studied are very less (Table. 3.14).

There are several studies regarding the varioan in the waters of coastal inshore and oceanic offshore water. For the spatial variation studies the grouping of the data is carried out as given in Table. 3.15.

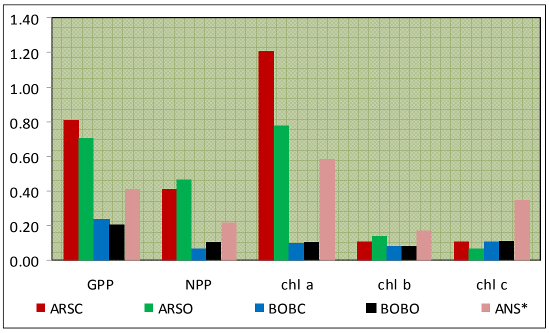
Table 3.15. Depth wise variation in the biological variables, Primary productivity and chlorophyll in EEZ

	GPP ($gC/m^3/day$)	NPP ($gC/m^3/day$)	chl *a* µg/l	chl *b* µg/l	chl *c* µg/l
ARSC	0.815	0.411	1.216	0.111	0.113
ARSO	0.712	0.470	0.777	0.147	0.070
BOBC	0.244	0.070	0.104	0.084	0.109
BOBO	0.205	0.100	0.103	0.086	0.111
ANS*	0.417	0.224	0.585	0.170	0.351

(* There is no differentiation of coastal and oceanic regions in the present study.)



(a)



(b)

Graph 3.5 Spatial variation in GPP, NPP, Chl *a*, Chl *b* and Chl *c*

a: EEZ b: Region wise

GPP and NPP in $gC/m^3/day$ Chl concentration in µg/l

The variation in the coastal and oceanic region is having several supportive evidences. GPP is found to be higher in the coastal areas of Arabian Sea and Bay of Bengal. But there are certain evidences from the central Arabian Sea having a higher primary productivity than the inshore waters. NPP showed a much lower value in the coastal area than oceanic area. The same feature is found in the present study also, as in the case of NPP.

Diurnal variation in the productivity is found to be interesting; the GPP is steadily increasing from the morning hours to evening. But a higher GPP in the evening may be due to the inclusion of a bloom station data. The NPP was found to be oscillating, but with a peak in the evening (Table3.16).

The diurnal variation in the EEZ may be studied for the first time. There is a need of more and more studies to observe the natural phenomena in a scientific way. Primary production of the randomly sampled stations is taken for averaging and the present classification also may have some demerits.

Table 3.16. Diurnal variation in the biological variables, Primary productivity and chlorophyll in Arabian Sea

ARS	GPP ($gC/m^3/day$)	NPP ($gC/m^3/day$)	chl *a* µg/l	chl *b* µg/l	chl *c* µg/l
DSR	0.473	0.294	0.847	-	-
DMO	0.580	0.303	0.568	0.124	0.098
DMN	0.900	0.261	1.203	0.120	0.080
DAN	0.878	0.321	0.743	0.085	0.050
DEV	1.704	1.883	0.722	0.173	0.103
N	-	-	1.253	0.120	0.169

The diurnal variation in the Bay of Bengal was also showed much variation from sunrise to the afternoon, a general trend of lowering of GPP from the time of sun rise to the after noon. But the NPP had a reverse trend (Table.3.17).

Table 3.17. Diurnal variation in the biological variables, Primary productivity and chlorophyll in Bay of Bengal. Sea

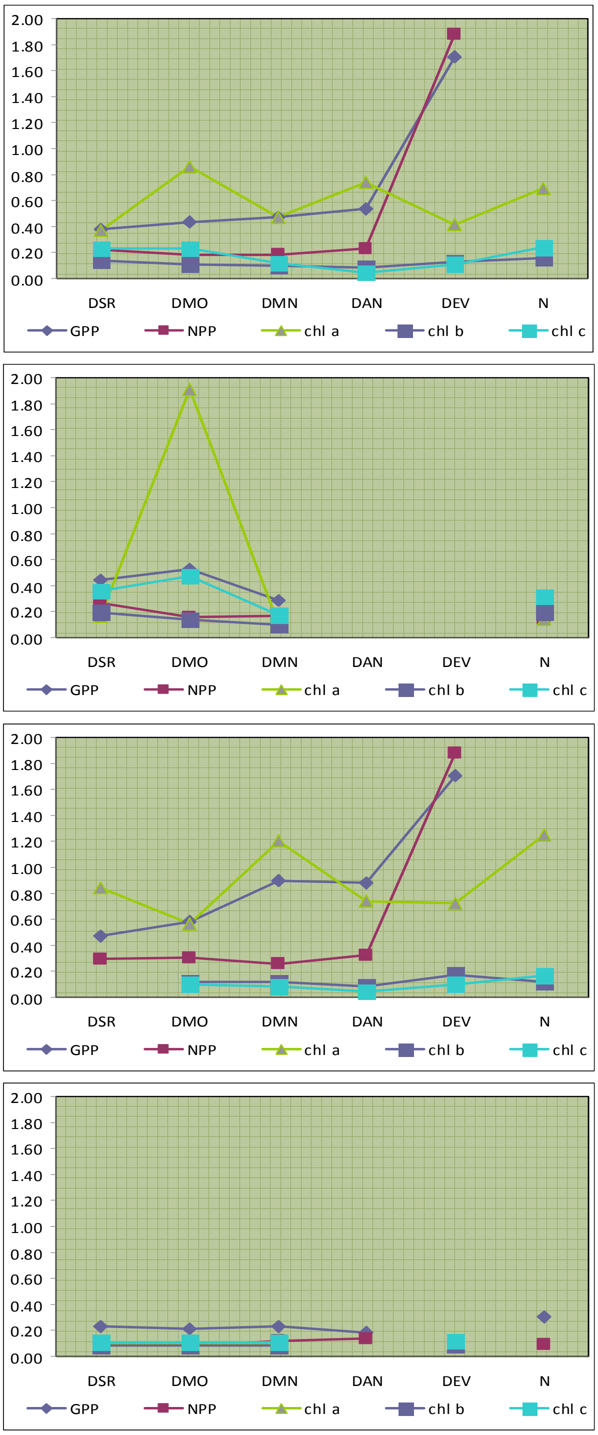
BOB	GPP (gC/m^3/day)	NPP (gC/m^3/day)	chl *a* µg/l	chl *b* µg/l	chl *c* µg/l
DSR	0.233	0.094	0.104	0.084	0.109
DMO	0.211	0.082	0.103	0.085	0.111
DMN	0.228	0.120	0.103	0.085	0.111
DAN	0.188	0.140	-	-	-
DEV	-	-	0.108	0.095	0.116
N	-	-	-	-	-

The variation in GPP and NPP is to be explained with the help of several references.

Table 3.18. Diurnal variation in the biological variables, Primary productivity and chlorophyll in Andaman Sea

ANS	GPP (gC/m^3/day)	NPP (gC/m^3/day)	chl *a* µg/l	chl *b* µg/l	chl *c* µg/l
DSR	0.444	0.273	0.163	0.196	0.361
DMO	0.525	0.158	1.905	0.135	0.474
DMN	0.285	0.165	0.102	0.103	0.177
DAN	-	-	-	-	-
DEV	-	-	-	-	-
N	-	-	0.143	0.192	0.318

The diurnal variation in the Andaman waters is found to be increasing from the sunrise to the morning hours and then it regularly lowers to night, although there is no data on GPP and NPP during the afternoon and evening hours.



(a)

(b)

(c)

(d)

Graph 3.6 Diurnal variation in GPP, NPP, Chl *a*, Chl *b* and Chl *c*

(a) EEZ (b) ANS (c) BOB (d) ARS

GPP and NPP in gC/m^3/day Chl concentration in µg/l

Chlorophyll '*a*'

The absorption of light and subsequent conversions into chemical energy is facilitated by the pigments present in the chloroplast of autotrophs. The capacity to convert the energy thus depends on the pigments, present in these organelles. Generally the estimation of standing crop or productivity is measured in terms of chlorophyll *a*. the All models of primary productivity use chlorophyll as their index of phytoplankton biomass (Huot et al, 2007). However, due to the pronounced variability of its cellular content and its ratio with respect to phytoplankton carbon, the concentration of total chlorophyll *a* is a biased estimator of phytoplankton biomass as organic carbon (Cullen, 1982). This variability could also reduce the ability to estimate PP. The variation in chlorophyll a is depicted in the tables.3.8-3.16.

The mean surface water chlorophyll *a* concentration of the EEZ (combined data of three sampling locations, ie., ARS, ANS and BOB) was found to be 0.689µg/l during the study period. It was reported that the annual average of chlorophyll *a* from the south west coast of India (Kerala coast) was 28.57µg/l (Sanilkumar, 2009). However, Sarupria and Bhargava, (1998) reported that it was 13.4µg/l for the entire euphotic zone of EEZ of Arabian Sea from 1962 to 1988. The surface water off Gopalpur, in the Bay of Bengal, chlorophyll *a* was found between 3.31 to 99.12µg/l (Panigraphy *et al*., 2006). The concentration of surface chlorophyll *a* varied between 0.21 to 30.82µg/l off Mangalore, west coast of India (Lingadhal *et al*., 2003). The highest chlorophyll *a* value observed during the post monsoon off Cape Comorin was 8.28µg/l (Gopinathan et al., 2001). The present investigation was carried out extensively in the off shore waters where the contribution of nutrient loading from the estuaries as well as the upwelling was meagre, a comparatively lower values of chlorophyll *a* has been detected.

Statistical analysis:

Diversity indices:

Shannon - Wiener index (H’), Margalef richness index (d), Pielou’s evenness index (J’), and Simpson index (λ) are calculated using PRIMER 6 (See Annexure III)

ARABIAN SEA

Species richness (Margalef’s index, d): The species richness of the micro phytoplankton among the entire Arabian Sea stations showed highest value at station number 960 (12.43) and lowest value at station number 1150 (1.44) with a mean value of 3.88±2.47 (n=93)

Evenness index (Pielou’s index, J’): The species evenness of the micro phytoplankton among the entire Arabian Sea stations showed highest value at station number 1147a (0.97) and lowest value at station number 1147 b (0.006) with a mean value of 0.70±0.25(n=93)

Species diversity (Shannon index, H’): The species diversity of the micro phytoplankton among the entire Arabian Sea stations showed highest value at station number 960 (4.00) and lowest value at station number 1147 b (0.01) with a mean value of 2.04±0.90(n=93)

Species dominance (Simpson’s index, λ): The species diversity of the micro phytoplankton among the entire Andaman Sea stations showed highest value at station number 1147 b (0.99) and lowest value at station number 960 (0.02) with a mean value of 0.27±0.25(n=93)

BAY OF BENGAL

Species richness (Margalef’s index, d): The species richness of the micro phytoplankton among the entire Bay of Bengal stations showed highest value at station number 1231 (5.31) and lowest value at station number 866 (0.65) with a mean value of 2.79±0.82 (n=73)

Evenness index (Pielou's index, J'): The species evenness of the micro phytoplankton among the entire Bay of Bengal stations showed highest value at station number 1171 (0.99) and lowest value at station number 874 (0.00002) with a mean value of 0.84±0.21(n=73)

Species diversity (Shannon index, H'): The species diversity of the micro phytoplankton among the entire Bay of Bengal stations showed highest value at station number 1240 (3.11) and lowest value at station number 874 (0.00006) with a mean value of 2.29±0.64(n=73)

Species dominance (Simpson's index, λ):

The species diversity of the micro phytoplankton among the entire Bay of Bengal stations showed highest value at station number 874 (0.99) and lowest value at station number 1240 (0.04) with a mean value of 0.17±0.19(n=73)

ANDAMAN SEA

Species richness (Margalef's index, d): The species richness (the number of species occupying a particular area or biological entity without regard to any other properties of the species) of the micro phytoplankton among the entire Andaman Sea stations showed highest value at station number 1213 (3.99) and lowest value at station number 1209 bl (1.94) with a mean value of 3.18±0.54(n=16)

Evenness index (Pielou's index, J'): The species evenness (ie how evenly the species are distributed in an area) of the micro phytoplankton among the entire Andaman Sea stations showed highest value at station number 1201 (0.98) and lowest value at station number 1209 bl (0.008) with a mean value of 0.81±0.25(n=16)

Species diversity (Shannon index, H'): The species diversity (ie the number of species in a given community and the way the species abundance are distributed among species) of the micro phytoplankton among the entire Andaman Sea stations showed highest value at station number 1203 (2.90) and lowest value at station number 1209 bl (0.02) with a mean value of 2.22±0.69(n=16)

Species dominance (Simpson's index, λ): The species diversity (ie the relative occurrence of the species with respect to other species) of the micro phytoplankton among the entire Andaman Sea stations showed highest value at station number 1209 bl (0.99) and lowest value at station number 1203 (0.05) with a mean value of 0.19±0.23(n=16)

SIMILARITY PLOTS:

Similarity plots are prepared for the assessment of variation among the stations based on the species composition and abundance of microaglae. Seasonal – PRM, SWM and NEM; spatial –coastal and oceanic, latitudinal- clusters of three degrees and diurnal factors are used for the preparation of Bray Curtis similarity plots and MDS plots. It is done separately for the three parts of EEZ, namely Arabian Sea, Bay of Bengal and Andaman Sea and the analysis revealed that the best factor that can be used for the similarity plot is the season, i.e., there is great seasonal variation in the planktonic microalgae in the surface waters of EEZ.

Bray Curtis Similarity Cluster Plots:

The analysis of the similarity plot for Arabian Sea, gives an idea on clustering of stations based on seasons. The most similar five stations have more than 70% of similarity and two stations of them are belonging to SWM (Station no.744 and 745 and 753 and 754) and three of them to NEM (station no. 980 and 981; 1124 and 1148; 1127 and 1138). All the five pairs given above are having a similarity of 70%. The most dissimilar ones are 944 and 945. The *Trichodesmium* bloom stations of Arabian Sea 1107b and 1147 bl are having a similarity of 40% (Figure 3.1).

Similarity plot of Bay of Bengal revealed the clustering of three *Trichodesmium* bloom stations of north east monsoon season having a similarity of more than 60%; and they are most dissimilar cluster with other stations. The other stations with 60% similarity are 865 and 890 of NEM and 1157 and 1165 of SWM (Figure 3.2).

In Andaman Sea, the most similar ones are belonging to SWM and 50 % similarity between 1207 and 1210 as the highest similarity. The most dissimilar one is the bloom station of south west monsoon season, 1209 bl. The taxonomic distinctiveness of the stations can be studied by this method. The variation in species diversity, abundance and influence of the coexisting biota are revealed through the similarity cluster plots (Figure 3.3).

MDS Plot:

MDS plots are drawn two get an idea on the characters of the clusters and distinctiveness at a particular percentage of similarity. 6 clusters exist in the Arabian Sea with four outer most clusters of SWM season and two large clusters one mainly composed of SWM stations and the other with NEM and PRM stations are distributed in both (Figure 3.4).

The MDS plot of Bay of Bengal prepared by the seasonal factor at 10% similarity yielded with 5 clusters, 3 larger representing the three seasons- namely PRM, SWM and NEM and 2 smaller clusters. The clustering in PRM cluster is more intense and thus very distinct from the other seasonal clusters. SWM cluster is also distinct, but with more spread nature. The PRM cluster is having both SWM and NEM stations in between. The bloom stations were clustered together and it is highly different from other clusters. Another smaller cluster was only one station, Station No. 1164, but it is related to the south west monsoon cluster in some way or the other (Figure 3.5).

The MDS plot of Andaman waters based on seasons is found to have 4 clusters at 25% similarity. The Larger cluster is of SWM season and the bloom station of SWM is distinct and forms a mono station cluster, where as the other two is having three clusters in each (Figure 3.6).

The analysis of the similarity plots revealed that the similarity among species is having a relationship within a season; but it is not so rigid and distinct. The diurnal variations, latitudinal factors are taken for preparing the MDS plots. It is found that the clustering is more distinct if the selection of season is taken as a factor for grouping.

K-Dominance Curve

The k dominance curve is prepared for all the three regions, viz. ARS, BOB and ANS and it was found that they are different from one another, depicting high variation in the dominance of the species seasonally. In order to demonstrate there influence of high standing crop during bloom two types of curves are prepared one excluding bloom station and other including bloom station. Group averaging is carried out for the analysis. In Arabian Sea, the diversity and relative contribution of each species is uniform in the case of NEM than SWM and PRM, if the plot is using the bloom station. When the exclusion has carried out the SWM is found to be more diverse. The pattern of monsoonal curves is found to be similar (Figure 3.7).

All the three blooms of Bay of Bengal were within the season of warmer PRM, by which the curve of PRM is somewhat parallel to the X axis. And the dominance of the first species over others is illustrated by this diagram. The surface water of the pre-monsoon season is found to be diverse and stable than the other two seasons, monsoonal seasons (Figure 3.8).

In the k-dominance plots of Andaman waters, the bloom condition was responsible for the paralleling of the SWM curve with X axis. The distinctiveness is more in the NEM curve (Figure 3.9).

Funnel plot:

The funnel plots of Arabian Sea, both Delta+ and lambda + skewness gives the idea about the community structure. The stations having high ecological stability, healthier, having diversity is seen in the middle region of the pointed portion of the funnel. The stations seen outer to the funnel is entirely different within the system. The bloom stations are seen within the clustering seen at the base of the funnel. The delta + plots are much better to the stations of Arabian Sea. The stations of south west monsoon season of cruise no. 198 are found to have better performance. Most of them are coastal stations having a higher species number (Figure 3.10)

The plots of Bay of Bengal had a clustering of the stations at the neck of the funnel. There are several stations, outer to the funnel. All of them are from the cruise no. 193. The station no. 867 is lacking diatoms, the reason for its peripheral positioning (Figure. 3.11).

Both the funnel plots of Andaman Sea is having stations in the pipe part of the funnel and having a consistent performance. In the lambda curve there is a clustering of stations, than the delta plots(Figure. 3.12).

Several trends present in the microalgal distribution were observed during the present study. Even though the trends in variation were not so conspicuous on grouping and averaging, there was considerable impact of seasons, regions, latitude and depths on the microalgal distribution.

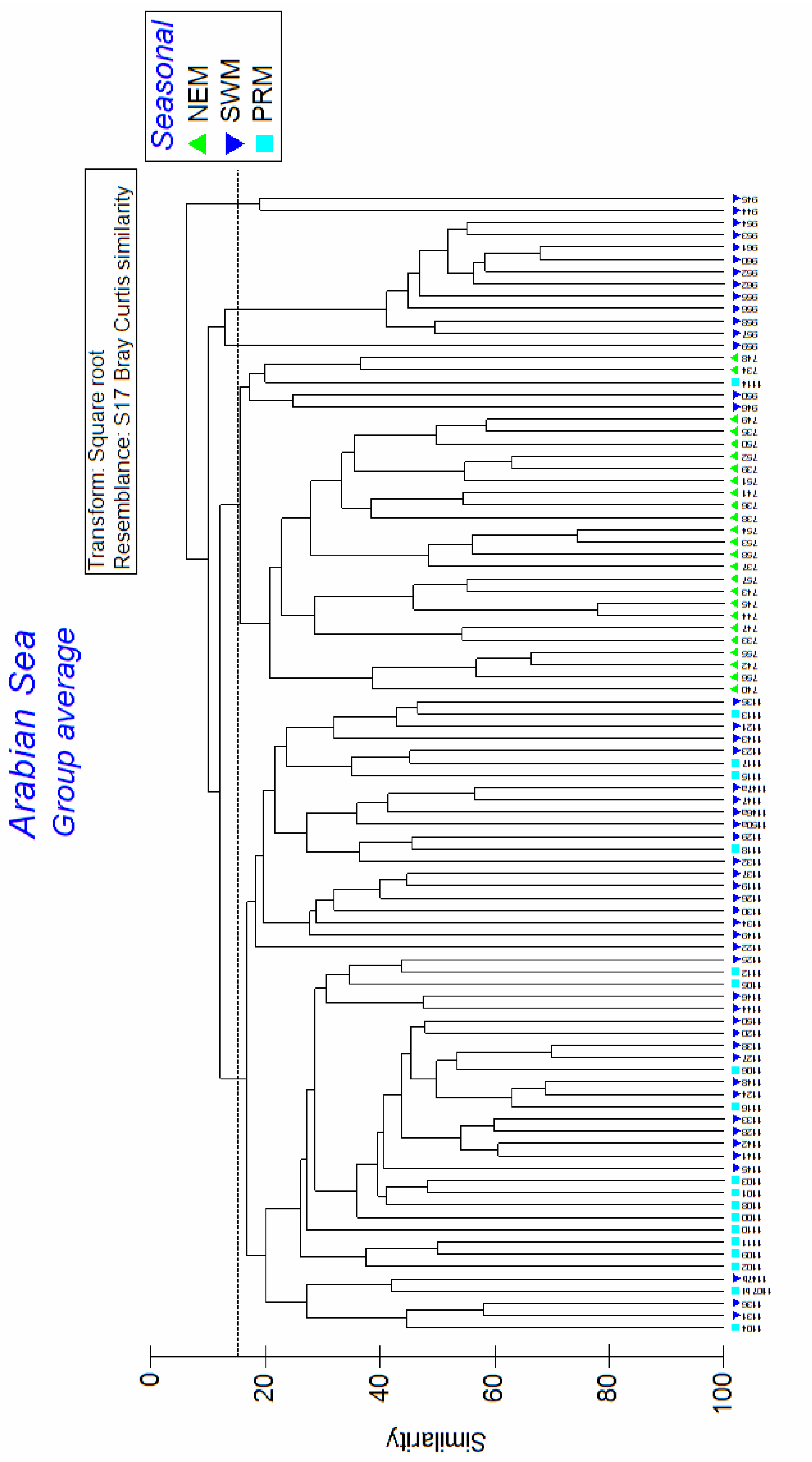


Figure 3.1 Cluster Plot of Arabian Sea

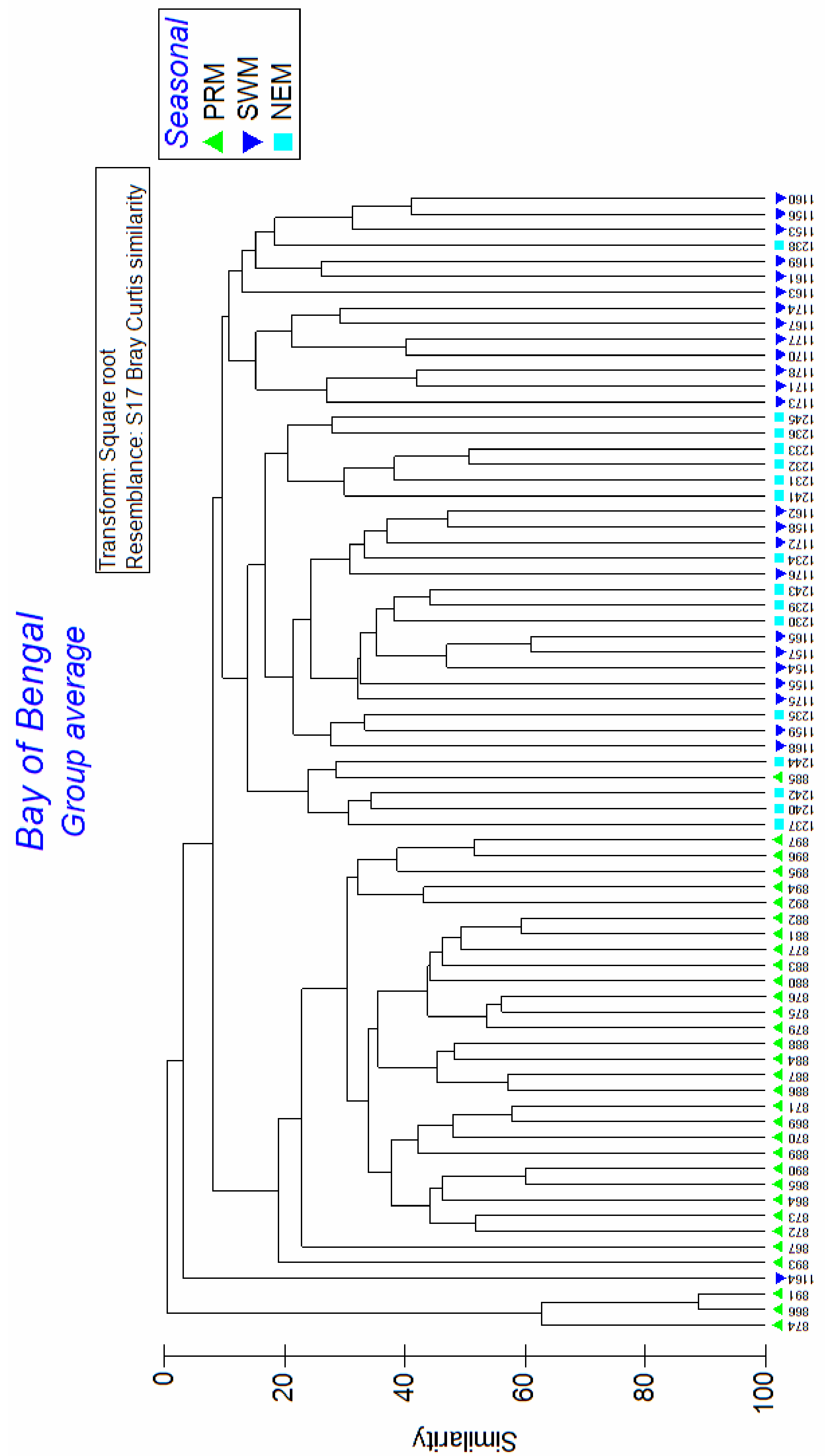


Figure 3.2 Cluster Plot of Bay of Bengal

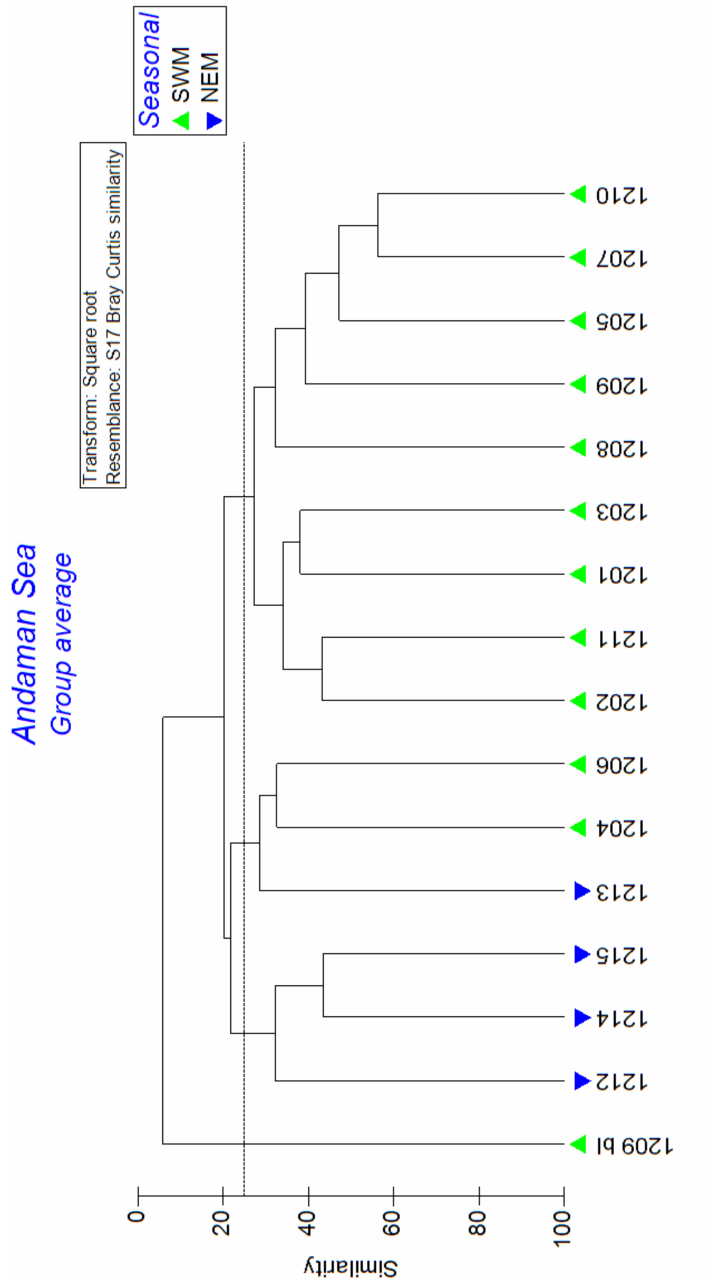


Figure 3.3 Cluster Plot of Andaman Sea

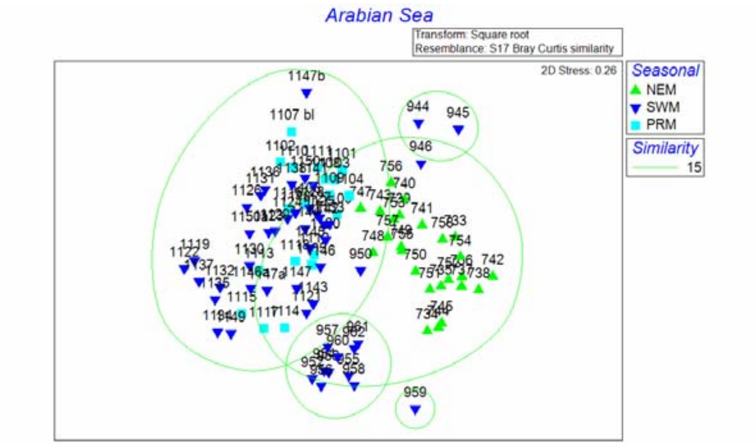


Figure 3.4. MDS Plot of Arabian Sea

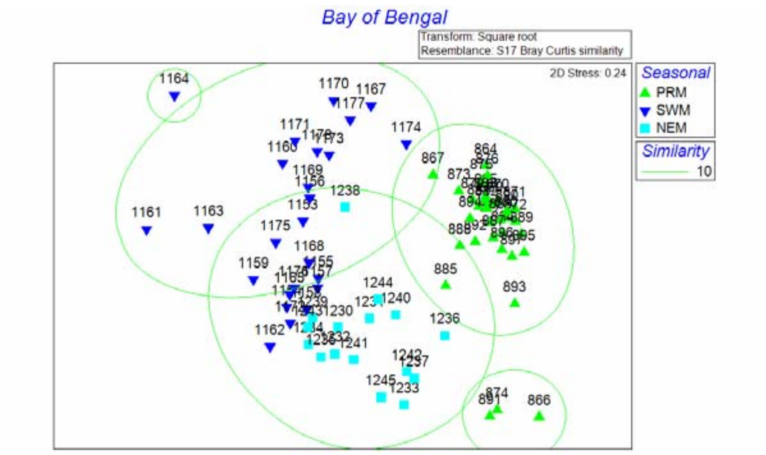


Figure 3.5. MDS Plot of Bay of Bengal

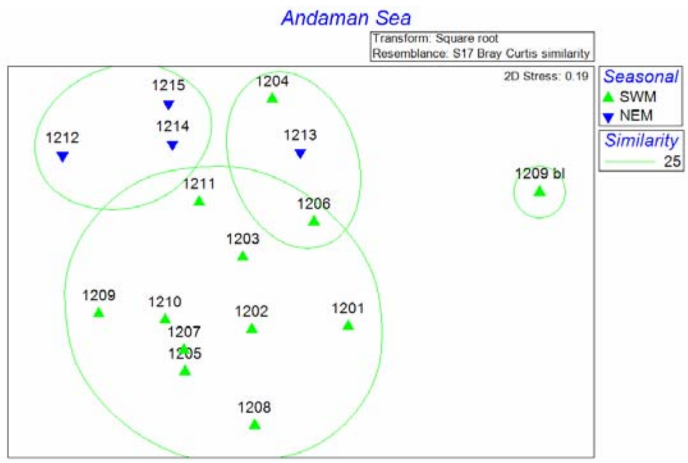
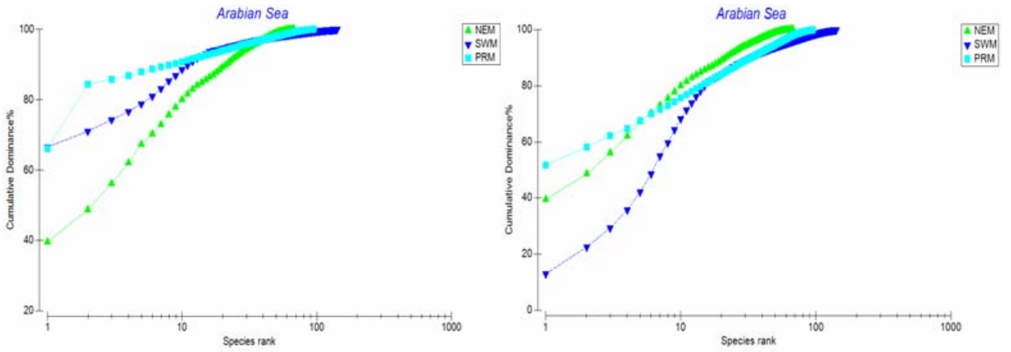
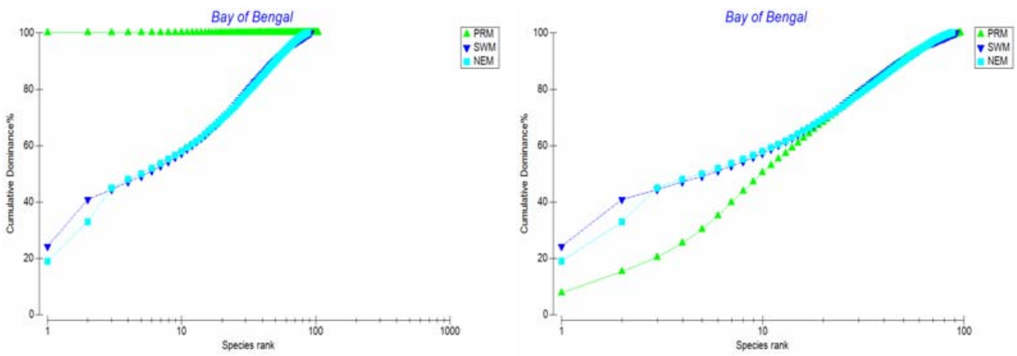


