Ecological Studies on the Seagrass Ecosystem of Minicoy Lagoon Lakshadweep

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in

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By

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Declaration

I, Prabhakaran, M. P., hereby declare that the thesis entitled, **'Ecological Studies on the Seagrass Ecosystem of Minicoy Lagoon, Lakshadweep'** is an authentic record of the research work carried out by me, under the supervision of Dr. N. G. K. Pillai, Director, Central Marine Fisheries Research Institute, Kochi, in partial fulfillment of the requirement for the degree of Doctor of Philosophy of the Cochin University of Science and Technology, under the Faculty of Marine Sciences and that no part of this has been presented before for any other degree, diploma or associateship in any University.

Kochi – 18
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(Prabhakaran, M. P.)

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Certificate

This is to certify that this thesis entitled **'Ecological Studies on the Seagrass Ecosystem of Minicoy Lagoon, Lakshadweep'** is an authentic record of the research work carried out by Prabhakaran, M.P., (Reg. No. 2241, CUSAT) under my supervision at Central Marine Fisheries Research Institute, Kochi and that no part thereof has previously formed the basis for the award of any degree, diploma or associateship in any University.

Dr. N.G.K. Pillai
Supervising Guide and Director

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16-02-2008

Dedicated to All my Teachers

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(Prabhakaran, M.P.)

" To myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me".

- Sir Isaac Newton

Contents

Preface

The importance of seagrasses in coastal and near shore environments and their contribution to the productivity of the world's oceans has become increasingly recognized over the last four decades. They occur in most shallow, soft-bottomed marine coastlines, estuaries and lagoons. Generally seagrasses are associated with coral reefs. They are submerged marine angiosperms and mainly distributed in Southeast Asian countries, Australian and Caribbean coasts. The growth and distribution of seagrasses are controlled by a number of physical parameters such as temperature, salinity, light regime, sediment type and availability of nutrients. Seagrasses form the nursery and feeding ground for a number of marine organisms. They are highly involved in the detritus food web and play an important role in the recycling of nutrients.

Seagrasses stabilize and hold sediments, thus preventing erosion. Since, they are found in lagoons, which are generally subjected to anthropogenic activities, such as water sports, dredging, sewage disposal, etc. When considering all these, seagrass bed monitoring demands prime importance in the integrated coastal zone management. Minicoy lagoon has abundant growth of seagrasses. Studies on seagrass meadow in this region are very less and there is no comprehensive study on different aspects of the ecosystem. Present study was carried out during two consecutive years. The study aspects include seasonal and spatial variations in hydrography and associated floral and faunal composition. A statistical attempt was also made to study the interrelationship between the independent variables and dependant variables to find out any significant correlation.

The thesis is organized under seven chapters and a conclusion section. Each chapter is organized as a complete unit, having introduction, results, discussion and references. In Chapter I, a general account of the seagrass ecosystem, geomorphology of the Lakshadweep islands and its climate, review of the research work carried out in these islands and the objectives of the study are highlighted. Chapter II deals with the materials and methods employed for conducting the study. Chapter III, deals with the distribution patterns and interactions of hydrographic parameters in the lagoon.

In Chapter IV, the systematics and functions of seagrasses are highlighted in the introductory part. The mapping of seagrass meadow by transect line method, species composition and the variations in shoot density and biomass of five species of seagrasses and community structure are discussed in detail. The Chapter V deals with the species composition, distribution and abundance of macro algae associated with the seagrass ecosystem. The details about the species composition, abundance, *distribution and community structure of the fauna associated with seagrass ecosystem are described in the Chapter VI.*

Chapter VII elucidates the details of the fishery survey conducted in the seagrass meadow, using beach seine. The major findings of the study, including the interactions of various components of the ecosystem are summarized under the Conclusion section.

Seagrass ecology has evolved as a major part of aquatic ecology, from a descriptive stage, focused on the distribution and biology of the plants, to a quantitative, process-oriented stage. Research efforts over the past four decades have generated widespread awareness of the importance of seagrass meadows as marine ecosystems, thereby placing seagrass ecosystems as primary targets for marine conservation and restoration programmes. These achievements have resulted from the efforts of a growing community of seagrass ecologists. The scientific studies on seagrass ecology are still limited compared to many marine ecosystems. Moreover, understanding the ecology of seagrass meadows would enable a better basis to sustainably manage these ecosystems, because seagrass meadows are still being lost from the world's coastal ocean at alarming rates.

Here, the current status of the seagrass ecosystem of Minicoy lagoon is focused to evaluate its strengths and weaknesses, with the aim to develop a solid base for the management and conservation of seagrass meadows, and in turn, the very existence of coral atolls of Lakshadweep islands.

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Acronyms and Abbreviations

ml/l	**milliliter per litre**
°C	**degree Celsius**
%	**percentage**
ppt	**parts per thousand**
mm	**millimeter**
m	**metre**
km	**kilometre**
nm	**nanometre**
hrs	**hours**
Fig	**figure**
DO	**dissolved oxygen**
µgm at/l	**microgram atom per litre**
gm wet wt./m^2	**gram wet weight per square metre**
gm dry wt./m^2	**gram dry weight per square metre**
no./m^2	**number per square metre**
indls./m^2	**individuals per square metre**
et. al.	**et alli (Latin word, meaning 'and others)**
viz	**videlicet (Latin word, meaning 'namely'**
etc	**et cetera (Latin word, meaning and other similar things; and so on'**
sp.	**species**

Chapter I

Introduction

Chapter I
Introduction

1.1. Seagrass Ecosystem- General Account

Seagrass ecosystem forms one of the important coastal ecosystems of tropical and temperate regions. This ecosystem is conspicuous and often dominant habitats in shallow water coastal areas (den Hartog, 1970). This ecosystem is well known for its high primary and secondary productivity, ability to stabilize sediments, production of vast quantities of detritus and support of diverse faunal and floral communities (Phillips and Mc Roy, 1980).

Seagrasses are the marine monocots, which constitute about 0.01% of flowering plants and have adapted to the submerged marine habitat. There is a pronounced latitudinal gradient in structural complexity and spatial heterogeneity of seagrass environments. Seagrass ecosystem is associated with several faunal and floral assemblages such as algae, sponges, corals, crustaceans, molluscs and fishes.

Seagrass meadows may include mono-specific or multi-species communities. They exhibit a variety of leaf shapes, shoot densities and rhizome characteristics (Fig.1.1). Many meadows are not uniform in appearance, due to biological and physical disturbances. Seagrasses grow in soft sediments, from the low water mark to the depths of about 3-5 m and are inhabited by a rich associated biota. At the deeper end of the seagrass meadows, light becomes a limiting factor, strongly affecting photosynthesis and the lower limit is usually related to light irradiance. As the rhizome system grows and extends laterally, shoots may be sent up. A well-developed seagrass bed may extend laterally into bare sediments by means of the rhizome system. Dissolved nutrients are taken up by the rhizomes and roots mainly from the pore water present in sediments.

Seagrasses are flowering plants and the pollens are transported through the water currents. They produce seeds and are borne by water currents. Seagrasses appear to reproduce more by asexual method, through the rhizome system. Colonization of new areas by seedlings is difficult unless the sediment is already physically stable and rich in dissolved nutrients. This can be accomplished by the presence of other plants such as seaweeds, which stabilize the sediments and add nutrients. Thus, through succession a patch of bare sand may change to a bed of seagrass.

The complex ecology and multiple roles (Fig.1.2) that seagrass communities carry out thrust the need for maintaining and improving these communities. Like mangrove and salt marsh communities, seagrasses are important primary producers. They stabilize substrata, serve as habitats and nurseries, and are direct and indirect food source for a diverse fauna. The abundance and diversity of ichthyo-fauna in seagrass meadows is well known. The roles of benthic algae are less understood, although drift species are known to serve as habitats and food source for gammaridean amphipods. Further, these submerged flowering plants can be used to monitor the health of coastal ecosystems. So the need for conservation and management of seagrass meadows is evident when their extensive ecological roles are considered.

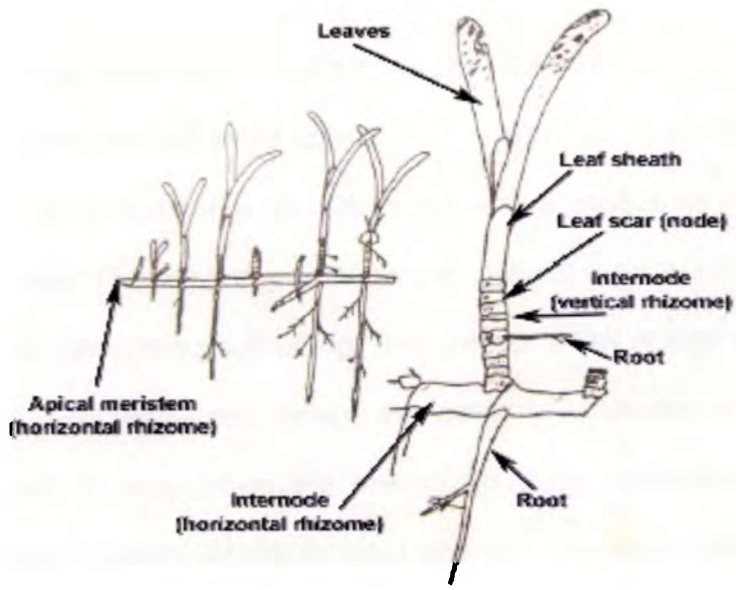

Fig. 1.1. Key morphological features of seagrass (adapted from Hemminga and Duarte, 2000)

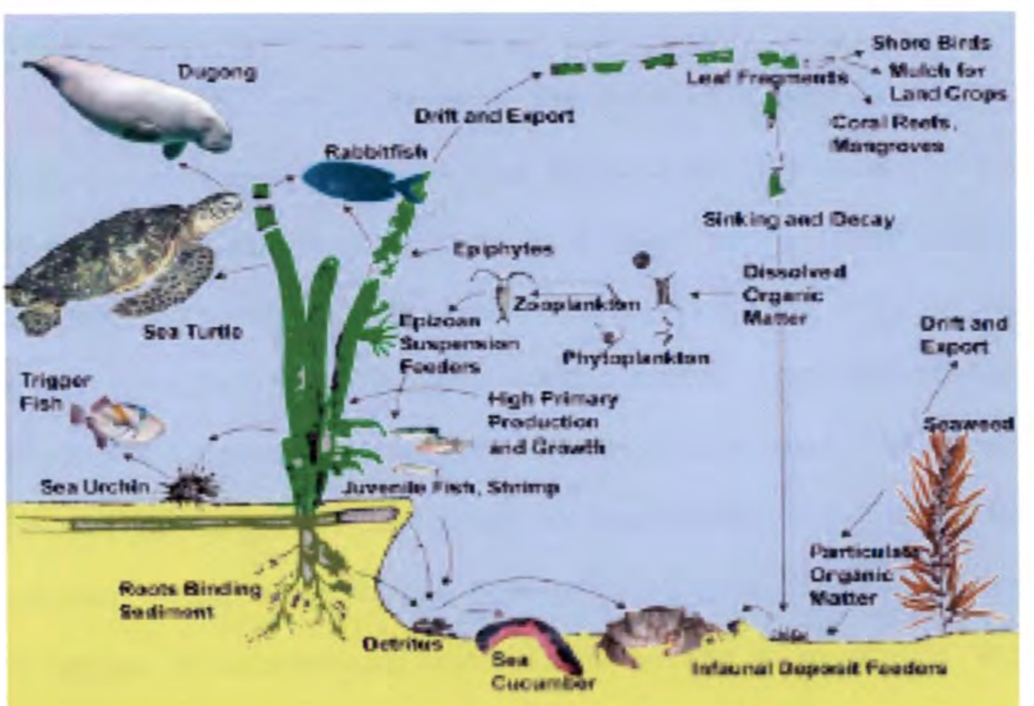

Fig. 1.2. Summary of seagrass ecosystem (adapted from Fortes, 1990)

In tropics, seagrasses are often associated with coral reefs. Coral reefs are constructional wave resistant features, which are built by a variety of species and are often cemented together. Coral reefs and seagrasses interact physically in a number of ways. Reefs are active producers of carbonate skeletal material. The upward growth of these skeletal materials is an effective barrier, which dissipates wave energy and creates a low energy environment in their lee. The reefs also reduce the action of currents on shorelines. Biological and physical processes breakdown these calcareous materials, resulting in the formation of gravel, sand and silt. The accumulation of these sediments by the action of waves and currents create a favorable condition for the colonization of seagrasses. Seagrasses trap and stabilize sediments, which is important for adjacent coral reefs, because it prevents abrasion or burial of reefs during storm conditions.

The seas around Lakshadweep and the reef lagoons are of great ecological significance as they influence the fauna and flora associated with the coral reefs and seagrass beds, to a great extent. Coral reefs of Lakshadweep consist of a wide variety of plants and animals and show high rates of productivity in nutrient poor oceanic waters. Each island except Androth has a lagoon on the western side with a sandy beach. The lagoons and reefs provide suitable coral habitat, for innumerable varieties of animals and plants. About 112.38 hectares of seagrass areas have been identified in the lagoons of Lakshadweep, which covers an area of about 4200 km^2. Minicoy, the southern most island of Lakshadweep Archipelago has the largest lagoon among the group and has a rich vegetation of seagrasses in the intertidal zone of the lagoon.

1.2. Geomorphology of Lakshadweep islands- the Study Area

Lakshadweep group of islands consists of 36 islands, including 12 atolls, 3 reefs and 5 submerged banks, lying scattered in the Arabian sea, west cost of India and lies in between 8°N and 12°N latitudes and 71°E and 74°E longitudes (Fig.1.3). According to Survey of India, the geographical area of Lakshadweep is 32 km^2, 20000 $km^2$of territorial waters and 400000 km^2 of Exclusive Economic Zone (EEZ). There are 36 islands of which Agatti, Amini, Androth, Bitra, Chetlat, Kadamat, Kalpeni, Kavaratti, Kiltan and Minicoy are inhabited. Among the uninhabited islands, Bangaram is a tourist resort and Suheli, a coconut growing and fishing centre. Pitti, the bird island is a small reef with sand bank covering an area of 1.2 hectares, lying northwest of Kavaratti, where terns in thousands visit for nesting. The entire Lakshadweep group of islands lie on the northern edge of 2500 km long north – south aligned submarine Laccadive –Chagos ridge. The ridge is separated from the Malabar ridge by the Lakshadweep Sea and merges with the shelf at some places between 11°N and 14°N. The ridge rises from a depth of 4000 m in the Arabian Sea. The height of the land above the sea level in the islands is generally 1 to 2 m without any major topographical features. The reefs of all the atolls are widest on the southwest side. The atoll consists of islands and lagoons, which are in various stages of development. Lagoons vary considerably in size, bottom topography, and geomorphology. The central part of the lagoon is usually deep with numerous coral knolls. According to Glenny's Gravity data, this represents a continuation of the Aravalli Mountains.