Figure 3.6. MDS Plot of Andaman Sea



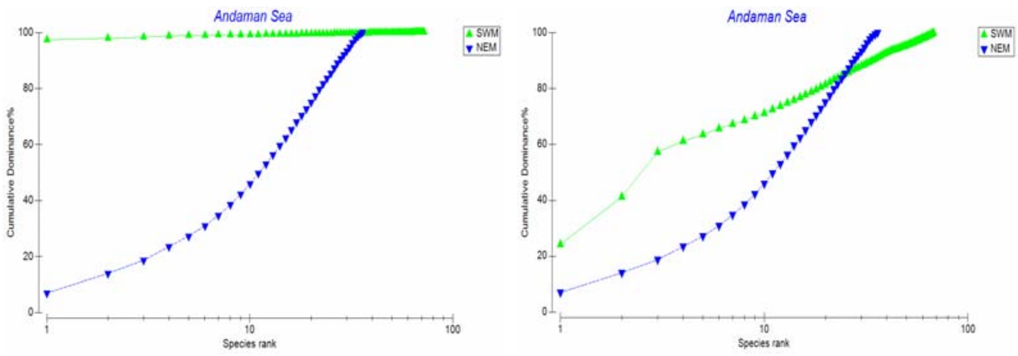
(a) (b)

Figure 3.7 K-Dominance Curve of Arabian Sea



(a) (b)

Figure 3.8 K-Dominance Curve of Bay of Bengal



(a) (b)

Figure 3.9 K-Dominance Curve of Andaman Sea

(a) With Bloom (b) Without Bloom

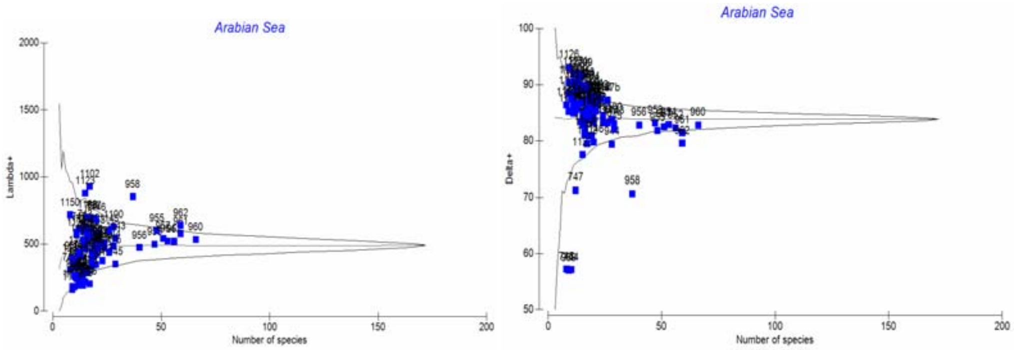


Figure 3.10 Funnel plot of Arabian Sea

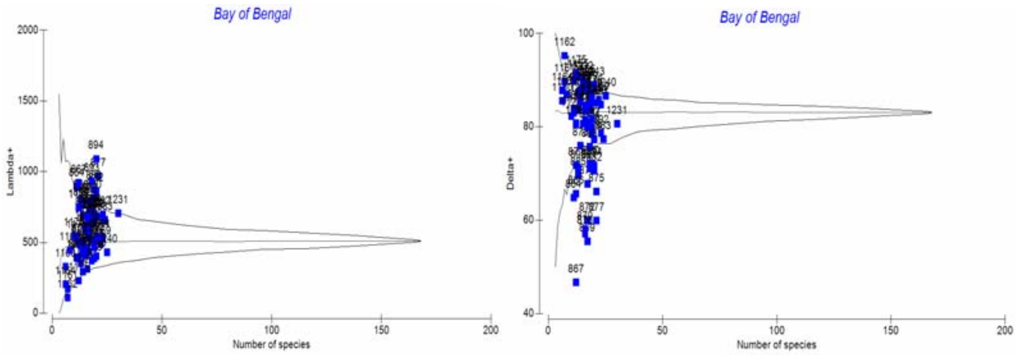


Figure 3.11 Funnel plot of Bay of Bengal

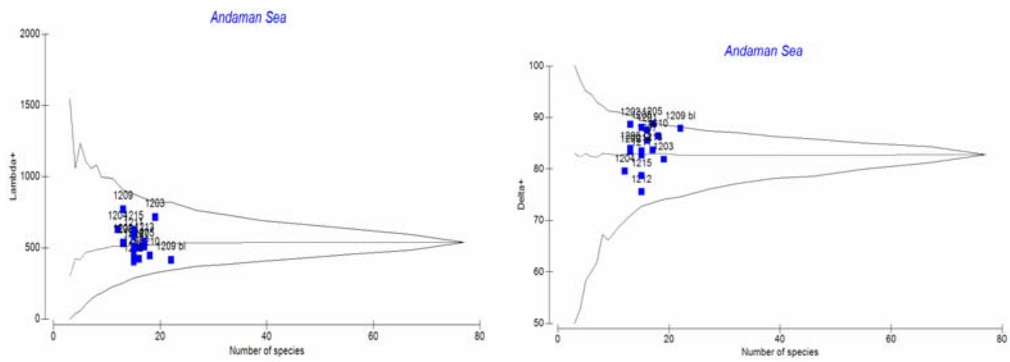


Figure 3.12 Funnel plot of Andaman Sea

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Chapter 4

HYDROGRAPHY AND PLANKTONIC MICROALGAE

Contents

4.1 Introduction

The elemental composition of the sea water is representing the steady state ratio of the oxidized organic matter. Autotrophic organisms utilize nitrogen and phosphorous in the proportion in which they are found in sea water and return these elements back to sea water upon their death and decomposition. Hydrographic conditions determine the existence of communities in an aquatic ecosystem and the knowledge of these conditions are inevitable during the study of dynamics of oceanic biome especially microalgae. The interaction of an organism with its environment and its cohabitants determines the size of its population and distribution. Phytoplankton biomass, distribution and species composition change continuously with variations in environmental temperature, light, nutrient availability, grazing pressure, tide and water movements, seasons and even with time of day. Planktonic microalgae are the primary producers of the pelagic marine ecosystems and naturally variation in the algal community reflects in subsequent trophic levels and communities. The interaction of these microscopic organisms with the surrounding living and nonliving factors, modifies the features of these living and nonliving factors. In the case of an algal bloom, the sudden proliferation of one or two microalgal species in the water column results in modification of the community structure based on the nature of the species bloomed and the hydrographical features like viscosity, transparency, dissolved oxygen, pH, etc., may change in that particular area. The astonishing species diversity in phytoplankton communities known as the paradox of phytoplankton diversity (Hutchinson, 1961), has stimulated many studies of the importance of competition for light and/or nutrients, or of the intermediate disturbance hypothesis (Elliott *et al*., 2001).

Coastal marine microplankton is composed of species with short life cycles, strongly affected by the seasonal fluctuation of the abiotic factors (Moscatello *et al*., 2004). Environmental changes could prevent phytoplankton diversity from reaching a state of stable equilibrium if those changes are frequent enough to reverse competitive hierarchies before exclusion occurs (Hutchinson, 1961; Sommer *et al*., 1993; Floder and Sommer, 1999). The variation of phytoplankton succession is strongly linked with meteorological and water stratification mixing processes, patterns in temperate ecosystems differ considerably from those of tropical waters (Wetzel, 2001).

This chapter analyses the influence of hydrographic parameters that have a physico chemical nature and their correlation studies to standing crop, primary productivity and pigment composition.

4.2 Review of Literature

The distribution of phytoplankton biomass is largely associated with nutrient availability at large, medium and small spatial scales by biophysical processes like the light environment, water column stratification/turbulence, temperature and grazing. (Platt, 1972; Joint and Pomroy, 1981; Pennock and Sharp, 1994). Increased N loading has been associated with eutrophication and declines in water quality. It has been well documented that initial changes in aquatic communities due to increasing eutrophication begin with the successions in the species composition and abundance of phytoplankton

(Ignatiades *et al*., 1985, Smith *et al.,* 1999, Danilov and Ekelund, 1999). Eutrophication as a result of anthropogenic input of nutrients has been reported in many aquatic systems (Smith *et al*., 1999). Many nutrients may potentially limit algal growth and accumulation in aquatic systems (Fisher *et al*., 1999). In highly turbid coastal waters where nutrients are present at moderate to high concentrations, light availability is usually the limiting factor for primary production (Underwood and Kromkamp, 1999). In such conditions, the distribution of phytoplankton biomass can be expected to reflect horizontal gradients in those variables that modulate light availability (Pennock, 1985; Cloern, 2001). Environmental disturbances in aquatic systems, such as nutrient additions associated with inflow events, are known to influence phytoplankton community composition, species diversity, and biomass (Buyukates and Roelke, 2005). In many coastal waters, increasing nutrient enrichment accompanied by a variation in nutrient ratio profoundly affects the phytoplankton species composition and production, and eventually alters the ecosystem structure and function (Aktan *et al*., 2005). The environmental influences on phytoplankton and zooplankton in the African coastal lagoons was studied by Ramdani et al., (2009).

Endogenous rhythms also affect the diel distribution patterns of phytoplankton (Sournia, 1974; Nelson and Brand, 1979; Kamykowski, 1981; Cullen and Horrigan, 1981; Kana *et al.,* 1985; Demers *et al.,* 1986; Hsiao, 1992).

Several studies have shown that biodiversity and production decreases with the rise of human influence (Lehman and Smith, 1991; Turner and Rabalais, 1994; Lehman, 2000; Huang *et al*., 2004). Changes in the phytoplankton community representing an ecological succession also occur associated with such environmental gradients (Underwood and Kromkamp, 1999) in estuaries and coastal waters and because of their hydrodynamics and massive human settlements, especially estuaries are susceptible to anthropogenic impact. The integrity of marine ecosystem and microalgae is currently under risk worldwide (Flindt *et al.*, 1999; Kiddon *et al.*, 2003). Biomass, the species composition of phytoplankton communities influences the ecological status of a site, with particular species being good indicators of either high or low ecological status (Fathi et al., 2001; Borja, 2005).

Indian Scenario

The pioneer study on the hydrography and the phytoplankton ecology was also that of Subrahmanyan (1959a, 1959b) and Subrahmanyan and Sharma (1960). They studied not only about phytoplankton but also about zooplankton crop and their relationship to fish landings; physical and chemical factors influencing the distribution and abundance of phytoplankton and observations on meteorological and hydrological conditions with seasonal variation.

The results of investigations carried out along the shelf regions of India and Lakshadweep Sea were discussed in relation to the potential living resources by Nair et al. (1968) and Nair (1970, 1974). Shah (1973) presented the seasonal variation of phytoplankton pigments in the Lakshadweep Sea, off Cochin. The variation in physicochemical and biological variables in the eastern Arabian Sea from Cape Comorin to Kandla was described by Pillai et al. (2000). The concentration of major pigments in the west coast of India and their relation to major nutrients during the post-monsoon of October to November, 1999 was studied by Gopinathan et al. (2001). Distribution of chlorophyll pigments in the Arabian Sea off Mangalore in relation to nutrients was done by Lingadhal et al. (2003).

Similar studies have also been conducted along the east coast. The phytoplankton characteristics along the east coast has been studied very early by Ganapati and Rao (1953, 1958) and in the inshore waters of Mandapam by Prasad (1954, 1958) and Prasad and Nair (1960).

Cochin backwaters have been studied intensively for plant pigments (Qasim and Reddy, 1967), light penetration (Qasim et al., 1968), tidal amplitude (Qasim and Gopinathan, 1969), organic production (Qasim et al., 1969), nutrient cycle (Sankaranarayanan and Qasim, 1969), salinity tolerance of phytoplankton (Qasim et al., 1972), seasonal abundance of phytoplankton (Gopinathan, 1972) spatial and temporal distribution of the phytoplankton (Gopinathan et al., 1974; Joseph et al., 1975), contribution of nannoplankton (Qasim et al., 1974; Vijayaraghavan et al., 1974) and on primary productivity of entre estuarine system (Nair et al., 1975).

In East coast, Marichamy et al. (1985) studied the primary and secondary production in relation to hydrography in the inshore waters of Tuticorin for a period from 1983 to 1984. Primary production of the same region in relation to hydrographic parameters for the period from 1985 to 1987 was done by Gopinath and Rodrigo (1991). Krishnamoorthy (1954) studied the nutrients in relation to the plankton production in the inshore and the estuarine waters of Porto Novo and Krishnamoorthy and Santhanam (1974) and Santhanam et al. (1975) gave a descriptive account of the species distribution and quantitative ecology of the phytoplankton of the same region.

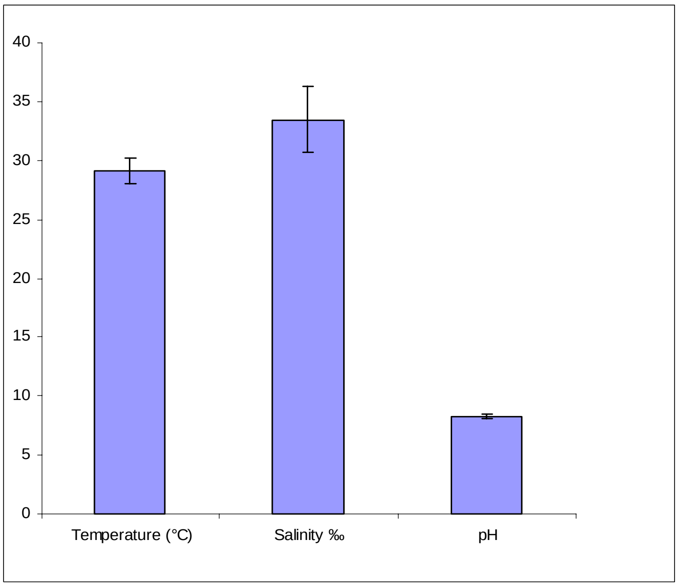
4.3 Results

Physical variables

The physical nature of the Indian EEZ showed much unevenness in all the three regions, Arabian Sea, Andaman Sea and Bay of Bengal (Table 4.1, Graph.4.1). The Physical variables studied, station depth, salinity, pH and temperature, showed considerable variations at different stations.

Table.4.1: Variation in studied Physical parameters in the EEZ

	Depth m		Salinity ‰		pH		Temperature °C	
	Range	Average	Range	Mean	Range	Mean	Range	Mean
ARABIAN SEA	30.6 to 4525	994.2	16.2 to 36.8	35.06	7.77 to 8.48	8.15	24.2 to 34.0	29.16
BAY OF BENGAL	21 to 2662	1772.4	24.1 to 34.4	31.75	8.00 to 8.66	8.35	26.6 to 30.5	29.19
ANDAMAN SEA	55 to 4064	2143.1	29.6 to 34.1	32.58	8.22 to 8.34	8.31	28.1 to 30.4	28.98
EEZ of INDIA	21 to 4525	1424.0	16.2 to 36.8	33.47	7.77 to 8.66	8.27	24.2 to 34.0	29.15



Graph.4.1. Mean value of Physical variables in the EEZ of India.

Station depth

The study of 191 stations during these cruises revealed the nature of Indian EEZ. Depth of the stations studied varied from 21m (station no. 1170 of cruise no. 205) in Bay of Bengal to 4525m (station no. 1133 of cruise no. 203) in Arabian Sea; with an average depth of 1424.01m. The depth of the three divisions also showed much variation in range and average. Andaman Sea is deeper than other seas of the EEZ, with a depth range of 55 m to 4064m having an average of 2143.1m; whereas Bay of Bengal has a depth range of 21m to 2662m with an average of 1772.4m. Arabian Sea has an average depth of 994.2 m with a wide range of 30.6 m to 4525m. Based upon the variation in the station depth the stations are subdivided into two, coastal stations and oceanic stations. There is no coastal station in the Andaman Sea because of a depth greater than 200m for all the stations studied (except station no. 878 of cruise no. 193 with a depth of 55 m). In the Arabian Sea, out of the 89 stations where microalgae have been collected and studied, 24 were coastal stations. The planktonic microalgae of Bay of Bengal were studied from 73 stations, out of which 16 were coastal ones. The microalgal biomass, composition and chlorophyll *a* and productivity showed positive correlation with depth (Table 4. 1.).

Salinity

Variation in salinity also influences the microalgal abundance and that may be the outcome of seasonal and spatial influence. The salinity had a range of 16.2‰ (station no. 944 of cruise no. 195) to 36.8‰ (station no.737 of cruise no. 184) in the EEZ as well as in Arabian Sea, 24.1‰ to 34. 4‰ in Bay of Bengal and 29.6‰ to 34.1‰ in Andaman Sea. The overall mean is 33.47‰; 35.06‰ in Arabian Sea, 31.75‰ in Bay of Bengal and 32.58‰ in Andaman Sea. The hypersaline condition was not observed during the study; but hyposaline ‘estuarine’ nature was found, starting from 16.2‰ (Table 4. 1.).

pH

The variation in pH was also very conspicuous during the study. The pH change in Arabian Sea was from 7.77 to 8.48, in Bay of Bengal from 8.00 to 8.66 and in Andaman Sea with very slight variation of 8.22 to 8.34. The region wise mean of the pH during the study was 8.15 in Arabian Sea, 8.35 in Bay of Bengal and 8.31 in Andaman Sea; an overall mean of 8.27 (Table 4. 1).

Temperature

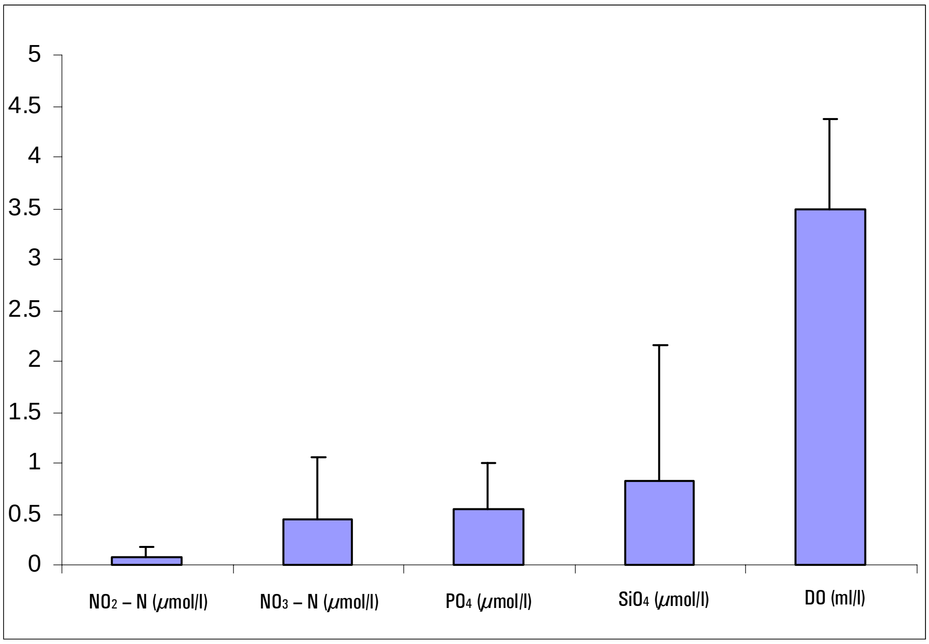
The sea surface temperature (SST) showed much variation from 24.2°C to 34.0°C having a mean temperature of 29.15°C with slight variation among the three regions of EEZ, 29.16°C at Arabian Sea and 29.19°C at Bay of Bengal, Bay of Bengal showed an average of 28.98 °C. The range of temperature showed at Arabian Sea is 24.2°C to 34.0°C the same as the overall average. Bay of Bengal had a temperature range of 26.6°C to 30.5°C whereas Andaman waters with a temperature range of 28.1°C to 30.4°C (Table 4. 1). Variation in temperature is correlated with seasonal diurnal variations and also on the biomass of microalgae.

Chemical variables

Out of 191 stations studied, two cruises were having no facility for nutrient analysis (cruise no. 189 and 194). Moreover most of the stations lack a significant amount of NO_2, NO_3 and SiO_4. The PO_4 was estimated in 145 stations (only 136 have values) and DO estimated from 156 stations. Lack of nutrient data of the surface water in most of the samples, especially of NO_2, NO_3 and SiO_4 makes the correlation study difficult. Significant amount of all the nutrients was found to be present in the deeper waters beyond 50m, in most of the stations. Bay of Bengal and Arabian Sea of the EEZ are having more SiO_4 and PO_4 enriched water than the Andaman waters (Table. 4. 2 and Graph.4.2).

Table.4.2: Variation in Chemical parameters of the sampled stations in the EEZ

	DO ml/l		NO_2 µmol/l		NO_3 µmol/l		SiO_4 µmol/l		PO_4 µmol/l	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
ARABIAN SEA	1.25 to 5.56	3.38	0.004 to 0.430	0.075	0.09 to 0.23	0.16	0.5 to 4.05	1.02	0.001 to 1.96	0.69
BAY OF BENGAL	1.69 to 5.35	3.60	-	-	0.01 to 2.23	0.47	0.01 to 7.97	1.05	0.09 to 4.12	0.52
ANDAMAN SEA	1.29 to 4.12	3.59	-	-	-	-	0.01 to 0.22	0.20	0.16 to 0.99	0.29
EEZ of INDIA	1.25 to 5.56	3.51	0.004 to 0.430	0.075	0.01 to 2.28	0.44	0.01 to 7.97	0.89	0.001 to 4.12	0.54



Graph. 4.2. Mean value of nutrients and DO in the EEZ of India

Dissolved Oxygen (DO)

The eastern part of the EEZ was found to have more DO than the Arabian Sea while considering the mean value of dissolved oxygen. The mean dissolved oxygen present in the EEZ was found to be 3.51 ml/l and the pattern of dissolved oxygen was BOB (3.60)>ANS (3.59)>ARS (3.38). Arabian Sea had a wide range of dissolved oxygen from 1.25 to 5.56 ml/l which was the same for EEZ also. The range of dissolved oxygen showed a pattern of ARS>BOB>ANS (Table. 4. 2).

NO_2

NO_2 in surface water was estimated only from Arabian Sea with a lower limit of undetectable amount to a higher concentration of 0.430 µmol/l and there is no data on NO_2 of surface water in any other areas of EEZ. The average value of nitrite was found to be 0.075 µmol/l in the surface waters of the Arabian Sea and EEZ (Table. 4. 2). The undetectable amount of NO_2 in most of the stations of EEZ makes it difficult to draw any statistical relationship between the variables.

NO_3

Nitrate -Nitrogen, was also less in the EEZ with a mean value of 0.438µ mol/L and the tendency of distribution is found to be BOB (0.46) >ARS (0.16)> ANS (0.07) (Table. 4. 2). Most of the stations with detectable amount of nitrate in surface water were in the Bay of Bengal, and there was no much relationship with the depth, season, or any other variable studied.

SiO_4

Silicate was found with a mean value of 0.89µmol/L in the EEZ and the pattern of quantitative distribution was found to be the same as that of NO3, but with very low value in the Andaman Waters (Table. 4. 2). Arabian Sea water has an average of 1.02 µ mol/l within the range of 0.5 to 4.05. The surface waters of BOB have a range from 0.01 to 7.97 (Station no. 1245 of cruise no. 209); average of which is 1.05 µ mol/l. The range of silicate in Andaman waters is found to be very less in comparison with that of BOB and ARS, ie, 0.01 to 0.22, with an average of 0.20µmol/l. Higher amount of silicate is found in the stations of Bay of

Bengal, all of which were sampled during November 2002. These stations of higher silicate content were from the latitudes of 17, 19 and 20^{o} N.

PO_4

The estimated average value of phosphate in the EEZ was higher in the Arabian Sea region followed by Bay of Bengal and Andaman waters. While 0.544 µmol/l was the average concentration of phosphate in the EEZ, it was 0.691 µmol/l in the ARS, 0.523 in the BOB and 0.292 µmol/l in the Andaman waters (Table. 4. 2). The range of Phosphate-P in the surface waters is found to be 0.01 to 1.96, 0.09 to 4.12, 0.16 to 0.99 and 0.01 to 4.12 µ mol/l in ARS, BOB, ANS and EEZ respectively. Highest amount of phosphate (4.12µmol/l) was measured from the samples of Cruise no. 205, station no.1163 of latitude 14.99^{o}N and 80.56 ^{o}E. The higher values were recorded during southwest monsoon season, irrespective of ARS or BOB.

Statistical Analysis

The results of the statistical analysis are given below in Table 4.3 -4.6.

Correlation

The correlation studies have been carried out to identify the relationship of standing crop with the nutrients. There was a significant correlation between total algae and salinity at 5% level and with nitrite at 1% level. Both of these correlations are negative correlations. Diatom also showed a negative correlation with salinity and nitrite at 1% level. The standing crop of dinoflagellate had a positive correlation with temperature and pH at 5% level and a negative correlation with nitrite and a positive correlation with Dissolved oxygen at 1% level (Table. 4. 3).

Table. 4.3. The correlation between the standing crop and hydrography.

	Total Algae	Total Diatom	Total Dinoflagella
Temperature	0.002	-0.010	0.147*
Salinity	-0.186*	-0.180*	-0.083
pH	0.073	0.067	0.215*
NO2 - N	-0.488**	-0.382*	-0.484**
NO3 - N	-0.282	-0.103	-0.254
PO4	0.028	0.027	0.004
SiO4	-0.063	-0.057	-0.119
DO	0.149	0.116	0.433**

(*****Correlation significant at 5% level; ******Correlation significant at 1% level)

Analysis of Variance (ANOVA)

Inorder to study the regional, seasonal, diurnal and spatial variation in standing crop of microalgae analysis of variance (ANOVA) has been carried out. The details of analysis are given in the Table 4.4. Region means the parts of EEZ, namely Arabian Sea, Bay of Bengal and Andaman Sea. Spatial variation is studied based on the grouping of stations having depth upto 200m as inshore coastal station and above 200m depth as oceanic offshore waters. The dominant classes of microalgae dinoflagellate and diatoms are also statistically analysed for variation (Table 4. 5 and Table 4. 6).

Table. 4. 4. The result of ANOVA, for the relationship between the total standing crop with Ocean, Season, Time and Depth.

Factor	Sum of Squares	df	Mean Square	F - value	Sig.
Region	1658901	2	829451	0.647^{NS}	0.525
Season	440020	2	220010	0.172^{NS}	0.842
Time	3838878	5	767776	0.599^{NS}	0.701
Depth	8022688	2	4011344	3.128^{S}	0.046
Error	223137098	174	1282397		
Total	237097585	185			

S- Significant NS → Not significant

Table. 4.5. The result of ANOVA, for the relationship between the diatom standing crop with Ocean, Season, Time and Depth.

Factor	Sum of Squares	df	Mean Square	F - value	Sig.
Ocean	2794396	2	1397198	1.112 NS	0.331
Season	1587573	2	793787	0.632 NS	0.533
Time	3978454	5	795691	0.633 NS	0.675
Depth	8071018	2	4035509	3.212 S	0.043
Error	218616356	174	1256416		
Total	235047797	185			

S ➔ Significant NS ➔ Not Significant

Table. 4. 6. The result of ANOVA, for the relationship between the dinoflagellate standing crop with Ocean, Season, Time and Depth.