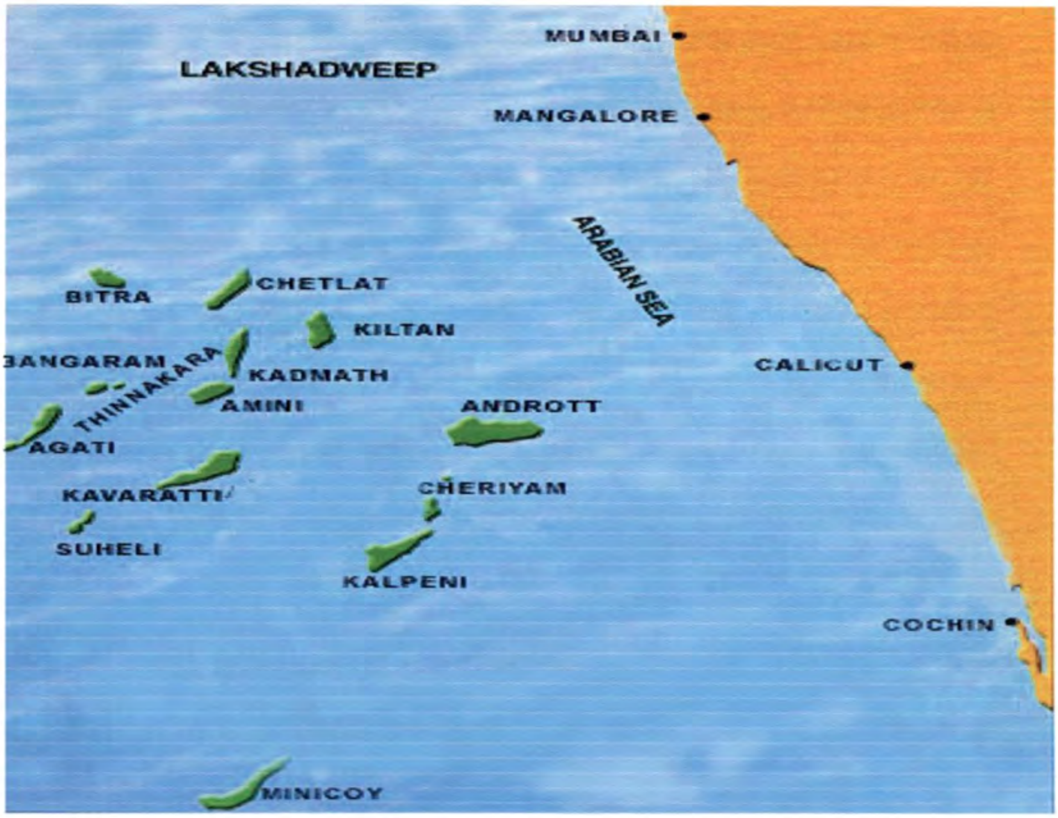

Fig. 1.3. Location of Lakshadweep group of Islands

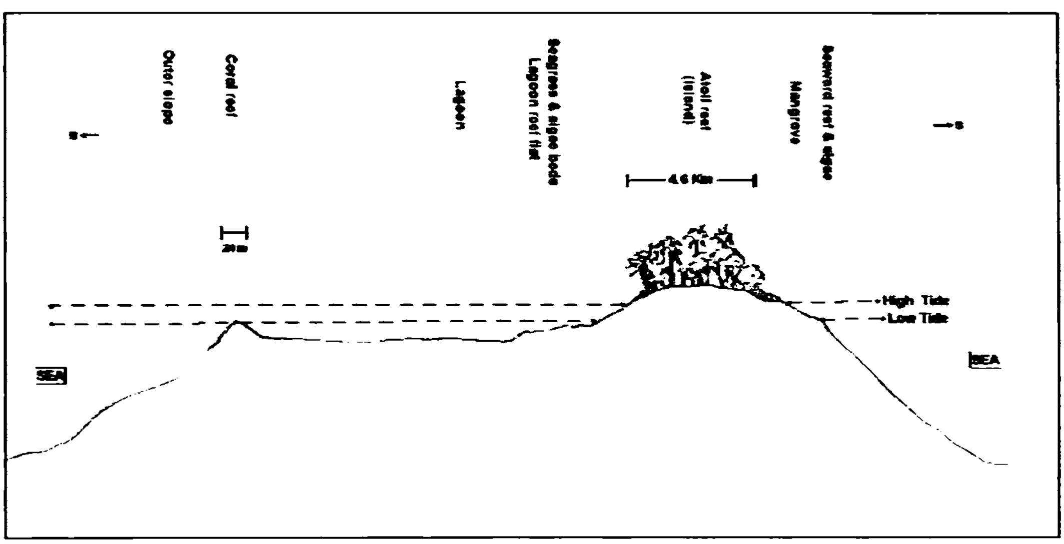

Fig.1.4. General Profile of Minicoy Atoll

There is a chain of shoals or banks between 16°N - 17°N and between 18°N - 19°N and 72°E, which are supposed to be the continuation of Lakshadweep ridge with the Aravalli. According to geologists, there was a submergence of land during late Miocene and Pliocene in the west of Malabar Coast. Lakshadweep islands are low coralline islands. Except Androth, all of them extend in north-south direction in the form of crescent shaped banks (Ahmed, 1972). The coral reefs have a steeper shore on the eastern side and there is a lagoon on the west (Fig. 1.4), so that the crescent shaped reefs is developed on the leeward side of the southwest monsoon.

1.3. Climate

The island experiences a tropical humid climate, with an average rainfall of about 1600 mm, from May to October. Since there are no streams in any of the islands, the only natural water source is ground water. Due to its location, the region experiences the overlapping of both the southwest and northeast monsoon. The temperatures are almost uniform with a slight increase from south to north.

Oceanic islands of coral origin in the deep sea are very important from the viewpoint of oceanography. The islands normally lead to the development of stable eddy systems in the middle of the ocean, which in turn make the atolls very productive and rich in fauna and flora.

1.4. Marine Research in Lakshadweep Islands – A Review

Recognition of the scientific importance of island ecosystems dates back well over a century to the observations of Charles Darwin in the Galapagos Islands in 1835. The marine biological and fisheries research in Lakshadweep area dates back to the later half of the nineteenth century, when attempts were made by some British naturalists to study the flora and fauna of the Lakshadweep and Maldives Archipelagoes. The Cambridge University expedition under the leadership of Prof. J. Stanley Gardiner was a significant event in the marine biological and oceanographic research and the results were published in two volumes of *Fauna and Geography of the Maldives and Laccadive Archipelagoes.* The atoll of Minicoy has been described by Gardiner (1903). Information in detail about Lakshadweep, relating to geographical features, land flora, fauna, history, *etc.* is well documented by Ellis (1924) and Mannadiar (1977). The Central Marine Fisheries Research Institute under took a comprehensive and indicative survey of the marine living resources of Lakshadweep Sea, under the leadership of Dr. P. S. B. R. James, in 1987 and published the details of the survey in 1989.

The hydrobiological parameters of marine environment of Lakshadweep islands have been studied by different groups of scientists, based on the data collected during the survey of these islands and during oceanographic cruises. Sankaranarayanan (1973) studied the chemical characteristics of waters around Kavaratti Atoll (Lakshadweep). Other studies include Naqvi and Reddy (1979); Jagtap and Untawale (1984) and Gopinath (2002). The primary production of seagrass beds of Kavaratti Atoll has been determined by Qasim and Bhattathiri (1971). Other major investigations on primary production in Lakshadweep waters were, those of Bhattathiri and Devassy (1979); Kaladharan, (1998); Kaladharan *et al.,* (1998); Kaladharan and David Raj (1989); Mohammed *et al.*, (1999); Koya *et al.*, (1999) and Dhargalkar *et al.,* (2000). Kannan *et al.*, (1999) reported the distribution and the present status of seagrasses from Lakshadweep area.

Studies related to seaweeds were limited in the Lakshadweep area. Anon (1979) made a report on the marine algal resources of Lakshadweep. Untawale and Jagtap (1984) gave an account of marine macrophytes of Minicoy lagoon. Productivity of the coral reef algae *Halimeda gracilis* at Minicoy lagoon was studied by Koya *et al.*, (1999). Mohammed *et al.*, (1999) studied the impact of domestic waste on the production of *Caulerpa racemosa* at Minicoy lagoon. Desai *et al.*, (2003) made a detailed study on the distribution and diversity of marine flora in the coral reef ecosystem of the Kadamat Island in Lakshadweep. Chemical composition of marine macrophytes of Minicoy atoll was estimated by Jagtap and Untawale (1984) and Gopinath (2002). Mohammed (1999) obtained high yield of *Acanthophora spicifera* through mariculture at Minicoy. Kaliaperumal *et al.*, (1989) made a detailed survey of seaweed and seagrass resources of Lakshadweep. Jagtap (1998) studied the structure of major seagrass beds from three coral reef atolls of Lakshadweep. Koya (2000) presented a detailed study on the distribution, biomass and chemical composition of seaweeds from Minicoy lagoon.

Results of the detailed ecological survey of the macro fauna of Minicoy Atoll have been presented by Nagabhushanam and Rao (1972). The studies carried out on marine fauna are mainly from Minicoy (Gardiner, 1903; 1906); Pillai, (1986); Jones and Kumaran, (1980) and Suresh and Mathew, (1998). Anzari (1984) described seagrass habitat complexity and macro invertebrate abundance in Lakshadweep coral reef lagoon. Inspite of a plethora of information, there has been no concerted attempt to study the seagrass ecosystem of Minicoy lagoon. Hence a pioneering attempt in this regard has been made to study the seagrass habitat structure and function in Lakshadweep islands.

1.5. Objectives and scope of the Study

The main objectives of the study are-

1. To study the temporal and spatial variations in hydrographic parameters prevailing in the Minicoy lagoon,
2. To study the interactions of hydrographic parameters in the lagoon,
3. To study the species composition, distribution, abundance, biomass and community structure of seagrasses.
4. To study the species composition, distribution, abundance and biomass of macro-algae present in the seagrass meadow,
5. To investigate the species composition, distribution, abundance and community structure of macro-invertebrate fauna found in seagrass meadow,
6. To examine the species composition, distribution, abundance and community structure of ichthyofauna community structure of seagrass meadow,
7. To delineate the ecological relationships between flora and fauna with the hydrographic parameters.
8. To study the interactions between flora and fauna and,
9. To highlight the importance of seagrass ecosystem for the existence of an oceanic coral island.

Seagrass ecology have evolved as most other research programmes within aquatic ecology, from a descriptive stage, focused on the distribution and biology of the plants, to a quantitative, process oriented stage. In this transition stage, research topics have diversified and new approaches and tools have appeared. Research efforts over past four decades have generated widespread awareness of the importance of seagrass meadows as marine ecosystems, thereby placing seagrass ecosystems as primary targets of marine conservation and restoration programmes. These achievements have resulted from the efforts of a growing community of seagrass ecologists. On the other hand, the scientific studies on seagrass ecology are still limited compared to many other marine ecosystems. Moreover, the increase of knowledge on the ecology of seagrass meadows does not appear to be conferring a better basis to suastainably manage these ecosystems, for seagrass meadows are still being lost from the world's coastal ocean at alarming rates. This situation suggests a lack of awareness and dearth of relevant information being generated. The development of seagrass ecology has either been insufficient or has left important gaps leading to negligence on the subject.

Studies on seagrass ecosystems have demonstrated the importance of seagrass meadows in various parts of the world. Current research is also showing how susceptible these systems are to human perturbations. The changes were related to reduce water quality conditions, specifically, excessive nutrients and sediment input. The loss of seagrass habitats has resulted in faunal changes, decline in some commercial stocks and increased shoreline erosion. Under the above backdrop it is imperative that proper assessment of Indian seagrass meadows be undertaken and understanding gained of their importance to fishery resources of India's coastal waters. The seagrass ecosystem of Lakshadweep Archipelago was the least studied part of the Indian Coastal waters. In this study, the current status of seagrass ecology in Minicoy lagoon was evaluated to provide a baseline diagnose of its strengths and weaknesses with the aim to develop a solid basis for the management and conservation of seagrass meadows.

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Chapter II

Materials and Methods

Chapter II
Materials and Methods

This chapter describes the study area, sampling locations, and the collection and analysis methods of water, flora and fauna. The collected data were analyzed using statistical methods for finding out the variations and interactions between different parameters.

2.1. Study Area

The area selected for study is the Minicoy Island (8°17'N and 73°04'E) of Lakshadweep group of islands. It is the southern most island of the group, having an area of 4.4km^2 with an elevation of 1.8m from the mean sea level and is located 215 nautical miles south-west off Kochi. The island lies in the north south direction and the lagoon in the western side. It has the largest lagoon among the group, with an area of 25km^2. The average depth is 4m, with a maximum depth of 15m and is connected to the sea by the Saleh Magu Channel in the northeast. The lagoon, which is oval in shape and elongated in the northeast - southwest direction. It has two distinct habitats - the coral shoals which occupy about 75% of the area and the sand flats in the southern parts of the lagoon. The lagoon has a rich vegetation of seagrasses and seaweeds in the intertidal zone, which extends to an area of 2.2 km^2 (Kaladharan *et al.*, 1998).

The present study was conducted during the period of June 2000 to May 2002. Based on the weather, the year may be divided into three seasons, namely, pre monsoon (February – May), monsoon (June – September) and post monsoon (October – January).

2.2. Sampling locations

Four stations were selected in the lagoon along the length of the island, based on a preliminary survey (Fig. 2.1). The criteria fort the selection of stations are-

i) Distribution of seagrasses, **ii)** Abundance of different species of seagrasses and **iii)** Geography of the Island. The whole seagrass meadow in the Minicoy lagoon is divided into 4 sampling stations (Zones).

Station I: This station is located in the south end, which is characterized by the interaction of coral reefs, mangroves and seagrass ecosystems and has a direct contact with the open sea. The area is characterized by the patchy seagrass meadow and the presence of corals. Strong tidal currents prevailed here.

Station II: Located near to the lighthouse area. This station has a wider seagrass area with thick meadow near to the coast and has less abundant growth in the outer areas.

Station III: This is a typical seagrass meadow with abundant growth of different species of seagrasses and is located near to the middle of the island. This area is away from the direct influence of tidal currents.

Station IV: Located at the northern part of the island having comparitively less abundant seagrass meadow with patchy coral reefs. The seaward side of this area is characterized by the presence of a large coral, *Goniastrea retiformis* and the top of adjacent ones being fused into an almost level platform. Highly populated areas are located in between Station III and

Station IV. Sewage input, fishing activities and the alteration of coastal zone destroyed a major part of the seagrass vegetation of this region.

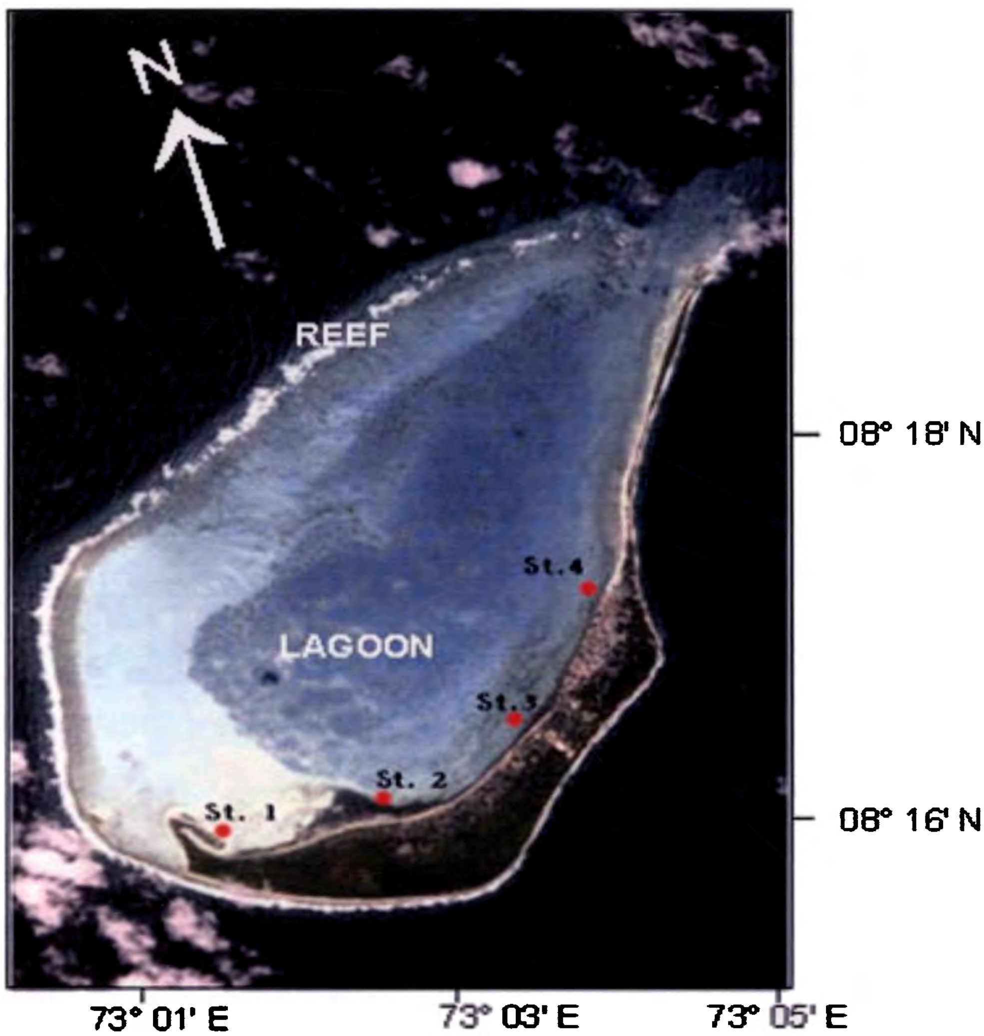

Fig. 2.1. Study area showing the sampling locations

2.3. Sampling and Analysis Methods

I. Hydrographical Parameters

Water samples were collected thrice in a month from the surface using plastic bucket every month during low tide from all the stations for the measurement of temperature, pH, salinity, dissolved oxygen and nutrients. Monthly average values were used for the analysis.

i) Water temperature: Water temperature was measured from the field itself by using a thermometer of the range 0°C to 50°C and 0.1°C accuracy.

ii) pH: pH was measured using a pH meter (Mettler Toledo MP - 120) having a glass electrode and a calomel electrode as reference. Before taking the pH of the sample, the meter was calibrated with buffer solutions, having pH 5, 7 and 9 at room temperature.

iii) Salinity: For the estimation of salinity water samples were collected in plastic bottles and taken to laboratory and stored in an insulated box till they were analysed. The samples were estimated by Mohr's Titration method (Strickland and Parsons, 1972). 10ml of the sample was titrated against silver nitrate ($AgNO_3$) solution using potassium chromate as indicator. $AgNO_3$ solution was standardized using standard seawater. Titration was repeated for concordant values. The values were recorded in parts *per thousand* (*ppt*) unit.

iv) Dissolved Oxygen: For the estimation of dissolved oxygen water was taken in 125ml stoppered glass bottle, taking care that no air bubbles were trapped in the samples. Dissolved oxygen was estimated by Winkler method (Strickland and Parsons, 1972). 50ml of the sample was pipetted out and titrated against standard sodium thiosulphate solution. This method depends on the oxidation of manganous dioxide by the oxygen dissolved in the samples resulting in the formation of a tetravalent compound, which on acidification liberates iodine equivalent to the dissolved oxygen present in the sample. The iodine liberated can be determined by titration with sodium thiosulphate. Titration repeated for concordant values. The results were expressed in the unit, *ml/litre (ml/l)*.

v) Nutrients: All nutrients (nitrite, nitrate, phosphate and silicate) were analyzed using the method outlined by Strickland and Parsons (1968; 1972) and measured on Erma AE II photoelectric colorimeter. A standard graph was prepared for each nutrient factor using known concentrations of standards. The nutrient values were expressed in the unit of *microgram atom/litre (µg at/l)*. Advanced methods of nutrient estimation could not be carried out due to the remoteness of the study area.