Factor	Sum of Squares	df	Mean Square	F - value	Sig.
Ocean	164545	2	82273	18.994 S	0.000
Season	357861	2	178931	41.309 S	0.000
Time	62917	5	12583	2.905 S	0.015
Depth	6012	2	3006	0.694 NS	0.501
Error	753675	174	4331		
Total	1345010	185			

S ➔ Significant NS ➔ Not Significant

4.4 Discussion

Physical Variables

The mean of the depth, salinity, pH and temperature is given in the Table. 4.7 and variations in the physical variables are given in the tables 4.8-4.17.

Depth

Depth of the sea is a salient feature of the biome commonly used to demarcate the coastal and oceanic regions as well as the continental shelf, continental slope and abyssal regions. Arabian Sea is found to have a lesser average depth of 994.2 than the other two regions; although the deepest part of the EEZ belongs to Arabian Sea. Deeper parts of Indian EEZ are located between 10-15^{o}N and 71-75^{o}E of south eastern Arabian Sea, central Bay of Bengal (11-15^{o}N and 80-85^{o}E) and western part (5-10^{o}N and 90-93^{o}E) of Andaman Sea. There was no sampling station which can be classified as coastal in the Andaman Sea, except one at the central bay of Bengal with a depth of 55 m. The station might be having a geological structure that is different from that of the other ones. All the stations having a lower depth in the Bay of Bengal region had a distribution on the river mouths and transition from a region of lower depth to a deeper region is abrupt especially in the 11-15^{o}N regions. In Arabian Sea the costal stations are evenly distributed throughout the coast and the transition from deeper region to deepest region is very gradual, with some exceptional cases. (Figure 4. 1). The statistical analysis, ANOVA, using SPSS 11 revealed that there is a significant relationship between the standing crop of microalgae and depth (F-value 3.128 and a significance of +0.046). The number of diatom per liter and depth is also had a significant relationship (F-value 3.212 and a significance of +0.043). The standing crop of dinoflagellates and cyanophytes had no significant relationship with the depth, in the present study. The physical as well as chemical features of the coastal as well as oceanic region is different, thus a highly significant relationship is expected between the depth and standing crop.

In Arabian Sea the deeper parts are present in the cluster II, III and IV regions. Coastal stations have an average depth of 115.8 m where as the oceanic station were with 1382.4m depth.

Salinity

There is a clear variation in salinity seasonally, temporally and spatially. The average value of salinity is 33.49‰ with a standard deviation of ±2.79 (Table.4.7). According to Dawes (1998), the salinity of the ocean is generally between 32 ppt to 38 ppt. Salinity less than this magnitude is generally considered as estuarine. The hyper saline condition was not observed during the study whereas the hypo salinity with 16.2‰ at station no. 944 of cruise 195 in the Arabian Sea was observed. There are 29 stations having hypo salinity. Out of these 24 were from Bay of Bengal, between the latitudes of 15-20°N and longitudes of 82-89°E. Total stations covered in this region are 46 and thus 52% of the stations have an estuarine condition. These stations are having an input of water from Rivers Krishna, Godavari, Ganga and Brahmaputra. The hypo saline stations, station no.748 and 944, of Arabian Sea were near to the coastal regions, Off Vizhinjam and Off Goa; besides that both of them were during the monsoon season. The hypo salinity could be attributed to these two factors.

Table. 4.7 Mean and standard deviation of physical variables- surface temperature, salinity and pH in the EEZ

	Mean	Standard deviation
Temperature (°C)	29.11	1.08
Salinity (‰)	33.49	2.79
pH	8.26	0.17

There is a regional demarcation in salinity. In Arabian Sea, 10 stations having relatively higher salinity were noticed in the north eastern Part, nearby areas Off Mumbai. 26 stations were studied from this region. Seasonal variation cannot explain the high salinity, since the sampling was carried out in all the three seasons. The lack of mixing of surface water with the bottom water due to some hindrances may be the reason behind the higher salinity. Bay of Bengal had a higher salinity below the latitude of 15°N. Lack of mixing up of lower layers of water with the surface water during the non-monsoon season of the area may be the reason behind the higher salinity of the region. North eastern part of the Andaman Sea surface is found to be less saline which may be due to rain and riverine output of Iravathi. Southwestern as well as the south eastern part of the Andaman Sea experienced a higher salinity. The open ocean nature, well mixing of the surface layer along with the feeble influence of the season may be responsible for this variation. Salinity and total microalgae (correlation coefficient -0.186) along with diatom (-0.180) were found to be significantly correlated inversely at 5 % level. Dinoflagellate and salinity were found to be having an insignificant relation.

Temperature

The temperature also showed much variation in the EEZ. The mean sea surface water temperature of EEZ is 29.11±1,08^{o}C. The south as well as eastern part of the Andaman Sea had a lower temperature than the western Andaman Sea. Seasonal influence also may be there in such a thermal differentiation of the surface water. The cooler surface water was present in the northern Bay of Bengal during November and hotter surface water was mostly in the southern Bay of Bengal during April. In Arabian Sea, such delimitation was found to be meaningless. The correlation study revealed that the standing crop of dinoflagellate is having a positive relation with the temperature (0.147 at 1% level). The present study also revealed that there is no correlation of temperature with diatom and total microalgae.

In Arabian Sea, the region between the 10-13^{o}N was found to be cooler. The cluster wise thermal pattern of surface water is II<I <III<IV< V. The coastal regions are cooler than the oceanic surface waters, showing an average of 28.9^{o}C and 29.1^{o}C respectively. Seasonality of sea surface temperature was found to be PRM>NEM>SWM with average values of 29.94 ^{o}C, 29.15 ^{o}C and 28.62 ^{o}C. The high precipitation rate and upwelling along the west coast may be the reasons behind the cooling of surface water during south west monsoon season.

pH

Variation in pH was with a standard deviation of 0.17 from the mean pH of 8.26 in the surface waters of EEZ. The lower pH was observed in the surface waters of Arabian Sea during the May–June months where as more alkaline surface water was present in the Bay of Bengal during November. The variation in pH was not so conspicuous in the Andaman part of Indian EEZ. In Arabian Sea the acidic nature of the surface water was prominent during May-June months in the oceanic waters. Bay of Bengal experienced a lower pH in surface waters mostly in the southern part upto 15^{o}N during July. Alkaline surface waters were present in Bay of Bengal during November in the north eastern part. pH and dinoflagellate standing crop were found to be having a correlation at 5% level (correlation coefficient, 0.215); without significant relation with total standing crop of microalgae.

Table. 4.8. Latitudinal variation in physical variables- surface temperature, salinity and pH in Arabian Sea

ARS	depth	temp	salinity	pH
LC I	347.9	28.69	34.29	
LC II	1343.6	28.57	34.97	8.10
LC III	1453.1	29.54	35.21	8.14
LC IV	942.2	29.45	34.26	8.20
LC V	797.7	29.35	36.03	8.11

Table. 4.9. Latitudinal variation in physical variables- surface temperature, salinity and pH in Bay of Bengal

BOB	depth	temp	salinity	pH
LC I	2648.5	29.71	33.68	8.19
LC II	2005.2	29.49	33.23	8.21
LC III	2017.6	28.88	31.38	8.49
LC IV	1073.5	29.02	30.64	8.41

Table. 4.10. Latitudinal variation in physical variables- surface temperature, salinity and pH in Andaman Sea.

ANS	depth	temp	salinity	pH
LC I	2563.2	28.63	33.26	8.32
LC II	1910.6	28.44	32.70	8.31
LC III	1881.4	29.24	31.87	8.31

Table. 4.11. Seasonal variation in physical variables - surface temperature, salinity and pH in Arabian Sea.

ARS	depth	temp	salinity	pH
NEM	374.5	29.16	34.49	
PRM	1320.0	29.94	35.91	8.10
SWM	1257.9	28.63	34.85	8.16

Table. 4. 12. Seasonal variation in physical variables - surface temperature, salinity and pH in Bay of Bengal.

BOB	depth	temp	salinity	pH
PRM	1332.2	28.34	30.94	8.51
SWM	1806.6	29.42	31.77	8.2212
NEM	2283.5	29.36	32.63	8.47

Table. 4.13. Seasonal variation in physical variables - surface temperature, salinity and pH in Andaman Sea.

ANS	depth	temp	salinity	pH
NEM	2141.0	29.58	32.67	8.30
SWM	2034.3	28.59	32.41	8.32

Table. 4. 14. Spatial variation in physical variables - surface temperature, salinity and pH in the EEZ.

	depth	temp	salinity	pH
ARSC	115.8	28.90	34.91	8.18
ARSO	1382.5	29.18	35.08	8.12
BOBC	91.6	28.93	30.67	8.36
BOBO	2244.2	29.27	32.06	8.35

Table. 4.15. Diurnal variation in physical variables - surface temperature, salinity and pH in Arabian Sea.

ARS	depth	temp	salinity	pH
DSR	3100.7	29.96	35.31	8.10
DMO	601.6	29.08	34.84	8.18
DMN	897.7	29.20	35.27	8.10
DAN	900.8	28.55	35.51	8.14
DEV	1051.1	28.80	35.13	8.11
N	814.2	29.69	34.02	8.13

Table. 4.16. Diurnal variation in physical variables - surface temperature, salinity and pH in Bay of Bengal.

BOB	depth	temp	salinity	pH
DSR	1332.2	28.34	30.94	8.51
DMO	1613.5	29.50	32.62	8.25
DMN	2283.5	29.36	32.63	8.47
DAN	1648.2	29.46	30.28	8.37
DEV	2021.5	29.51	32.03	8.29
N	1957.8	28.83	30.65	8.52

Table. 4. 17. Diurnal variation in physical variables - surface temperature, salinity and pH in Andaman Sea.

ANS	depth	temp	salinity	pH
N	1897.4	28.67	32.67	8.32
DSR	2034.5	28.67	32.22	8.30
DMO	2396.9	28.94	32.39	8.32
DMN	1025.0	29.35	33.38	8.29

Chemical Variables

The mean and standard deviation of EEZ, for the studied chemical parameters are given below (Table.4.18). Variations in nutrient concentration of the three regions of EEZ is presented in the Table 4..8.

Table.4.18. Mean and standard deviation of the studied chemical parameters in the EEZ.

Parameter	Mean	Standard deviation
Nitrite ($NO_2 – N$)	0.075	0.105
Nitrate ($NO_3 – N$)	0.438	0.611
Phosphate (PO_4)	0.547	0.460
Silicate (SiO_4)	0.890	1.322
Dissolved Oxygen (DO)	3.51	0.889

Nitrite -NO_2

The mean value of nitrite in the surface water of EEZ was found to be 0.075 µmol/l with ±0.105µmol/l of standard deviation (Table4.8). The detectable amount of nitrite was found only in the Arabian Sea, there by the comparison of nitrite region wise and season was not possible. There is a seasonal variation having an average of 0.792µ mol/l during the south west monsoon and 0.575µ mol/l in the pre-monsoon season. The increase of nutrients in the monsoon season was reestablished during the present study. The latitudinal variation studied revealed that cluster II (10-13°N) is more nitrite rich than any other cluster and there is no detectable amount of nitrite in LC I (7-10°N) of Arabian Sea. Cluster II has an average of 0.177µ mol/l, LC III (13-16°N) with 0.058µ mol/l, LC IV (16-19°N) with 0.311µ mol/l and LC V (19-22°N) with 0,506µ mol/l. Nitrite is found to be less in the coastal waters and comparatively more in the oceanic waters, 0.020 and 0.096µ mol/l respectively.

Nitrate-NO_3

Nitrate is having an average of 0.438 ±.611µmol/l (Table 4.8). The variation in the amount of NO3 is found to have a seasonal, temporal and spatial influence along with the variation in surface water currents. The nitrate content of the surface water is found to be lesser than the detectable limit, for which there is no data in the ARS. In Bay of Bengal the presence of Nitrate is noticed which is available for variation studies. The amount of nitrate is found to be higher in the cluster II of Bay of Bengal. Open Ocean is having more nitrate content than the coastal region, which may be due to the utilization of nitrate by the photoautotrophs. The lower amount of nitrate during also favours the concept of utilisation for the reduction of the nitrate in surface water. The coastal and open ocean waters of Bay of Bengal exhibited frequent blooms of *Trichodesmium*. The southern part of BOB is found to be having lesser amount of nitrate, may be triggering the nitrogen fixation by the cyanophytes.

Phosphate-PO_4

The average amount of phosphate is found to be 0.547µmol/l with a deviation of 0.460 (Table 4.8). The phosphate content of the Arabian Sea is more; may be responsible for the higher species diversity, standing crop and thereby by for more primary productivity. The upper latitudes are found be having a lower phosphate than the lower latitudes. There is a sudden decrease when average of the phosphate in surface water was taken, in the present study. Open ocean waters have a higher amount of phosphate, because of the loss of stock on demand. There was a higher amount of phosphate during PRM in Arabian Sea as well as in Bay of Bengal. But there was not much relationship with the diel rhythm or latitudinal position.

Silicate-SiO_4

Silicate concentration showed an irregular nature, because of its undetectability. The average value is found to be smaller than the standard deviation, because of higher range of concentration of the silicate. The irregularity in the data even after the grouping and averaging makes the discussion inadequate.

Dissolved Oxygen- DO

The latitudinal variation in chemistry of Andaman Sea had a tendency to increase the dissolved oxygen and silicate. But the PO_4 decreases with increase in latitude. There was bloom in the second latitudinal cluster of the Andaman Sea. There was a heavy rain during the days of sampling along the Andaman. The lowering of pH and salinity in the surface waters may be associated with that heavy rain. The decrease in the amount of nitrate and nitrite along with slight decrease in the salinity and pH might be the reasons for blooming of *Trichodesmium*.

The variation in chemistry of Bay of Bengal waters showed a zigzag pattern while considering NO_3, SiO_4 and PO_4. The dissolved oxygen was steadily increasing from cluster I to cluster IV.

The nutritional status of the Arabian Sea is also similar to that of the other two regions of the EEZ in the case of NO_2 and NO_3, with trace amount of presence. Second cluster from latitude 7 to 10 two stations with detectable amount of nitrite. Both of them from 18.9 latitude during southwest monsoon and the sampling were carried out in cruise no. 193. All the other chemical parameters studied have a fluctuating nature with latitudinal variation. The variations in the chemical variables are given in the following tables 4.8-4.17.

Table 4.8. **Latitudinal variation in chemical variables- surface temperature, salinity and pH in Arabian Sea**

ARS	NO_2-N (µmol/L)	NO_3-N (µmol/L)	PO_4- (µmol/L)	SiO_4- (µmol/L)	DO (ml/L)
LC I	*	*	*	*	3.49
LC II	0.177	*	0.880	0.680	3.21
LC III	0.058	*	0.723	*	3.21
LC IV	0.031	*	0.527	1.530	3.49
LC V	0.051	*	0.644	*	3.32

Table . 4. 9. **Latitudinal variation in chemical variables- surface temperature, salinity and pH in Bay of Bengal**

BOB	NO_2-N (µmol/L)	NO_3-N (µmol/L)	PO_4- (µmol/L)	SiO_4- (µmol/L)	DO (ml/L)
LC I	*	0.088	0.572	0.707	3.43
LC II	*	0.948	0.718	0.440	3.61
LC III	*	0.369	0.330	1.472	3.65
LC IV	*	0.629	0.447	0.743	3.68

Table. 4. 10. Latitudinal variation in chemical variables- surface temperature, salinity and pH in Andaman Sea.

ANS	NO_2-N (µmol/L)	NO_3-N (µmol/L)	PO_4- (µmol/L)	SiO_4- (µmol/L)	DO (ml/L)
LC I	*	*	0.550	*	2.79
LC II	*	*	0.242	0.125	3.41
LC III	*	*	0.189	0.197	3.95

Table. 4. 11. Seasonal variation in physical variables - surface temperature, salinity and pH in Arabian Sea.

	NO_2-N (µmol/L)	NO_3-N (µmol/L)	PO_4- (µmol/L)	SiO_4- (µmol/L)	DO (ml/L)
ARSC	0.021	*	0.564	1.530	3.37
ARSO	0.096	*	0.750	0.680	3.28
BOBC	*	0.400	0.374	0.723	3.63
BOBO	*	0.494	0.566	1.151	3.59

Table. 4. 12. Seasonal variation in physical variables - surface temperature, salinity and pH in Arabian Sea.

ARS	NO_2-N (µmol/L)	NO_3-N (µmol/L)	PO_4- (µmol/L)	SiO_4- (µmol/L)	DO (ml/L)
NEM	*	*	*	*	4.17
PRM	0.061	*	0.728	*	3.19
SWM	0.079	*	0.657	1.247	3.16

Table. 4. 13. Seasonal variation in physical variables - surface temperature, salinity and pH in Bay of Bengal.

BOB	NO_2-N (µmol/L)	NO_3-N (µmol/L)	PO_4- (µmol/L)	BOB	DO (ml/L)
PRM	*	0.442	0.283	PRM	3.88
SWM	*	0.656	0.653	SWM	2.67
NEM	*	0.303	0.376	0.815	3.76

Table. 4. 14. Seasonal variation in physical variables - surface temperature, salinity and pH in Andaman Sea.

ANS	NO_2-N (µmol/L)	NO_3-N (µmol/L)	PO_4- (µmol/L)	SiO_4- (µmol/L)	DO (ml/L)
NEM	*	*	0.200	*	3.90
SWM	*	*	0.328	0.168	3.35

Table. 4. 15. Diurnal variation in physical variables - surface temperature, salinity and pH in Arabian Sea.

	NO_2-N (µmol/L)	NO_3-N (µmol/L)	PO_4- (µmol/L)	SiO_4- (µmol/L)	DO (ml/L)
DSR	0.088	*	0.684	0.860	3.14
DMO	0.021	*	0.578	0.690	3.59
DMN	0.025	*	0.644	*	3.60
DAN	0.089	*	0.407	0.500	3.16
DEV	0.131	*	1.262	*	2.90
N	0.060	*	0.764	0.690	3.11

Table. 4. 16. Diurnal variation in physical variables - surface temperature, salinity and pH in Bay of Bengal.

BOB	NO_2-N (µmol/L)	NO_3-N (µmol/L)	PO_4- (µmol/L)	SiO_4- (µmol/L)	DO (ml/L)
DSR	*	0.442	0.283	1.692	3.88
DMO	*	0.090	0.495	0.333	3.74
DMN	*	0.303	0.376	0.815	3.76
DAN	*	0.060	0.460	0.443	4.27
DEV	*	0.640	0.533	0.333	3.21
N	*	0.360	0.406	1.710	3.76

Table. 4. 17. Diurnal variation in physical variables - surface temperature, salinity and pH in Andamn Sea.

ANS	NO_2-N (µmol/L)	NO_3-N (µmol/L)	PO_4- (µmol/L)	SiO_4- (µmol/L)	DO (ml/L)
N	*	*	0.278	0.205	3.72
DSR	*	*	0.358	0.125	3.50
DMO	*	*	0.283	0.180	2.98
DMN	*	*	0.250	*	3.78

(*below detectable quantity and/or lack of data due to instrumental failure)

The correlational studies of microalgae showed some positive and negative correlations with physico-chemical factors but much intensive studies are required to explain the real influence of these factors.

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Chapter 5

MICROALGAL BLOOMS

Contents

5.1 Introduction

Planktonic microalgae show fluctuations in abundance, in all aquatic bodies including marine and coastal environment. Sudden proliferation leading to very high concentrations of microalgae, upto millions of cells per litre, under favourable conditions of light and nutrients are generally referred to as algal blooms. The change in water colour gives the phenomena different names such as ‘red tides’, ‘red water’, ‘brown tides’, ‘green tides’ and ‘yellow tides’, etc. Mostly a reddish-brown colour is due to the blooms of dinoflagellates. All discolourations present in the aquatic ecosystem may not be an algal bloom. The blooms need not be accompanied by the discoloration of the water; instead, the water quality may show significant changes especially in viscosity and odour due to the evolution of hydrogen sulphide and/or amine. The change in water quality changes the name of the phenomenon to ‘stinking water’, ‘baccy juice’ and ‘weedy water’. Red tides can be defined as the water colour change due to the outbreaks of microscopic plankton, which can some time cause death of fish or other animals, irrespective of the colour (Okaichi, 2003). The number of algal cells involved in bloom formation and its impact on other flora and fauna varies with the age, nutritional status and the species involved in blooming. The proliferation of the phytoplankton is generally followed by an increase in the secondary production. Unfortunately, the presence of some algae is found to be potentially harmful to other flora and fauna, the blooming of which makes the condition more worse and is known as Harmful Algal Bloom (HAB). Harmful algal blooms can be defined as a sudden multiplication of toxic or non toxic algae which may or may not discolour the water, but are dangerous to other flora and fauna by their toxins or by their capacity to make physical or ecological hazards. If the bloomed alga is having the capacity to produce toxins, then the bloom is termed as Toxic Algal Blooms (TAB). Colour, intensity, endurance and impacts of bloom depend on the nature of the bloomed species, cell density, age and the state of Sea. International Council for Exploration of the Seas (ICES) has defined algal blooms as 'those which are noticeable, particularly to general public, directly or indirectly through their effects such as visible discolouration of the water, foam production, fish or invertebrate mortality or toxicity to humans' (ICES, 1984).

HAB research has been first emerged as a discipline at the First International Conference on Toxic Dinoflagellate Blooms held in Boston, Massachusetts, in November 1974 (Lo Cicero, 1974) after a massive New England red tide caused by the toxic dinoflagellate *Alexandrium* (*Gonyaulax*) *tamarense* in 1972. This meeting was followed by two further International Conferences on Toxic Dinoflagellate Blooms held in Miami, Florida, in 1978 and in St Andrews, Canada in 1985. The First International Symposium on Red Tides was held in 1987 at Takamatsu, Japan, which broadened its scope to include bloom events caused by other algal groups and this tradition of conferences were followed (Hallegraeff *et al.*, 1995). In 1989, the fourth international conference on Harmful Marine Phytoplankton reached a consensus "that some human activities may be involved in increasing the intensity and global distribution of blooms and recommended that international research efforts be undertaken to evaluate the possibility of global expansion of algal blooms and man's involvement in this phenomenon". Afterward, a number of new international programmes were conducted to study and manage harmful algal blooms and their linkages to environmental changes in a manner consistent with the global nature of the phenomena involved. The establishment of a Harmful Algal Bloom programme by the Intergovernmental Oceanographic Commission (IOC) of UNESCO has been one such outcome. Now several international agencies such as International Council for Exploration of the Seas (ICES), Scientific Committee for Oceanic Research (SCOR), European Union (EU), Asia Pacific Economic Cooperation Program (APEC) and PICES (North Pacific Marine Organisation), have established programmes or working groups focused specifically on HABs and their impacts along with IOC of UNESCO. ECOHAB, GEOHAB, Euro HAB.etc, are the major international programmes on HABs. Besides, many of the coastal nations have local monitoring programmes, which have resulted in increased sampling intensity and frequency for identifying the presence of harmful microalgae.

This chapter includes a detailed review of literature on algal bloom, both national and international. Present study include the collection of bloom samples, oceanic blooms encountered during *FORV Sagar Sampada* cruises, as well as those collected from the coastal waters of Kerala. All the parameters that were studied for microalgae during oceanic sampling is followed also in the case of bloom stations. microalgal studies. A preliminary survey about the prevalent blooming areas of Kerala coast is conducted and its report is also included in this chapter. Samples were collected from the areas of bloom for analysis and culture. The microalgal composition of oceanic and coastal bloom have been described and tried to understand the relationship of algal blooming with hydrographic factors. A distributional record of harmful algae, reported by UNESCO, in the EEZ is prepared based on the present study.

5.2 Review of Literature

Okaichi (2003) divided the history of algal bloom reports with the help of Mead (1989), into two periods before and after 1850. Algal blooms were reported as an abnormal phenomenon of sea before 1850. The scientific reporting started after 1850 and it can be subdivided into two phases, first phase of 1850-1950 and the second phase 1950 -till date.

A description in the *Old Testament* (*Exodus*, 7:20-21) is referred to as an algal bloom by Halstead (1965) and as a dinoflagellate bloom by Kofoid and Swezy (1921). There were many such events before 1850, described in the memoirs and travelogues of the mariners and merchants of the sea. On 18 March 1832, Charles Darwin observed the reddish brown sea water near Abrolhos Island, and the causative organism was identified as *Trichodesmium erythraeum* and another red water phenomenon at the south of Valparaiso and the species postulated was *Mesodinium rubrum* (Taylor and Blackbourn, 1971). In Japan, there were reports of '*akashiwo*'(red tides) from A. D. 731 June 13, appeared at the south west coast of Wakayama Prefecture and it was also noted that the normal colour of the sea water is recovered by 5 days! On September 1234, there was a human mortality associated with the consumption of fishes from an area of red water phenomena (Okaichi, 2003). English survey programme, Challenger revealed the occurrence of red tides all over the world and started the scientific inquiry about discolorations of the sea water. In 1793, a fatal case of human by shell fish poisoning was recorded when Captain George Vancouver and his crew landed in British Columbia and the area now known as Poison Cove. He also noted that local Indian tribes never eat shellfish when the seawater became phosphorescent due to dinoflagellate blooms (Dale and Yentsch, 1978).

Though algal blooms are natural phenomenon, the exceptional bloom forming species constitute only 200 species (5.5-6.7%) of the total marine phytoplankton (4000 species) flora of the world's oceans (Sournia, 1995). Recent studies indicate that they have increased in frequency and geographic distribution all over the world within the last few decades. Ho and Hodgkiss (1991) in a review on the red tides in subtropical coastal waters from 1928 to 1989 showed that the number of blooms increased from 1 or 2 every 10 year at the beginning of the period to over 220 between 1980 and 1989. Increase in frequency of algal blooms has been reported along South African coasts (Horstman, 1981), Dutch coastal waters (Cadee, 1986), Seto inland sea, Japan (Imai and Itoh, 1987), Hong Kong harbour (Lam and Ho, 1989), Chinese coastal waters (Qi *et al.*, 1995), coastal waters of North America (Horner *et al.*, 1997) and in Black Sea (Turkoglu and Koray, 2002). Maclean (1989) has noted a spread of the bloom of the toxic dinoflagellate *Pyrodinium bahamense var. compressa* to new locations in the coastal waters of Philippines, with increased occurrence of human deaths by PSP caused by this species. Hallegraeff, (1993) made a review on harmful algal blooms and their apparent global increase. It is considered as one of the greatest literature work dealing with HABs. According to Hallegraeff (1995), there has been increased reports of harmful algal bloom (HAB) occurrences worldwide, due to increased scientific awareness, improved analytical techniques and also because increased coastal mariculture activities have resulted in regular monitoring of these waters. He also commented that HAB events have been on a rise and has spread to previously pristine waters as a result of eutrophication, unusual climatological conditions, and transport of dinoflagellate cysts in ships ballast water and with shellfish imports. All these point to a `global epidemic of algal blooms' as referred to by Smayda (1997).

Nutrient enrichment in coastal waters is generally regarded as one of the major reason for the increased occurrence of algal blooms, especially red tides. There has been an increased input of nitrogen and phosphorous to the coastal waters mainly as a result of anthropogenic activities resulting in the transformation of previously pristine or oligotrophic coastal waters to eutrophic conditions. This has been accompanied by a corresponding increase in the appearance and persistence of algal blooms. Eutrophication from anthropogenic inputs has been linked to the increased recurrence of blooms in Tolo harbour, Hong Kong (Lam and Ho, 1989) and in Seto Inland Sea (Kotani *et al.*, 2001). With governmental regulations against anthropogenic inputs, the red tide occurrences were brought down in both the areas clearly supporting the relation between eutrophication and HAB occurrence. Paerl (1988) in his review has concluded that favourable physical conditions must act synergistically with nutrient enrichment to yield maximum biomass.

Increased ground water and atmospheric deposition of nitrogen to coastal waters derived mainly from urban, industrial and agricultural sources has been linked to expansion of HAB's by Paerl (1997). Altered ratios of major nutrients has been found to be more significant than the total concentration of nutrients in the increased recurrence of HAB's because it results in selective stimulation HAB species over the others (Smayda, 1990). Radach *et al.* (1990) has studied the change in phytoplankton composition over a 23 year period at Helgoland, Germany and has linked the change from a diatom dominated to a dinoflagellate dominated community with general nutrient enrichment and altered nutrient ratios of the region. Selection of harmful species as a result of altered nutrient ratios has also been suggested by Anderson (1995) and Richardson (1997). Hodgkiss and Ho (1997) who reviewed the studies on bloom dynamics done in Tolo harbour, Japan and North European coastal waters supports this theory.

Physical factors such as wind driven currents, tides, upwelling and downwelling, convergence and divergence and related frontal boundaries have also been indicated as initiation factors for red tide formation (Carreto *et al.*, 1986; Franks and Anderson, 1997; Tester and Steidinger, 1997). A study on the development of a bloom of *Gonyalux polyedra* in Katsela bay, Adriatic sea by Marasovic *et al.* (1991) links the increased phytoplankton density to lowered salinities and higher temperatures.

According to Cushing (1959), spring and autumn blooms which are typical of temperate waters and are mainly diatom events, occur during the period when there is a break in temperature stratification and the waters are well mixed, allowing phytoplankton, nutrient and light simultaneously to be in the surface waters prior to the development of grazing populations. Paerl (1988) has reviewed the major reasons for the occurrence of nuisance blooms in coastal, estuarine and inland waters. It is generally held that HAB outbreaks often follow a period of intense rainfall and runoff which increases water mass stratification, possibly enclosing a patch of chemically modified surface layer of water favourable for phytoplankton growth (Smayda, 1995). Trainer *et al.* (1998) supported the stratification as a reason behind the bloom of *Pseudonitzschia* bloom. Ryther *(1955)*, Eppley and Harrison (1975) and Hartwell (1975) have studied the roles that vertical and horizontal water column stability play in the build up and persistence of bloom population. According to Paerl (1988), in stratified waters, motility allows a red tide organism to orient itself near the surface during the photosynthetically active day light hours while having the option of seeking deeper nutrient rich waters during potentially photo inhibitory mid day or night time hours. This favours their bloom over the less motile phytoplankton taxa which coexist during the initiation of bloom. Marasovic *et al.* (1991) links the increased phytoplankton density to lowered salinities and higher temperatures. Bloom of the chrysophyte *Aureococcus anaphagefferens* has been associated with high salinities following anomalous winter and spring drought periods characterised by rainfall levels below the average of previous four decades (Cosper *et al.,* 1987).

Bloom of *Aureococcus anaphagefferens* has been linked to a combination of physicochemical and hydrographic parameters in a study conducted by Bricelj and Lonsdale (1997). Relationship between *Noctiluca* swarming and hydrological features of the western coast of Brittany was studied by Le Levre *et al.* (1990). Bloom of a species is further supported by large scale meteorological changes, anomalous weather events like *El Nino,* upwelling of nutrient rich bottom waters, heavy precipitation and runoff, eutrophication and biological factors like species competition and differential grazing (Maclean, 1987; Van Dolah, 2000; Yin 2003). A massive bloom of the dinoflagellate *Karenia digitata* has been linked to distinct weather patterns, hydrographic and chemical factors by Yang and Hodgkiss (2004).