(a) Inorganic phosphate: Phosphorus present in seawater in the form of dissolved orthophosphate was determined quantitatively by the ascorbic acid (Strickland and Parsons, 1968). For the determination of orthophosphate ions by the formation of a reduced phosphomolybdenum blue complex in an acid containing molybdic acid, ascorbic and trivalent antimony, 8ml of mixed reagent is added to 50ml of the sample. After 5 minutes and preferably within the first 30 minutes, the optical density was measured colorimetrically at 660nm.

(b) Nitrite-Nitrogen: Nitrite-nitrogen in seawater was estimated by the method described by Strickland and Parsons, (1968). 50ml of the seawater sample was measured out in conical flask. After 2 minutes but not later than 8 minutes, 1ml of NNED (N-Naphthyl Ethylene diamine Dihydrochloride) solution was added and mixed thoroughly. The optical density was measured at 530nm.

(c) Nitrate-Nitrogen: Nitrate-Nitrogen in seawater sample was reduced to nitrate and then measured in the same way as described for nitrate.

(d) Silicate-silicon: Silicon present in seawater in the dissolved form was estimated by the method described by Strickland and Parsons (1972). The determination of dissolved silicon compound was based on the formation of a yellow silicomolybdic acid, when a more or less acidic sample was treated with molybdate reagent. Since this acid is weak, the same was reduced by ascorbic acid to intensely coloured blue complexes. The absorption of the sample was measured against distilled water at a wavelength of 660nm. 20ml of the sample pipetted out into 50ml-graduated flask containing 3ml of the acid molybdate reagent and mixed thoroughly. After 10 minutes, 15ml of reducing agent was made up to 50ml with distilled water. The solution was allowed to stand for 3hrs and measured colorimetrically at 660nm.

II. Biological Parameters: The biological parameters studied were the mapping of seagrass meadow for finding out the area and distribution of seagrasses, the collection and identification of seagrasses and seaweeds for finding out the species composition, distribution and biomass of individual species and the species density and diversity associated macro-fauna.

i) Mapping: Since, the seagrass meadow in Minicoy Lagoon extends only a few kilometers, transect-line method (English, *et al.*, 1997) is used for studying the distribution and mapping. First, the seagrass meadow is examined carefully by underwater tows. The transects were fixed at specific intervals of 100m. At regular intervals of 0.5 km, a reference point is fixed as permanent markers. Along the transect, the species composition, abundance and relevant characteristics of the meadow were noted. Description was included 50m each side of the transect line. The survey carried during low tides. The results were recorded in the form of a profile. Two annual surveys were conducted for detecting any changes in seagrass cover.

ii) Collection of seaweeds and seagrasses: Seaweeds and seagrasses were collected monthly during low tides from the specified stations, by using 0.25m^2 quadrate (Lewis and Stoner, 1981). Random sampling method was employed for the collection. The samples collected were taken to the laboratory, sorted out and identified by using standard references (Gopinathan and Panigrahy, 1983; Jagtap, 1983; Chennubotla *et al.,* 1987; Kaliaperumal *et al.,* 1989; Krishnamurthy and Balasubrahmanyam, 1990; Koya, 2000; Dawes, 1998) to the maximum possible taxonomic level. Wet weight of individual species of seaweeds were found out after removing the epiphytes and recorded in the unit of gm wet wt/m^2. Shoot density of each seagrass species were found and recorded in the unit of shoots/m^2. For finding out the biomass of seagrass species, the samples were rinsed with freshwater and epiphytes were removed by careful scraping of the leaves. Species wise dry weight was found out by drying at 60 to 80°C to constant weight in an oven (Erftemeijer and Stapel, 1999). The biomass was expressed in the unit of gm dry wt./m^2. The temperature and time of drying varies according to the species, which have different shoot structure. From the trials it was confirmed that the desired time for drying ranges between 8 to12hrs.

iii) Collection of macro-invertebrate fauna: For this study, the epifauna, including those attached to the leaves and stems, creeping fauna on the seagrass meadow and the mobile fauna in between seagrass leaves including crabs and prawns were collected monthly from all the stations.

For the collection of attached and less mobile macro-invertebrate fauna (>0.5mm) quadrate ($0.25m^2$) method (Lewis and Stoner, 1981) was employed as in the case of seaweeds and seagrasses. Presence of crabs and prawns were noted in the area before taking the seagrass and seaweed samples. The observed crabs in the area were collected using small traps.

The samples were collected, sorted out in the laboratory, made into groups, and preserved in formaldehyde. Species level identification was done later using standard references. The density was represented in the unit of no./m^2.

iv) Fishery survey in seagrass beds:

Monthly surveys for fishery resources were conducted in all the stations. For the collection of fishes a beach seine net, having the length of 30m, a width of 2m and a mesh size of 9mm was used (Gilmore, 1990; English, *et al.,* 1997). The disadvantages of beach seine netting have been discussed by English, *et al.,* (1997) and Nagelkerken, *et al.*, (2001). The major concerns are that seine nets under-sample fast swimming fish species and also small fish such as gobies and blennies. Additionally, large fish may also have greater avoidance ability. Despite these drawbacks, this approach remains the only non-destructive method for sampling fish populations in seagrass beds. The non-destructive nature of seine netting has been challenged (Gray and Bell, 1986), however, observations made of the net being pulled through the seagrass beds coupled with its small size, found no evidence of damage to the seagrass. From the trials it was confirmed that beach seine nets are more appropriate for determining the relative proportion of species in a seagrass habitat and estimating the density of most species.

The collection was made in the seagrass meadow with an average extend of 100m from the coastline. The net was deployed as swiftly and quietly as possible along a set measured transect between shore and the edge of seagrass meadow. Care should be taken not to lift the lead line when the seine was pulled when the line is observed to leave the bottom. The hauling area covered 3000m^2 (100m across x 30m along) of the seagrass bed. The collected samples were sorted and counted. The density was expressed as indls./haul. Species identification was done at maximum possible level using standard references.

x) Rainfall and Tide Data

Rainfall data of Minicoy were obtained from the Meteorological observatory, Minicoy. Tide level was estimated using the Tide Tables, published by the Surveyor General of India.

2.4. Statistical Analysis

The software programmes *viz.*, ***SPSS*** (*Statistical Programme for Social Sciences version 11.0*) and ***PRIMER v 6*** *(Plymouth Routines in Multivariate Ecological Research, version 6.1.9)*, were used for univariate and multivariate analyses of data.

Statistical analysis for **3 Way ANOVA**, standard deviation and correlation was done based on ***SPSS 11*** software packages *for Windows* for testing the presence of significant differences among the parameters between stations and between seasons. Correlation results were used to correlate the environmental parameters with the biological parameter. Draftsman scatter plots were made in appropriate sections for finding out the pair wise interactions between variables.

BEST Analysis: The ***BEST*** routine available in PRIMER v6 (Clarke and Gorley, 2006) combines the *BIO ENV* and *BV STEP* procedures of PRIMER v5. This routine uses all the available environmental variables to find out the combination that 'best explains' the patterns in the biological data. Starting with the variable showing the maximum matching coefficient, variables are successively added, the combinations tested at each stage. The variable contributing least, eliminated. Several iterations of the procedure are carried out from a random selection of (= 6) variables to ensure that the 'best' match is found.

Community structure: *PRIMER v6 for windows* was used for the analysis of community structure.

(a) Diversity Indices:

i) Shannon - Wiener index (H')

In the present study, the data were analysed for diversity index (H') using the following Shannon - Wiener's formula (1949):

$$H' = -\sum_{i=1}^{S} P_i \log_2 P_i \ldots\ldots$$

which can be rewritten as,

$$H' = \frac{3.3219\,(N \log N - \sum ni - \log ni}{N}$$

where, H'= species diversity in bits of information per individual ni = proportion of the samples belonging to the ith species

(number of individuals of the *i* th species)

N = total number of individuals in the collection and

Σ = sum.

ii) Margalef richness index (d)

d = (S-1) / log N

iii) Pielou's evenness index (J')

The equitability (J') was computed using the following formula of Pielou (1966):

$$J' = \frac{H'}{\log_2 S} \text{ or } \frac{H'}{\ln S}$$

where, J' = evenness,

H' = species diversity in bits of information per individual and S = total number of species.

iv) Simpson index (D)

D = 1 – λ,

where, λ = Σ Pi2

$$Pi = \frac{ni}{N}$$

ni = number of individuals of i, i2 etc. and N = total number of individuals.

v) Taxonomic diversity index / Taxonomic distinctness index

Warwick and Clarke (1995) proposed two new biodiversity indices, capturing the structure not only of the distribution of abundances amongst species but also the taxonomic relatedness of the species in each sample.

The first index is taxonomic diversity (Δ) and the second one is taxonomic distinctness (Δ^*). The taxonomic distinctness can be divided based on presence/absence data into two types namely (i) average taxonomic distinctness ($\Delta+$) and (ii) variation in taxonomic distinctness ($\Lambda+$). The Δ and Δ^* were calculated using the following two equations:

$$\Delta = \frac{\sum\sum_{i<j} W_{ij} X_i X_j + \sum_i 0.X_i (X_i - 1)/2}{\sum\sum_{i<j} X_i X_j + \sum_i X_i (X_i - 1)/2}$$

$$\Delta^* = \frac{\sum\sum_{i<j} W_{ij} X_i X_j + \sum_i 0.X_i (X_i - 1)/2}{\sum\sum_{i<j} X_i X_j + \sum_i X_i (X_i - 1)/2}$$

Average taxonomic distinctness index (Δ +)

Average taxonomic distinctness (delta+) was calculated using the following formula:

$$\Delta+ = [\Sigma\Sigma i < j\ \omega ij] / [s\ (s-1)/2]$$

where S is the number of species present, the double summation is over the set {i= 1, S; j= 1, ...S, such that i< j} and ωij is the 'distinctness weight' between species i and j.

Variation in taxonomic distinctness index (Λ+)

Variation in taxonomic distinctness ($\Lambda+$) was calculated using the following formula:

$$\Lambda+ = [\Sigma\Sigma\ i \neq j\ (\omega\omega ij - \omega)\ 2] / [s\ (s-1)]$$

$$= [\{\Sigma\Sigma\ i \neq j\ \omega ij2\} / \{s\ (s-1)\}] - \omega\ 2$$

95% histogram, 95% confidence funnel and 2 – dimensional plot

Average taxonomic distinctness index (Δ^+) and variation in taxonomic distinctness (Λ^+) were studied graphically by the funnel method. Combined $\Lambda+$ and Δ^+ were represented by ellipse plot.

(b) Similarity Indices:

i) Cluster analysis

Cluster analysis was done to find out the similarities between groups. The most commonly used clustering technique is the hierarchical agglomerative method. The results of this are represented by a tree diagram or dendrogram with the x- axis representing the full set of samples and the y-axis defining the similarity level at which the samples or groups are fused. Bray - Curtis coefficient (Bray and Curtis 1957) was used to produce the dendrogram. The coefficient was calculated by the following formula:

$$Sjk = 100 \left\{ 1 - \frac{\sum_{i=1}^{p} |y_{ij} - y_{ik}|}{\sum_{i=1}^{p} (y_{ij} + y_{ik})} \right\}$$

$$= 100 \frac{\sum_{i=1}^{p} 2\min(y_{ij}, y_{ik})}{\sum_{i=1}^{p} (y_{ij} + y_{ik})}$$

where, yij represents the entry in the i th row and j th column of the data matrix i.e. the abundance or biomass for the i th species in the j th sample;

yik is the count for the i th species in the k th sample;

| ... | represents the absolute value of the difference;

'min' stands for, the minimum of the two counts and

Σ represents the overall rows in the matrix.

ii) SIMPROF Test: The significance of the cluster groups created was tested by similarity profile (SIMPROF) test.

iii) MDS (Non - metric Multi Dimensional Scaling)

This method was proposed by Shepard (1962) and Kruskal (1964) and this was used to find out the similarities (or dissimilarities) between each pair of entities to produce a 'map', which would ideally show the interrelation ships of all.

The relative abundances or biomasses of different species were plotted as a curve, which retains more information about the distribution than a single index. True to this, the data collected were considered for dominance plot, geometric abundance class plot and species area plot.

iv) Geoplot (x^2 geometric abundance class plot)

Geometric abundance class plot was performed following the procedure outlined by Gray and Pearson (1982). The y-axis represents the percentage of species and geometric abundance class on the x- axis.

v) Dominance plot

The species were ranked in terms of abundance. The ranked abundances calculated as percentages of the total abundances of all species were plotted against the relevant species rank.

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Chapter III

Hydrography

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Hydrography

3.1. Introduction

Hydrographic conditions determine the existence of communities in an aquatic ecosystem and the knowledge about these parameters was important in understanding the dynamics of the ecosystem. The regulatory influence of the environment over the living community, which it supports, is the result of the independent and inter-related actions of the non-living elements, which are variable in space and time. The interaction of an organism with the environment determines the size of its population and distribution. In the coastal ecosystems, there occurs a combined effect of both terrestrial and nearby aquatic ecosystems. The hydrographical parameters in the coastal ecosystems such as mangroves, coral reefs, seagrasses and salt marshes vary to a great extent and are controlled by climate, tidal activities and fresh water influx. The tidal flow and the seasonal rainfall mainly determine the hydrological conditions in the lagoon.

The hydrographical conditions in the reef and lagoons further determined by the factors such as regional precipitation and the radiation resulting in surface heating and cooling (Andrews and Pickard, 1990). Strong winds during southwest and northeast monsoon, abundant light energy available in the clear waters of the lagoon and the complex current pattern around the Islands will therefore have a strong influence on the water characteristics. The water circulation in coastal lagoons is dominated by tides that fill water in accordance with the tidal intensities, through the inlets in the reef. Because of the ratio of surface to depth is larger than that of open sea, lagoon is subjected to extreme variations in properties that depend on the interaction with the atmosphere. The chemical composition of seawater is influenced by a wide variety of chemical transport mechanisms. Each element in the oceans tends to exhibit spatial and temporal variations in concentration. The influence of physical mixing and biogeochemical input and removal mechanisms result in the variability of hydrography of the lagoon.

The environmental factors considered were temperature (atmospheric and surface water), salinity, pH, dissolved oxygen and nutrients such as phosphate, silicate, nitrite and nitrate. The study area experienced tropical climate with an average rainfall of about 1600mm from May to October (Gopinath, 2002). Temperature is an important physical factor controlling the dynamics of ecosystem and may have an indirect effect on the growth and distribution of plants and animals. It results in zonation and stratification. Temperature specificity and intolerance to even small changes are developed in organisms, which are found in areas where the temperature normally remain stable. Other ecological factors are also affected by temperature.