Zingone and Enevoldsen, in 2000, reviewed the effects of natural and man induced environmental fluctuations on the frequency and apparent spreading harmful algal blooms. The article also highlighted the need for interdisciplinary research aimed at shedding light on basic mechanisms governing the occurrence and succession of microalgae in coastal seas. Meteorological factors like wind speed and direction, rainfall have been reported to be important in the initiation of the bloom. In addition to increasing water mass stratification, rainwater brings in a fresh input of nutrients, which favours bloom formation. Yamamoto *et al*., in 2002, carried out a study on effects of winds, tides and river water runoff on the formation and disappearance of the *Alexandrium tamarense* bloom in Hiroshima Bay, Japan from March to June of 1992–1998. The north wind at the initial growth phase of *A. tamarense* appeared to have prevented bloom formation by dispersing the organism offshore and/or through turbulent mixing.

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Pseudonitzschia sp bloom in Penncove Washington has been linked strongly to stratification by Trainer *et al.* (1998).

Nutrient enrichment in coastal waters is generally regarded as one of the major reason for the increased occurrence of algal blooms, especially red tides. There has been an increased input of nitrogen and phosphorous to the coastal waters mainly as a result of anthropogenic activities resulting in the transformation of previously pristine or oligotrophic coastal waters to eutrophic conditions. This has been accompanied by a corresponding increase in the appearance and persistence of algal blooms. Eutrophication from anthropogenic inputs has been linked to the increased recurrence of blooms in Tolo harbour, Hong Kong (Lam and Ho, 1989) and in Seto inland sea (Kotani *et al.*, 2001). With governmental regulations against anthropogenic inputs, the red tide occurrences were brought down in both the areas clearly supporting the relation between eutrophication and HAB occurrence. Paerl (1988) in his review has concluded that favourable physical conditions must act synergistically with nutrient enrichment to yield maximum biomass. Phytoplankton blooms are common events in eutrophic estuaries throughout the world.

The relationship between high phosphate loading and reduced salinity leading to the development of diatom and blue green algal bloom in Peel-Harvey estuarine system has been studied by Lukatlelich and Mc Comb (1986). Increased ground water and atmospheric deposition of nitrogen to coastal waters derived mainly from urban, industrial and agricultural sources has been linked to expansion of HAB's by Paerl (1997). Altered ratios of major nutrients has been found to be more significant than the total concentration of nutrients in the increased recurrence of HAB's because it results in selective stimulation HAB species over the others (Smayda, 1990). Radach *et al.* (1990) has studied the change in phytoplankton composition over a 23 year period at Helgoland, Germany and has linked the change from a diatom dominated to a dinoflagellate dominated community with general nutrient enrichment and altered nutrient ratios of the region. Selection of harmful species as a result of altered nutrient ratios has also been suggested by Anderson (1995) and Richardson (1997). Hodgkiss and Ho (1997) who reviewed the studies on bloom dynamics done in Tolo harbour, Japan and North European coastal waters support this theory.

Blooming Microalgae

Exceptional bloom forming species form a very low percentage of the total marine phytoplankton. Of these, only 1.8 to 1.9% has been so far identified to be toxic. 73-75% of these toxic species are dinoflagellates (Dinophyceae) followed by diatoms (Bacillariophyceae). Algal classes Raphidophyceae, Cyanophyceae, Prymnesiophyceae, Cryptophyceae, Prasinophyceae, Chlorophyceae and Euglenophyceae, have members which produce exceptional blooms but their percentage is very low compared to that of the first two (Smayda,1995). Of the dinoflagellates, four genera, *Alexandrium, Dinophysis*, *Gymnodinium* and *Prorocentrum* are responsible for majority of the toxic events. Zingone and Envoldson (2000) also support Smayada, about the number of species that can bloom and/or toxic/harmful. Number of identified HAB species and toxic species by Smayda (1995) is given below in table 5. 1

Table. 5.1. No. of Identified HAB and Toxic Microalgae (Smayda, 1995)

	HAB species	Toxic species
Dinophyceae	127	57
Bacillariophyceae -Centrales	65	2
Bacillariophyceae- Pennales	18	4
Prymnesiophyceae	9	5
Raphidophyceae	9	6
Chrysophyceae	6	1
Cyanophyceae	4	2
Euglenophyceae	8	1
Total	246	78

In Scandinavian waters the algal bloom is caused by *Gyrodinium aureolum*, *Prorocentrum minimum* and *Chrvsochromulina polylepis* (Dundas et al, 1989). Potentially toxic microalgal species in Nigerian water bodies include cyanobacteria (*Microcystis* spp., *Oscillatoria* spp., *Anabaena* spp. and *Trichodesmium thiebautii*), diatoms (*Pseudo-nitzschia* spp., *Nitzschia* spp. and *Chaetoceros convolutus*) and dinoflagellates (*Dinophysis acuta, Gonyaulax* spp., *Gymnodinium* spp., *Noctiluca scintillans* and *Prorocentrum lima*). The most hazardous species are *Chattonella marina*, *C. antiqua, Heterosigma akashiwo* and dinoflagellates *Gymnodinium mikimotoi, Cocholodinium polykrikoides* and *Gonyaulax polygramma* and raphidoflagellate are the most hazardous species in Japan (Fukuyo et al., 2001).

Bloom Dynamics

Long term studies on the phytodynamics were carried out in the Narragensett Bay by Karentz and Smayda (1984) and in North Sea by Reid *et al.* (1990). Distribution of *Dinophysis* sp and *Alexandrium* sp along French coasts since 1984 was studied by Belin (1993). Long term studies on the changes in physicochemical and biological factors in Victoria harbour, Port shelter and Tolo harbour in Hongkong, where there was a recent increase in intensity of algal blooms was done by Yung *et al.* (1997, 1999, 2001). Uhling and Sahling (1990), Huang and Qi (1997) and Jocelyn (2000) have all studied the population dynamics of *Noctiluca scintillans* in detail. Imai and Itoh, (1986, 1987) have studied the annual life cycle and population dynamics of *Chattonella marina* in the Seto inland sea, Japan. Blooms generally mediated through top down control by zooplankton grazing, by flushing due to tidal movement or high flow conditions, or by decaying and being incorporated into the microbial food chain (Cattani and Corni, 1992).

Fogg, in 2002, described the role of planktonic as benthic microalgae and its capacity to produce toxins. Godhe, *et al.*, 2002, described the PCR

(Polymerase Chain Reaction) detection of dinoflagellate cysts in field sediment samples from tropic and temperate environments. They described a method for cyst lysis, which include grinding with a pestle in a mortar under liquid nitrogen followed by microwave boiling. Wang *et al*., (2004) studied the surface sediments were collected from 10 locations to study the distribution of dinoflagellate resting cysts in Chinese coastal waters from July 2000 to May 2002. Sixty-one cyst morphotypes representing 14 genera were identified. Seventeen cyst types were new reports from Chinese coasts. Rich cyst assemblages were recorded in closed or semi-closed near shore harbors.

Impacts of Bloom

Bloom of toxic or harmful microalgae pose a serious threat to human health, coastal activities and fishery resources throughout the world. In addition to the toxicological effects on humans, several kinds of microalgae may directly affect wild and cultivated fish or marine invertebrates that are valuable seafood and cause significant economic impacts through fish kills, farm closures, avoidance of shellfish by consumers etc. (Shumway, 1990; Anderson *et al.*, 1989).

Ecological impact

Iizuka (1963, 1985) studied about the community structure of microalgae as a function of eutrophication and impacts are assessed. The allelopathic chemicals from the bloomed algae and their reactions were studied by Chan et al., 1980. The circardian vertical migration behaviour of phytoflagellates, especially of *Heterosigma akashiwo* was stuided by Watanabe et al., (1982) and Yamochi and Abe (1982). The influence of grazing of copepods and other herbivores on red tides as well as the behavioural changes in copepods were studied by Nakamura and Watanabe (1983) and Kamiyama (1994). Huntley et al., (1986) considers the toxin production as a chemical defense against grazers.

The decline in species population after a period of growth is also given to certain algicidal bacteria.

Health problem to Human Beings

Red tides can have harmful effects and certain species of dinoflagellates produce potent toxins. These toxins are carried up in the food chain, ultimately to humans and can, sometimes result in permanent neurological damage or even death (Fukuyo, 1981). Magana *et al.*, in 2003, made a historical assessment of *Karenia brevis* in the western Gulf of Mexico. *K. brevis* commonly causes human respiratory distress

Paralytic Shell fish Poisoning (PSP)

It is the effect of eating shellfish contaminated with several dinoflagellates having water soluble saxitoxins which affect nerve and brain. The major symptoms numbness around lips, prickly sensation in finger tips, headache and vomiting in extreme cases may result in choking leading to muscular paralysis (Anderson, 1996).

Paralytic shellfish poisoning (PSP) produced by dinoflagellates of the genera *Alexandrium, Gymnodinium* and *Pyrodinium* which was observed only from temperate waters of Europe, North America and Japan until 1970s. At present, these have been reported throughout the southern hemisphere in South Africa, Australia, New Zealand, India, Thailand, Brunei, Sabah, Phillippines and Papua New Guinea (Hallegraeff, 1995). The dinoflagellate *Pyrodinium bahamense var. compressa* has been associated with severe PSP outbreaks in South East Asia (Maclean, 1987). In addition to PSP production, they have also been reported to be responsible for fish and shellfish mortalities (Shumway, 1990). 2000 cases of human poisonings, with an overall mortality rate of 15% have been reported by the consumption of fish/ shellfish contaminated with algal toxins (Hallegraeff, 1995). Usup *et al.*, in 2002, carried out a study of five species of *Alexandrium viz., Alexandrium affine,* A*lexandrium leei, Alexandrium minutum, Alexandrium tamarense* and *Alexandrium tamiyavanichii,* to determine the presence of paralytic shellfish poisoning (PSP) in the coastal waters of Malaysian Peninsula. Emura *et al*., in 2004, found out that *Alexandrium taylori* an produce a hemolytic exotoxin that can act on cell membrane which is toxic not only to *Artemia* but also to mammalian cultured cells.

Diarrhetic Shellfish Poisoning (DSP)

This is also a shellfish poisoning due to a fat soluble toxin, okadaic acid produced by dinoflagelletes such as *Dinophysis* and *Prorocentrum*. The action on metabolic enzymes results in diarrhoea, vomiting,nausea and abdominal pain; chronic exposure may lead to cancerous growths (Anderson, 1996). DSP reported for the first time in the late 1970's from the dinoflagellate *Dinophysis fortii* in Japan (Yasumoto *et al.,* 1978), has been at present reported from South America, New Zealand, Australia, Thailand, Europe, Chile, Canada and possibly Tasmania and New Zealand (Van Dolah, 2000). It may be more widespread in occurrence since the symptoms are very similar to that of the common bacterial gastroenteritis. Production of DSP toxins has been confirmed in several species of *Dinophysis* like *D. acuminata, D.acuta, D.fortii. D.norvegica, D.rotunda, D.tripos* and suspected in *D.caudata, D. hasta and D.sacculus* (Lee *et al.,* 1989). In 2001, Marasigan, *et al*., reported the accumulation of a high level diarrhetic shellfishtoxins in the green mussel *Perna viridis* during a bloom of *Dinophysis caudata* and *Dinophysis miles* in Sapian Bay, in a Philippine island. The results shown that the green mussels accumulate high levels of DSP toxins when *D. caudata* and *D. miles* bloom at a high density.

Amnesic Shellfish Poisoning (ASP)

ASP is the health hazard produced by a toxin, domoic acid from the diatom *Pseudonitzschia*. This water soluble toxin is responsible for the mental problems of confusion, short term memory loss, dizziness and hallucinations, thus mainly affecting the brain (Anderson, 1996). ASP was reported for the first time in 1987 in Prince Edward Island Canada, where cultured blue mussel was implicated in 127 cases of poisoning and two deaths. *Pseudo-nitsczhia multiseries* was identified as the harmful microalga (Bates *et al.,* 1989). A recent study by Bates *et al.* (1998) points out that *Pseudo-nitsczhia* spp is more cosmopolitan in occurrence than previously thought, with reported occurrence from Canada, North America, Holland, Denmark, Spain and New Zealand. Jeffery *et al*., 2004, made review on Amnesic shellfish poison. Amnesic shellfish poisoning (ASP) is caused by consumption of shellfish that have accumulated domoic acid, a neurotoxin produced by some strains of phytoplankton. The neurotoxic properties of domoic acid result in neuronal degeneration and necrosis in specific regions of the hippocampus. A serious outbreak of ASP occurred in Canada in 1987 and involved 150 reported cases, 19 hospitalisations and 4 deaths after consumption of contaminated mussels.

Ciguatera Fish Poisoning (CFP)

Cigua toxin, a fat soluble one, is responsible for the neurological symptoms of numbness, low heart rate, imbalance and also death due to respiratory failure. This type of toxin is present in *Gambierdiscus toxicus* and *Ostreopsis siamensis*. produced CFP results from a consumption of reef fishes contaminated with algal toxins and humans consuming such fishes suffer from gastrointestinal and neurological illness and in extreme cases can die from respiratory failure. The benthic dinoflagellate *Gambierdiscus toxicus, Osteropsis siamensis, Coolia monotis and Prorocentrum lima* are thought to be the causative organisms. From being a rare occurrence two centuries ago, Ciguatera has now reached epidemic proportions in French Polynesia, with more than more than 24,000 patients of CFP reported from the area between 1966 and 1989 (Hallegraeff, 1995).

Neurotoxic Shellfish Poisoning (NSP)

NSP caused by the dinoflagellate *Gymnodinium breve,* which was earlier thought to be endemic to the Gulf of Mexico region, has been now reported from other regions of the world like New Zealand (Richardson, 1997). Fat soluble breve toxin is produced by these microalgae and affects nerve, muscle, lung and brain (Anderson, 1996). Kirkpatrick *et al*., (2004) made a review on Florida red tides from 1840 to 2004 having significant fish kills and NSP. Toxic algal blooms occur almost annually on the west coast of Florida.

Cyano Bacterial Toxins (CBT)

Fleming *et al*., (2002) investigated the cyanobacterial toxins, surface drinking water in Florida. The monitoring survey aimed to reveal the organisms and microcystins in surface water drinking sources. A pilot ecological study was performed using a Geographic Information System (GIS) to evaluate the risk of primary hepato-cellular carcinoma (HCC) and proximity to a surface water treatment plant at cancer diagnosis. *Microcystis aeruginosa*, *Lyngbya majuscula*, *Trichodesmium* spp. are the major cyanobacteria having a potential for toxin production.

Other algae

Gastrich *et al*., (2004) conducted a 3 year study in Barnegat Bay in New Jersey (USA). The brown tide species, *Aureococcus anophagefferens* was enumerated and associated environmental factors were analyzed. The study indicated a potentially important impact of these harmful brown tide bloom events on shellfish resources and submerged aquatic vegetation. Miller and Belas (2003) reiewed on the estuarine dinoflagellates, *Pfiesteria piscicida* and *Pfiesteria shumwayae* which are thought to be responsible for massive fish deaths and associated human illnesses in the southeastern United States. These dinoflagellates are described as having a complex life cycle involving flagellated zoospores, cysts, and amoeboid stages.

Health issues to other fishes and animals/birds

Algal toxins can also alter the marine ecosystem, structure and function as they are passed through the food web affecting fecundity and survival at different trophic levels. Some of the microalgae kill wild and farmed fish populations. Fish mortalities are due primarily to *Gymnodinium nagasakiense* in the North Sea region, *Heterosigma akashiwo* in British Columbia, Chile and New Zealand and due to *Chattonella antiqua* in Japan. Besides direct fish kills caused by toxins produced by these algae, indirect kills can also occur as caused by the spine like process present on the setae of the diatoms *Chaetoceros convolutus* and *Chaetoceros concavicornis.* Some other harmful microalgae like *Gymnodinium breve* produce toxic and irritating aerosols. The silicoflagellate *Dictyocha speculum* and the prymnesiophyte *Chrysochromulina polylepis* which have been recorded as the causative species in many recent marine faunal kills (International Oceanographic Commission workshop, 1991). Imai and Itoh, (1986, 1987) have studied the annual life cycle and population dynamics of the species, *Chattonella marina* in the Seto inland sea, Japan. Mortality in fishes exposed to blooms of *Chattonella marina* has been studied by Matsusato and Kobayashi, 1974; Ishimatsu *et al.*, 1990; Doi *et al.*, 1981; Endo *et al.*, 1992; Toyoshima *et al.*, 1985 and Tiffany, 2001. Recently neurotoxins have been isolated from these organisms (Onoue and Nozawa, 1980). *Chattonella spp.* though reported as the major killer of fishes in aquaculture farms of Japan has not caused any severe problems along our coast, except for the small scale regional fish kills during the time of bloom.

Fish kills are mainly due to *Gymnodinium nagasakiense* in the North Sea region and due to *Heterosigma akashiwo* in British Columbia, Chile and New Zealand. *Gymnodinium breve* has also been implicated in many fish kills (IOC report, 1991). A massive fish kill by *C. polylepis* in 1988 in the North Sea was reported to cause death of 900 tonnes of fishes such as cod, salmon and trout

(Moestrup, 1994). Blooms of *Noctiluca,* a heterotrophic dinoflagellate has resulted in fish and faunal kills in their regions of occurrence, as it is capable of build up of extracellular ammonia which rapidly kills the species which are unable to escape the bloom areas (Paerl, 1988). Predation by *Noctiluca scintillans* on the eggs of *Engraulis japonica* (Enomoto, 1956) has also been reported. *Pfesteria piscida,* has been linked with fish kills in the mid Atlantic region. (Burkholder *et al.,* 1992 and 1995). Besides producing chemical substances which are directly toxic, some micro algae physically damage the fish gills which result in osmoregulatory problems and death. Gelationous secretion during the bloom of the diatom *Coscinodiscus waleisii* in North Sea negatively affected the commercial fishery of the region (Boalch, 1984). The spine bearing algae *Chaetoceros convolutus* and C. *concavicornis* can cause mechanical clogging or lesion of gills (Bell, 1961; Yang and Albright, 1992; Rensel, 1993). *Chattonella antiqua* and *Chattonella marina* are the major cause of fish mortality in aquaculture farms in Japan. The rapidophytes has been identified to produce neurotoxic, haemolytic and haemoagglutinating compounds as well as superoxide and hydroxyl radicals which cause severe damage to fish gills leading to osmoregulatory problems and death (Endo *et al,* 1992; Tanaka *et al.,* 1994; Ahmed et al., 1995).

Large-scale mortality of marine fishes has also been reported to occur as a result of the transfer of algal toxins through the food web. The toxic dinoflagellate *Gonyaulax excavata* has been reported to cause mortality in Atlantic herring, sand lance and menhaden as a result of PSP toxin transferred through the herbivorous zooplankton which grazed upon it (Adams, et.al., 1968; White, 1981). Juvenile and larval stages of fish have been found to be more vulnerable to algal toxins. According to Gosselin et al., (1989) the emergence of fish larvae and early post larvae at a time when planktonic food web is contaminated by algal toxins could lead to a significant reduction of early survival and threaten recruitment to local stocks.

Vulnerability of fish larvae to toxic dinoflagellates has been discussed in detail by Rodineau (1991).

Mortality in fishes exposed to blooms of *Chattonella marina* has been studied by Matsusato and Kobayashi, 1974; Ishimatsu *et al.,* 1990; Doi *et al.,* 1981; Endo *et al.,* 1992; and Toyoshima *et al.,* 1985. Neurotoxins have been isolated from these organisms (Onoue and Nozawa, 1989). *Chattonella spp* though reported as the major killer of fishes in aquaculture farms of Japan has not caused any severe problems along our coast, except for the small scale regional fish kills during the time of bloom

Magana *et al*., in 2003, made an assessment that *Karenia brevis* commonly causes major fish kills, in the western Gulf of Mexico. Shumway *et al*., in 2003, put a question whether the marine birds are sporadic victims or under-reported events of harmful algal blooms. The impacts of toxic algae on seabirds revealed an array of responses ranging from reduced feeding activity, inability to lay eggs, and loss of motor coordination to death.

Economic impact

Commercial fishery impacts from HAB's, including wild harvest and aquaculture losses due to NSP, PSP, ASP, Ciguatera and brown tides has been estimated to be around US $18 million in the United States (Anderson *et al*., 2000) and around 1.2 m US $ in China (Yan *et al.,* 2003). Magana *et al*., in 2003, studied about the economic disruption caused by the algal bloom of *Karenia brevis* in the western Gulf of Mexico.

Indian Scenario

Along the Indian coast, algal blooms and associated mortality have been recorded since the early half of the 20th century by many workers (Hornell, 1917; Aiyar, 1936; Jacob and Menon, 1948; Bhimachar and George, 1950;

Subrahmanyan, 1954). Phytoplankton blooms which occurred along the Indian coast during the period from 1982 to 1987 has been documented by Mathew *et al.* (1988). Algal blooms particularly HAB occurrences along the Indian coast has been reviewed by Karunasagar and Karunasagar (1990), including the major reasons for these blooms and the harmful effects they have caused. Revikala (1986) studied the effect of blooms on pelagic fishes. The blooms recorded by these researchers include the blooms of microalgal genera, *Trichodesmium* (Cyanophyceae); *Noctiluca, Dinophysis, Gonyaulax* and *Gymnodinium* (Dinophyceae); *Pleurosigma, Navicula, Fragilaria, Coscinodiscus* and *Skeletonema* (Bacillariophyceae) and Chattonella (Exuviaella) of Raphidophyceae. A bloom of coccolihtophorids are also reported.

Algal blooms have been reported to be more prevalent along the west coast than on the east coast. Earlier several researchers recorded blooms of blue-green algae (*Trichodesmium spp*) and dinoflagellates (*Navicula spp, Dinophysis spp and Gonyaulax spp*) in Indian waters. *Noctiluca Trichodesmium, and Chattonella marina* are the species with regular bloom occurrence along the Indian coast (Subrahmanyan, 1954; Karunasagar and Karunasagar, 1990).Of the harmful algae, the species most often reported from our waters is the dinoflagellate *Noctiluca* species. *Gonyaulax spp.* and *Dinophysis* no direct mass-mortality was indicated due to release of toxins by blooming species.

***Trichodesmium* Blooms:**

The filamentous blue green alga *Trichodesmium erythraeum* is the most common red tide species in the tropical seas. All species of *Trichodesmium* are known to possess gas vacuoles and form characteristic bundles and clumps. Each clump of *Trichodesmium* consists of 14-18 filaments. These clumps are large enough to be seen from ship board and look dark-gray giving an impression of saw-dust sprinkled all over the sea surface. They occur in low abundance throughout the year and only in certain season, they occur as blooms (Desikachary, 1959).

Prabhu *et al* (1965) recorded an unusual swarming of the planktonic blue-green algae *Trichodesmium erythraeum* off Mangalore. Two separate blooms of *Trichodesmium erythraeum* and *T.hildenbrantii* were recorded during March 1964 off Mangalore (Prabhu *et al*., 1965). They didn't observe any mortality during blooming periods. Panikkar (1966) has given details of mass mortalities of fishes in the Arabian Sea between 1955 and 1958. He observed that on the Indian coast the cause of mass mortalities is the rapid increase of dinoflagellate *Noctiluca* in particular and the blue-green alga *Trichodesmium*. These algae were observed during the months of June, January and October between Longitudes 60^{o}E and 64^{o}E and Latitudes 9^{o}N and 22^{o}N. He pointed out that these regions were chiefly associated with regions of upwelling and high productivity. He opined that mass mortalities may be due to oxygen depleted up-welled waters. Prabhu *et al* (1971) recorded the occurrence of *Trichodesmium erythraeum* off Mangalore in February and March 1968. They recorded a salinity of 35-37‰ during bloom period. Failure of sardine fishery was attributed to the phenomenon of blooming.

Ramamurty *et al* (1972) did not notice any ill effects or mortalities of organisms due to blooming of *Trichodesmium erythraeum* off central west coast of India during March 1972 which lasted for 9 days and during April 1972 which lasted for 4 days. The bloom was 40-50 m in length and 5-7 m in width. They recorded zooplankton and phytoplankton growth during blooming period. The salinity was 34‰. Sakthivel and Haridas (1974) reported co-occurrence of blooming of *Trichodesmium erythraeum* and swarming of the pteropod *Cresis acicula* and the cladoceran *Penilia avirostris*, off Cochin during March 1973. This microalgal was not associated with mortality but with low concentration of phosphates and nitrates besides a slightly high concentration of ammonia (2.95µg. at.N/lit). Rajagopalan *et al* (1992) recorded *Trichodesmium* blooms during February and March in 1984 and in 1987 off Vizhinhjam, southwest coast of India. They recorded salinity of 34.9‰ Bloom of *Trichodesmium* has been reported off the Mangalore coast by Prabhu *et al.* (1965), along the Goa by Ramamurthy *et al.* (1972) and Devassy *et al.* (1978). Sreekumaran *et al.* (1992) have shown that the algae regularly bloom in the Arabian Sea during the pre-monsoon season every year.

Nagabhushanam (1967) recorded the *Trichodesmium erythraeum* bloom around Minicoy Island (Arabian sea) during May and June 1965 spread over an area of 35 miles and commented on its effect on local tuna fisheries. Qasim (1970) recorded *Trichodesmium* bloom in Kavaratti Islands. Laccadives. He recorded low nitrate (0.2µg atom/lit) concentration, low plankton production and without any harmful impact. During the present study nitrate concentration was 0.4 µg atom/lit (cr. 185) and the bloom associated with the high abundance of *Temora turbinata*, a copepod zooplankter.

Chacko (1942) recorded the bloom of *Trichodesmium* during the first week of May 1942 on southern side of Krusadai Island and noted dead holothurians and fishes. The gills of fishes were blocked with algae. The salinity was 35.5‰ and the temperature was 30.5° C. Chidambaram and Unni (1944) recorded the blooms of *Trichodesmium erythraeum* during May 1944 in Pamban area and commented on the pollution generated by putrifying algae. Chacko and Mahadevan (1956) reported the swarming of *Trichodesmium erythraeum* around Krusadai Island waters. James (1972) recorded the bloom of *Trichodesmium thiebautii* in the Gulf of Mannar at Mandapam May 25-27, 1968. He too didn’t observe any mass mortality during bloom period. Chellam and Alagarswami (1978) also didn’t notice any mortality during blooming of *Trichodesmium thiebautii* at Veppalodai Gulf of Mannar in March 1973 and in September 1973. Santhanam *et al* (1994) reported the occurrence of *Trichodesmium thiebautei* bloom on March 2, 1989 in Tuticorin Bay, south east coast and they too did not observe any mass mortality.

No mortality of marine organisms has been reported in the above bloom events but Naqvi *et al.* (1998) reported fish mortality associated with the bloom of *Trichodesmium* off Cochin. *Trichodesmium* generally blooms during warmer periods, during February to April in Arabian Sea and sporadically in Bay of Bengal during April-May (James, 1972; Gopinathan and Balachandran, 2000).

***Noctiluca* blooms:**

Noctiluca blooms have been reported and studied in the coastal waters along south west coast of India by Bhimachar and George (1950); Prasad and Jayaraman (1954); Subramanyan (1959a); Venugopal *et al.* (1979); Devassy and Nair (1987); Mathew *et al.*, (1988); Katty *et al.* (1988); Nayak *et al.*, (2000) and by Eashwar *et al.* (2001).

Hornell (1917) recorded the blooming of *Peridinium* spp. along west coast and did not observe mortality among fishes during abundant occurrence of *Noctiluca* and considered that it is not an active agent causing mortality and is innocuous. Bhimachar and George (1950) recorded *Noctiluca miliaris* bloom on October 23, 1948. They stated that the water rendered slimy by decaying *Noctiluca* causing mechanical obstruction to the movement of the fish, while its foulness was found toxic to fish life. Subrahmanyam (1954) recorded the occurrence of symbiotic *Noctiluca miliaris* causing discolouration of water off Calicut. Subrahmanyam (1954, p 189) also observed no correlation between Noctiluca occurrence and oxygen depletion, Off Calicut. Venugopal et al (1988) reported the occurrence of “green tide” in the Arabian Sea, off Mangalore during January 1987 and in May 1987. The causative organism was *Noctiluca miliaris.* They noted low oxygen concentration (0.2 ml/lit) during decomposition of dead

Noctiluca. Rajagopalan et al (1992) recorded *Noctiluca* blooms off Vizhinhjam, south west coast of India. They recorded non-symbiotic *Noctiluca miliaris* bloom on July 8, 1985 when low salinity (30.6‰) and low temperature (24º C) prevailed in the waters. Green symbiotic *Noctiluca* blooms were recorded by them during November and December, 1987 when salinity (30.9‰) and temperature (30º C) were relatively high. They didn't record any harmful/toxic condition or mortality of organisms in the waters. Nayak et al (1993) recorded the incidence of *Noctiluca miliaris* bloom off Mangalore (12º 4'; 74º 49' E). They also not recorded any mass mortality.

Aiyar (1936) attributed fish mortality to oxygen depletion by the occurrence of *Noctiluca* bloom off Madras Coast during June 1935 . Prasad (1958) also didn't notice any mortality of marine life during the swarming of neither *Noctiluca* in the Palk Bay in the April 1952 nor any appreciable reduction in the oxygen saturation during the period. Sargunam *et al* (1989) recorded the occurrence of *Noctiluca scintillans* bloom on October 11 and 17, 1988 in Kalpakkam coastal waters south east coast. The water had normal physico-chemical characteristics except for low concentration of nitrates (0.01µg at/lit).

Noctiluca blooms were recorded on more occasions along west coast than along east coast. Along the east coast, *Noctiuca* bloom followed by mortality has been reported as early as 1935 by Aiyar (1936) along the Madras coast. Sasikumar *et al.* (1989) reported fish mortality in Kalpakkam waters along the Tamilnadu coast.

***Gonyaulax* blooms:**

Blooms of *Gonyaulax polygramma* were recorded sporadically in Indian waters. Prakash and Sarma (1964) reported "Red water" phenomenon in November 5, 1963, North West of Cochin harbour caused by *Gonyaulax polygramma*. Gopinathan and Pillai (1976) also observed *Gonyaulax* blooms along coastal waters off Cochin. . They proved through their “acid extract” tests that the *Gonyaulax polygramma* was non-toxic and they too didn’t record any mass mortality during blooming period.