Salinity forms one of the determining factors in the distribution and abundance of fauna and flora in coastal marine ecosystems, which are subjected to variations. Salinity is a function of evaporation, precipitation, land run-off, etc. It affects the structural and functional responses of marine organisms and also causes indirect effects by modifying the species composition of an ecosystem. Since the Minicoy lagoon is associated with the oceanic island and the absence of any major fresh water sources, the salinity of the lagoon is determined by the surrounding oceanic region and the rainfall. Land runoff due to rainfall has less influence on the salinity structure of the lagoon. So the salinity of the lagoon is determined by the properties of the oceanic region with its seasonal properties. The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen and carbon).

Oxygen dissolved in water plays a significant physical as well as biochemical role in the life of aquatic organisms. The distribution of dissolved oxygen in the marine environment is controlled by the exchange with the atmosphere and the biological processes of photosynthesis and respiration. Oxygen from the atmosphere dissolves in seawater at the surface. The amount that can be dissolved is dependant upon the temperature and salinity.

Nutrients are inextricably linked to almost all the ecological processes. The inorganic nutrients such as phosphorus, nitrogen and silicon are essential to the primary producers of all ecosystems. Coral reef systems utilize dissolved nutrients as water passes over them. The best coral development is always found on the nutrient depleted oligotrophic waters, as they are least tolerant of nutrient enrichment. Phosphorus in seawater is found in living organisms or as dissolved inorganic phosphorus, dissolved organic phosphorus and particulate phosphorus. In most aquatic environments the amount of particulate phosphorus is much greater than that of dissolved part. In the marine environment, dissolved phosphorus is utilised during primary production. Most of the regeneration of phosphorus occurs in the water column itself. In shallow environment, sediments play an important role in its regeneration. The supply and subsequent availability of nitrogen has fundamental consequences for primary producers.

In marine environments, nitrogen is transformed and transported in a complex pattern. Mechanisms that transport nitrogen in and out of the system include biological and physical pathways (Dawes, 1998). Though a large amount of atmospheric nitrogen is dissolved in water, only some blue green algae and certain bacteria are able to utilize nitrogen in its free dissolved state and convert it into organic molecules. Plants have to obtain their nitrogen from nitrogen compounds such as nitrites and nitrates. Normally only a small portion of these compounds occur in solution in natural waters and these are usually derived from organic decomposition. Nitrogen compounds and other essential nutrients may become scarce due to the phytoplankton production. The non-availability of these compounds has a limiting effect on plant growth and thus indirectly affects the animal populations. Measurements of nitrites and nitrates in an aquatic system help to predict the productivity of the system.

Silica occurs in water in a colloidal or particulate state or as dissolved silicates and never occurs as a free element. The amount of silicate varies in different water bodies. Silicon dynamics in coral reefs have received less attention than nitrogen and phosphorus, primarily because coral reef organisms are calcareous and not siliceous and silicon is not an essential element for most flora and fauna.

In this chapter, the spatial and temporal variations and interactions of hydrographical parameters in Minicoy lagoon are discussed.

3.2. Results

Monthly average values of air temperature, rainfall, and tide level in the lagoon during the sampling period are represented in the Figs. 3.1, 3.2. and 3.3. Monthly average values of hydrographic parameters and the variations in distribution were represented by Figs. 3.4 to 3.11 for two consecutive years (24 months). The mean variations (Mean±SD) in hydrographic parameters for all the four stations together (pooled data) were represented in the Figs. 3.13 and 3.14

respectively. The Draftsman (pair wise scatter plot) plot showing the interactions of hydrographic parameters were shown in the Fig. 3.14. Station wise and seasonal mean and standard deviation (SD) and Coefficient of Variation (CV) of hydrographic parameters in all the stations were given in Table 3.1 and 3.2. respectively. Results of ***ANOVA*** and correlation are given in Table 3.3a to3.3h and Table 3.4. respectively. Correlation results of Draftsman scatter plot analysis were given in the table 3.5.

3.2.1. Meteorological parameters

The meteorological parameters that were discussed in this section include rainfall and atmospheric temperature. The highest rainfall recorded during the study period was 320mm during October (II Year). There was no rainfall during March 2000. The range of rainfall was 7 to 320mm during the entire period. The average rainfall during I year was 123mm and 149mm during the II year, whereas the atmospheric temperature varied from 25.2 to 31.2°C in the region, during the study period.

3.2.2. Hydrographical parameters

Tide Level: All the samplings are done in the morning hours with the tidal amplitude ranging between 0.26 and 0.68m. The lowest tide height during the sampling period was observed during November and highest during March.

Temperature: For the entire period, the temperature observed was in the range of 26.0 to 31.2°C for all the stations. Lowest values were observed in August and October months and highest during April and May. During the first year of study period, the range of temperature was 26.0 to 30.6°C (Av. = 28.3°C) and in the second year, it was 26.3 to 31.2°C (Av. = 28.75°C). Seasonally, the average temperature was 27.67°C during monsoon 27.99°C during post monsoon and

29.34°C during pre monsoon. Spatially, lowest temperature was observed at station I and II with a value of 26.0°C and maximum at station II (31.2°C).

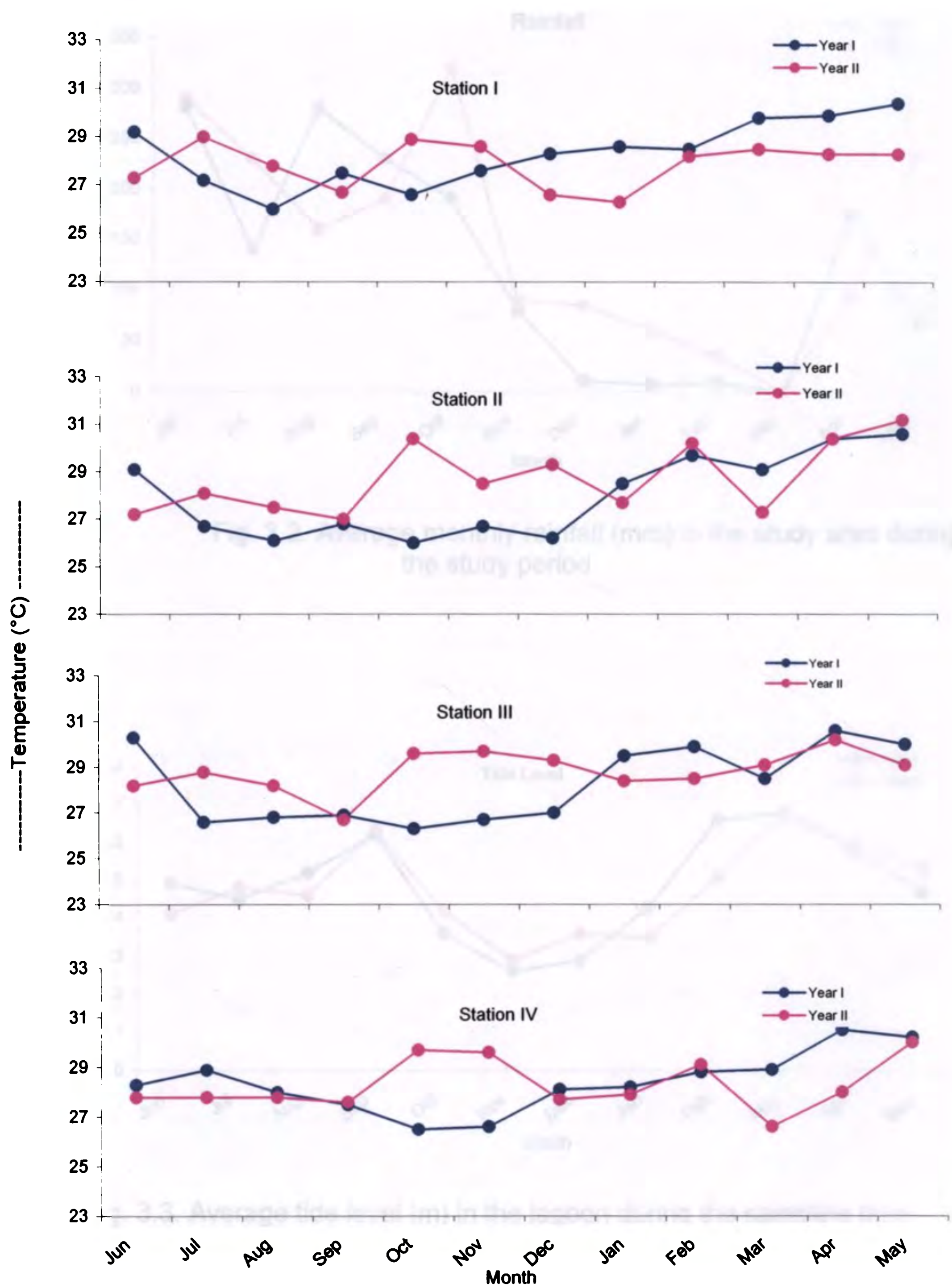

Fig. 3.1. Monthly variations in Air Temperature in Stations I to IV during the study period

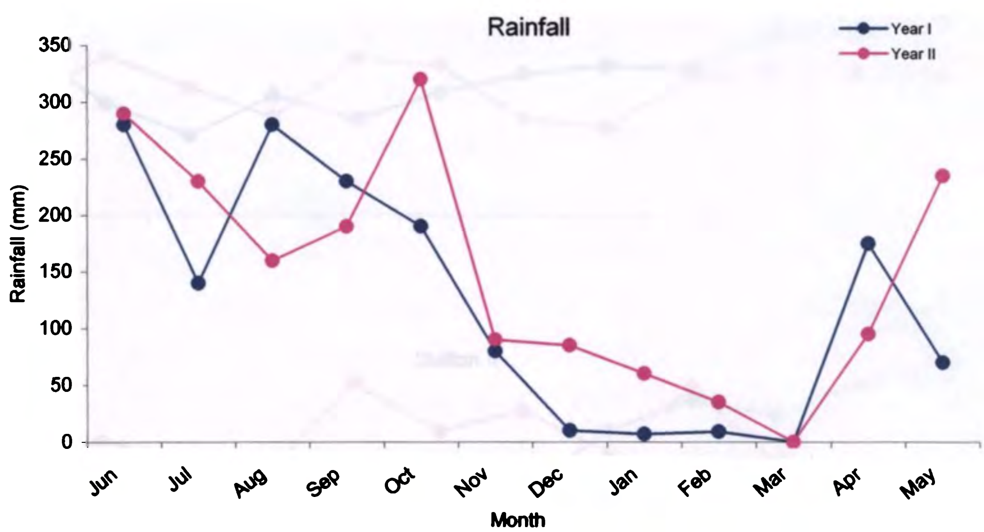

Fig. 3.2. Average monthly rainfall (mm) in the study area during the study period

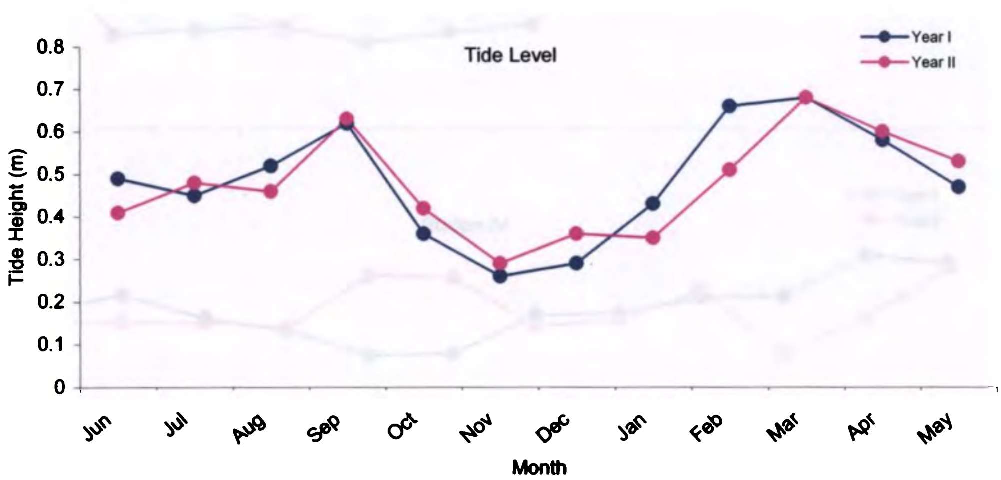

Fig. 3.3. Average tide level (m) in the lagoon during the sampling time

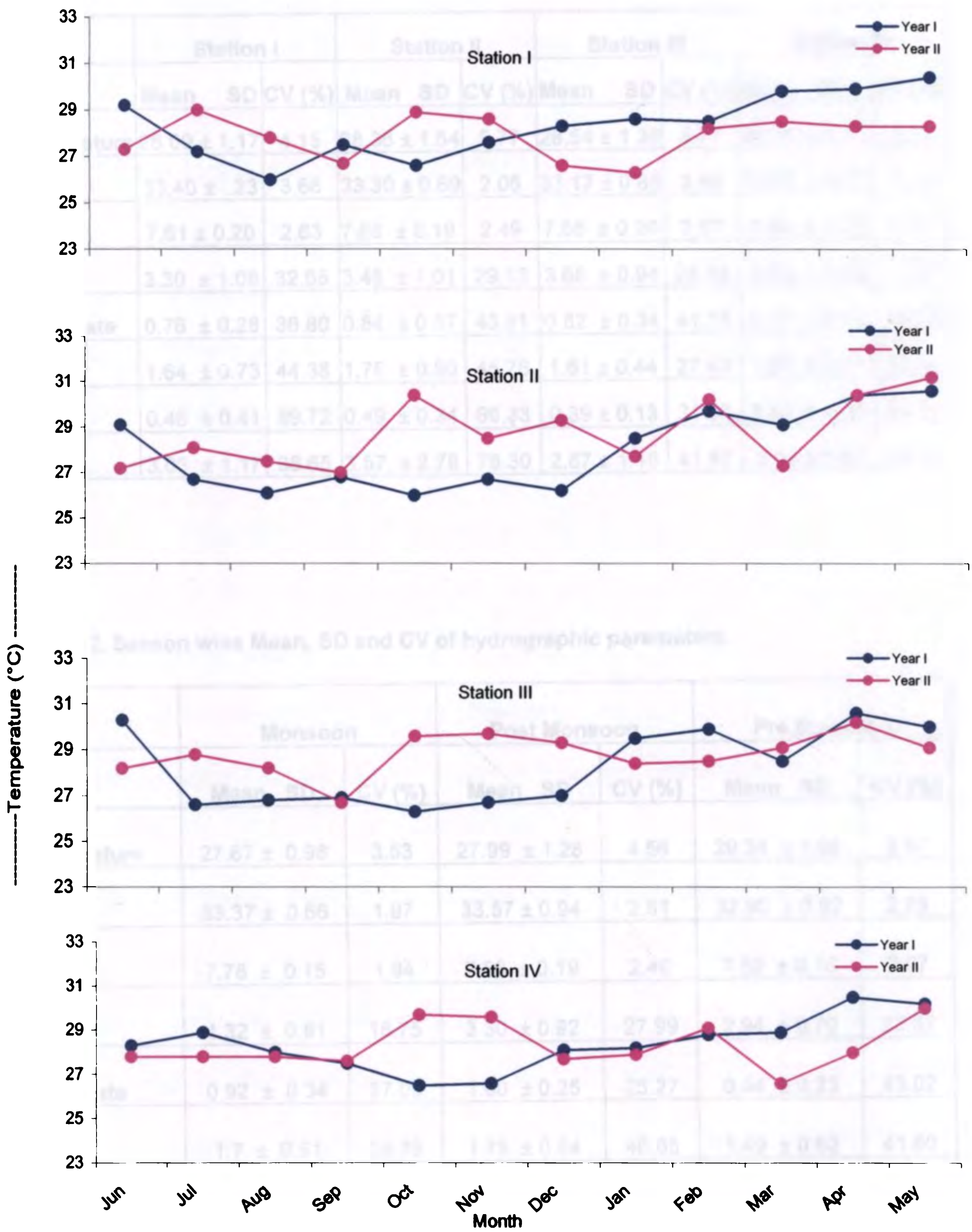

Fig.3.4. Monthly variations of water temperature (°C) in Stations I to IV during the study period

Table3.1. Station wise Mean, SD and CV of hydrographic parameters

	Station I		Station II		Station III		Station IV	
	Mean SD	CV (%)	Mean SD	CV (%)	Mean SD	CV (%)	Mean SD	CV (%)
Temperature	28.09 ± 1.17	4.15	28.36 ± 1.64	5.77	28.54 ± 1.36	4.77	28.34 ± 1.11	3.91
Salinity	33.40 ± .23	3.68	33.30 ± 0.69	2.06	33.12 ± 0.85	2.58	33.30 ± 0.71	2.14
pH	7.61 ± 0.20	2.63	7.66 ± 0.19	2.49	7.68 ± 0.20	2.57	7.63 ± 0.18	2.36
DO	3.30 ± 1.08	32.65	3.48 ± 1.01	29.13	3.68 ± 0.94	25.38	3.62 ± 0.99	27.31
Phosphate	0.76 ± 0.28	36.80	0.84 ± 0.37	43.81	0.82 ± 0.34	41.18	0.87 ± 0.38	44.22
Nitrate	1.64 ± 0.73	44.38	1.75 ± 0.80	45.76	1.61 ± 0.44	27.40	1.65 ± 0.71	43.03
Nitrite	0.46 ± 0.41	89.72	0.49 ± 0.34	69.33	0.39 ± 0.13	31.93	0.51 ± 0.26	50.67
Silicate	3.03 ± 1.17	38.65	3.57 ± 2.78	78.30	2.87 ± 1.19	41.57	2.91 ± 1.67	57.45

Table 3.2. **Season wise Mean, SD and CV of hydrographic parameters**

	Monsoon		Post Monsoon		Pre Monsoon	
	Mean SD	CV (%)	Mean SD	CV (%)	Mean SD	CV (%)
Temperature	27.67 ± 0.98	3.53	27.99 ± 1.28	4.56	29.34 ± 1.08	3.67
Salinity	33.37 ± 0.66	1.97	33.57 ± 0.94	2.81	32.90 ± 0.92	2.79
pH	7.78 ± 0.15	1.94	7.56 ± 0.19	2.49	7.59 ± 0.16	2.07
DO	4.32 ± 0.81	18.75	3.30 ± 0.92	27.99	2.94 ± 0.70	23.82
Phosphate	0.92 ± 0.34	37.03	1.00 ± 0.25	25.27	0.54 ± 0.23	43.02
Nitrate	1.7 ± 0.51	29.76	1.79 ± 0.84	46.85	1.49 ± 0.62	41.60
Nitrite	0.41 ± 0.15	36.77	0.44 ± 0.12	27.00	0.53 ± 0.48	90.07
Silicate	2.78 ± 1.99	71.82	3.09 ± 1.96	63.38	3.42 ± 1.47	43.18

SD = Standard deviation; CV = Coefficient of Variation (%)

Salinity: During the study period, the salinity ranges from 31.15 to 35.48ppt during the period of study. Lowest salinity of 31.33ppt was observed in March and the highest value of 35.48ppt during November. During the first year, the range of salinity was 31.33ppt in February to 34.88ppt in November (Av. = 34.41ppt) and in the second year, it was 31.15ppt in January and 35.48ppt in November (Av. = 33.32ppt). The average value for monsoon was 33.37ppt and during post monsoon and pre monsoon, it was 33.57ppt and 32.90ppt respectively. Spatially, it was lowest (31.5ppt during January) in the Station III and highest (35.48ppt during November) in the Station I.

pH: Lowest pH value of 7.3 was recorded in February and highest value of 8, in September and October. It ranges from 7.43 to 8 during the first year (Av. = 7.72) and 7.4 to 8 in the second year (7.7). No significant variation was observed seasonally and it was 7.78 during monsoon and 7.56 and 7.59 during post monsoon and pre monsoon. Spatially, the lowest average pH (7.3) was observed at Station I during February and highest of 8 during September and October at Station III.

Dissolved Oxygen: Lowest value of dissolved oxygen was 1.46ml/l, which was recorded during the month of February and highest during October, which was 5.62 ml/l. During the first year it was in the range of 1.46 to 5.52ml/l (Av. = 3.49ml/l) and in the second year, it was 2.07 to 5.62ml/l (Av. = 3.85mi/l). Seasonally it was 4.32 ml/l in the monsoon, 3.30ml/l in the post monsoon and 2.94ml/l during pre monsoon. Station wise average highest value of 3.68 ml/l was recorded in the Station III and lowest value of 3.3 ml/l in the station I.

Nutrients:

a) Phosphate: During the entire period of study, the phosphate values ranges from 0.25µgat/l during March, April and May and highest during July and

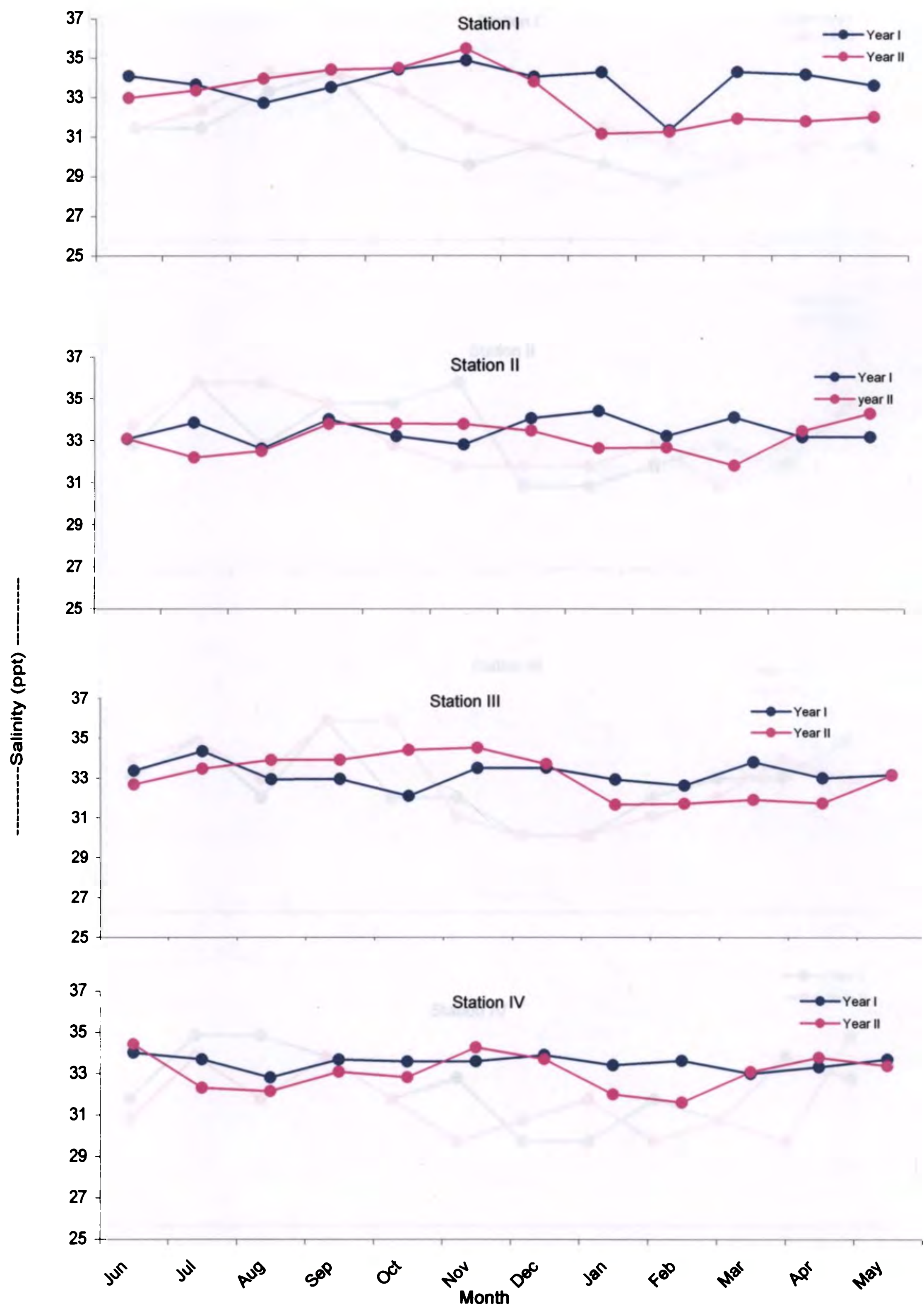

Fig. 3.5. Monthly variations of salinity (ppt) in the Stations I to IV during the study period

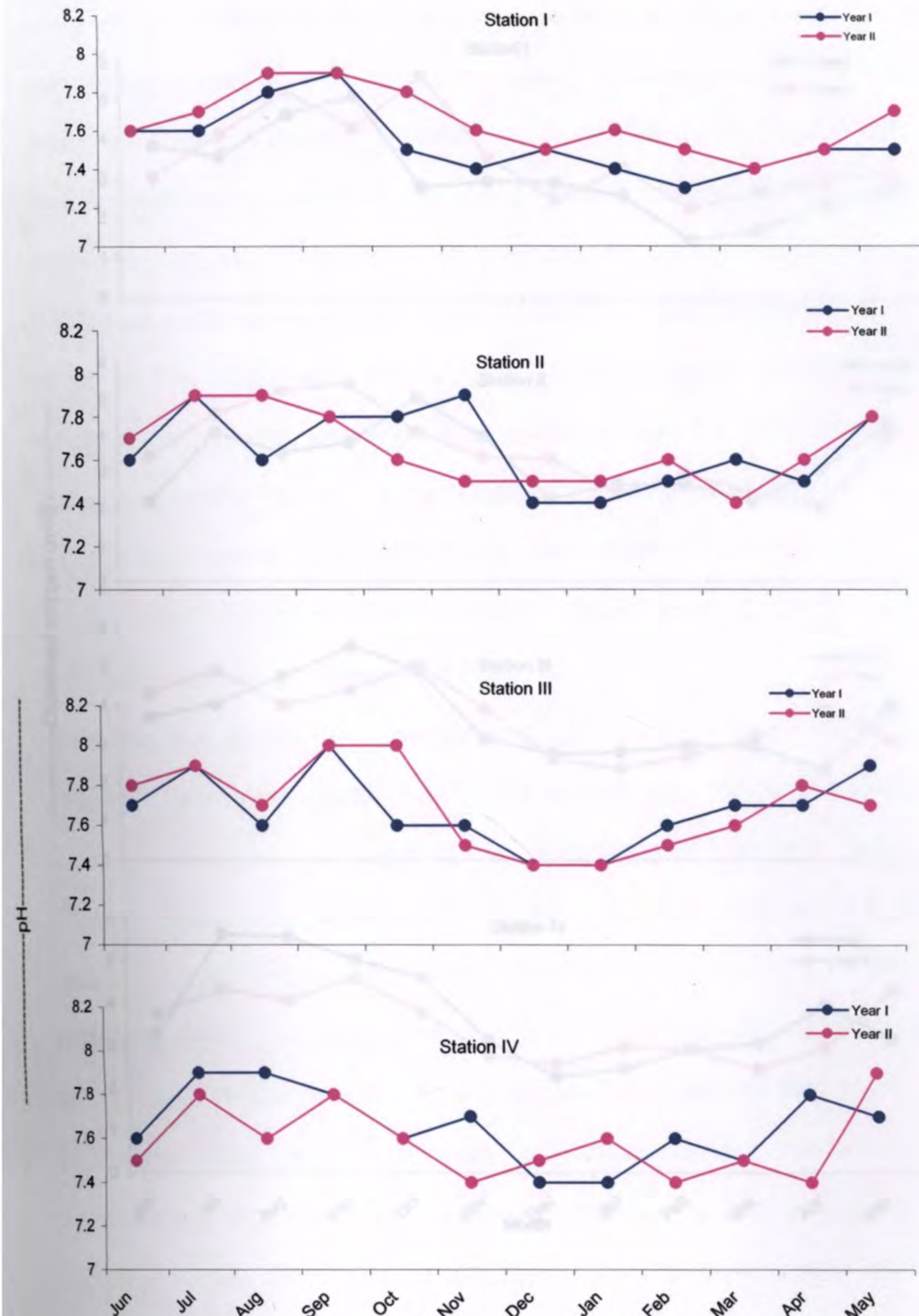

Fig.3.6. Monthly variations of pH in the Stations I to IV during the study period

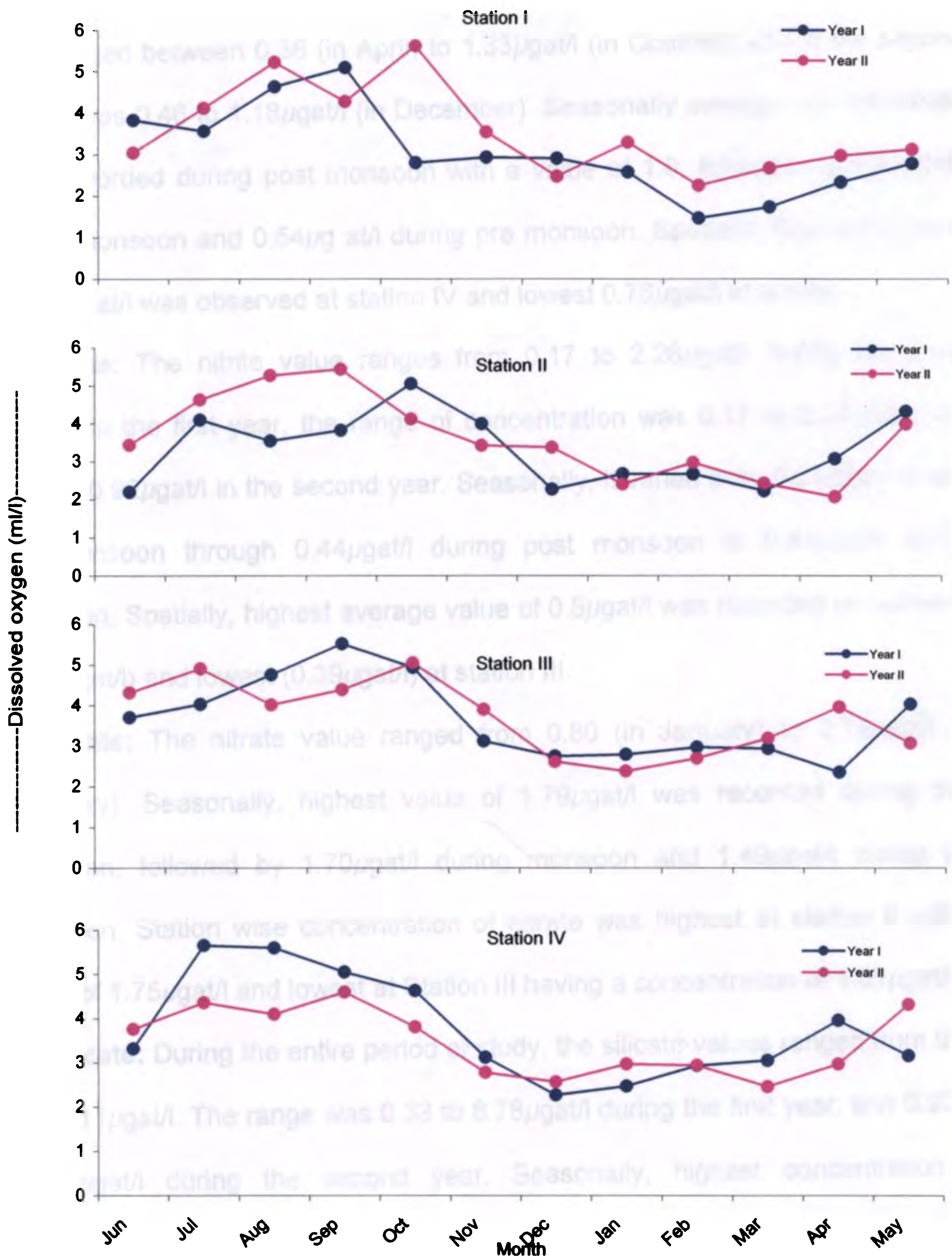

Fig.3.7. Monthly variations of dissolved oxygen (ml/l) in the Stations I to IV during the study period

with a value of 1.58μgat/l. The annual average value of phosphate for the first year ranged between 0.36 (in April) to 1.33μgat/l (in October) and in the second year, it was 0.46 to 1.18μgat/l (in December). Seasonally average highest values were recorded during post monsoon with a value of 1.0, followed by 0.92μgat/l during monsoon and 0.54μg at/l during pre monsoon. Spatially, highest value of 0.867μg at/l was observed at station IV and lowest 0.76μgat/l at station I.

b) Nitrite: The nitrite value ranges from 0.17 to 2.28μgat/l during the study period. In the first year, the range of concentration was 0.17 to 2.28μgat/l and 0.17 to 0.92μgat/l in the second year. Seasonally, it varied from 0.53μgat/l during pre monsoon through 0.44μgat/l during post monsoon to 0.41μgat/l during monsoon. Spatially, highest average value of 0.5μgat/l was recorded at station IV (0.58μgat/l) and lowest (0.39μgat/l) at station III.

c) Nitrate: The nitrate value ranged from 0.80 (in January) to 3.73μgat/l (in February). Seasonally, highest value of 1.79μgat/l was recorded during post monsoon, followed by 1.70μgat/l during monsoon and 1.49μgat/l during pre monsoon. Station wise concentration of nitrate was highest at station II with a value of 1.75μgat/l and lowest at Station III having a concentration of 1.61μgat/l.

d) Silicate: During the entire period of study, the silicate values ranged from 0.33 to 10.11μgat/l. The range was 0.33 to 8.78μgat/l during the first year, and 0.93 to 10.11μgat/l during the second year. Seasonally, highest concentration of 3.42μgat/l was recorded during pre monsoon followed by 3.09μgat/l during post monsoon. Lowest average value of 2.78μgat/l was recorded during monsoon. Spatially, average lowest concentration of 2.867μgat/l was recorded at station III and highest of 3.574μgat/l was at station II.