***Dinophysis* blooms:**

The sporadic blooms of *Dinophysis caudata* were reported by Santhanam and Srinivasan (1996) reported the dinoflagellates *Dinophysis caudata* bloom off Tuticorin, South India during April –May 1994. They attributed the occurrence of bloom to high inorganic Phosphate (5.23 µg at PO_4 P/lit) in local waters due to sewage pollution. They didn’t record any mass mortality of the marine organisms.

***Gymnodinium* blooms:**

Dinoflagellate bloom events of *Gymnodinium mikimotoi* and associated benthic fish mortality was reported by Karunasagar and Karunasagar (1992, 1993) and its impact on shrimp farms at Kundapur, southwest coast of India (Karunasagar *et al.*, 1993).

Diatom Blooms:

A diatom bloom is usually considered favourable for the fishery production of the region. An increased phytoplankton density has been linked to an abundance of oil sardine and mackerels by Subrahmanyan (1959 a,b). The abundance of the diatom *Fragilaria oceanica* is considered as an indicator for the abundance of oil sardine. Diatoms have been observed to bloom regularly along the Indian coast during June to October. Diatom blooms are reported along the Indian coast by Nair and Subarahamnayan (1955); Ramamirtham and Jayaraman (1963); Ramamuthy *et al.* (1972); Devassy (1974) and by Devassy and Bhattathiri (1974). *Asterionella glacialis* blooms appeared in the north western Bay of Bengal in March-April, 2004 (Sasammal, et al., 2005). Sanilkumar et al., (2009) and Padmakumar, et al., (2007) have reported the bloom of *Coscinodiscus* and *Pleurosigma* from off Kodikkal and off Mahe of northern Kerala coast.

The harmful algae with regular bloom occurrence along the Indian coast are *Noctiluca scintillans* and *Trichodesmium* sp. *Chattonella marina* is a regular bloom forming species along the Calicut coast

Cyst Studies

The majority of red tide dinoflagellate species resting as cysts lie dormant on the ocean sediments, where they can stay for years (Pfiester and Anderson, 1987). When the conditions of temperature, light, nutrients and water salinity are appropriate, the cysts germinate causing a swimming cell that reproduces by simple division within a few days (Daranas et al., 2001). Planktonic and cyst forms of *Gymnodinium catenatum* have been reported along the coastal waters of Karnataka by Godhe *et al.* (1996).

These microscopic organisms fluctuated in response to climatic changes, water movements, seasonal variations, nutrient content of the water (Gopinathan and Balachandran, 2000) etc. The concentration of major nutrients was monitored and related to a bloom of *Fragilaria oceanica* by Devassy (1974). Physical and chemical parameters during a *Trichodesmium* bloom was studied by Qasim (1970) and Devassy *et al.* (1978). Reasons for the red tide along the south Kerala coast was studied by Venugopal *et al.* (1979). Bacteriological and physicochemical factors associated with *Noctiluca milaris* bloom along Mangalore, southwest coast of India was done by Nayak *et al.* (2000).

IMPACTS OF BLOOM

Fishes are found to avoid such areas of bloom either due to the heavy biomass or due to the production of toxic substances. *Chattonella marina* first described by Subrahmanyan (1954) along the Calicut coast has been associated with the mortality of various fauna including fish (Homell, 1917; Chacko, 1942; Jacob and Menon, 1948). A set back to fisheries operations in Malabar and Kanara coast due to the bloom of *Noctiluca* has been reported by Bhimachar and George (1950).

A decrease in landings of oil sardine and mackerel was noted by Prabhu *et al.* (1971), during the bloom of *Trichodesmium erythraeum* along the Mangalore coast. A sudden fall in tuna catches was noticed during the bloom of the same species around Minicoy Island (Naghabushanam, 1967). Red tide and its deleterious effects on the fishery of the Goa coast were reported by Devassy (1989).

Shellfish poisoning from algal toxins have also caused human fatalities along the Indian coast. In 1981, an incident of paralytic shellfish poisoning resulted in the hospitalization of 85 people and death of 3 persons due to consumption of the bloom affected clam *Mereterix casta* in Tamil Nadu. A similar incidence took place in Mulki estuary, Mangalore, in 1983 (Karunasagar, et al., 1984; Bhat, 1981; Devassy and Bhat, 1991). In both the cases the toxic species could not be identified. Similarly at Poovar, near Vizhinjam in Kerala, 5 children died and more than 300 people were hospitalized in October 1998, due to shellfish poisoning from *Gonyaulax polygramma* (Karunasagar *et al.*, 1997). Recently, on 17th September 2004, a massive fish kill was noticed along the Trivandrum coast, along with foul smell coming from the sea. Many people, especially children, residing in the coastal districts of Trivandrum and Kollam, who got exposed to the stench, were hospitalized due to vomiting and nausea (The New Indian Express, 17th September, 2004). The toxic species were identified as *Gonyaulax diegensis* and *Cochlodinium* spp. (CMFRI Newsletter, 2004). Due to its global distribution, the problem of HAB can be addressed comprehensively and effectively only through international, interdisciplinary and comparative research. Global monitoring programmes are designed and implemented to manage this problem more effectively.

Another harmful algae which regularly blooms along the Calicut coast of Kerala is the marine raphidophyte *Chattonella marina*, associated with fish mortalities was reported by Hornell (1917) and Jacob and Menon (1948).

Harmful algal blooms involve a wide diversity of organisms, bloom dynamics, and mechanisms of impact. The effects of natural and man-induced environmental fluctuations on the frequency and apparent spreading of these phenomena are studied by Zingone and Envoldson, 2000. Early warnings when harmful species or toxins reach critical concentration is the most widely used management strategy, which helps in implementing specific plans to avoid health problems and to minimise the economic losses. Sellner *et al.*, 2003, written a review on develop effective strategies for the management and mitigation of HABs and their frequently devastating impacts on the coastal environment. At a long time scale, it is essential to assess the risk of harmful events while planning the utilisation of coastal areas and for this, basic knowledge and a firm database about the species distribution, species succession and population dynamics of the bloom forming species is required. Hydrodynamic and ecologic conditions that lead to their blooming has to be studied which would help to build predictive models.

Along the Indian coast, exceptional algal blooms can lead to serious constraints for the sustainable development of coastal areas, which calls for a coordinated scientific and management approach. The potential danger lurking behind the bivalve farmers and the consumers, through unpredicted harmful algal blooms has to be prioritized and precautionary steps taken to avoid human causalities and large scale economic losses. The degree to which the eco-physiological requirements of the species are matched by the physical and chemical habitats determine the blooming of these species. Studies on bloom dynamics will thus help in developing predictive models and for putting forth management measures at the earliest. Several researchers have focused their attention on bloom dynamics, through which they have tried to identify the major reasons for the selection of these harmful species, in preference to the normal flora of the region and their sudden proliferation.

5.3 Results

Survey along Kerala coast

A preliminary survey was conducted for evaluating the awareness of people along Kerala coast about this natural phenomenon. Visited 90 selected sites along Kerala coast and more than 400 persons were interviewed for the survey. In the survey it was found that they are aware of the discolourations, in the sea, prawn farms and shellfish farms. These discolourations of the sea are termed as '*chaappa vellam'*, '*pola'*, '*maantha*' and '*kadalkkara'*, etc. More than 97 % of the fishermen and 70% of the coastal inhabitants have the knowledge of these discolourations. Discolourations may be green, brown red, orange red, yellow coloured and sometime even black. Some people of Kasargod coast observed black colour of the underwater during May-June. The laymen consider it as a result of runoff water, a soil coloured water, and some others believe that it is due to the incorporation of organic waste and industrial waste. Only 4% people have the knowledge that it is a result of multiplication of "organisms"; and all of them are educated youngsters.

They have the first hand experience of blooms, the changes due to these phenomena in water column such as the increase in water viscosity and increase in bioluminescence. The endurance and migration of algal blooms depend on the wind and water currents. There is a difference in movement of algal bloom as with the oceanic wind and water currents, some move southward, others northward and most of them from west to the coast. These discolourations are present in the March-May Season as well as from August to October.

All the fishermen are aware of the fact that it is having an impact over fisheries, both beneficial and harmful. While fishing, it creates irritation to skin, watering of eyes, nausea etc. A few fishermen (5%) explained that the smell and taste of fish will change, on the occurrence of blooms. Beneficial effect includes the increase in catch of benthic fishes, such as *Nung*, the sole fish (*Cynoglossus semifasciatus*). Some fishes avoid the coloured patches, by tracking the shoal they can be caught. Highly viscous waters with fishes and shell fishes are known as "*chaakara*", which is periodically observed in the coastal regions of Kerala. Some fishes and molluscs become dead during discolourations. They also observed that some fishes develop some "mathth" (dizziness) during "*kadalkkara*".

There are several fishes that are being affected. *Karutha aakoli* (*Parastromateus niger*) is dead during '*udd*' or '*matt*' (means sediment or precipitate). 'Ayala' (*Rastrelliger* spp.), 'kanambu' (*Mugil cephalus*), 'maalaan', 'thirandi (*Rhinoptera* spp., *Dasyaatis* spp.), 'nangu' (*Cynoglossus sp.*) and several fishes generally not collected food are being affected. The coast of North Malabar also experienced the mortality of 'kallummakka' (*Perna spp.*). The fishermen /inhabitants of Bekal, Mahe, Puthiyappa, Kannamali, Thangasserry and Valiyathura are found to have more experience of discolourations and ill effects on fishes.

Oceanic Blooms

During the nine *FORV Sagar Sampada* cruises, seven blooms were observed; all the discolourations were by the N_2 fixing filamentous cyanophyte, *Trichodesmium erythraeum* (Annexure VI). Four of them belong to the PRM season, whereas the other three in the SWM. The details of the bloomed stations are given below (Table. 5.2).

There were 3 stations from ARS, three from BOB and one from ANS. The blooms of the BOB, namely, Station nos. 891, 866 and 874 are located in the clusters, namely LC-IV, LC-II and LC-I respectively. All the bloomed stations of BOB reported in the study spatially belong to BOBO. The bloom of Andaman waters also belong to the SWM season and LC-II, having a depth of 988 m (Annexure VI).

The bloom stations of the Arabian Sea were 1107 and 1147b (Photo 5.1) along with a sample collected during the Cruise 196 without anchoring. 1107 is a station belonging to coastal region and 1147b is oceanic, the former of PRM and latter of SWM. They belong to LC- II (1147 b) and LC- V(1107).

Table 5.2 Details of bloom stations encountered during FORV Sagar Sampada cruises

Cruise No.	Station no.	Date	Latitude	Longitude	Time	Sea	Station depth m
193	866	06-04-01	10-59-88	81-52-07	10.40	BOB	3662
193	874	11-04-01	13-00-22	80-42-14	13.35	BOB	344
193	891	25-04-01	19-43-54	89-03-43	16.35	BOB	1517
196	*	14-07-01	11-55-79	74-52-61	14.30	ARS	*
203	1107	22-05-02	19-00-37	71-59-31	00.40	ARS	719
204	1147 B	02-07-02	11-02-95	74-44-53	16.30	ARS	891
207	1209 bl	28-09-02	12-45-46	94-37-48	10.00	ANS	1988

(* no data available)

All of these blooms were having a yellowish colour with clusters of hey like filaments. During microscopic examination only very few of the filaments had a blue green or red colour; mostly yellowish green in colour (Annexure VI). There was no fish mortality, foul smell or any other commonly expected observable features recorded during these oceanic blooms.

Table. 5.3 is showing the physico-chemical parameters of the six bloom area. The details of the biological variables, GPP, NPP and chlorphyll *a* are given in Table.5.4. The average of the data on physicochemical parameters are taken and depicted in the Graph. 5.2

Coastal blooms

Table. 5.3. The details of the bloom events obesrved from the coastal regions of Kerala

Date	Latitude °N	Longitude °E	Time	Area	Microalgae
29.07.'01	11.73	75.57	09.30	Chombala	*Noctiluca scintillans* and *Chattonella marina*
11.08.'01	11.26	75.36	10.30	Puthiyappa	*Noctiluca scintillans* and *Chattonella marina*
9-11. 9.01	11.86 to12.71	75.36 to 74.88	-	North Kerala coast Puthiyangadi (kannur) to Kanhangad.	*Gymnodinium* and *Noctiluca*
10-10-01	11.44	75 26	9.30	Andalur- prawn farm.	Gymnodinium sp.
18-10-01	-	-	18.30	Irinavu -prawn farm	Dinoflagellates and Prasinophytes?
11 -11-02	11.86 - 12.71	75.36 - 74.88	19.00	North Kerala coast	*Noctiluca scintillans* and *Chattonella marina*
22-25-09-2003	9'58"	76'17"	17-30	Kannamali	*Chattonella marina*
9 -09-04	8'89"	76'60"	12.00	Kollam	*Cochlodinium polykrikoides*
18-09- 04	8.29	76.59	17.30	Trivandrum	*Cochlodinium polykrikoides*
20-09-04	9'58"	76'17"	16.30	Kannamali	*Cochlodinium polykrikoides*

The reports of algal blooms observed in the media, such as television channel reports and information from friends and coastal inhabitants were used for the visit of the coastal bloom area. The collection and analysis of water sample was carried out in the laboratory. The bloom sample, without adding preservative, was used for microscopic analysis and culture. In the early periods of research, i.e, during 2001-2002, a survey along the Kerala coast is carried out as a preliminary study. Padanna (Kasargod), Chombala (Kozhikkode), Kodikkal (Kozhikkode), Puthiyappa (Kozhikkode), Kannamali (Eranakulam), Thangasserry (Kollam), Puthenthura (Thiruvananthapuram) and Valiyathura (Thiruvananthapuram) are the sites visited (Table 5. 2) on reports of bloom.

5.4 Discussion

Oceanic *Trichodesmium* blooms:

Out of the four physical parameters studied the salinity and pH is not having much variation in the vertical profile; but, in the case of the bloom of Andaman Sea, there is a higher salinity in deeper layers, contradictory to the normal condition. The DO as well as temperature lowers with depth. Among the bloom stations a lower pH in the surface water observed in the case of the oceanic station of the Arabian Sea belonging to Southwest monsoon.

The chemical variables had much variation from the surface to 75m depth having a higher concentration in the deeper layers, which one was a general pattern in the oceanic waters in the case of NO_2, NO_3, SiO_4 and PO_4 and DO. In the surface water, the concentration of NO_2 and NO_3 is found to be very low, especially at the station, 1209 bl. The nitrate concentration in the surface layers are also similar to these bloom stations. The life stage of *Trichodesmium erythraeum* may also influence the amount of nitrogenous compounds in water.

The GPP and NPP is found to be higher than the surrounding stations in all the cruise blooms. The increase in the cell no of the Trichodesmium is also reflected tin the surface chlorophyll of the bloom area (Table.5.4). The blooming autotrophs surely will result in the higher chlorophyll concentration and primary productivity; that general condition seen in all the bloomed stations.

The *Trichodemsium erythraeum* blooms (Annexure VI) is a typical feature of tropical seas. There are several reports of the bloom events from the Indian waters (Desikachary, 1959; Prabhu et.al., 1965, Ramamurty et., al, 1972; Haridas and Sakthivel, 1974; Sreekumaran et al, 1992; Gopinathan and Balachandran, 2000) including all the parts of EEZ. Researchers such as Panikkar (1970), have the opinion that there is latitudinal restriction regarding the blooming, that is also found to be not true. Tyrrel, et. al., 2003 concluded that there is a latitudinal difference in the occurrence of *Trichodesmium* bloom, high abundance within the latitude of 0-15^{o}N and sparse or absent in the 5-30^{o}S, along the African coast of the Atlantic Ocean. In the present study there two occurrences of bloom events in the 19-20^{o}N.

Qasim, 1970 and Devassy et al, 1978, reported the blooms from Southwest coast of India, but the present study evidenced that there is no latitudinal or regional restriction in the blooming of *Trichodesmium*, at least in the EEZ of India. In Pacific Ocean the blooms of *Trichodesmium* were present in both the coastal and open ocean, as seen in the present study also. The coastal and oceanic blooms were reported from ARS as well as BOB.

The seasonal distribution of the presently observed blooms itself is against the opinion of *Trichodesmium* bloom happens during warmer periods or during the low nutrient especially, nitrate and phosphate, conditions. The nitrate, nitrite and phosphate content of the surface water having bloom is found to be lesser than the average of EEZ (Table. 4.2). The relatively lower amount of nitrite and nitrate (Table.5.4) may be the reason behind the blooming of this N_2 fixing cyanobacterium. The reports of the influence of iron on blooming of *Trichodesmium* is more and more strengthens during the recent years. The actual contribution of these 'nitrostats' are yet to be estimated.

Species composition of the bloom area revealed the presence of more dinoflagellates in the Bay of Bengal where as the diatom was found to be dominant in number of species and species abundance in Arabian Sea. The Andaman bloom was also had more association with diatoms in both number of species and standing crop. The bloom at Station no. 866 was lacking diatom species, in the detectable amount (table.

Most of the bloom *Trichodesmium erythraeum* observed in the EEZ had no ill effect over fishes and other fauna or even foul smell. The prsent observations are also supporting that opinion, although (Landsberg, 2002) reported the toxicity.

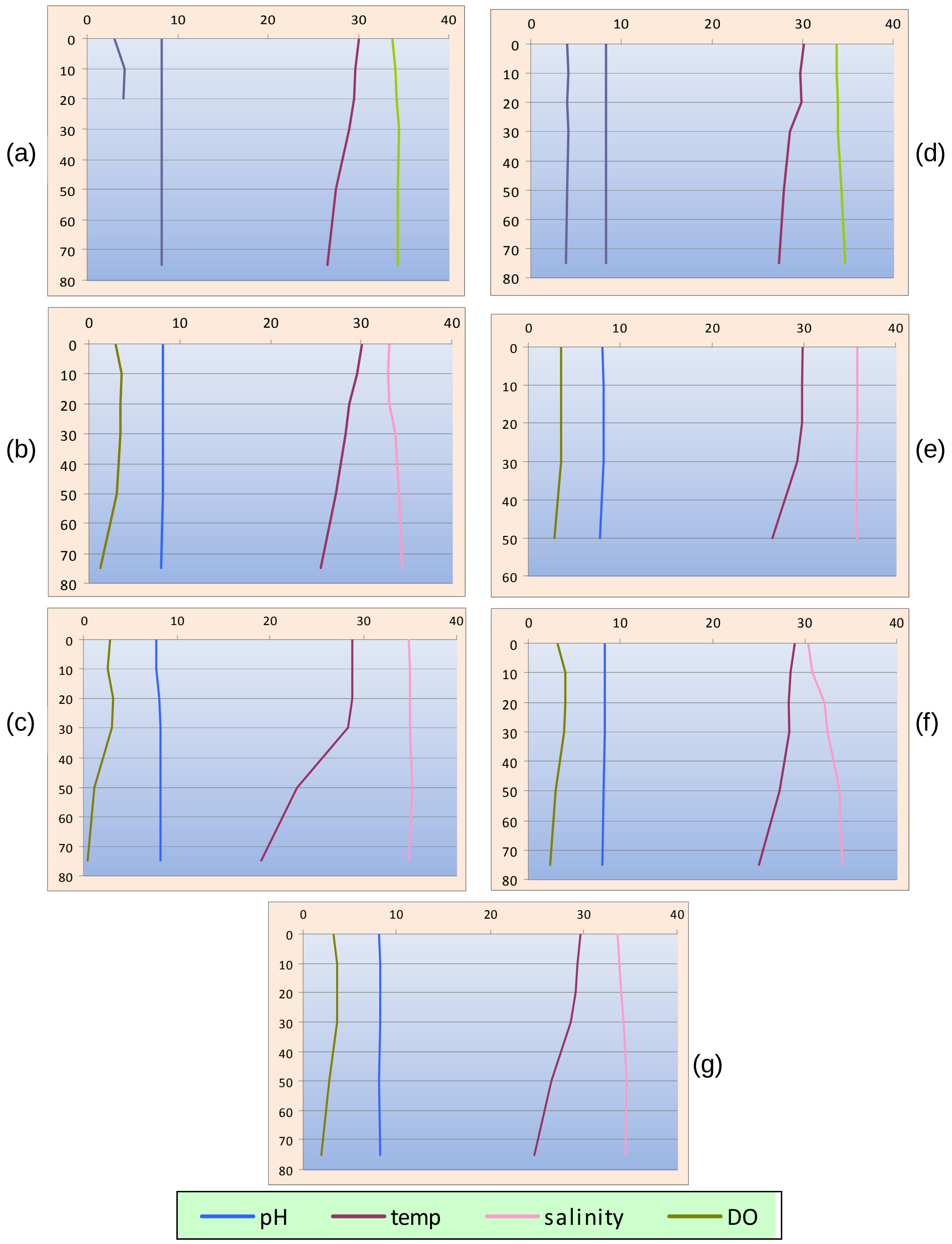
Because of the absence of zooplankton and other marine faunal studies during the bloom, the present study is not rejecting that 'there is no harmful effect'.

Table. 5.4. Physico – Chemical Parameters of bloom area

station no.	station depth	depth	pH	Temp	Salinity	DO	NO_2	NO_3	SiO_4	PO_4
866	3662	0	8.26	30.03	33.77	3.10	0.02	0.01	0.93	0.64
		10	8.33	29.7	34.2	4.25	0.02	-	1.92	1.3
		20	8.31	29.55	34.25	4.09	0.02	-	2.03	0.77
		30	8.33	29.07	34.52	-	-	-	-	-
		50	8.32	27.53	34.34	-	-	-	-	-
		75	8.31	26.57	34.38	-	-	-	-	-
874	344	0	8.23	30.17	33.79	4.07	0.03	0.01	0.50	0.63
		10	8.27	29.81	33.79	4.10	0.02	-	0.50	0.58
		20	8.28	29.96	33.91	4.01	0.03	-	0.47	0.57
		30	8.28	28.57	33.95	4.11	0.03	-	0.47	0.6
		50	8.29	27.98	34.25	3.96	0.02	0.01	0.47	0.64
		75	8.25	27.45	34.63	3.87	0.02	0.02	0.47	0.63
891	1517	0	8.22	30.13	33.05	2.99	0.03	-	-	0.61
		10	8.25	29.62	33.01	3.69	0.02	-	-	0.59
		20	8.26	28.6	33.04	3.50	0.01	-	0.03	0.56
		30	8.25	28.25	33.71	3.54	0.01	-	0.19	0.6
		50	8.22	27.17	34.12	3.12	0.11	2.20	1.18	0.69
		75	8.10	25.57	34.47	1.34	0.12	7.82	1.87	1.31
1107	71.9	0	8.10	29.91	35.86	3.51	0.06	-	-	0.80
		10	8.20	29.85	35.86	3.51	0.02	0.01	-	0.90
		20	8.19	29.83	35.86	3.50	0.02	-	-	0.97
		30	8.19	29.33	35.71	3.54	0.17	0.02	0.3	1.06
		50	7.78	26.54	35.72	2.83	0.16	2.54	6.3	1.13
1147	1607	0	7.77	28.86	34.97	2.84	-	-	-	-
B		10	7.84	28.85	34.98	2.6	-	-	-	-
		20	8.14	28.8	34.99	3.17	-	-	-	-
		30	8.24	28.32	35.04	3.10	-	-	-	-
		50	8.26	22.97	35.27	1.15	-	-	-	-
		75	8.25	19.13	34.87	0.40	-	-	-	-
1209	988	0	8.30	28.98	30.38	3.24	-	-	0.18	0.17
Bloom		10	8.32	28.52	30.89	4.00	-	-	0.19	0.17
		20	8.33	28.24	32.12	4.01	-	-	0.19	0.16
		30	8.31	28.31	32.54	3.96	-	-	0.19	0.18
		50	8.23	27.31	33.83	2.97	-	2.52	0.19	0.37
		75	8.12	25.07	34.02	2.35	-	6.42	-	0.84

Table. 5.5. GPP, NPP and Chl*a* of bloom area

station no.	depth	GPP	NPP	chl *a*
866	0	0.084	0.075	-
	10	0.201	0.099	-
	20	0.069	0.039	-
	30	-	-	-
	50	-	-	-
	75	-	-	-
874	0	0.26	0.116	-
	10	0.228	0.156	-
	20	0.304	0.14	-
	30	0.084	0.028	-
	50	0.08	0.068	-
	75	0.1	0.024	-
1107	0	0.707	0.417	0.85
	10	0.533	0.315	0.93
	20	0.814	0.675	1.05
	30	0.187	0.036	1.22
	50	0.398	0.024	1.84
1147	0	-	-	5.44
B	10	-	-	3.00
	20	-	-	3.00
	30	-	-	1.84
	50	-	-	1.66
	75	-	-	1.44
1209	0	0.795	0.195	6.99
Bloom	10	-	-	0.64
	20	-	-	0.54
	30	-	-	0.33
	50	-	-	0.17
	75	-	-	0.33



Graph.5.1. Vertical profile upto 75 m of physical variables and DO in the bloom area.

a. Station no. 866 (cruise no.193, BOB)
b. Station no. 874 (cruise no. 193, BOB)
c. Station no. 891 (cruise no. 193, BOB)
d. Station no. 1107 (cruise no. 203, ARS)
e. Station no. 1147b (cruise no. 204, ARS)
f. Station no. 1209 bl (cruise no. 207, ANS)
g. Average of the bloom stations in the EEZ

Coastal blooms

Padanna of Kasargod is one of the main centres of fish landing in the northern Kerala and there are several small and large scale mussel culture farms. It is situated in the Southern part of Kasargod district and it is geographically in between the *Valiyapoyil* Lake and River *Thejaswini* (*Kariyankod puzha*). The media report was regarding the fish mortality and foul smell along the coast, and the smell reached the far-east villages of Kasargod district. The site was visited in the evening, at 05:30 pm. The report was true and it was found that several small fishes which are generally having an estuarine and benthic nature were affected and mortality occurred. The affected fishes included small ones, 'mullan' (*Leognathus* sp.), 'eel', 'paambada' etc. The foul smell created head ache for the people around. The fishermen were of the opinion that the foul smell was due to the upward movement of the marine water which is of a common occurrence. The dominant microalgal species of the bloom waters found to be *Gymnodinium veneficum* (185 cells/l) and *Noctiluca scintillans* (100 cells/l). The other microalgae include *Prorocentrum micans, P. lima* and *Skeletonema costatum*. Chombala is one of the largest fishing harbour of north Kerala where there was a bloom of *Noctiluca miliaris* on 29-07-2001. The bloom was reddish orange in colour. The water samples were collected from the most intense coloured region of the inshore waters, 0.5 km away west of the fishing harbour. Sprinkling of rain was there during collection. There was no mortality of fishes or any other noticeable ill effects. The physico-chemical and biological parameters of the bloom area are studied. The pH of the area was 6.5 and the temperature is found to be $23^{o}C$ and salinity was 34‰.

Near to the fishing harbour at Puthiyappa there was two blooms, *Noctiluca scintillans* during August 2001 and the other one was of *Chattonella marina* during November 2002. Both of them had a red orange colour, but the latter one had a lighter green tinge. Both days were well illuminating. The fish catch was more for 'nangu' (*Cynoglossus* sp.).

On 11 August 2001, the bloom station of Puthiyappa, had a pH 7.6, with a surface temperature of 27^{o}C and a salinity of 34‰. *Noctiluca scintillans* was with a cell density of 3.2 x 10^{4}cells/l. *Chattonella marina* was also there but with a lesser density of 105 cells /l. The major species of microalgae present in the bloom water was that of *Asterionella japonica*, *Nitschia closterium*, *Prorocentrum micans* and *Noctiluca miliaris*. There were no cyanophytes. The viscosity of the water was more.

The bloom of September 2002, was that of *Chattonella marina,* with a cell density of 3.8 x 10^{5}, with *Asterionella japonica* (530 cells/l), *Noctiluca scintillans* (950cells/l), *Ceratium fusus* (100 cells/l). Salinity 33%, surface water temperature 26.5 and a pH of 7.8. The bloom in later stages spread to Thikkodi along North Kerala coast and resulted in the death of several bottom dwelling fishes and shell fishes along the sea coast of Payyoli and Thikkodi in the same week of September 2002. The productivity and pigment composition of the these three blooms of Kozhikkode is given in Table. 5.6.

Table. 5.6. Productivity, pigment composition of blooms of chombala and Puthiyappa, Kozhikkode district.

	GPP	NPP	Chl *a*	Chl *b*	Chl *c*	carotenoids
Chombala 2001	0.944	0.88	65.99	53.45	74.69	-
Puthiyappa 2001	0.985	0.745	69.56	23.05	46.53	3.3258
Puthiyappa 2002	1.213	0.785	76.2	46.4	59.4	3.2

Kannamali, a fish landing centre near to Cochin, was hit by two blooms, one that of *Chattonella marina* and the other of *Cochlodinium polykrikoides*. Both of them were without any noticeable impact on other flora and fauna. The information of the bloom was recieved in the evening hours. Visited the place and noticed the discolouration and collected the bloom samples. The details are given in the table 5.7. The bloom of *Chattonella marina* was light greenish yellow coloured one but that of Cochlodinium was brownish red. The dominant microalgae includes *Ceratium fusus*, *Asterionella japonica*, *Rhizosolenia castracanei* and *Skeletonema costatum*. *Chattonella* taken to the laboratory for the culture studies.

Table. 5.7. Productivity, pigment composition of *Chattonella* bloom hit Kannamali, on 22-09-2003.

	Salinity ‰	**pH**	**Temperature °C**	**GPP gC/m^3/day**	**NPP gC/m^3/day**	**chl *a* µg/L**	**Chl *b* µg/L**	**chl *c* µg/L**
22-09-03 - 4.15 pm	36	8.1	28.2	4.3	1.293	72.5	10.03	11.2

The discolouration due to *Cochlodinium polykrikoides* hit the Kannamali coast on 20 September 2004, within two days after a bloom of the same species hit at Trivandrum coast (18-09-2004). The concentration of *Cochlodinium* was found to be 3.2 x 10^3 (70% of standing crop) at Kannamali coast, 2000 cells per litre at Thangasserry of Kollam (50 %) and 5.7 x 10^6 cells per litre at Valiyathura of Trivandrum (95%). The dominant spp. includes *Nitzschia closterium*, *Coscinodiscus centralis, Biddulphia aurita* and *Chaetocersos decipiens*. There were several new phytoflagellates seen in the sample especially of the Kannamali sample, but preservation failure resulted in the identification. The phytoflagellates are found to burst, and very much similar to *Chattonella*, but they were found be very slender.

The species was a menace at the southern most coasts of Kerala, but there were no conspicuous ill-effects at the Kannamali coast. The site was visited, after the panic situation created among the laymen by the media. There were the incidents of hospitalisation of residential school children at

Trivandrum coast and mortality of bottom dwelling fishes, namely, ‘eel’, ‘kanambu’, ‘kora’ and puffer fishes. The colour of water was coffee coloured and the water was highly turbulent. A firsthand experience of head ache and vomiting occurred on the visit to the coastal area.

During the period of investigation two bloom reports and mortality of prawns were reported from Andalur and Irinave of Kannur district. Both of them were due to *Gymnodinium* spp. and the species composition was not diverse as that of natural waters.

The bursting of *Chattonella marina* while using any preservative or fixative before analysis was a major threat for analysis. Later, there were several papers on the mixotrophy of dinoflagellates and the requirement of certain organic substances for the culturing of *Noctiluca*, *Cochlodinium* and *Gymnodinium*. The failure of the culturing will be because of the scarcity of organic compounds in the media. The bursting of phyoflagellates was also described by Padmakumar et al., 2011. The bursting of *Chattonella* on the microscopic slide as well as in the sample while adding the preservative has given a concept of the sensitivity of the organism to the subtle changes in the environment. The existence of a bloom in a highly dynamic sea with turbulent nature becomes more magical in the struggle for existence and the survival of the fittest. These sensitive microscopic cells have the ability to withstand the violent and dynamic features of the environment; or they have the capacity to draw the optimum conditions from the non cooperative circumstances of the nature. Their presence is marked by the bloom events.

Microalgal culture

The laboratory culture of *Noctiluca miliaris*, *Chattonella marina* and *Cochlodinum polykrikoides* were tried in the culture facility, marine botany laboratory of the department. *Noctilua miliaris* collected during the local collection on 11-08-01 from the coastal waters of Calicut remained alive only for two weeks in laboratory, the algal biomass decreased drastically day by day. *Chattonella* and *Cochlodinium* samples disintegrated within hours. The culture medium used for the culture practice was Walne's medium; with the same pH and salinity as that of the natural condition. The laboratory temperature was 24^{o}C and the 14 hr:10 hr light and dark periods were given with a light intensity of 3000 lux.

The scarcity of organic compounds in the medium was identified as the reason for non-establishment of cultures. Absence of endosymbiotic bacteria and suitable algal prey in the culture media also responsible for the failure in the establishment of unialgal cultures.

Impact of Bloom

Although there was a report of influence of the *Trichodesmium* bloom on the sardine fishery (Prabhu et. al., 1971), in the present study, no direct link was found regarding the harmful nature of the *Trichodesmium* bloom. The dead shell fishes were collected from the *Noctiluca* bloom sites of Payyoli and fishes collected from valiyathura of Thiruvananthapuram were used to find out the stress enzymes in the gills. The amount of fresh sample collected was not enough for the standardisation and enzymatic estimation.

The reports of *Trichodemsium* as a harmful species, is yet to be ascertained. A stress from the environment generally influences the physiology of any organism. Cyanobacteria generally have so many extreacelluar products; the allelopathic interactions produced by these chemicals being responsible for calling those diazotrophs as 'harmful' or even 'toxic'.

Impact on livelihood of coastal people

The socio-economic impact of the algal blooms was quite visible during the visit to bloom sites all over Kerala coast. People stopped the consumption of fish based on media reports of harmful algal bloom. The reduction in the demand of fish resulted in clashes between the fishermen community and the local media persons.

Many blooms of Ichthyotoxic or harmful nature, reported as harmful or toxic in the temperate, are not having much effect on flora and fauna of the tropical seas. The scientific community should be more responsible while reporting and publishing an alga as harmful or toxic.

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Chapter 6

SUMMARY AND CONCLUSION

As the title of the thesis indicates, a detailed analysis of microalgae, the major primary producers and the first link in aquatic food chains, was carried out during this study. Microalgae are either planktonic or benthic. The studies on these microscopic autotrophs are having an upsurge of interest recently due to their variations, adaptations, short generation time and various utilitarian aspects, including food, fodder and fuel.

The aquatic ecosystems are being modified under the anthropogenic pressure. Threat by pollution, infiltration of UV rays to the atmosphere and global warming may affect each and every organism of the biosphere. Absence of a baseline data on each and every microclimate of this biosphere is a matter of ignorance. Collective efforts are required to know, understand and appreciate each and every organism of the living world, which happens in the case of genomic studies.

Planktonic microalgae are the major primary producers contributing of 4/5 of the aquatic primary productivity. Primary productivity of EEZ influences the entire fishery resources in the EEZ of India. Being a major seafood exporting country with an annual exporting income of 4.5×10^6 million dollars, it is very essential to have a baseline data on the factors which influences the fishery resources of India.

The qualitative and quantitative distribution of the photosynthetic microalgae was studied in the EEZ, by several researchers. Most of the available literature is confined to the coastal and estuarine microalgae. The diversity and variations in diversity of microalgae with physico-chemical and climatic conditions are to be assessed for studying the potentiality of EEZ. The algal bloom events, sudden proliferation of microalgae are increasing globally. The reasons behind the proliferation and ecological, biological and economic impacts of these blooms are being studied by several national and international agencies. Present study is the first of its kind that addresses the planktonic microalgal diversity, the relationship of these microalgae with hydrographic parameters existing in the surface waters and blooms of coastal and oceanic regions.

191 samples were analyzed collected through nine cruises of *FORV Sagar Sampada*, from different locations of the Indian EEZ covering Arabian Sea, Bay of Bengal and Andaman waters for the qualitative and quantitative studies of microalgae. The variation in the species diversity and abundance is analysed with the grouping of data based on latitude, station depth, sampling time, season and region.

Altogether, 245 species of microalgae were recorded during the study which belongs to the classes Dinophyceae, Bacillariophyceae, Dictyochophyceae and Cyanophyceae .They include 116 species of dinoflagellates, 121 species of diatoms, 6 species of blue green algae and 2 species of silicoflagellates. The most abundant genus was *Ceratium* (class dinophyceae) with 31 species, and *Chaetoceros* (class bacillariophyceae) with 28 species, where as *Oscillatoria* being the abundant genus with 3 species from the class cyanophyceae. 28 species of dinoflagellates and 13 diatoms were common in all the three regions of the EEZ.

The distribution of the microalgae showed regional, seasonal and latitudinal variation. 28 species of dinoflagellates and 13 species of diatoms had an occurrence in Arabian Sea, Bay of Bengal and Andaman Sea. 27 dinoflagellates and 36 diatoms were commonly present in Arabian Sea and Bay of Bengal. The presence of 9 dinoflagellates and 6 diatoms was restricted to the Eastern part of the EEZ. As the latitude increases there found a steady increase in the species diversity, in all the three regions of EEZ. The diversity among dinoflagellates was found to be less in the lower latitudes.

There is a marked difference in the species composition and standing crop of the coastal region inshore waters and the oceanic off shore waters in both the parts of Indian EEZ, ARS and BOB. The coastal regions of Arabian Sea were found to be more productive than the oceanic region. Even after excluding three blooms of *Trichodesmium,* the average standing crop as well as the number of species of microalgae was higher in the open Sea of Bay of Bengal. In the present investigation, the average standing crop of the eastern Andaman Sea is found to be more than that in the western part. This could be due to the comparatively higher values of hydrographic variables of western region, which was found to be warmer and saline than the eastern region.

The statistical analysis for similarity and diversity among the microalgae and that for their taxonomic distinctiveness concluded that the seasonal influence is more prominent in all the three parts of the EEZ than diurnal spatial and latitudinal influence.

The present study of surface water primary productivity, also supports the view that Arabian Sea is considered as more productive than Bay of Bengal. The factors attributed for the phenomenon were composition of microalgae, upwelling, wind and water current pattern. Andaman Sea is having an average value of primary productivity in between that of Arabian Sea and Andaman waters. The central region of Andaman waters is found to be more productive than the northern and southern parts. The ratio between the average GPP and NPP of Arabian Sea, Andaman Sea and Bay of Bengal is found to be 5:2:1.

The annual average gross primary productivity for Arabian Sea, Bay of Bengal and Andaman Sea was estimated as 394gC/m^3, 77.75gC/m^3 and 152.21gC/m^3 respectively. The corresponding annual net primary productivity values were 169gC/m^3, 34.31 gC/m^3 and 81.76gC/m$^{3.}$ The annual average gross production for the entire EEZ of India is estimated to be 225.57gC/m^3 and the corresponding net production was 97.1gC/m^3, which is only 43.37% of the gross production. In Arabian Sea the net production was 42.8% of gross production, in Bay of Bengal it was 44.13% and in the Andaman Sea it was 53.71% of the gross primary production.

The diurnal variation in the EEZ has probably been studied for the first time. Diurnal variation in the productivity showed that the GPP is steadily increasing from the morning hours to evening. But a higher GPP in the evening may be due to the inclusion of a bloom station data. The NPP was found to be oscillating, but with a peak in the evening

The mean chlorophyll *a* concentration of the EEZ (combined data of three sampling locations, ie., ARS, ANS and BOB) was found to be 0.689µg/l during the study period. The present investigation was carried out extensively in the off shore waters. Due to the contribution of nutrient loading from the estuaries and also due to the meager occurrence upwelling, comparatively lower values of chlorophyll *a* have been accounted.

The physical and chemical variables influenced the primary productivity, chlorophyll *a* and microalgal standing crop of the EEZ, although statistical analysis of the present data fails to draw some relationships. The total standing crop and diatom concentration per litre is found to be negatively correlated with salinity and nitrite concentration. The dinoflagellates have experienced a positive correlation with the temperature and dissolved oxygen where as negatively correlated with the nitrite concentration.

Salinity was found to be more in the northern parts of west coast and southern parts of east coast. The upper latitudes of Bay of Bengal were found to have an estuarine nature.

The nitrite and nitrate concentration in most of the stations were very low. Phosphate concentration was highest with 0.69µmol/l in the Arabian Sea, and it was 0.52µmol/l in the Bay of Bengal. It was least in the Andaman Sea reaching only 0.29µmol/l. The Mean PO_4 value was 0.54µmol/l in the EEZ.

Seven blooms of *Trichodemsium erythraeum* were observed during the period. Arabian Sea and Bay of Bengal had three blooms each, in the southwest monsoon and Pre-monsoon periods. A bloom was observed during SWM, from Andaman waters. There was no fish mortality or foul smell for these oceanic blooms.

Preliminary survey carried out along Kerala coast revealed the awareness of the coastal inhabitants regarding the bloom events. Although most of them had an experience of discolorations of the sea water, they have no idea on the process of blooming and impact of bloom toxicity on human health. These discolourations are present in the March-May Season as well as from August to October. Coastal inhabitants have experiences of both harmful and beneficial nature by discolourations. The mortality of fishes and foul smell were the major features of the discolouration observed by them. They believe that bloom happens because of the mixing up of river run off water during the rainy season with the sea water, associated with the movement of water current.

The observed algal blooms along Kerala coast comprises of *Noctiluca scintillans*, *Gymnodinium veneficum*, *Cochlodinium polykrikoides* and *Chattonella marina*, all of them associated with the fish mortality and foul smell. These harmful effects are not manifested in all places. So the phenomenon of bloom is a highly complex natural event with several impacts.

It is very essential to have coastal research stations for algal monitoring along Kerala coast. The future studies on microalgae should be multidisciplinary in nature, so that we could better understand the assemblages of phytoplankton and their population dynamics.

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Annexure -I

Marine Microalgae: Diatoms

DINOFLAGELLATES				
Scientific name	Genera	Family	Order	Class
Amphiprora gigantea Grunow	Amphiprora	Amphipleuraceae	Naviculales	Bacillariophyceae
Asterionella japonica Cleve	Asterionella	Fragilariaceae	Fragilariales	Bacillariophyceae
Asteromphalus wyvillii Castracane	Asteromphalus	Asterolampraceae	Asterolamprales	Coscinodiscophyceae
Aulacodiscus orbiculatus Subrahmanyan	Aulacodiscus	Aulacodiscaceae	Coscinodiscales	Coscinodiscophyceae
Bacillaria paradoxa Gmelin	Bacillaria	Bacillariaceae	Bacillariales	Bacillariophyceae
Bacteriastrum cosmosum Pavillard	Bacteriastrum	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Bacteriastrum delicatulum Cleve	Bacteriastrum	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Bacteriastrum elongatum Cleve	Bacteriastrum	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Bacteriastrum hyalinum Lauder	Bacteriastrum	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Bacteriastrum varians Lauder	Bacteriastrum	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Biddulphia heteroceros Grunow	Biddulphia	Biddulphiaceae	Biddulphiales	Mediophyceae
Biddulphia indica (Ehrenberg) Roper	Biddulphia	Biddulphiaceae	Biddulphiales	Mediophyceae
Biddulphia mobiliensis (Bailey)Grunow	Biddulphia	Biddulphiaceae	Biddulphiales	Mediophyceae
Biddulphia pulchella Gray	Biddulphia	Biddulphiaceae	Biddulphiales	Mediophyceae
Biddulphia rhombus (Ehrenberg) Smith	Biddulphia	Biddulphiaceae	Biddulphiales	Mediophyceae
Biddulphia sinensis Greville	Biddulphia	Biddulphiaceae	Biddulphiales	Mediophyceae
Biddulphia tridens (Ehrenberg) Ehrenberg	Biddulphia	Biddulphiaceae	Biddulphiales	Mediophyceae
Cerataulina bergonii (Pergallo)Schutt	Cerataulina	Hemiaulaceae	Hemiaulales	Mediophyceae
Chaetoceros affinis Lauder	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros atlanticus Cleve	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros breve Schutt	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros calcitrans (Paulsen) Takano	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros coarctatus Lauder	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros compressus Lauder	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros convolutum Castracane	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros curvisetum Cleve	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros denticulata Lauder	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros didymus Ehrenberg	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros diversus Cleve	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae

Chaetoceros eibenii Grunow	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros flexuosus Mangin	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros gibberrula	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros indicus Karsten	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros laciniosus Schutt	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros lauderi Ralfs	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros lorenzianus Grunow	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros messanense Castracane	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros paradoxus Cleve	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros pelagicus Cleve	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros peruvianus Brightwell	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros seriacanthus Gran	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros siamense Ostenfeld	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros tetrastichon Cleve	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Chaetoceros tortissimus Gran	Chaetoceros	Chaetocerotaceae	Chaetocerotales	Mediophyceae
Climacodium biconcavum Cleve	Climacodium	Hemiaulaceae	Hemiaulales	Mediophyceae
Climacodium frauenfeldianum Grunow	Climacodium	Hemiaulaceae	Hemiaulales	Mediophyceae
Climacosphenia moniligera Ehrenberg	Climacosphenia	Climacospheniaceae	Climacospheniales	Bacillariophyceae
Corethron hystrix Hensen	Corethron	Corethraceae	Corethrales	Coscinodiscophyceae
Corethron inerme Karsten	Corethron	Corethraceae	Corethrales	Coscinodiscophyceae
Coscinodiscus apiculatus Ehrenberg	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae
Coscinodiscus centralis Ehrenberg	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae
Coscinodiscus concentricus Harting	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae
Coscinodiscus gigas Ehrenberg	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae
Coscinodiscus granii Gough	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae
Coscinodiscus jonesianus (Greville) Ostenfeldt	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae
Coscinodiscus marginatus Ehrenberg	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae
Coscinodiscus nitidus Gregory	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae
Coscinodiscus nodulifer Schmidt	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae
Coscinodiscus rothii (Ehrenberg) Grunow	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae
Coscinodiscus sublineatus Frenguelli	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae
Coscinodiscus subtilis Ehrenberg	Coscinodiscus	Coscinodiscaceae	Coscinodiscales	Coscinodiscophyceae

Ditylum brightwellii (West) Grunow	Ditylum	Lithodesmiaceae	Lithodesmiales	Mediophyceae
Ditylum sol Cleve	Ditylum	Lithodesmiaceae	Lithodesmiales	Mediophyceae
Eucampia cornuta (Cleve) Grunow	Eucampia	Hemiaulaceae	Hemiaulales	Mediophyceae
Eucampia zoodiacus Ehrenberg	Eucampia	Hemiaulaceae	Hemiaulales	Mediophyceae
Fragilaria cylindrus Grunow	Fragilaria	Fragilariaceae	Fragilariales	Bacillariophyceae
Fragilaria oceanica Cleve	Fragilaria	Fragilariaceae	Fragilariales	Bacillariophyceae
Grammatophora undulata	Grammatophora	Striatellaceae	Striatellales	Bacillariophyceae
Guinardia flaccida (Castracane)Peragallo	Guinardia	Rhizosoleniaceae	Rhizosoleniales	Coscinodiscophyceae
Guinardia striata (Stolterfoth) Hasle	Guinardia	Rhizosoleniaceae	Rhizosoleniales	Coscinodiscophyceae
*Gyrosigma macrum (*Smith)Cleve	Gyrosigma	Pleurosigmataceae	Naviculales	Bacillariophyceae
Hemiaulus indicus Karsten	Hemiaulus	Hemiaulaceae	Hemiaulales	Mediophyceae
Hemiaulus membranaceus Cleve	Hemiaulus	Hemiaulaceae	Hemiaulales	Mediophyceae
Hemiaulus sinensis Greville	Hemiaulus	Hemiaulaceae	Hemiaulales	Mediophyceae
Lauderia glacialis (Grunow) Gran	Lauderia	Lauderiaceae	Thalassiosirales	Mediophyceae
Leptocylindrus danicus Cleve	Leptocylindrus	Leptocylindraceae	Leptocylindrales	Coscinodiscophyceae
Melosira subtilis Goor	Melosira	Melosiraceae	Melosirales	Coscinodiscophyceae
Melosira sulcata (Ehrenberg) Kutzing	Melosira	Melosiraceae	Melosirales	Coscinodiscophyceae
Navicula angulata Queckett	Navicula	Naviculaceae	Naviculales	Bacillariophyceae
Navicula elegans Smith	Navicula	Naviculaceae	Naviculales	Bacillariophyceae
Navicula forcipata Greville	Navicula	Naviculaceae	Naviculales	Bacillariophyceae
Navicula hennadyie	Navicula	Naviculaceae	Naviculales	Bacillariophyceae
Navicula longa (Gregory) Ralfs ex Pritchard	Navicula	Naviculaceae	Naviculales	Bacillariophyceae
Navicula membranacea Cleve	Navicula	Naviculaceae	Naviculales	Bacillariophyceae
Navicula crucifera Grunow ex Schmidt	Navicula	Naviculaceae	Naviculales	Bacillariophyceae
Nitzschia lanceolata Smith	Nitzschia	Bacillariaceae	Bacillariales	Bacillariophyceae
Nitzschia longissima (Brebisson)Ralfs	Nitzschia	Bacillariaceae	Bacillariales	Bacillariophyceae
Nitzschia seriata Cleve	Nitzschia	Bacillariaceae	Bacillariales	Bacillariophyceae
Nitzschia sigma (Kutzing) Smith	Nitzschia	Bacillariaceae	Bacillariales	Bacillariophyceae
Planktoniella sol (Wallich) Schutt	Planktoniella	Thalassiosiraceae	Thalassiosirales	Mediophyceae
Pleurosigma angulatum (Queckett) Smith	Pleurosigma	Pleurosigmataceae	Naviculales	Bacillariophyceae
Pleurosigma directum Grunow	Pleurosigma	Pleurosigmataceae	Naviculales	Bacillariophyceae
Pleurosigma elongatum Smith	Pleurosigma	Pleurosigmataceae	Naviculales	Bacillariophyceae

Pleurosigma normanii Ralfs	Pleurosigma	Pleurosigmataceae	Naviculales	Bacillariophyceae
Pleurosigma rectum Donkin	Pleurosigma	Pleurosigmataceae	Naviculales	Bacillariophyceae
Pleurosigma rigidum Smith	Pleurosigma	Pleurosigmataceae	Naviculales	Bacillariophyceae
Rhabdonema arcuatum (Lyngbye)Kutzing	Rhabdonema	Rhabdonemataceae	Rhabdonematales	Bacillariophyceae
Rhizosolenia acuminata (Peragallo) Peragallo	Rhizosolenia	Rhizosoleniaceae	Rhizosoleniales	Coscinodiscophyceae
Rhizosolenia alata Brightwell	Rhizosolenia	Rhizosoleniaceae	Rhizosoleniales	Coscinodiscophyceae
Rhizosolenia castracanei Peragallo	Rhizosolenia	Rhizosoleniaceae	Rhizosoleniales	Coscinodiscophyceae
Rhizosolenia crassispina Schroder	Rhizosolenia	Rhizosoleniaceae	Rhizosoleniales	Coscinodiscophyceae
Rhizosolenia cylindrus Cleve	Rhizosolenia	Rhizosoleniaceae	Rhizosoleniales	Coscinodiscophyceae
Rhizosolenia hebetata Bailey	Rhizosolenia	Rhizosoleniaceae	Rhizosoleniales	Coscinodiscophyceae
Rhizosolenia robusta Norman ex Ralfs	Rhizosolenia	Rhizosoleniaceae	Rhizosoleniales	Coscinodiscophyceae
Rhizosolenia setigera Brightwell	Rhizosolenia	Rhizosoleniaceae	Rhizosoleniales	Coscinodiscophyceae
Rhizosolenia styliformis Brightwell	Rhizosolenia	Rhizosoleniaceae	Rhizosoleniales	Coscinodiscophyceae
Skeletonema costatum (Greville) Cleve	Skeletonema	Skeletonemaceae	Thalassiosirales	Coscinodiscophyceae
Streptotheca tamesis Shrubsole	Streptotheca	Bellerocheaceae	Hemiaulales	Mediophyceae
Thalassionema frauenfeldii (Grunow) Hallaegraff	Thalassionema	Thalassionemataceae	Thalassionematales	Bacillariophyceae
Thalassionema nitzschioides (Grunow) Merenschkowsky	Thalassionema	Thalassionemataceae	Thalassionematales	Bacillariophyceae
Thalassiosira hyalina (Grunow) Gran	Thalassiosira	Thalassiosiraceae	Thalassiosirales	Coscinodiscophyceae
Thalassiosira rotula Meunier	Thalassiosira	Thalassiosiraceae	Thalassiosirales	Coscinodiscophyceae
Thalassiosira subtilis (Ostenfeldt) Gran	Thalassiosira	Thalassiosiraceae	Thalassiosirales	Coscinodiscophyceae
Thalassiothrix delicatula Cupp	Thalassiothrix	Thalassionemataceae	Thalassionematales	Bacillariophyceae
Thalassiothrix frauenfeldii (Grunow) Grunow	Thalassiothrix	Thalassionemataceae	Thalassionematales	Bacillariophyceae
Thalassiothrix longissima Cleve and Grunow	Thalassiothrix	Thalassionemataceae	Thalassionematales	Bacillariophyceae
Thalassiothrix nitzschioides (Grunow) Grunow	Thalassiothrix	Thalassionemataceae	Thalassionematales	Bacillariophyceae
Triceratium alternans Bailey	Triceratium	Triceratiaceae	Triceratiales	Mediophyceae
Triceratium favus Ehrenberg	Triceratium	Triceratiaceae	Triceratiales	Mediophyceae
Triceratium reticulatum Greville	Triceratium	Triceratiaceae	Triceratiales	Mediophyceae
Tropidoneis semistriata Cleve	Tropidoneis	Lithodesmiaceae	Lithodesmiales	Mediophyceae

Annexure -II

Marine Microalgae : Dinoflagellates

Scientific name	Genera	Family	Order	Class
Actiniscus pentasterias (Ehrenberg) Ehrenberg	*Actiniscus*	Actiniscaceae	Actiniscales	Dinophyceae
Amphisolenia bidentata Schröder	*Amphisolenia*	Amphisoleniaceae	Dinophysiales	Dinophyceae
Blepharocysta compressa Gaarder	*Blepharocysta*	Podolampadaceae	Peridiniales	Dinophyceae
Blepharocysta splendor-maris (Ehrenberg) Ehrenberg	*Blepharocysta*	Podolampadaceae	Peridiniales	Dinophyceae
Ceratium belone Cleve	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium bigelowii Kofoid	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium buceros Zacharias	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium candelabrum (Ehrenberg) Stein	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium carriense Gouret	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium coarctatum Pavillard	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium concilians Jorgenson	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium contortum (Gourret) Cleve	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium declinatum Karsten	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium dens Ostenfeld and Schmidt	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium extensum (Gourret) Cleve	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium furca (Ehrenberg) Claparède & Lachmann	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium fusus (Ehrenberg) Dujardin	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium gibberum Gourret	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium hexacanthum Gourret	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium hircus Schröder	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium inflatum (Kofoid) Jorgenson	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium kofoidii Joregenson	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium longirostrum Gourret	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium lunula Schimper ex Karsten	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium macroceros Schrank	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium massiliense (Gourret) Karsten	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium pentagonum Gourret	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium pulchellum Schröder	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium ranipes Cleve	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium schroteri Schröder	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium symmetricum Pavillard	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae

Ceratium teres Kofoid	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium trichoceros (Ehrenberg) Kofoid	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium tripos (O.F.Müller) Ehrenberg	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratium vultur Cleve	*Ceratium*	Ceratiaceae	Gonyaulacales	Dinophyceae
Ceratocorys horrida Stein	*Ceratocorys*	Cearatocoryaceae	Gonyaulacales	Dinophyceae
Coolia monotis Meunier	*Coolia*	Ostreopsidaceae	Gonyaulacales	Dinophyceae
Dinophysis acuminata Claparède & Lachmann	*Dinophysis*	Dinophysiaceae	Dinophysiales	Dinophyceae
Dinophysis caudata Saville Kent	*Dinophysis*	Dinophysiaceae	Dinophysiales	Dinophyceae
Dinophysis hastata Stein	*Dinophysis*	Dinophysiaceae	Dinophysiales	Dinophyceae
Dinophysis miles Cleve	*Dinophysis*	Dinophysiaceae	Dinophysiales	Dinophyceae
Dinophysis ovum Schutt	*Dinophysis*	Dinophysiaceae	Dinophysiales	Dinophyceae
Diplopsalis lenticula Bergh	*Diplopsalis*	Protoperidiniaceae	Peridiniales	Dinophyceae
Dissodinium lunula (Schütt) Pascher	*Dissodinium*	Pyrocystaceae	Pyrocystales	Dinophyceae
Gonyaulax catenella Whedon & Kofoid	*Gonyaulax*	Gonyaulacaceae	Gonyaulacales	Dinophyceae
Gonyaulax diacantha Athanassopaulos	*Gonyaulax*	Gonyaulacaceae	Gonyaulacales	Dinophyceae
Gonyaulax diegensis Kofoid	*Gonyaulax*	Gonyaulacaceae	Gonyaulacales	Dinophyceae
Gonyaulax digitalis (Pouchet)Kofoid	*Gonyaulax*	Gonyaulacaceae	Gonyaulacales	Dinophyceae
Gonyaulax fragilis (Schutt) Kofoid	*Gonyaulax*	Gonyaulacaceae	Gonyaulacales	Dinophyceae
Gonyaulax polyedra Stein	*Gonyaulax*	Gonyaulacaceae	Gonyaulacales	Dinophyceae
Gonyaulax polygramma Stein	*Gonyaulax*	Gonyaulacaceae	Gonyaulacales	Dinophyceae
Gonyaulax turbynei Murray& Whitting	*Gonyaulax*	Gonyaulacaceae	Gonyaulacales	Dinophyceae
Gymnodinium breve Davis	*Gymnodinium*	Gymnodiniaceae	Gymnodiniales	Dinophyceae
Gymnodinium catenatum Graham	*Gymnodinium*	Gymnodiniaceae	Gymnodiniales	Dinophyceae
Gymnodinium coeruleum Dogiel	*Gymnodinium*	Gymnodiniaceae	Gymnodiniales	Dinophyceae
Gymnodinium falcatum (*Gyrodinium falcatum* Kofoid and Swezy)	*Gymnodinium*	Gymnodiniaceae	Gymnodiniales	Dinophyceae
Gymnodinium veneficum Ballentine	*Gymnodinium*	Gymnodiniaceae	Gymnodiniales	Dinophyceae
Heteraulacus acuminatus (Ehrenberg)Diesing	*Heteraulacus*	Goniodomataceae	Gonyaulacales	Dinophyceae
Heteraulacus sphaericus (Murray & Whitting) Loeblich III	*Heteraulacus*	Goniodomataceae	Gonyaulacales	Dinophyceae
Histioneis elongata Kofoid & Michener	*Histioneis*	Dinophysiaceae	Dinophysiales	Dinophyceae
Kofoidinium pavillardii Cachon & Cachon	*Kofoidinium*	Kofoidiniaceae	Noctilucales	Dinophyceae
Noctiluca miliaris Suriray	*Noctiluca*	Noctilucaceae	Noctilucales	Dinophyceae
Noctiluca scintillans (Macartney) Kofoid et Swezy	*Noctiluca*	Noctilucaceae	Noctilucales	Dinophyceae
Ornithocercus heteroporus Kofoid	*Ornithocercus*	Dinophysiaceae	Dinophysiales	Dinophyceae

Ornithocercus magnificus Stein	*Ornithocercus*	Dinophysiaceae	Dinophysiales	Dinophyceae
Ornithocercus quadratus Schutt	*Ornithocercus*	Dinophysiaceae	Dinophysiales	Dinophyceae
Ornithocercus splendidus Schutt	*Ornithocercus*	Dinophysiaceae	Dinophysiales	Dinophyceae
Ornithocercus steinii Schutt	*Ornithocercus*	Dinophysiaceae	Dinophysiales	Dinophyceae
Ornithocercus thumii (Schmidt) Kofoid & Skogsberg	*Ornithocercus*	Dinophysiaceae	Dinophysiales	Dinophyceae
Oxytoxum milneri Murray & Whitting	*Oxytoxum*	Oxytoxaceae	Peridiniales	Dinophyceae
Oxytoxum periclaudicans	*Oxytoxum*	Oxytoxaceae	Peridiniales	Dinophyceae
Oxytoxum solopax Stein	*Oxytoxum*	Oxytoxaceae	Peridiniales	Dinophyceae
Oxytoxum tesselatum (Stein) Schutt	*Oxytoxum*	Oxytoxaceae	Peridiniales	Dinophyceae
Peridinium abei Paulsen	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium biconicum Abe	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium brochii Kofoid and Swezy	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium claudicans Paulsen	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium conicum (Gran) Ostenfeld & Schmidt	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium crassipes Kofoid	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium depressum (Bailey)Peters	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium divergens (Ehrenberg) Bergh	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium elegans Cleve	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium excentricum Paulsen	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium globulus Stein	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium grande Kofoid	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium leonis Pavillard	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium longipes Bailey	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium nipponica Abe	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium oblongum (Aurivillius) Cleve	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium pallidum Ostenfeld	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium pellucidum (Bergh) Schutt	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium pentagonum Gran	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium polonicum Wolozynska	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium spiniferum Claparède & Lachmann	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium tuba Schiller	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Peridinium venustum Metzenauer	*Peridinium*	Peridiniaceae	Peridiniales	Dinophyceae
Phalacroma apicatum Kofoid and skogsberg	*Phalacroma*	Dinophysiaceae	Dinophysiales	Dinophyceae