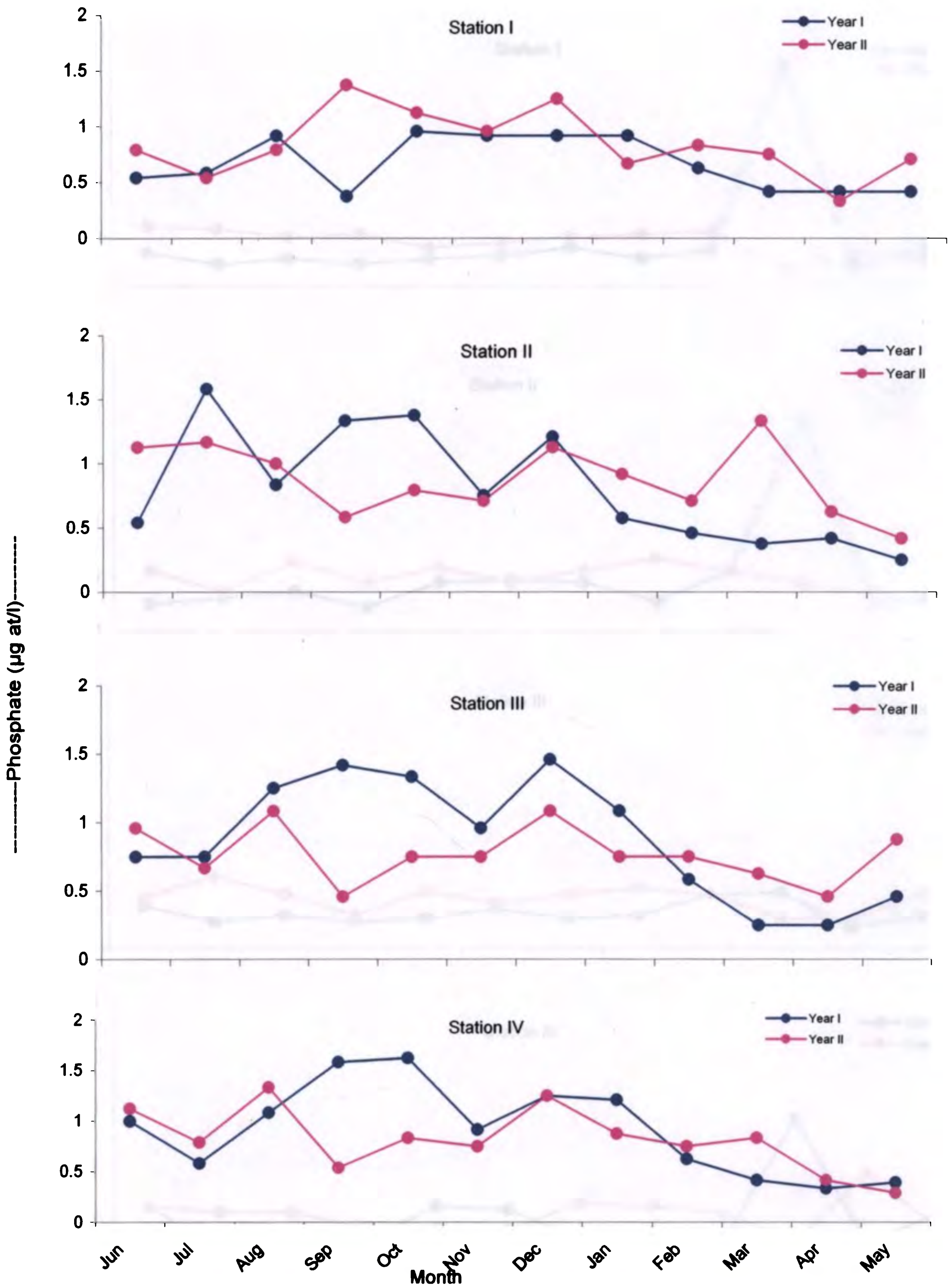

Fig. 3.8. Monthly variations of phosphate (µg at/l) in the Stations I to IV during the study period

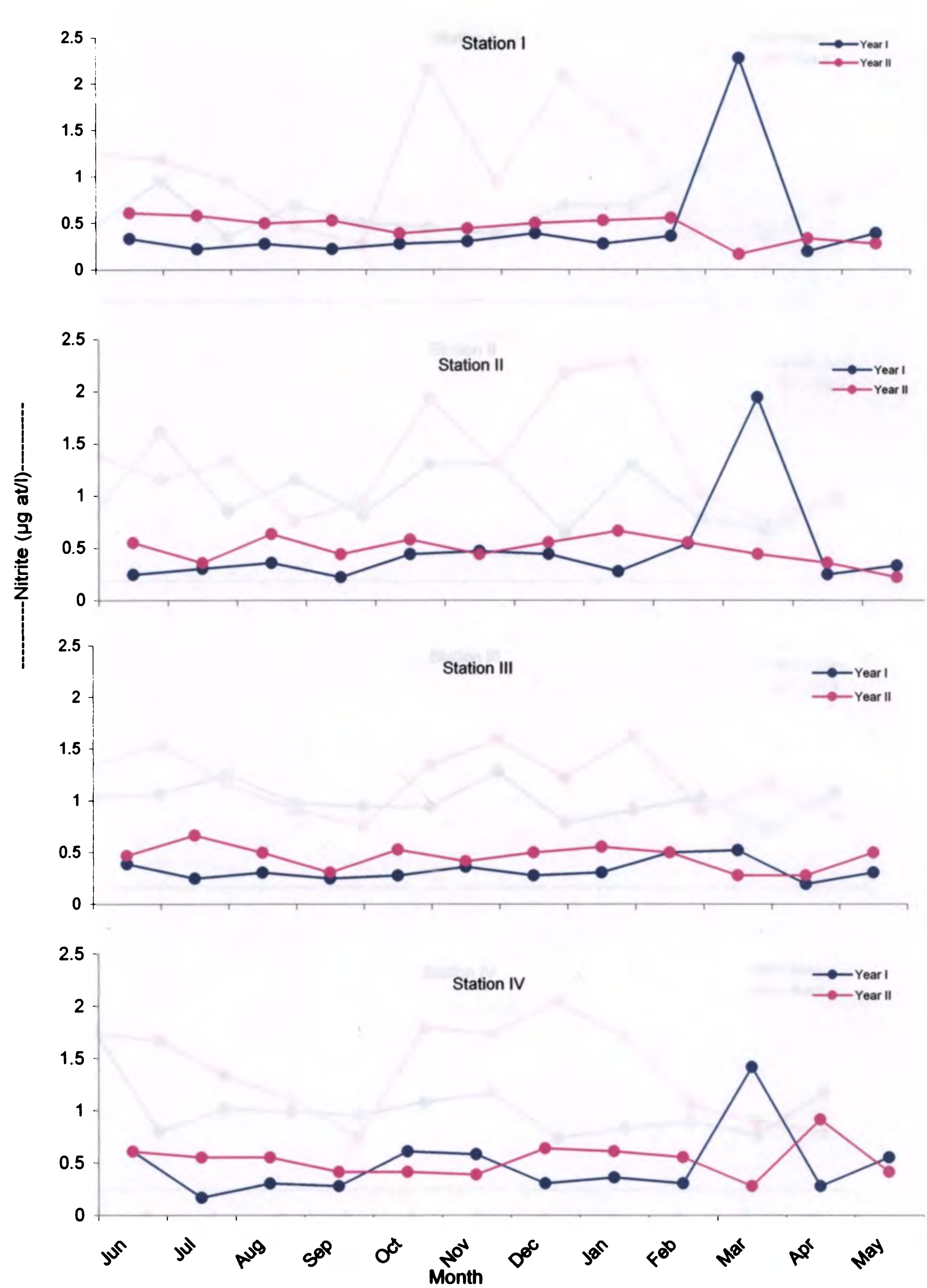

Fig. 3.9. Monthly variations of nitrite (µg at/l) in the Stations I to IV during the study period

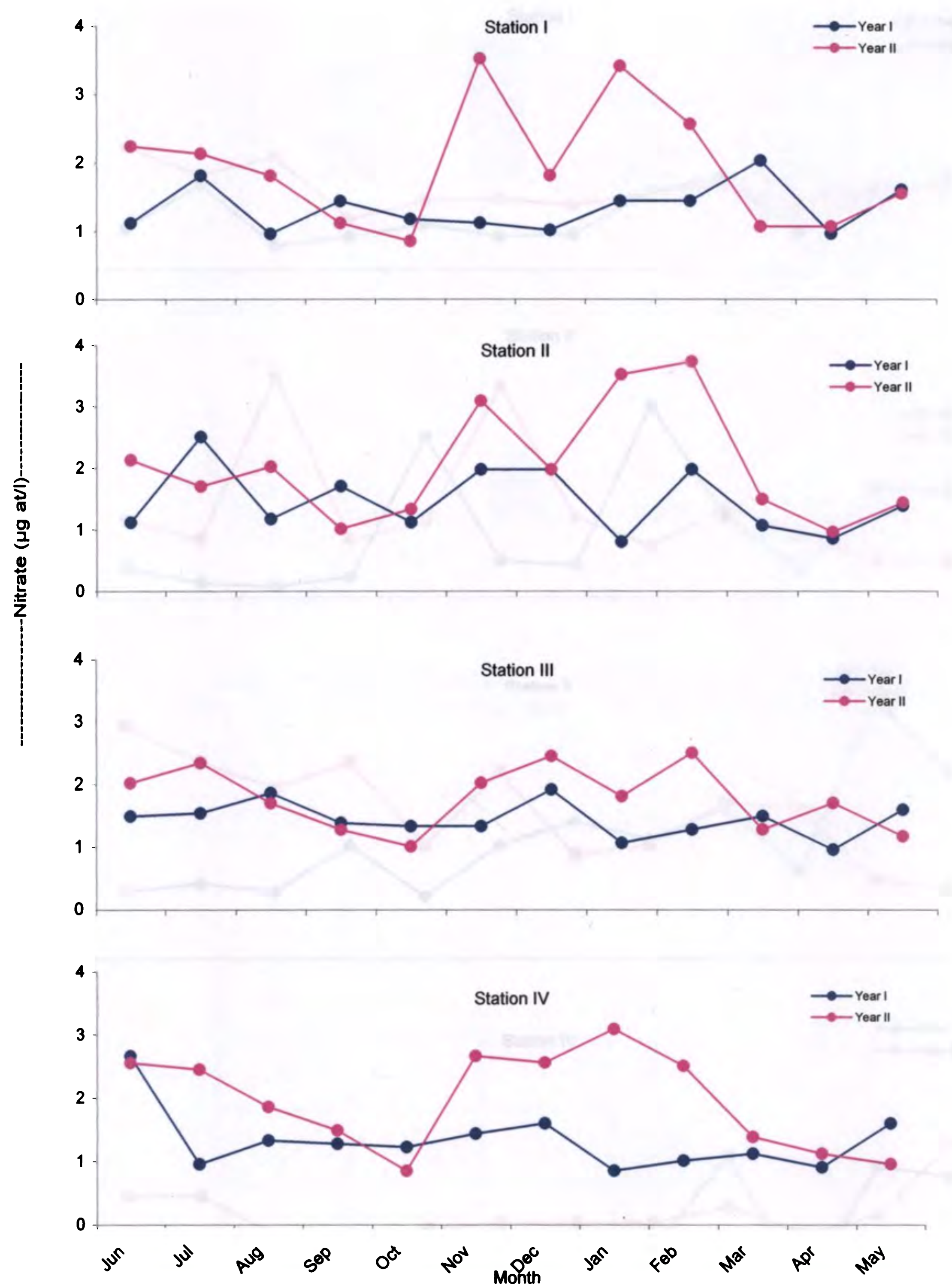

Fig. 3.10. Monthly variations of nitrate (µg at/l) in the Stations I to IV during the study period

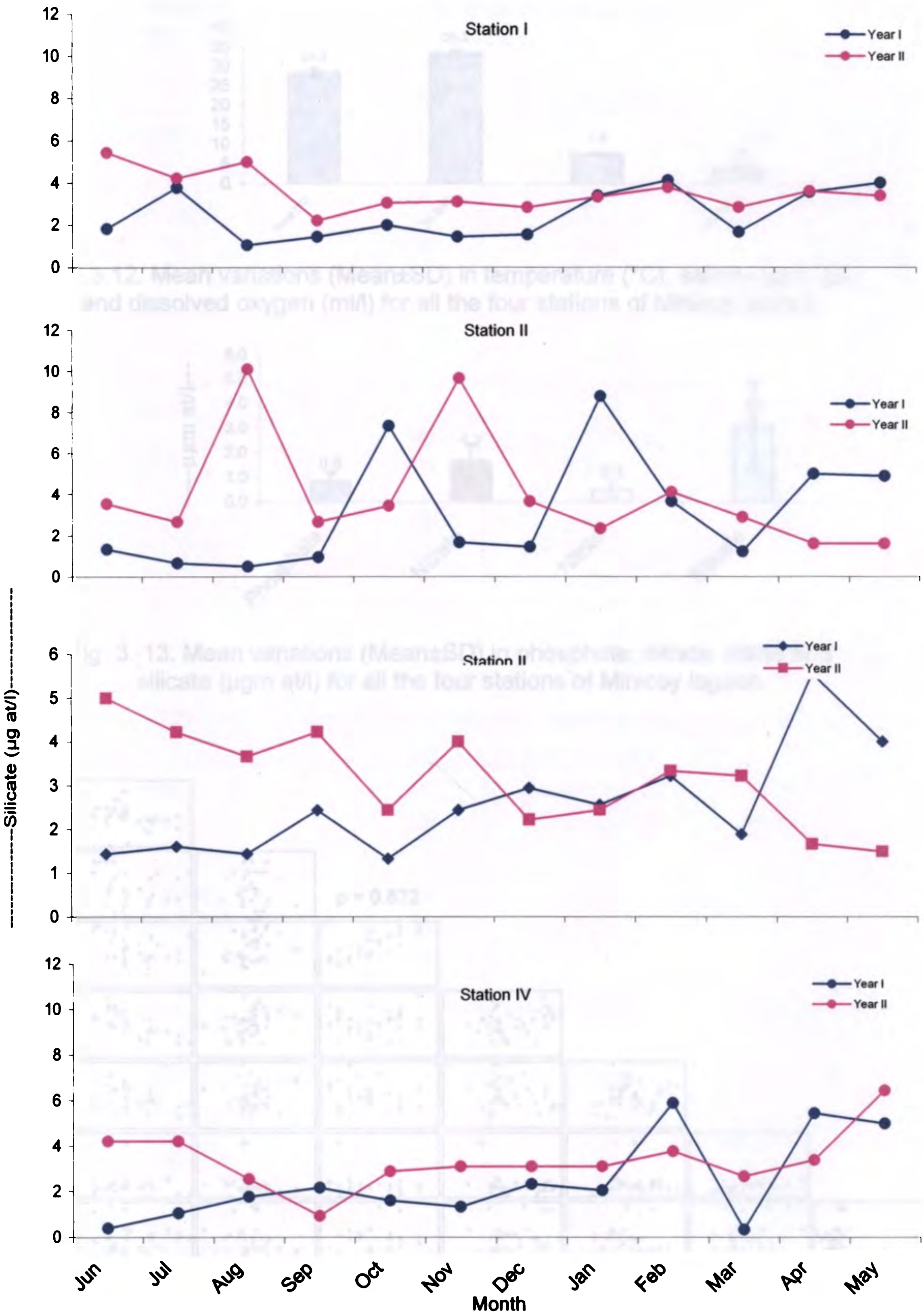

Fig. 3.11. Monthly variations of silicate (µg at/l) in the Stations I to IV during the study period