Phalacroma argus Stein	*Phalacroma*	Dinophysiaceae	Dinophysiales	Dinophyceae
Phalacroma cuneus Schutt	*Phalacroma*	Dinophysiaceae	Dinophysiales	Dinophyceae
Phalacroma rotundatum (Claparéde & Lachmann) Kofoid & Michener	*Phalacroma*	Dinophysiaceae	Dinophysiales	Dinophyceae
Podolampas bipes Stein	*Podolampas*	Podolampadaceae	Peridiniales	Dinophyceae
Podolampas elegans Schutt	*Podolampas*	Podolampadaceae	Peridiniales	Dinophyceae
Podolampas reticulata Kofoid	*Podolampas*	Podolampadaceae	Peridiniales	Dinophyceae
Podolampas spinifera Okamura	*Podolampas*	Podolampadaceae	Peridiniales	Dinophyceae
Pronoctiluca acuta (Lohmann) Schiller	*Pronoctiluca*	*Protodeniferaceae*	Noctilucales	Dinophyceae
Prorocentrum compressum (Bailey)Abe ex Dodge	*Prorocentrum*	Prorocentraceae	Prorocentrales	Dinophyceae
Prorocentrum gracile Schutt	*Prorocentrum*	Prorocentraceae	Prorocentrales	Dinophyceae
*Prorocentrum lima (*Ehrenberg) Stein	*Prorocentrum*	Prorocentraceae	Prorocentrales	Dinophyceae
Prorocentrum micans Ehrenberg	*Prorocentrum*	Prorocentraceae	Prorocentrales	Dinophyceae
Prorocentrum pyriforme (Schiller) Taylor	*Prorocentrum*	Prorocentraceae	Prorocentrales	Dinophyceae
Prorocentrum reticulatum Faust	*Prorocentrum*	Prorocentraceae	Prorocentrales	Dinophyceae
Prorocentrum rostratum Stein	*Prorocentrum*	Prorocentraceae	Prorocentrales	Dinophyceae
Protoceratium reticulatum (Claparède & Lachmann) Butschli	*Prortoceratium*	Gonyaulacaceae	Gonyaulacales	Dinophyceae
Pyrocystis lunula (Schutt) Schutt	*Pyrocystis*	Pyrocystaceae	Pyrocystales	Dinophyceae
Pyrocystis pseudonoctiluca Whyville and Thompson	*Pyrocystis*	Pyrocystaceae	Pyrocystales	Dinophyceae
Pyrophacus horologium Stein	*Pyrophacus*	Pyrophacaceae	Gonyaulacales	Dinophyceae

Marine Microalgae : Others

Dictyocha	Dictyochaceae	Dictyochales	Dictyochophyceae	*Dictyocha fibula*
Dictyocha	Dictyochaceae	Dictyochales	Dictyochophyceae	*Dictyocha staurodone*
Oscillatoria	Oscillatoriaceae	Oscillatoriales	Cyanophyceae	*Oscillatoria agardhii*
Oscillatoria	Oscillatoriaceae	Oscillatoriales	Cyanophyceae	*Oscillatoria acutissima*
Oscillatoria	Oscillatoriaceae	Oscillatoriales	Cyanophyceae	*Oscillatoria nigroviridis*
Trichodesmium	Phormidiaceae	Oscillatoriales	Cyanophyceae	*Trichodesmium theibautii*
Trichodesmium	Phormidiaceae	Oscillatoriales	Cyanophyceae	*Trichodesmium erythraeum*

Annexure -III

Diversity indices – Arabian Sea

Stn.No:	S	N	d	J'	ES(100)	H'(loge)	Lambda	1-Lambda'	N1	N2	Delta	Delta*	Delta+	sDelta+	Lambda+	Phi+	sPhi+
733	20	126	3.93	0.84	19.02	2.51	0.11	0.90	12.34	8.99	77.81	86.85	86.49	1729.82	449.09	58.33	1166.67
734	14	136	2.65	0.78	13.77	2.06	0.18	0.82	7.87	5.43	72.21	87.86	83.33	1166.67	592.19	54.76	766.67
735	20	121	3.96	0.81	18.77	2.42	0.14	0.87	11.24	7.38	76.54	87.80	84.04	1680.70	417.64	55.83	1116.67
736	24	269	4.11	0.75	18.85	2.38	0.16	0.85	10.85	6.42	69.20	81.68	83.15	1995.65	506.21	47.22	1133.33
737	19	373	3.04	0.62	11.88	1.81	0.26	0.75	6.13	3.89	51.41	69.00	80.90	1537.04	690.94	49.12	933.33
738	16	257	2.70	0.74	13.16	2.04	0.19	0.82	7.70	5.39	66.71	81.59	83.61	1337.78	532.33	54.17	866.67
739	20	391	3.18	0.62	12.70	1.86	0.24	0.76	6.45	4.21	58.82	76.97	87.46	1749.12	502.01	57.50	1150.00
740	16	501	2.41	0.50	9.80	1.38	0.36	0.65	3.96	2.81	58.64	90.90	87.22	1395.56	591.36	54.17	866.67
741	20	338	3.26	0.77	14.91	2.30	0.14	0.87	9.94	7.28	69.11	79.87	87.02	1740.35	451.34	57.50	1150.00
742	13	57	2.97	0.88	13.00	2.25	0.13	0.89	9.51	7.72	73.41	82.86	85.68	1113.89	332.79	64.10	833.33
743	15	558	2.21	0.49	10.69	1.34	0.43	0.57	3.81	2.31	37.41	65.78	83.02	1245.24	629.53	57.78	866.67
744	10	108	1.92	0.76	9.99	1.75	0.24	0.76	5.74	4.10	42.51	55.68	57.04	570.37	327.02	46.67	466.67
745	8	75	1.62	0.74	8.00	1.53	0.33	0.68	4.62	3.00	37.24	55.14	57.14	457.14	306.12	47.92	383.33
747	12	117	2.31	0.64	11.50	1.58	0.32	0.69	4.86	3.12	61.68	90.03	71.21	854.55	610.65	55.56	666.67
748	13	108	2.56	0.80	12.92	2.06	0.18	0.83	7.87	5.50	73.88	89.48	88.46	1150.00	401.05	69.23	900.00
749	18	94	3.74	0.92	18.00	2.66	0.08	0.93	14.27	12.24	82.88	89.29	83.66	1505.88	441.07	61.11	1100.00
750	20	119	3.98	0.87	19.17	2.62	0.10	0.91	13.69	10.21	78.44	86.22	83.25	1664.91	519.00	55.00	1100.00
751	18	148	3.40	0.72	15.52	2.09	0.18	0.83	8.08	5.62	71.37	86.24	80.83	1454.90	689.07	52.78	950.00
752	18	180	3.27	0.68	14.77	1.96	0.25	0.76	7.10	4.07	64.81	85.41	85.51	1539.22	383.78	55.56	1000.00
753	21	539	3.18	0.74	13.83	2.25	0.14	0.86	9.46	7.19	71.85	83.30	86.19	1810.00	581.78	51.59	1083.33
754	15	627	2.17	0.60	8.77	1.62	0.26	0.74	5.07	3.79	58.03	78.71	82.70	1240.48	592.19	54.44	816.67
755	19	86	4.04	0.89	19.00	2.62	0.09	0.92	13.70	11.17	80.14	86.99	86.84	1650.00	413.29	62.28	1183.33
756	17	163	3.14	0.78	14.95	2.21	0.15	0.85	9.16	6.65	72.94	85.31	89.83	1527.08	200.87	72.55	1233.33
757	19	474	2.92	0.76	14.29	2.23	0.14	0.86	9.29	6.99	78.90	91.88	85.67	1627.78	475.36	59.65	1133.33
758	20	3275	2.35	0.23	7.30	0.70	0.74	0.26	2.01	1.35	22.56	87.11	86.23	1724.56	449.22	59.17	1183.33
944	28	7521	3.03	0.68	13.11	2.25	0.14	0.86	9.51	7.34	66.36	76.82	79.32	2220.99	482.87	52.98	1483.33
945	29	9619	3.05	0.69	14.27	2.31	0.13	0.87	10.09	7.50	65.26	75.29	82.06	2379.76	349.37	51.15	1483.33
946	24	998	3.33	0.85	19.42	2.69	0.09	0.91	14.80	11.29	73.41	80.47	84.42	2026.09	469.83	52.78	1266.67
950	11	135	2.04	0.76	10.74	1.81	0.24	0.76	6.11	4.08	68.35	89.86	87.88	966.67	348.03	69.70	766.67
952	56	141	11.11	0.95	49.30	3.81	0.03	0.98	45.35	36.61	79.68	81.34	82.25	4606.06	517.23	38.39	2150.00
953	47	112	9.75	0.95	45.29	3.66	0.03	0.98	38.93	32.00	82.76	84.67	83.12	3906.52	495.89	42.20	1983.33

954	53	132	10.65	0.95	48.50	3.79	0.03	0.98	44.20	36.30	80.99	82.65	82.80	4388.46	519.79	38.68	2050.00
955	48	117	9.87	0.96	45.48	3.70	0.03	0.98	40.52	35.01	80.86	82.52	81.77	3924.82	599.40	37.15	1783.33
956	40	95	8.56	0.96	40.00	3.54	0.03	0.98	34.33	29.98	81.56	83.48	82.71	3308.55	472.19	42.92	1716.67
957	51	120	10.44	0.95	48.21	3.74	0.03	0.98	42.07	33.33	79.63	81.41	82.44	4204.67	539.08	40.52	2066.67
958	37	82	8.17	0.96	37.00	3.47	0.04	0.98	32.12	27.33	69.21	70.96	70.60	2612.04	852.51	35.14	1300.00
959	9	56	1.99	0.50	9.00	1.10	0.55	0.46	3.00	1.83	30.04	65.26	56.94	512.50	391.59	48.15	433.33
960	66	186	12.44	0.96	52.47	4.01	0.02	0.98	54.97	47.39	80.88	82.18	82.71	5458.97	531.86	37.88	2500.00
961	59	158	11.46	0.96	50.05	3.90	0.02	0.98	49.59	43.04	78.10	79.45	81.39	4802.30	575.99	40.40	2383.33
962	59	151	11.56	0.96	51.02	3.90	0.02	0.98	49.16	40.94	78.07	79.50	79.50	4690.23	638.23	37.57	2216.67
1100	28	183	5.18	0.61	22.27	2.05	0.31	0.69	7.74	3.20	60.29	87.21	83.64	2341.98	626.74	51.19	1433.33
1101	20	368	3.22	0.31	11.10	0.94	0.67	0.33	2.56	1.49	32.82	98.87	87.89	1757.89	344.69	61.67	1233.33
1102	17	87	3.58	0.89	17.00	2.53	0.10	0.91	12.61	10.27	74.23	81.29	79.41	1350.00	928.25	52.94	900.00
1103	22	286	3.71	0.42	13.81	1.28	0.51	0.49	3.61	1.96	32.43	65.97	87.66	1928.57	500.74	50.76	1116.67
1104	18	245	3.09	0.55	14.12	1.58	0.40	0.61	4.84	2.52	52.24	86.25	89.22	1605.88	339.40	62.04	1116.67
1105	21	56	4.97	0.92	21.00	2.79	0.08	0.94	16.27	13.07	82.85	88.11	85.95	1805.00	499.75	55.56	1166.67
1106	18	264	3.05	0.40	13.01	1.17	0.58	0.42	3.22	1.72	39.29	93.21	88.56	1594.12	437.44	57.41	1033.33
1107 bl	21	4392	2.38	0.05	2.90	0.16	0.96	0.04	1.17	1.04	3.69	89.16	87.14	1830.00	461.68	57.14	1200.00
1108	16	191	2.86	0.44	12.97	1.22	0.55	0.46	3.38	1.83	44.88	98.35	82.50	1320.00	698.38	56.25	900.00
1109	15	88	3.13	0.73	15.00	1.97	0.25	0.76	7.17	4.07	73.93	96.92	91.59	1373.81	217.59	73.33	1100.00
1110	10	69	2.13	0.65	10.00	1.50	0.37	0.64	4.50	2.72	62.57	97.61	90.37	903.70	178.88	78.33	783.33
1111	12	63	2.65	0.93	12.00	2.32	0.11	0.90	10.16	8.80	81.92	90.95	90.15	1081.82	336.51	70.83	850.00
1112	23	61	5.35	0.91	23.00	2.84	0.08	0.94	17.13	13.06	84.29	89.78	87.35	2009.09	373.62	58.70	1350.00
1113	14	48	3.36	0.92	14.00	2.43	0.11	0.91	11.33	9.44	83.58	91.54	88.83	1243.59	244.54	71.43	1000.00
1114	11	26	3.07	0.96	11.00	2.31	0.11	0.93	10.09	9.39	81.28	87.47	85.45	940.00	586.41	63.64	700.00
1115	15	57	3.46	0.89	15.00	2.41	0.11	0.90	11.13	8.90	76.45	84.62	84.60	1269.05	464.00	56.67	850.00
1116	13	153	2.39	0.40	11.53	1.02	0.62	0.38	2.77	1.61	37.81	99.03	90.81	1180.56	253.90	74.36	966.67
1117	16	66	3.58	0.82	16.00	2.27	0.16	0.86	9.64	6.35	68.75	80.36	80.97	1295.56	547.67	52.08	833.33
1118	15	40	3.80	0.93	15.00	2.51	0.10	0.93	12.34	10.26	82.65	89.29	86.83	1302.38	511.62	64.44	966.67
1119	14	38	3.57	0.92	14.00	2.42	0.12	0.91	11.25	8.60	78.95	86.99	86.63	1212.82	300.49	64.29	900.00
1120	18	112	3.60	0.63	17.22	1.81	0.33	0.68	6.10	3.05	65.85	97.13	87.36	1572.55	395.88	64.81	1166.67
1121	11	31	2.91	0.94	11.00	2.26	0.12	0.91	9.56	8.50	73.33	80.42	84.85	933.33	568.41	63.64	700.00
1122	12	41	2.96	0.90	12.00	2.24	0.13	0.89	9.40	7.75	72.64	81.38	85.35	1024.24	399.96	62.50	750.00
1123	15	86	3.14	0.77	15.00	2.08	0.17	0.84	7.99	5.72	77.16	92.40	77.46	1161.90	878.21	56.67	850.00
1124	12	130	2.26	0.42	11.22	1.05	0.60	0.40	2.85	1.67	39.84	98.59	89.65	1075.76	233.71	73.61	883.33

1125	16	83	3.39	0.47	16.00	1.30	0.53	0.48	3.65	1.89	46.41	97.56	81.53	1304.44	554.61	60.42	966.67
1126	9	33	2.29	0.83	9.00	1.83	0.21	0.82	6.25	4.80	76.83	94.12	93.06	837.50	160.11	83.33	750.00
1127	11	186	1.91	0.33	9.66	0.80	0.71	0.30	2.23	1.42	29.27	99.17	91.82	1010.00	241.14	77.27	850.00
1128	14	440	2.14	0.16	6.48	0.41	0.87	0.13	1.51	1.15	13.12	99.70	89.56	1253.85	272.58	72.62	1016.67
1129	16	65	3.59	0.85	16.00	2.35	0.14	0.87	10.52	6.98	82.45	94.75	89.44	1431.11	286.73	66.67	1066.67
1130	12	52	2.78	0.77	12.00	1.90	0.25	0.77	6.71	4.05	67.45	87.85	89.14	1069.70	189.33	75.00	900.00
1131	13	277	2.13	0.40	10.14	1.02	0.59	0.41	2.77	1.70	32.25	78.30	91.88	1194.44	218.97	75.64	983.33
1132	11	50	2.56	0.90	11.00	2.16	0.14	0.88	8.70	7.40	77.01	87.26	86.67	953.33	266.67	69.70	766.67
1133	16	404	2.50	0.18	7.73	0.51	0.84	0.16	1.66	1.19	16.01	99.45	89.44	1431.11	282.10	69.79	1116.67
1134	11	36	2.79	0.86	11.00	2.06	0.17	0.85	7.81	5.84	73.62	86.37	85.76	943.33	266.85	69.70	766.67
1135	9	33	2.29	0.81	9.00	1.77	0.24	0.79	5.89	4.24	69.10	87.70	85.19	766.67	382.37	68.52	616.67
1136	14	442	2.13	0.31	7.75	0.82	0.65	0.35	2.27	1.55	24.65	69.47	91.39	1279.49	191.47	73.81	1033.33
1137	9	24	2.52	0.96	9.00	2.11	0.13	0.91	8.22	7.58	80.68	89.07	88.43	795.83	182.40	75.93	683.33
1138	9	227	1.47	0.19	6.19	0.41	0.86	0.14	1.51	1.17	14.33	99.62	90.28	812.50	376.16	75.93	683.33
1141	12	362	1.87	0.28	6.22	0.70	0.70	0.30	2.02	1.43	29.68	97.95	86.36	1036.36	436.95	65.28	783.33
1142	17	424	2.64	0.26	8.27	0.73	0.73	0.27	2.07	1.38	27.21	99.37	85.42	1452.08	598.19	54.90	933.33
1143	29	137	5.69	0.83	26.80	2.80	0.12	0.89	16.40	8.66	68.52	76.90	83.00	2407.14	540.40	45.40	1316.67
1144	17	130	3.29	0.71	15.26	2.01	0.21	0.80	7.47	4.85	72.23	90.29	84.31	1433.33	558.68	56.86	966.67
1145	26	166	4.89	0.58	21.52	1.88	0.37	0.63	6.53	2.69	60.62	95.93	83.13	2161.33	596.54	49.36	1283.33
1146	20	47	4.93	0.92	20.00	2.76	0.08	0.94	15.88	11.81	79.39	84.88	79.74	1594.74	678.59	50.00	1000.00
1146a	18	47	4.42	0.94	18.00	2.71	0.08	0.94	14.99	13.07	77.80	82.45	84.31	1517.65	425.69	54.63	983.33
1147	21	44	5.29	0.94	21.00	2.87	0.07	0.95	17.67	14.67	84.36	88.47	85.32	1791.67	481.51	50.79	1066.67
1147a	18	31	4.95	0.98	18.00	2.82	0.06	0.97	16.76	15.75	82.65	85.41	85.84	1545.10	362.28	61.11	1100.00
1147b	26	46575	2.33	0.01	1.20	0.02	1.00	0.00	1.02	1.00	0.40	97.36	87.13	2265.33	436.88	51.28	1333.33
1148	12	145	2.21	0.34	10.75	0.86	0.69	0.31	2.35	1.45	31.04	98.85	89.14	1069.70	223.00	75.00	900.00
1149	10	17	3.18	0.92	10.00	2.12	0.15	0.90	8.29	6.72	79.41	87.80	87.41	874.07	261.18	73.33	733.33
1150	8	127	1.45	0.30	7.27	0.62	0.75	0.25	1.87	1.33	24.70	99.61	86.31	690.48	715.35	70.83	566.67
1150a	14	33	3.72	0.94	14.00	2.49	0.09	0.94	12.07	10.78	85.32	91.19	86.63	1212.82	526.37	63.10	883.33

Diversity indices – Andaman Sea

Station no.	S	N	d	J'	ES(100)	H'(loge)	Lambda	1-Lambda'	N1	N2	Delta	Delta*	Delta+	sDelta+	Lambda+	Phi+	sPhi+
1201	16	59	3.68	0.99	16.0	2.74	0.07	0.95	15.53	15.07	83.75	88.18	87.50	1400.00	422.45	59.38	950.00
1202	13	77	2.76	0.90	13.0	2.30	0.13	0.88	10.02	7.79	71.35	80.80	88.68	1152.78	537.70	60.26	783.33
1203	19	91	3.99	0.99	19.0	2.90	0.06	0.95	18.23	17.51	78.77	82.62	81.87	1555.56	714.24	50.00	950.00
1204	12	40	2.98	0.97	12.0	2.41	0.10	0.92	11.18	10.13	77.88	84.26	79.55	954.55	629.59	58.33	700.00
1205	17	183	3.07	0.69	15.8	1.96	0.23	0.78	7.07	4.41	47.98	61.70	88.73	1508.33	506.06	57.84	983.33
1206	13	54	3.01	0.96	13.0	2.45	0.10	0.92	11.63	10.20	82.56	89.85	83.97	1091.67	530.22	64.10	833.33
1207	16	261	2.70	0.68	13.9	1.88	0.23	0.77	6.52	4.31	43.98	57.06	85.56	1368.89	499.69	60.42	966.67
1208	15	159	2.76	0.56	14.4	1.53	0.42	0.59	4.60	2.40	44.66	76.00	88.10	1321.43	458.81	60.00	900.00
1209 bl	22	50146	1.94	0.01	1.3	0.03	0.99	0.01	1.03	1.01	0.58	99.98	87.88	1933.33	413.44	57.58	1266.67
1209	13	88	2.68	0.78	13.0	1.99	0.21	0.80	7.33	4.77	60.75	76.00	83.33	1083.33	769.23	55.13	716.67
1210	18	166	3.33	0.73	17.2	2.12	0.20	0.81	8.35	5.09	55.16	68.24	86.38	1554.90	444.58	62.96	1133.33
1211	15	56	3.48	0.98	15.0	2.66	0.07	0.94	14.35	13.63	80.34	85.15	82.70	1240.48	576.32	54.44	816.67
1212	15	51	3.56	0.98	15.0	2.66	0.07	0.95	14.36	13.76	71.12	75.19	75.56	1133.33	402.47	61.11	916.67
1213	17	55	3.99	0.98	17.0	2.78	0.06	0.95	16.17	15.51	80.02	83.98	83.70	1422.92	545.21	53.92	916.67
1214	15	52	3.54	0.94	15.0	2.55	0.09	0.93	12.82	10.90	81.55	88.06	83.49	1252.38	510.56	58.89	883.33
1215	15	55	3.49	0.95	15.0	2.59	0.08	0.94	13.27	12.25	70.40	75.27	78.73	1180.95	626.96	58.89	883.33

Diversity indices – Bay of Bengal

Stn.No:	S	N	d	J'	ES(100)	H'(loge)	Lambda	1-Lambda'	N1	N2	Delta	Delta*	Delta+	sDelta+	Lambda+	Phi+	sPhi+
733	20	126	3.93	0.84	19.02	2.51	0.11	0.90	12.34	8.99	77.81	86.85	86.49	1729.82	449.09	58.33	1166.67
734	14	136	2.65	0.78	13.77	2.06	0.18	0.82	7.87	5.43	72.21	87.86	83.33	1166.67	592.19	54.76	766.67
735	20	121	3.96	0.81	18.77	2.42	0.14	0.87	11.24	7.38	76.54	87.80	84.04	1680.70	417.64	55.83	1116.67
736	24	269	4.11	0.75	18.85	2.38	0.16	0.85	10.85	6.42	69.20	81.68	83.15	1995.65	506.21	47.22	1133.33
737	19	373	3.04	0.62	11.88	1.81	0.26	0.75	6.13	3.89	51.41	69.00	80.90	1537.04	690.94	49.12	933.33
738	16	257	2.70	0.74	13.16	2.04	0.19	0.82	7.70	5.39	66.71	81.59	83.61	1337.78	532.33	54.17	866.67
739	20	391	3.18	0.62	12.70	1.86	0.24	0.76	6.45	4.21	58.82	76.97	87.46	1749.12	502.01	57.50	1150.00
740	16	501	2.41	0.50	9.80	1.38	0.36	0.65	3.96	2.81	58.64	90.90	87.22	1395.56	591.36	54.17	866.67
741	20	338	3.26	0.77	14.91	2.30	0.14	0.87	9.94	7.28	69.11	79.87	87.02	1740.35	451.34	57.50	1150.00
742	13	57	2.97	0.88	13.00	2.25	0.13	0.89	9.51	7.72	73.41	82.86	85.68	1113.89	332.79	64.10	833.33
743	15	558	2.21	0.49	10.69	1.34	0.43	0.57	3.81	2.31	37.41	65.78	83.02	1245.24	629.53	57.78	866.67
744	10	108	1.92	0.76	9.99	1.75	0.24	0.76	5.74	4.10	42.51	55.68	57.04	570.37	327.02	46.67	466.67
745	8	75	1.62	0.74	8.00	1.53	0.33	0.68	4.62	3.00	37.24	55.14	57.14	457.14	306.12	47.92	383.33
747	12	117	2.31	0.64	11.50	1.58	0.32	0.69	4.86	3.12	61.68	90.03	71.21	854.55	610.65	55.56	666.67
748	13	108	2.56	0.80	12.92	2.06	0.18	0.83	7.87	5.50	73.88	89.48	88.46	1150.00	401.05	69.23	900.00
749	18	94	3.74	0.92	18.00	2.66	0.08	0.93	14.27	12.24	82.88	89.29	83.66	1505.88	441.07	61.11	1100.00
750	20	119	3.98	0.87	19.17	2.62	0.10	0.91	13.69	10.21	78.44	86.22	83.25	1664.91	519.00	55.00	1100.00
751	18	148	3.40	0.72	15.52	2.09	0.18	0.83	8.08	5.62	71.37	86.24	80.83	1454.90	689.07	52.78	950.00
752	18	180	3.27	0.68	14.77	1.96	0.25	0.76	7.10	4.07	64.81	85.41	85.51	1539.22	383.78	55.56	1000.00
753	21	539	3.18	0.74	13.83	2.25	0.14	0.86	9.46	7.19	71.85	83.30	86.19	1810.00	581.78	51.59	1083.33
754	15	627	2.17	0.60	8.77	1.62	0.26	0.74	5.07	3.79	58.03	78.71	82.70	1240.48	592.19	54.44	816.67
755	19	86	4.04	0.89	19.00	2.62	0.09	0.92	13.70	11.17	80.14	86.99	86.84	1650.00	413.29	62.28	1183.33
756	17	163	3.14	0.78	14.95	2.21	0.15	0.85	9.16	6.65	72.94	85.31	89.83	1527.08	200.87	72.55	1233.33
757	19	474	2.92	0.76	14.29	2.23	0.14	0.86	9.29	6.99	78.90	91.88	85.67	1627.78	475.36	59.65	1133.33
758	20	3275	2.35	0.23	7.30	0.70	0.74	0.26	2.01	1.35	22.56	87.11	86.23	1724.56	449.22	59.17	1183.33
944	28	7521	3.03	0.68	13.11	2.25	0.14	0.86	9.51	7.34	66.36	76.82	79.32	2220.99	482.87	52.98	1483.33

945	29	9619	3.05	0.69	14.27	2.31	0.13	0.87	10.09	7.50	65.26	75.29	82.06	2379.76	349.37	51.15	1483.33
946	24	998	3.33	0.85	19.42	2.69	0.09	0.91	14.80	11.29	73.41	80.47	84.42	2026.09	469.83	52.78	1266.67
950	11	135	2.04	0.76	10.74	1.81	0.24	0.76	6.11	4.08	68.35	89.86	87.88	966.67	348.03	69.70	766.67
952	56	141	11.11	0.95	49.30	3.81	0.03	0.98	45.35	36.61	79.68	81.34	82.25	4606.06	517.23	38.39	2150.00
953	47	112	9.75	0.95	45.29	3.66	0.03	0.98	38.93	32.00	82.76	84.67	83.12	3906.52	495.89	42.20	1983.33
954	53	132	10.65	0.95	48.50	3.79	0.03	0.98	44.20	36.30	80.99	82.65	82.80	4388.46	519.79	38.68	2050.00
955	48	117	9.87	0.96	45.48	3.70	0.03	0.98	40.52	35.01	80.86	82.52	81.77	3924.82	599.40	37.15	1783.33
956	40	95	8.56	0.96	40.00	3.54	0.03	0.98	34.33	29.98	81.56	83.48	82.71	3308.55	472.19	42.92	1716.67
957	51	120	10.44	0.95	48.21	3.74	0.03	0.98	42.07	33.33	79.63	81.41	82.44	4204.67	539.08	40.52	2066.67
958	37	82	8.17	0.96	37.00	3.47	0.04	0.98	32.12	27.33	69.21	70.96	70.60	2612.04	852.51	35.14	1300.00
959	9	56	1.99	0.50	9.00	1.10	0.55	0.46	3.00	1.83	30.04	65.26	56.94	512.50	391.59	48.15	433.33
960	66	186	12.44	0.96	52.47	4.01	0.02	0.98	54.97	47.39	80.88	82.18	82.71	5458.97	531.86	37.88	2500.00
961	59	158	11.46	0.96	50.05	3.90	0.02	0.98	49.59	43.04	78.10	79.45	81.39	4802.30	575.99	40.40	2383.33
962	59	151	11.56	0.96	51.02	3.90	0.02	0.98	49.16	40.94	78.07	79.50	79.50	4690.23	638.23	37.57	2216.67
1100	28	183	5.18	0.61	22.27	2.05	0.31	0.69	7.74	3.20	60.29	87.21	83.64	2341.98	626.74	51.19	1433.33
1101	20	368	3.22	0.31	11.10	0.94	0.67	0.33	2.56	1.49	32.82	98.87	87.89	1757.89	344.69	61.67	1233.33
1102	17	87	3.58	0.89	17.00	2.53	0.10	0.91	12.61	10.27	74.23	81.29	79.41	1350.00	928.25	52.94	900.00
1103	22	286	3.71	0.42	13.81	1.28	0.51	0.49	3.61	1.96	32.43	65.97	87.66	1928.57	500.74	50.76	1116.67
1104	18	245	3.09	0.55	14.12	1.58	0.40	0.61	4.84	2.52	52.24	86.25	89.22	1605.88	339.40	62.04	1116.67
1105	21	56	4.97	0.92	21.00	2.79	0.08	0.94	16.27	13.07	82.85	88.11	85.95	1805.00	499.75	55.56	1166.67
1106	18	264	3.05	0.40	13.01	1.17	0.58	0.42	3.22	1.72	39.29	93.21	88.56	1594.12	437.44	57.41	1033.33
1107 bl	21	4392	2.38	0.05	2.90	0.16	0.96	0.04	1.17	1.04	3.69	89.16	87.14	1830.00	461.68	57.14	1200.00
1108	16	191	2.86	0.44	12.97	1.22	0.55	0.46	3.38	1.83	44.88	98.35	82.50	1320.00	698.38	56.25	900.00
1109	15	88	3.13	0.73	15.00	1.97	0.25	0.76	7.17	4.07	73.93	96.92	91.59	1373.81	217.59	73.33	1100.00
1110	10	69	2.13	0.65	10.00	1.50	0.37	0.64	4.50	2.72	62.57	97.61	90.37	903.70	178.88	78.33	783.33
1111	12	63	2.65	0.93	12.00	2.32	0.11	0.90	10.16	8.80	81.92	90.95	90.15	1081.82	336.51	70.83	850.00
1112	23	61	5.35	0.91	23.00	2.84	0.08	0.94	17.13	13.06	84.29	89.78	87.35	2009.09	373.62	58.70	1350.00
1113	14	48	3.36	0.92	14.00	2.43	0.11	0.91	11.33	9.44	83.58	91.54	88.83	1243.59	244.54	71.43	1000.00

1114	11	26	3.07	0.96	11.00	2.31	0.11	0.93	10.09	9.39	81.28	87.47	85.45	940.00	586.41	63.64	700.00
1115	15	57	3.46	0.89	15.00	2.41	0.11	0.90	11.13	8.90	76.45	84.62	84.60	1269.05	464.00	56.67	850.00
1116	13	153	2.39	0.40	11.53	1.02	0.62	0.38	2.77	1.61	37.81	99.03	90.81	1180.56	253.90	74.36	966.67
1117	16	66	3.58	0.82	16.00	2.27	0.16	0.86	9.64	6.35	68.75	80.36	80.97	1295.56	547.67	52.08	833.33
1118	15	40	3.80	0.93	15.00	2.51	0.10	0.93	12.34	10.26	82.65	89.29	86.83	1302.38	511.62	64.44	966.67
1119	14	38	3.57	0.92	14.00	2.42	0.12	0.91	11.25	8.60	78.95	86.99	86.63	1212.82	300.49	64.29	900.00
1120	18	112	3.60	0.63	17.22	1.81	0.33	0.68	6.10	3.05	65.85	97.13	87.36	1572.55	395.88	64.81	1166.67
1121	11	31	2.91	0.94	11.00	2.26	0.12	0.91	9.56	8.50	73.33	80.42	84.85	933.33	568.41	63.64	700.00
1122	12	41	2.96	0.90	12.00	2.24	0.13	0.89	9.40	7.75	72.64	81.38	85.35	1024.24	399.96	62.50	750.00
1123	15	86	3.14	0.77	15.00	2.08	0.17	0.84	7.99	5.72	77.16	92.40	77.46	1161.90	878.21	56.67	850.00
1124	12	130	2.26	0.42	11.22	1.05	0.60	0.40	2.85	1.67	39.84	98.59	89.65	1075.76	233.71	73.61	883.33
1125	16	83	3.39	0.47	16.00	1.30	0.53	0.48	3.65	1.89	46.41	97.56	81.53	1304.44	554.61	60.42	966.67
1126	9	33	2.29	0.83	9.00	1.83	0.21	0.82	6.25	4.80	76.83	94.12	93.06	837.50	160.11	83.33	750.00
1127	11	186	1.91	0.33	9.66	0.80	0.71	0.30	2.23	1.42	29.27	99.17	91.82	1010.00	241.14	77.27	850.00
1128	14	440	2.14	0.16	6.48	0.41	0.87	0.13	1.51	1.15	13.12	99.70	89.56	1253.85	272.58	72.62	1016.67
1129	16	65	3.59	0.85	16.00	2.35	0.14	0.87	10.52	6.98	82.45	94.75	89.44	1431.11	286.73	66.67	1066.67
1130	12	52	2.78	0.77	12.00	1.90	0.25	0.77	6.71	4.05	67.45	87.85	89.14	1069.70	189.33	75.00	900.00
1131	13	277	2.13	0.40	10.14	1.02	0.59	0.41	2.77	1.70	32.25	78.30	91.88	1194.44	218.97	75.64	983.33
1132	11	50	2.56	0.90	11.00	2.16	0.14	0.88	8.70	7.40	77.01	87.26	86.67	953.33	266.67	69.70	766.67
1133	16	404	2.50	0.18	7.73	0.51	0.84	0.16	1.66	1.19	16.01	99.45	89.44	1431.11	282.10	69.79	1116.67
1134	11	36	2.79	0.86	11.00	2.06	0.17	0.85	7.81	5.84	73.62	86.37	85.76	943.33	266.85	69.70	766.67
1135	9	33	2.29	0.81	9.00	1.77	0.24	0.79	5.89	4.24	69.10	87.70	85.19	766.67	382.37	68.52	616.67
1136	14	442	2.13	0.31	7.75	0.82	0.65	0.35	2.27	1.55	24.65	69.47	91.39	1279.49	191.47	73.81	1033.33
1137	9	24	2.52	0.96	9.00	2.11	0.13	0.91	8.22	7.58	80.68	89.07	88.43	795.83	182.40	75.93	683.33
1138	9	227	1.47	0.19	6.19	0.41	0.86	0.14	1.51	1.17	14.33	99.62	90.28	812.50	376.16	75.93	683.33
1141	12	362	1.87	0.28	6.22	0.70	0.70	0.30	2.02	1.43	29.68	97.95	86.36	1036.36	436.95	65.28	783.33
1142	17	424	2.64	0.26	8.27	0.73	0.73	0.27	2.07	1.38	27.21	99.37	85.42	1452.08	598.19	54.90	933.33
1143	29	137	5.69	0.83	26.80	2.80	0.12	0.89	16.40	8.66	68.52	76.90	83.00	2407.14	540.40	45.40	1316.67

1144	17	130	3.29	0.71	15.26	2.01	0.21	0.80	7.47	4.85	72.23	90.29	84.31	1433.33	558.68	56.86	966.67
1145	26	166	4.89	0.58	21.52	1.88	0.37	0.63	6.53	2.69	60.62	95.93	83.13	2161.33	596.54	49.36	1283.33
1146	20	47	4.93	0.92	20.00	2.76	0.08	0.94	15.88	11.81	79.39	84.88	79.74	1594.74	678.59	50.00	1000.00
1146a	18	47	4.42	0.94	18.00	2.71	0.08	0.94	14.99	13.07	77.80	82.45	84.31	1517.65	425.69	54.63	983.33
1147	21	44	5.29	0.94	21.00	2.87	0.07	0.95	17.67	14.67	84.36	88.47	85.32	1791.67	481.51	50.79	1066.67
1147a	18	31	4.95	0.98	18.00	2.82	0.06	0.97	16.76	15.75	82.65	85.41	85.84	1545.10	362.28	61.11	1100.00
1147b	26	46575	2.33	0.01	1.20	0.02	1.00	0.00	1.02	1.00	0.40	97.36	87.13	2265.33	436.88	51.28	1333.33
1148	12	145	2.21	0.34	10.75	0.86	0.69	0.31	2.35	1.45	31.04	98.85	89.14	1069.70	223.00	75.00	900.00
1149	10	17	3.18	0.92	10.00	2.12	0.15	0.90	8.29	6.72	79.41	87.80	87.41	874.07	261.18	73.33	733.33
1150	8	127	1.45	0.30	7.27	0.62	0.75	0.25	1.87	1.33	24.70	99.61	86.31	690.48	715.35	70.83	566.67
1150a	14	33	3.72	0.94	14.00	2.49	0.09	0.94	12.07	10.78	85.32	91.19	86.63	1212.82	526.37	63.10	883.33

Annexure -IV

Marine Microalgae: Region wise Distribution

ARS	BOB	ANS
Asterionella japonica	*Amphiprora gigantea*	*Actiniscus pentasterias*
Bacteriastrum cosmosum	*Asterionella japonica*	*Amphisolenia bidentata*
Bacteriastrum delicatulum	*Asteromphalus whyvellii*	*Ceratium buceros*
Bacteriastrum elongatum	*Aulacodiscus orbiculatus*	*Ceratium concilians*
Bacteriastrum hyalinum	*Bacillaria paradoxa*	*Ceratium contortum*
Bacteriastrum varians	*Bacteriastrum cosmosum*	*Ceratium declinatum*
Biddulphia heteroceros	*Bacteriastrum delicatulum*	*Ceratium extensum*
Biddulphia indicus	*Bacteriastrum elongatum*	*Ceratium furca*
Biddulphia mobiliensis	*Bacteriastrum hyalinum*	*Ceratium fusus*
Biddulphia pulchellum	*Bacteriastrum varians*	*Ceratium gibberum*
Biddulphia tridens	*Biddulphia heteroceros*	*Ceratium hexacanthum*
Cerataulina bergonii	*Biddulphia indicus*	*Ceratium inflatum*
Chaetoceros affinis	*Biddulphia mobiliensis*	*Ceratium kofoidii*
Chaetoceros atlanticus	*Biddulphia sinensis*	*Ceratium macroceros*
Chaetoceros breve	*Chaetoceros affinis*	*Ceratium massiliense*
Chaetoceros calcitrans	*Chaetoceros calcitrans*	*Ceratium trichoceross*
Chaetoceros coartactus	*Chaetoceros coarctatus*	*Ceratium tripos*
Chaetoceros compressum	*Chaetoceros curvisetus*	*Ceratium vultur*
Chaetoceros convolutes	*Chaetoceros denticulatum*	*Ceratocorys horrida*
Chaetoceros curvisetum	*Chaetoceros didymus*	*Dinophysis caudata*
Chaetoceros diversicus	*Chaetoceros diversicus*	*Dinophysis hastata*
Chaetoceros eibenii	*Chaetoceros lascinosus*	*Diplopsalis lenticula*
Chaetoceros flexuosus	*Chaetoceros lauderi*	*Gonyaulax catenella*
Chaetoceros gibberrula	*Chaetoceros lorenzianus*	*Gonyaulax fragilis*
Chaetoceros indicus	*Chaetoceros messanensis*	*Heteraulacus acuminatus*
Chaetoceros lorenzianus	*Chaetoceros paradoxum*	*Heteraulacus sphericus*
Chaetoceros messanensis	*Chaetoceros pelagicus*	*Histioneis elongata*

Chaetoceros pelagicus	*Chaetoceros peruvianus*	*Kofoidinium pavillardii*
Chaetoceros peruvianus	*Climacodium frauenfeldianum*	*Noctiluca scintillans*
Chaetoceros seriacanthus	*Climacosphenia moniligera*	*Orithocercus thumii*
Chaetoceros sinensis	*Corethron hystrix*	*Ornithocercus magnificus*
Chaetoceros tetrastichous	*Corethron inerme*	*Ornithocercus steinii*
Chaetoceros tortissimus	*Coscinodiscus concentricus*	*Oxytoxum solopax*
Climacodium biconcarum	*Coscinodiscus gigas*	*Oxytoxum tesselatum*
Climacodium frauenfeldianum	*Coscinodiscus granii*	*Peridinium abei*
Corethron inerme	*Coscinodiscus jonesia*	*Peridinium conicum*
Coscinodiscus centralis	*Coscinodiscus marginatus*	*Peridinium nipponicum*
Coscinodiscus nodulifer	*Coscinodiscus nitidus*	*Peridinium oblongum*
Coscinodiscus rothi	*Coscinodiscus rothii*	*Phalacroma cuneus*
Coscinodiscus subtilis	*Coscinodiscus sub-lineatus*	*Podolampas bipes*
Coscinodiscus marginatus	*Ditylum brightwellii*	*Prorocentrum gracile*
Ditylum brightwelli	*Eucampia cornuata*	*Prorocentrum pyriforme*
Ditylum sol	*Eucampia zoodiacus*	*Pyrocystis pseudonoctiluca*
Eucampia cornuata	*Fragilaria oceanica*	*Pyrophacus horologium*
Eucampia zoodiacus	*Grammatophora undulata*	*Bacillaria paradoxa*
Fragilaria cylindrus	*Guinardia flaccida*	*Bacteriastrum varians*
Fragilaria oceanica	*Hemiaulus sinensis*	*Biddulphia heteroceros*
Guinardia flaccida	*Leptocylindrus danicus*	*Biddulphia rhombus*
Guinardia striata	*Melosira sulcata*	*Chaetoceros coarctatus*
Gyrosigma macrum	*Navicula elegans*	*Chaetoceros curvisetus*
Hemialus membranaccus	*Nitzschia longissima*	*Chaetoceros didymus*
Hemiaulus sinensis	*Nitzschia seriata*	*Coscinodiscus apiculatus*
Hemiaulus indicus	*Nitzschia sigma*	*Coscinodiscus rothii*
Lauderia glacialis	*Planktoniella sol*	*Coscinodiscus sublineatus*
Leptocylindrus danicus	*Pleurosigma angulatum*	*Leptocylindrus danicus*
Melosira subtilis	*Pleurosigma directum*	*Melosira sulcata*
Navicula angulata	*Pleurosigma elongatum*	*Navicula hennadyie*

Navicula elegans	*Pleurosigma normanii*	*Navicula forcipata*
Navicula longa	*Rhizosolenia cylindrus*	*Nitzschia seriata*
Navicula membranacea	*Rhizosolenia alata*	*Nitzschia longissima*
Navicula crucifera	*Rhizosolenia castracanii*	*Nitzschia seriata*
Nitzschia lanceolata	*Rhizosolenia hebetata*	*Pleurosigma angulatum*
Nitzschia longissima	*Rhizosolenia robusta*	*Pleurosigma directum*
Nitzschia seriata	*Rhizosolenia setigera*	*Pleurosigma normanie*
Nitzschia sigma	*Rhizosolenia styliformis*	*Rhizosolenia alata*
Planktoniella sol	*Skeletonema costatum*	*Rhizosolenia crossispina*
Pleurosigma angulatum	*Thalassionema nitzschioides*	*Rhizosolenia hebetata*
Pleurosigma directum	*Thalassiosira hyalina*	*Rhizosolenia styliformis*
Pleurosigma elongatum	*Thalassiosira subtilis*	*Thalassionema frauenfeldii*
Pleurosigma rectum	*Thalassiothrix frauenfeldianum*	*Thalassiosira subtilis*
Pleurosigma rigidum	*Triceratium favus*	*Triceratium reticulatum*
Rhabdonema arcuatum	*Triceratium reticulatum*	*Oscillatoria agardhii*
Rhizosolenia acuminata	*Tropidoneis semistriata*	*Dictyocha fibula*
Rhizosolenia alata	*Actiniscus pentasterias*	*Dictyocha staurodone*
Rhizosolenia catracanei	*Amphisolenia bidentata*	*Oscillatoria acutissima*
Rhizosolenia cylndrus	*Blepharocysta compressa*	*Oscillatoria nigroviridis*
Rhizosolenia hebetata	*Blepharocysta splendormaris*	*Trichodesmium erythraeum*
Rhizosolenia robusta	*Ceratium belone*	
Rhizosolenia setigura	*Ceratium bigelowii*	
Rhizosolenia styliformis	*Ceratium buceros*	
Skeletonema costatum	*Ceratium candelabrum*	
Streptotheca tamesis	*Ceratium carriense*	
Thalassionema frauerfeldii	*Ceratium coarctatus*	
Thalassionema nitzschioides	*Ceratium concilians*	
Thalassiosira hyalina	*Ceratium contortum*	
Thalassiosira suibtlis	*Ceratium declinatum*	

Thalassiothrix frauenfeldianum	*Ceratium extensum*	
Thalassiothrix longissima	*Ceratium furca*	
Thalassiothrix nitzschioides	*Ceratium fusus*	
Thalassiosira rotula	*Ceratium gibberum*	
Thalassiothrix delicatula	*Ceratium hircus*	
Thalassiothrix longissima	*Ceratium inflatum*	
Triceratium alternans	*Ceratium longirostrum*	
Triceratium favus	*Ceratium lunula*	
Amphisolenia bidentata	*Ceratium macroceros*	
Ceratium bigelowii	*Ceratium massiliense*	
Ceratium carriense	*Ceratium pentagonum*	
Ceratium concilians	*Ceratium pulchellum*	
Ceratium contortum	*Ceratium ranipes*	
Ceratium declinatum	*Ceratium schroteri*	
Ceratium dens	*Ceratium teres*	
Ceratium extensum	*Ceratium trichoceros*	
Ceratium furca	*Ceratium tripos*	
Ceratium fusus	*Ceratium vultur*	
Ceratium gibberum	*Ceratocorys horrida*	
Ceratium inflatum	*Coolia monotis*	
Ceratium longirostrum	*Dinophysis caudata*	
Ceratium lunula	*Dinophysis hastata*	
Ceratium macroceros	*Dinophysis ovum*	
Ceratium massiliense	*Diplopsalis lenticula*	
Ceratium pentagonum	*Gonyaulax polygramma*	
Ceratium pulchellum	*Gonyaulax catenella*	
Ceratium ranipes	*Gonyaulax diegensis*	
Ceratium symmetricum	*Gonyaulax fragilis*	
Ceratium teres	*Gonyaulax polyedra*	
Ceratium trichoceros	*Gonyaulax turbynei*	

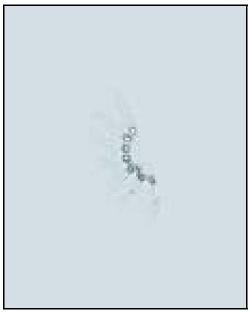
Ceratium tripos	*Gymnodinium breve*	
Ceratium vultur	*Gymnodinium coeruleum*	
Ceratocorys horrida	*Gymnodinium falcatum*	
Dinophysis acuminata	*Gymnodinium veneficum*	
Dinophysis caudata	*Heteraulacus acuminatus*	
Dinophysis hastata	*Heteraulacus sphericus*	
Dinophysis miles	*Noctiluca scintillans*	
Diplopsalis lenticula	*Ornithocercus steinii*	
Dissodinium lunula	*Ornithocercus heteroporous*	
Gonyaulax catenella	*Ornithocercus magnificus*	
Gonyaulax diacantha	*Ornithocercus quadratus*	
Gonyaulax diegensis	*Ornithocercus splendidus*	
Gonyaulax digitalis	*Ornithocercus thumii*	
Gonyaulax polygramma	*Oxytoxum milneri*	
Gymnodinium breve	*Oxytoxum periclaudicans*	
Gymnodinium catenatum	*Oxytoxum scolopax*	
Gymnodinium coerleus	*Peridinium abei*	
Gymnodinium veneficum	*Peridinium brochii*	
Noctiluca miliaris	*Peridinium claudicans*	
Noctiluca scintillans	*Peridinium conicum*	
Ornithocercus magnificus	*Peridinium crassipes*	
Ornithocercus steinii	*Peridinium depressum*	
Peridinium biconicum	*Peridinium divergens*	
Peridinium claudicans	*Peridinium elegans*	
Peridinium conicum	*Peridinium excentricum*	
Peridinium crassipes	*Peridinium grande*	
Peridinium depressum	*Peridinium leonis*	
Peridinium divergens	*Peridinium longipes*	
Peridinium elegans	*Peridinium nipponicum*	
Peridinium excentricum	*Peridinium oblongum*	

Peridinium globulus	*Peridinium spiniferum*	
Peridinium grande	*Peridinium tuba*	
Peridinium longipes	*Peridinium venustum*	
Peridinium nipponicum	*Phalacroma apicatum*	
Peridinium oblongum	*Podolampas bipes*	
Peridinium pallidum	*Podolampas reticulata*	
Peridinium pellucidum	*Podolampas spinifer*	
Peridinium pentagonum	*Pronoctiluca acuta*	
Peridinium polonicum	*Prorocentrum compressum*	
Peridinium spiniferum	*Prorocentrum gracile*	
Phalacroma apicatum	*Prorocentrum micans*	
Phalacroma argus	*Prorocentrum reticulatum*	
Phalacroma rotundum	*Protoceratium reticulatum*	
Podolampas bipes	*Pyrocystis pseudonoctiluca*	
Podolampas elegans	*Pyrophacus horologium*	
Prorocentrum lima	*Oscillatoria agardhii*	
Prorocentrum micans	*Dictyocha fibula*	
Prorocentrum reticulatum	*Dictyocha staurodone*	
Prorocentrum rostratum	*Oscillatoria acutissima*	
Pyrocystis lunula	*Oscillatoria nigroviridis*	
Pyrocystis pseudonoctiluca	*Trichodesmium theibautii*	
Pyrophacus horologium	*Trichodesmium erythraeum*	
Oscillatoria agardhii		
Dictyocha fibula		
Dictyocha staurodone		
Oscillatoria acutissima		
Trichodesmium erythraeum		

Annexure -V

Plate I (a)

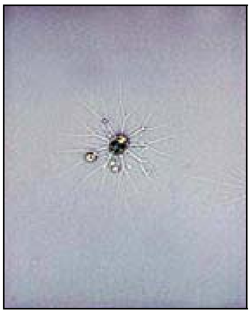

Amphiprora gigantea var. sulcata x 100


Asterionella japonica x 100


Bacillaria paradoxa x 100


Bacteriastrum comosum x 100

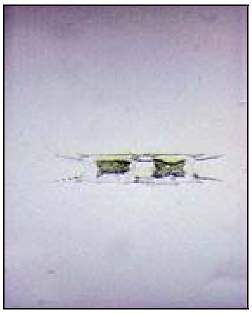

Bacteriastrum hyalinum x 200

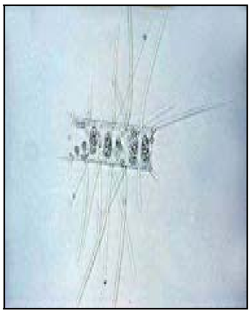

Bacteriastrum varians x 200

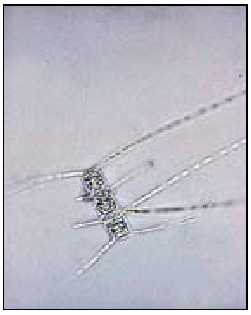

Biddulphia mobilensis x 400

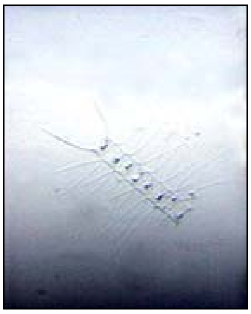

Biddulphia mobiliensis x 100

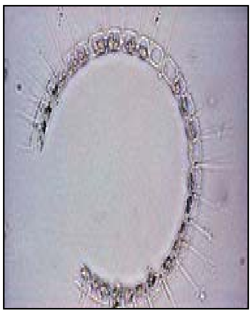

Biddulphia regia x 200


Biddulphia sinensis x 100


Chaetoceros lorenzianus x 200


Chaetoceros affinis x 100


Chaetoceros breve x 100


Chaetoceros curvisetus x 200


Chaetoceros decipiens x 100

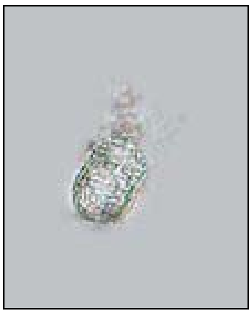
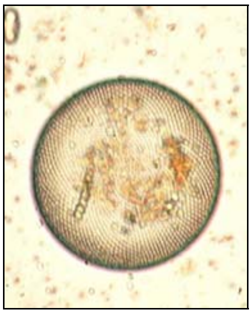
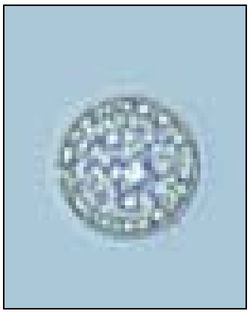

Corethron enerme x 200

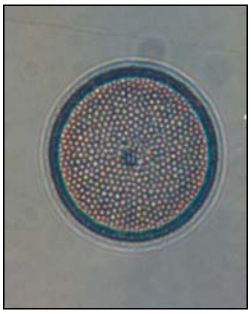
Plate I(b)



Coscinodiscus centralis x 200



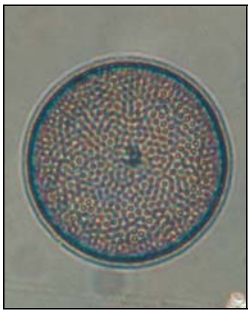
Coscinodiscus marginatus x 200



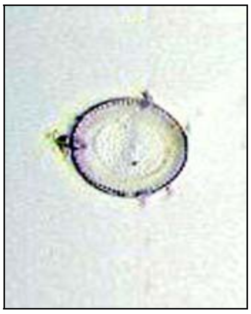
Coscinodiscus radiatus x 200

Coscinodiscus rothii x100

Coscinodiscus subtilis x 200

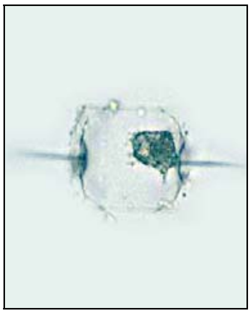


Coscinodisdus marginatus x 300



Cyclotella striata x 200

Diploneis littoralis x 200



Ditylum brightwellii x 200

Ditylum sol x 100

Guinardia flaccida x 200

Navicula bicapitata x 200

Navicula halophila x 300

Navicula mutica x 200

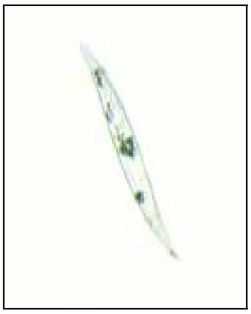
Nitzchia sigma x 200

Nitzschia longissima x 100

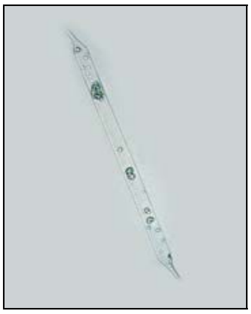
Plate I(c)

Nitzschia sigma x 300

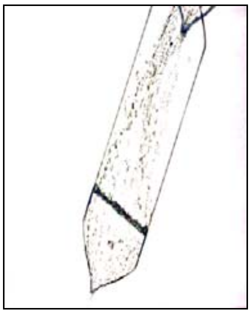
Pleurosigma falx x 300



Pleurosigma normanii x 200



Rhizosolenia alata x100



Rhizosolenia castracanei x 100

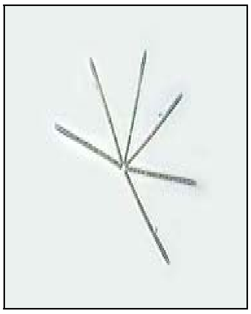
Rhizosolenia robusta x 100

Rhizosolenia setigera x 100

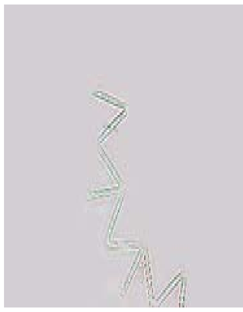
Rhizosolenia stolterfothii x 200

Skeletonema costatum x 100

Surirella flumiensis x 100

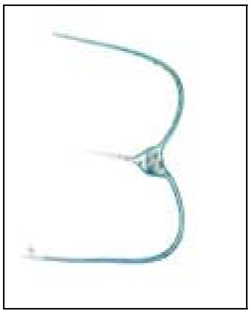


Thalassionema frauenfeldii x 200



Thalassionema nitzschioides x 200

Plate II (a)

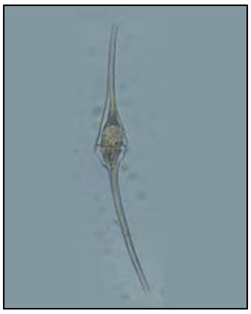


Ceratium trichoceros x 200

Ceratium candelabrum var. depressum x 200

Ceratium furca x 100

Ceratium fusus x 100

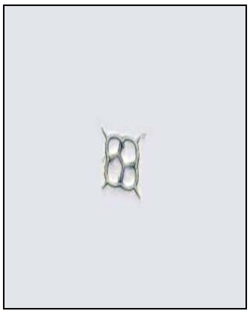


Ceratium fusus x 200

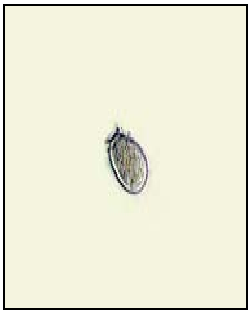
Ceratium gibberum x 100

Ceratium pentagonum x 100

Cochlodinium polykrikoides x 200



Dictyocha fibula x 200

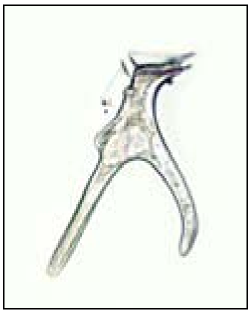


Dinophysis acuminata x 200

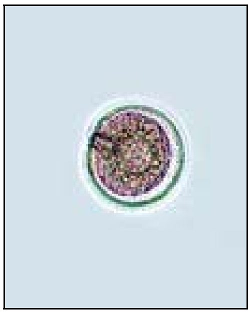
Dinophysis odiosa x 200

Dinophysis caudata x 200

Dinophysis hastate x 200



Dinophysis miles x 200

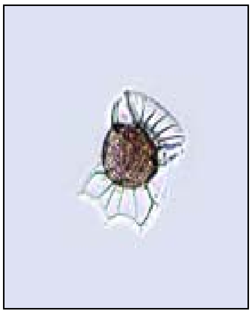


Diplopsalis lenticula x 200

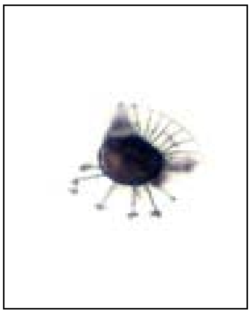
Trichodesmium sp x 200

Plate II (b)

Noctiluca miliaris x 50



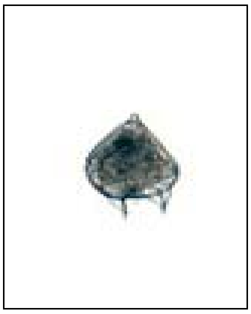
Ornithocercus magnificus x 200



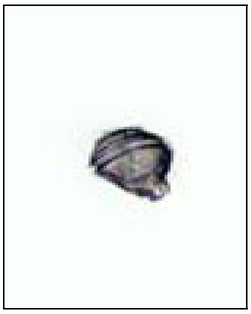
Ornithocercus steinii x 100

Oscillatoria laberenthiformis x 100

Oscillatoria sp x 100



Peridinium brevipes dorsal



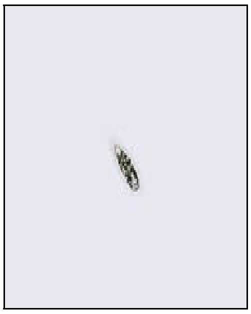
Peridinium brochii x 200

Peridinium coniaum x 100

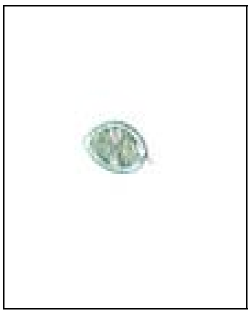
Peridinium depressum x 100

Peridinium leonis x 200

Prorocentrum compressum x 200



Prorocentrum gracile x 100



Prorocentrum micans x 200

Annexure -VI

Photograph of *Trichodesmium erythraeum* blooms Cruise No: 204)

Photograph of *Trichodesmium erythraeum* blooms Cruise No: 207)

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ANNEXURE