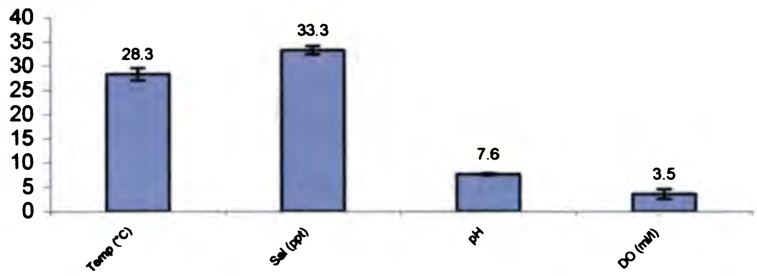

Fig. 3.12. Mean variations (Mean±SD) in temperature (°C), salinity (ppt), pH and dissolved oxygen (ml/l) for all the four stations of Minicoy lagoon

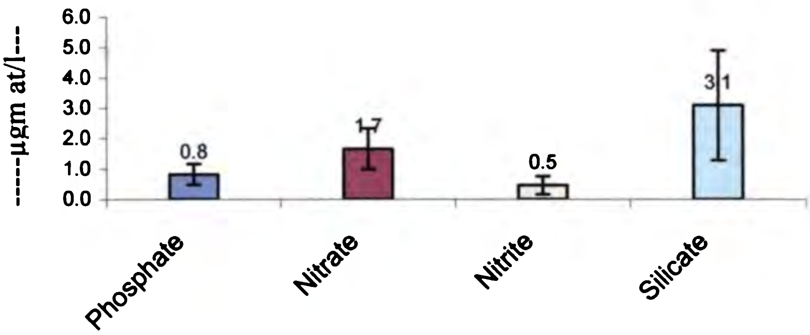

Fig. 3. 13. Mean variations (Mean±SD) in phosphate, nitrate, nitrite and silicate (µgm at/l) for all the four stations of Minicoy lagoon

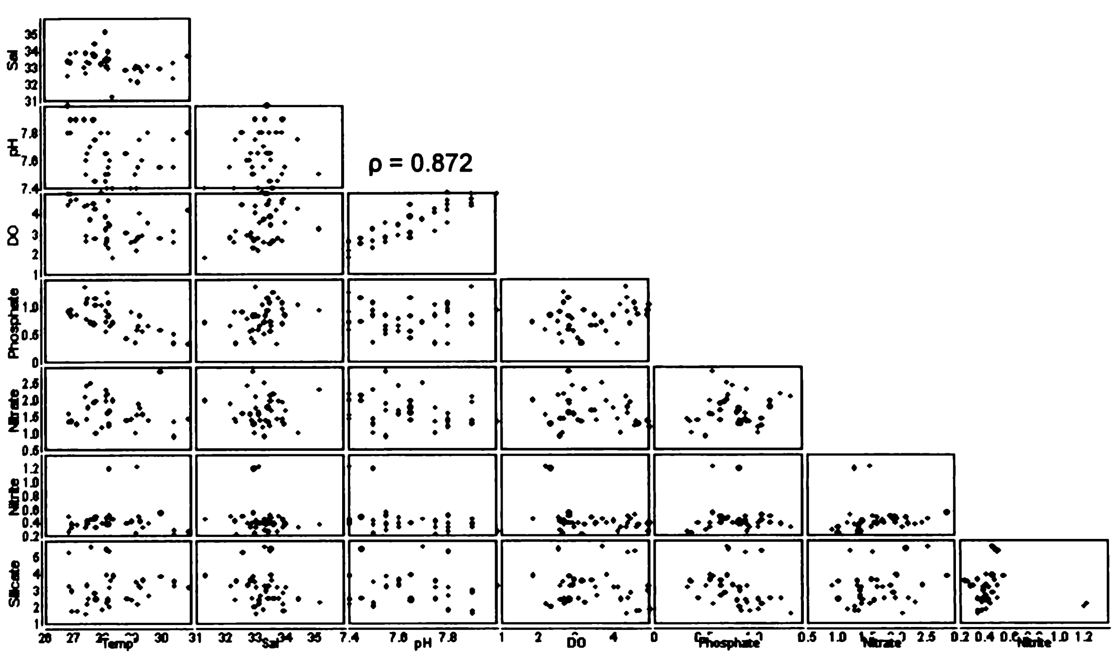

Fig. 3.14. Draftsman plot showing the interactions of hydrographic parameters for all the four stations of Minicoy lagoon

Table 3.3a. ANOVA of temperature in four Stations of Minicoy Lagoon during the study period

Source	df	Mean Square	F
Corrected Model	11	5.272	4.091
SEASON	2	25.114	19.491**
STATION	3	0.824	0.639
SEASON * STATION	6	0.882	0.685
Error	84	1.289	
Total	96		
R^2 = 0.349			

Table 3.3b. ANOVA of salinity in four Stations of Minicoy Lagoon during the study period

Source	df	Mean Square	F
Corrected Model	11	1.315	1.828
SEASON	2	3.829	5.324
STATION	3	0.319	0.444
SEASON * STATION	6	0.974	1.355
Error	84	0.719	
Total	96		
R^2 = 0.193			

Table 3.3c. ANOVA of pH in four Stations of Minicoy Lagoon during the study period

Source	df	Mean Square	F
Corrected Model	11	0.104	3.767
SEASON	2	0.453	16.348
STATION	3	0.0282	1.016
SEASON * STATION	6	0.0263	0.948
Error	84	0.0277	
Total	96		
R^2 = 0.330			

Table 3.3d. ANOVA of dissolved oxygen in four Stations of Minicoy Lagoon during the study period

Source	df	Mean Square	F
Corrected Model	11	3.4 65	5.119
SEASON	2	16.492	24.363
STATION	3	0.692	1.022
SEASON * STATION	6	0.509	0.752
Error	84	0.677	
Total	96		
R^2 = 0.401			

Table 3.3e. ANOVA of phosphate in four Stations of Minicoy Lagoon during the study period

Source	df	Mean Square	F
Corrected Model	11	0.395	4.903
SEASON	2	1.906	23.677
STATION	3	0.0539	0.67
SEASON * STATION	6	0.0614	0.762
Error	84	0.0805	
Total	96		
R^2 = 0.391			

Table 3.3f. ANOVA of silicate in four Stations of Minicoy Lagoon during the study period

Source	df	Mean Square	F
Corrected Model	11	4.317	1.349
SEASON	2	3.274	1.023
STATION	3	2.567	0.802
SEASON * STATION	6	5.54	1.732
Error	84	3.199	
Total	96		
R^2 = 0.150			

Table 3.3g. ANOVA of nitrite in four Stations of Minicoy Lagoon during the study period

Source	df	Mean Square	F
Corrected Model	11	0.0519	0.548
SEASON	2	0.13	1.375
STATION	3	0.0580	0.613
SEASON * STATION	6	0.0228	0.241
Error	84	0.0947	
Total	96		
R^2 = 0.067			

Table 3.3h. ANOVA of nitrate in four Stations of Minicoy Lagoon during the study period

Source	df	Mean Square	F
Corrected Model	11	0.235	0.485
SEASON	2	0.742	1.535
STATION	3	0.0955	0.198
SEASON * STATION	0	0.135	0.279
Error	84	0.484	
Total	96		
R^2 = 0.060			

Table. 3.4. Correlation between temperature, salinity, pH, DO and nutrients in (i) Station I (ii) Station II (iii) Station iii and (iv) Station IV during the study period

i) Station I

	Temperature	Salinity	pH	DO	PO_4	NO_3	NO_2	SiO_4
Temperature	1							
Salinity	0.163	1						
pH	-0.33	0.108	1					
DO	-0.264	0.269	.916(**)	1				
PO_4	-.517(**)	0.31	0.221	0.198	1			
NO_3	-0.101	-0.15	0.051	-0.12	-0.04	1		
NO_2	0.248	0.12	-0.128	-0.27	-0.15	0.29	1	
SiO_4	0.201	-0.32	0.023	-0.09	-0.18	0.37	-0.1	1

** Correlation is significant at the 1% level

ii) Station II

	Temperature	salinity	PH	DO	PO_4	NO_3	NO_2	SiO_4
Temperature	1							
Salinity	0.175	1						
pH	-0.253	-0.11	1					
DO	-0.248	-0.05	.814(**)	1				
PO_4	-.697(**)	-0.21	0.235	0.206	1			
NO_3	-0.085	-0.24	-0.053	-0.078	0.267	1		
NO_2	0.041	0.085	-0.091	-0.218	-0.184	0.042	1	
SiO_4	0.072	-0.019	0.036	0.286	-0.089	0.092	-0.07	1

** Correlation is significant at 1% level

III) Station III

	Temperature	Salinity	PH	DO	PO_4	NO_3	NO_2	SiO_4
Temperature	1							
Salinity	-0.082	1						
pH	-0.079	0.303	1					
DO	-0.35	0.227	.708(**)	1				
PO_4	-.563(**)	-0.01	-0.295	0.269	1			
NO_3	-0.076	-0.08	-0.287	-0.03	0.185	1		
NO_2	0.22	0.106	-0.08	-0.08	-0.13	.434(*)	1	
SiO_4	0.25	0.08	0.154	-0.08	-0.34	0.111	0.06	1

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

iv) Station IV

	Temp	Sal	pH	DO	PO_4	NO_3	NO_2	SiO_4
Temp	1							
Sal	0.015	1						
pH	0.115	-0.11	1					
DO	-0.016	-0.09	.834(**)	1				
PO_4	-.640(**)	0.063	-0.177	0.081	1			
NO_3	-0.157	-0.15	-0.293	-0.27	0.213	1		
NO_2	-0.072	-0.1	-0.363	-0.28	-0.17	0.166	1	
SiO_4	.511(*)	-0.03	0.063	-0.14	-0.38	-0.01	-0.23	1

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

Table 3.5. Correlation results of Draftsman scatter plot analysis for hydrographic parameters of all the four stations

Variable	Variable	Correlation
Temp	Sal	-0.371
Temp	pH	-0.279
Temp	DO	-0.480
Temp	**Phosphate**	**-0.664**
Temp	Nitrate	-0.118
Temp	Nitrite	-0.015
Temp	Silicate	0.100
Sal	pH	0.198
Sal	DO	0.398
Sal	Phosphate	0.331
Sal	Nitrate	0.019
Sal	Nitrite	-0.103
Sal	Silicate	-0.217
pH	**DO**	**0.872**
pH	Phosphate	0.001
pH	Nitrate	-0.291
pH	Nitrite	-0.352
pH	Silicate	-0.012
DO	Phosphate	0.302
DO	Nitrate	-0.231
DO	Nitrite	-0.339
DO	Silicate	-0.074
Phosphate	Nitrate	0.169
Phosphate	Nitrite	0.023
Phosphate	Silicate	-0.317
Nitrate	Nitrite	0.096
Nitrate	Silicate	0.263
Nitrite	Silicate	-0.087

Temp – Temperature Sal – Salinity DO – Dissolved Oxygen

3.3. Discussion

The southwest and northeast monsoons play a major role in climate and oceanography of the region. The southwest monsoon brings rain and the seas are moderate to rough during this season. The northeast monsoon is marked by calmer conditions. Surface currents and winds, humidity and rainfall, temperature and salinity are strongly affected by monsoons. The runoffs from inland sources are almost nil and hence the waters in the lagoons are very clear and exhibit ideal conditions for coral growth. Precipitation was high during southwest monsoon having an average of 1630mm for the entire study period.

Of all abiotic factors, tides are the primary controlling feature of intertidal zonation and tidal amplitude is critical for the organisms in this region. When the spring tide coincides with hot and dry whether, the severe exposure of intertidal organisms can result in the death. During the sampling such conditions are avoided and all the samplings were done in the tidal range of 0.26 to 0.68m. The tidal level effectively correlates with the distribution of organisms. The effect of wave action and desiccation are related to the tidal actions, which in turn are influenced by the topography. Desiccation is controlled by the exposure to climatic factors, including air temperature and sunlight. In the Minicoy region, the air temperature showed a variation between 25.2 to 31°C. So the area experiences a tropical condition that determines the hydrographic properties, the type, distribution and abundance of different organisms in the region.

The hydrographical studies of the marine environment of the Lakshadweep islands have been studied during different oceanographic surveys (James, 1989; Koya, 2000; Vargis, 2005). But the hydrographical studies related to the seagrass ecosystem were meager. The distribution and growth of seagrasses were regulated by a variety of factors such as temperature, salinity, nutrient availability, substratum characteristics, *etc.* (Dennison and Kirkman 1996; Abal and Dennison, 1996; Dawes, 1998). It is well known from overseas and temperate studies that the availability of nutrient resources affects the growth, distribution, morphology and seasonal cycling of seagrass communities (Short *et al.*, 1995). In addition seagrasses depend on an adequate degree of water clarity to sustain productivity in their submerged environment (Short and Wyllie-Echeverria, 1996).

Each species propagate best within a certain temperature range. Since, the seawater temperature influences the chemical processes, respiration and metabolism of the organisms; it is of prime importance to distribution. Temperature is however, largely controlled by weather and the thermal structure of the water column which is influenced by the subsurface currents. It is one of the fundamental factors, which controls the distribution of organisms. Plants are essentially poikilothermic as they do not regulate their temperature and must adapt to their environments. So the tolerance of temperature of these organisms should be considered at physiological and organismal levels. In the first year it was 4.6°C and in the second year, 4.9°C. Inter seasonal observations showed a narrow range of temperature variation of 1.67°C. Temperature patterns of the lagoon indicated that they were more or less homogeneous. Girijavallabhan *et al.*, (1989) studied the hydrobiology of the lagoon and made a comparative of all the lagoons during January-March. In their study, they observed a maximum temperature of 35°C during 1600 hrs. and minimum of 30°C at 0600hrs and found out that the temperature was always above 30°C throughout day and night. Koya (2000) and Vargis (2005) also noted a similar trend in thermal structure. This lack of marked seasonality may indicate that the sustained precipitation, during monsoon has no significant effect on the hydrography of Minicoy Lagoon.

Tidal mixing is one of the factors, which influences the hydrography of the lagoon. Firstly, the nature of the shelf induces tidal mixing and wind stirring in areas away from the shore. Secondly, the shoreward speed of the cold waters may be such that they cannot penetrate well into the lagoon. Thirdly, the low frequency currents in the lagoon tend to mix the waters horizontally. Virtually there is no information on the currents and circulation patterns of the lagoons of Lakshadweep.

The tropical seaweeds and seagrasses are usually tolerant of about 10°C variations and exist in an optimal temperature of 15°C to 30°C in temperate to tropical regions. Structural responses of marine plants to temperature include differences in size, as evidenced by the large morphologies of intertidal seaweeds in cold temperate waters (Dawes, 1998). In Minicoy lagoon, during the study period, inter annual variation showed a minor variation of 0.45°C. Spatially the coefficient of variation (CV) of temperature was low in Station IV (3.91) and high in Station II (5.77). Seasonally, monsoon season showed the lowest CV of 3.53.

Salinity can influence the local distribution of seaweeds and seagrasses. These groups are obligate halophytes, as they require saltwater for germination and growth. Photosynthesis and respiratory rates are also influenced by salinity. Among the hydrographical parameters, salinity showed least variation having CV of 2.06 at Station II, while the high CV value (3.68) was observed at Station I. During the entire period of observation, the salinity values showed a variation of 4.33ppt. Though the variation was small, a general decrease in salinity was observed during pre-monsoon season, especially at station I. This is due to the influence of the flow of low saline water of Bay of Bengal, which joins the northward flowing equatorial Indian Ocean water and flows as a northward surface current along the west coast of India (Pankajakshan and Ramaraju, 1987). The lower salinity during pre-monsoon at Station I, was due to the incursion of this low saline water into the lagoon. Vargis (2005) observed a salinity range of 27 to 35ppt in this region.

At a given temperature, pH is controlled by the dissolved chemical compounds and the biological processes (Chapman, 1977). Ellis (1924) pointed out that fish and common aquatic life prefer pH values between 6.7 and 8.4 and below 5 or above 8.6 are definitely detrimental or even lethal to aquatic life. pH is an important factor in regulating rates of phosphorus release from sediments. In the present study pH varied from 7.3 to 8 during the entire period. The slight alkalinity may be due to the calcium and carbonate deposits particular to the coral reef ecosystems. Temporal variations in pH were insignificant in all the stations. The pH is significantly correlated with the dissolved oxygen ($r = 0.56$). This was clearly indicated by the Draftsman scatter plot.

The two major sources of oxygen in seawater are atmosphere and plants. Levels of oxygen vary throughout marine waters. Polar seas contain about twice the amount of oxygen as tropical waters due to their lower water temperature and salinities (Dawes, 1998). Benthic communities tend to experience lower concentrations of oxygen than surface communities. Oxygen measurements are of particular values in the studies of intertidal communities, which are of the areas of high biological activity. Low dissolved oxygen in the water column of seagrass beds usually occurs in the eutrophication process and algal organic matter accumulates. Since the Minicoy lagoon is a confined area with the tidal influxes, the amount of dissolved oxygen is mainly contributed by the photosynthetic activity of macrophytes, such as seagrasses and seaweeds, present in the lagoon. Dissolved oxygen in low nutrient seagrass beds is usually high because these systems are net autotrophic and they release oxygen into the water column (Kaladharan, 1998). During the present study, very low oxygen concentration of 1.46ml/l was recorded during extremely low tides. 2.33 to 4.35 ml/l of dissolved oxygen concentration was observed by Vargis (2005). The blades of seagrass meadow reduce the currents generated by the winds, tides and waves, which in turn, reduce the oxygen exchange. Seagrass is an optimum source of detritus for food webs because it has a relatively low oxygen demand during decomposition, but relative to other vascular plants, it decays relatively quickly and becomes available to food webs (Twilley *et al.,* 1986). The results showed that post and pre monsoon periods are lower in the dissolved oxygen concentration when compared to the monsoon season, and the coefficient of variation was less during monsoon. This may be due to the high production and influence of increased wind speed of monsoon winds on mixing.

One of the universal processes inherent in all the ecosystems is the recycling of organic matter. This will release the nutrients to the surrounding environment. The dynamics of nutrients are linked to the ecological processes. A nutrient element is defined as one that is functionally involved in the processes of living organisms (Parsons, 1975). The study of nutrients would help in understanding the potential availability of life supporting elements in the aquatic system (Klump and Martens, 1983). Therefore qualitative and quantitative studies are important for understanding the basic processes governing the distribution and biogeochemical cycling of nutrients (Khelifi *et al.*, 2002).

In marine systems nitrogen is considered to be the most limiting nutrient and this is probably the case for coral reefs and seagrasses. The majority of coral reefs are found in the regions, where the concentrations of nutrients are low. The anomaly of the existence of highly productive reef ecosystem in a nutrient poor ocean has long been a topic in the literature. Hatcher and Hatcher (1981) found that the reef is not dependent on the surrounding oceans for the input of organic nitrogen, rather it generates and retains available nitrogen in a manner which is dependent on its structure, season and which is influenced by its benthic floral communities. According to Johannes *et al.*, (1983) nutrient uptake pattern by benthic macro algae is related to the dissolved nutrient concentrations. The inorganic nutrients, such as phosphorus and nitrogen are essential to the primary producers of all ecosystems. Nitrogenous nutrients in waters surrounding coral reef communities are usually extremely low in concentration as other elements, such as phosphorus (Gopinath, 2002). Each of these systems utilizes dissolved nutrients as water passes through the system. Seagrasses tolerate a higher level of eutrophication than coral reefs, while reefs are basically oligotrophic systems, least tolerant of nutrient enrichment. The cycling of primary nutrients such as nitrogen and phosphorus is one of the major interactions within and between coastal systems. In seagrass ecosystems, the understanding of nutrient cycles is a key to understanding the distribution and abundance of seagrasses and how these systems are developed and maintained (Dawes, 1998). Not all seagrass meadows are alike in function or structure. In most of the cases, the differences in seagrass systems are the result of nutrient cycle processes. Knowledge of these processes is crucial to predicting the response of a seagrass ecosystem to disturbances and hence useful to management strategies. Tropical seagrass ecosystems can occupy a gradient of habitats that range, in terms of their nutrient status, from oligotrophic condition to eutrophic habitats (Mc Roy, 1973). In Minicoy Lagoon, the interaction of seagrasses with coral reefs can greatly affect the nutrient status of the system. A particular seagrass system falls on this nutrient gradient depends on the processes that occur within the seagrass system as well as those between adjacent systems.

Phosphorus appeared to be the limiting factor in many coastal ecosystems (Harrison, *et al.*, 1990; Pardo, *et al.*, 1998). The global cycle of P is unique among the cycles of the major biogeochemical elements in having no significant gaseous component. Unlike the global cycle of nitrogen, the major source of reactive phosphorus in the global P cycle is mostly provided by microbial reactions. The surface sediment release or trap phosphate, which depends on its concentration in the overlying waters (Nair, 1990; Kleeberg, 2002). The range of phosphate concentration in the surface waters was 0 to 0.003μg at/l and 0 to 0.9µg at/l in the deeper waters. Inorganic phosphorus less than 0.4μg at/l is common in reef areas and at times so low that it approached the limit of detection (D'Elia and Weibe, 1990). In surface waters phosphate is usually low because of the uptake by primary producers. The regeneration of benthic phosphate affects the water column concentrations, which is related to the seasonal changes. The discussion demonstrates that the concentration of phosphate is to a very large extent determined by the biological activities. As a result, the uptake of oxygen is well correlated to the phosphorus and nitrogen concentrations, since; nutrients are released during aerobic respiration of organic matter, results in the regeneration of phosphorus. The range of phosphorus observed at Minicoy lagoon compares well with the values reported from other areas of the Indian Ocean (Johannes, *et al.*, 1983b; Rayner and Drew, 1984 and Wafar, *et al.*, 1985). Phosphate concentration at different locations seems to show an increasing trend from pre monsoon to post monsoon months. Increase or decrease of phosphorus in the water in relation to depth and also the time of the day has been reported

(Atkinson, 1981). But major changes in nutrient levels were not observed during the present study.

Nitrogen is transformed and transported in a complex pattern in marine environments. Mechanisms that transport nitrogen in and out of the system include biological and physical pathways. The biological cycling of nitrogen is of a complex nature because of varieties of chemical forms, in which the nitrogen is available for biological utilization. The factors, which influence the availability of various forms of nitrogen for biotic uptake is most important which in turn depends upon the concentration of the particular species of nitrogen. Due to the importance of nitrogen as a growth-limiting element in the sea, it's cycling and variability has been documented (Carpenter and Capone, 1983; Sathyanarayana *et al.*, 1992 and Koya, 2000). All the forms of nitrogen such as nitrite, nitrate, etc. have significant role in the marine environment. Nitrite and nitrate accounts for about 63% of the soluble combined nitrogen (Ryther and Dustan, 1971). Nitrite is formed as an intermediate in the oxidation of ammonia to nitrate or in the reduction of nitrate. It is usually present in lower concentrations in the sea than the other forms of combined inorganic nitrogen. Nitrite (NO_2) in the oceanic waters ranges from 0.01 to 3μg at/l. and that in the neritic waters; it was 0.1 to 50μg at/l (Dawes, 1998). A concentration range of 0.17 to 2.5μg at/l was recorded by Vargis (2005). In this study, NO_3-N concentrations were comparitively higher that of NO_2 -N. The relatively low levels of nitrite could be explained by the fact that ammonia oxidation (to nitrite) and nitrite oxidation (to nitrate) are closely coupled (Webb and Weibe, 1975). In Minicoy lagoon, there exists a decreasing profile towards seaside (Gopinath, 2002). This suggests that the inshore sources of nitrogen are not being transported offshore in measurable quantity or that they are metabolized before transported to offshore.

Nitrate is most abundant and thermodynamically stable form of combined nitrogen in well-oxygenated seawater. Further, nitrate is the final oxidation product of nitrogen compounds in seawater. In seawater, nitrate is considered to be the micro-nutrient controlling primary production in the euphotic surface layers. Nitrate (NO_3) concentration in the oceanic waters ranges from 0.1to 43μg at/l while in the neritic waters it was 1-to 600μg at/l. In Minicoy lagoon Vargis (2005) recorded a range of 0.13 to 3.75μg at/l of nitrate concentration. The concentration of this form in the surface layer is governed by the advective transport of nitrate into surface layer, the microbial oxidation of ammonia and the uptake by the primary producers (Grasshoff *et al.*, 1999). Evidence suggests that in many coastal environments, seasonal trends of denitrification are determined largely by NO_3 availability (Kioike and Sorenson, 1988), which itself tends to be controlled by rates of nitrification. Low organic contents in the coral reef area accounts for the absence of nitrifiers thus leading to low nitrate concentration both in the sediment and the overlying water column. Gopinath (2002) found out a positive correlation of nitrogen with organic carbon (r = 0.995) in Minicoy lagoon.

Silicon is critical to the cell wall formation in diatoms, which contribute major share in the marine productivity. Silicon dynamics of coral reefs and associated ecosystems have received less attention than nitrogen and phosphorus, primarily because, coral reef organisms are calcareous and not siliceous and silicon is not an essential element for most reef flora and fauna. There are wide ranges in the concentration of the element, from 0 to 0.5mg/l to in clear oceanic waters to 8.4 mg/l in neritic waters. The source of silicon in coastal waters consists of clays, where dissolved and undissolved forms exist. The dissolved forms obtained from weathering of clay and rocky substrates. In coastal systems, the silicon is not a limiting factor, and the condition is the same in the Minicoy lagoon. Vargis (2005) recorded the concentration of silicate in the range of 1to 9.5µg at/l. In the present study their variation was 4.14µg at/l with an average value of 3.27µg at/l. Spatially highest value of silicate was recorded in the Station II (3.57µg at/l) and also showed a highest CV value of 78.3.

Even though the coral reef and the associated ecosystems are highly productive, there exist an oligotrophic condition and this fact forms the basis for many heated discussions and investigations (Johannes *et al.,* 1984; Atkinson, 1992; Suzumura *et al.*, 2002), ever since Charles Darwin. In addition, coastal waters of oceanic islands are nutrient poor due to the oligotrophic nature of the terrestrial soils as sediment source. Much of the sediment is derived from coral rubble, which is primarily of calcium carbonate and low in nitrate and phosphate. In Minicoy lagoon the highest nutrients occur in association with major population centers (Mohammed, 1999) such as village areas.

Based on the *3 WAY ANOVA* done on a general linear model, the temperature variation was significant at 1% level between stations. Although significant seasonal variations were observed for most of the parameters studied, these variations were minimal when compared to those in other coastal ecosystems, since this ecosystem is far away from the fresh water influences. The different regions of Minicoy lagoon appear to be homogenous, as apparent from the Figs. 3.12 and 3.13, without any distinct differences between them.

The results of the Pearson's correlation showed that temperature and phosphate were negatively correlated at 1% level in the four stations (r = -0. 517; -0. 697; -0.563 and -0.640; p< 0.01, respectively), while silicate was significantly correlated with temperature only in station IV (r = 0. 511). DO and pH were also showed significant correlations in all the stations, having r-values, 0.916, 0.814, 0.708 and 0.834 ($p < 0.01$). This was strongly supported by the Draftsman scatter plot, in which the pooled data for all the stations showed that the correlation between DO and pH were 0.872. There is no significant correlation between nutrients. The nutrient concentration showed distinct seasonal patterns although variations in space were insignificant.

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Chapter IV

Seagrasses

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4.1. Introduction

Seagrasses are the submerged aquatic angiosperms occurring most shallow soft-bottomed marine coastal regions and lagoons of tropical and temperate regions. They are mainly distributed in southeastern countries, Australian and Caribbean coasts. Areas from where seagrass records are scarce include parts of South America, Africa and Indian subcontinent. The number of species is greater in the tropics than in the temperate zones. They have originated from freshwater and estuarine hydrophytic relatives (Arber, 1920) or from xerophytic salt marsh like plants (den Hartog, 1970). The proposal of a gradual transition of hydrophytic species into saline habitats was the prevailing view until den Hartog (1970) suggested that fossils from cretaceous deposits in Japan (*Archeozostera*) and the Netherlands (*Thalassocharis*) represent primitive seagrasses. According to him, seagrasses evolved from xerophytic plants that tolerated salt, they then would have to become tolerant of a hydrophytic habitat. Seagrasses probably arose in the mid- to late Cretaceous (65 to 40 million years) after angiosperms began to evolve and spread on land, in the earlier portion of this period (120 million years).

Seagrasses belong to the families Hydrocharitaceae and Cymodoceaceae. den Hartog (1970) recorded 49 species and 12 genera in

2 families of the class **Helobiae** (Monocotyldonae). Kuo and Mc Comb (1989) recorded 58 species and 12 genera, which are placed in 4 families, 2 orders (Hydrocharitales and Potamogetonales) and 1 class Liliopsida. They include 3 genera in the family **Hydrocharitaceae,** 5 genera in the family **Cymodoceaceae**, 1 genus in the family Posidoniaceae and 3 genera in Zosteraceae, Ruppiaceae also included in seagrass community. The genera *Enhaulus, Halophila,* and *Thalassia* belong to the family Hydrocharitaceae; *Syringodium, Halodule Cymodocea, Amphibolis* and *Thalassodendron* belong to the family Cymodoceaceae. Family Zosteraceae include *Zostera, Heterozostera* and *Phyllospadix,* and *Posidonia* included in the family Posidoneaceae. Lee Long *et al.,* (2000) described 60 species worldwide within 12 genera, 4 families and 2 orders. According to him, *Halophila* and *Thalassia* belong to the family Hydrocharitaceae and order Hydrocharitales; *Cymodocea, Halodule* and *Syringodium* belong to the family Cymodoceaceae and the order Potamogetonales.

Five characteristics have contributed to making seagrasses the most successful tropical shallow marine community. These characteristics (den Hartog, 1970) are:

i) The ability to live in a saline medium. Seagrasses are actually killed in low salinities.

ii) The ability to function physiologically while fully submerged, unlike mangroves, which rely on air exposure and pneumatophores for gas exchange.

iii) A well developed anchoring system and the ability to slow near bottom currents that aids in the accumulation of sediments.

iv) The ability to reproduce while submerged.

v) The ability to compete with other marine organisms for space and resources.

Seagrasses play a significant role in the processes and resources of near shore coastal ecosystems. Mostly found in bays, lagoons (*Plate.1a*), estuaries and coastal waters from mid intertidal region (*Plate. 1b*) down to a depth of approximately 50m in the areas which receive shelter from the prevailing winds, such as behind the islands, reefs and shoals. The most extensive beds occur on soft substrates like sand and mud. They are monocots, which constitute about 0. 01% of angiosperms (Dawes, 1998). They having adapted to the submerged aquatic environment, show morphological and anatomical features, which obviously form the constraints in their geographic distribution and speciation. They possess a well-developed creeping rhizome and an erect shoot bearing several foliage leaves. They grow densely in shallow waters only. A well-developed seagrass system may develop laterally into bare sediment by means of rhizome system. Thus bare sand may change by succession to a seagrass bed and appear to reproduce more by vegetative method i.e., through the rhizome system. Distribution of seagrass in the deeper areas of the water body is limited by intensity of light, since they depend on light for photosynthesis.

The intertidal zone of Minicoy lagoon supports an abundant growth of seagrasses. They constitute multi-species community and form a good habitat for diverse flora and fauna. A number of environmental parameters are critical to whether seagrass will grow and persist. These include physical

Plate I

Plate 1a. Aerial view of submerged seagrass bed of Minicoy lagoon

Plate 1b. Seagrass meadow of Minicoy lagoon exposed during low tide

parameters that regulate the physiological activity of seagrasses, natural phenomena that limit the photosynthetic activity of the plants and anthropogenic inputs that access to available light for growth. In this study, the species composition, distribution, abundance, biomass variations and community structure were discussed in relation to environmental parameters.

4.2. Results

4.2.1. Species composition

There are 5 species of seagrasses (*Plate.2*) present in Minicoy lagoon, along the intertidal zone of the lagoon. They include *Halophila ovalis, Thalassia hemprichii, Cymodocea serrulata, Halodule uninervis and Syringodium isoetifolium*, which belong to 5 genera, 2 families and two orders. Their systematic position (Lee Long *et al.,* 2000) and major identification characters are as follows and also consolidated as in the table 4.1.

1. ***Halophila ovalis*** *(R. Br.) Hook.*
   Kingdom: Plantae
   Division: Magnoliophyta
   Class: Liliopsida
   Order: Hydrocharitales
   Family: Hydrocharitaceae
   Genus: Halophila
   Species: H. ovalis

Plants show morphological diversity due to habitat variations. Separate male and female plants were present with branched, creeping, slender rhizomes. Roots are single with root hairs at each node of the rhizome. The leaves are paired at each node with long petiole. Flowers are solitary, axillary and covered by spathes. Three broad and elliptic tepals are present. Ovary and fruits are ellipsoid in shape. Seeds are globose and

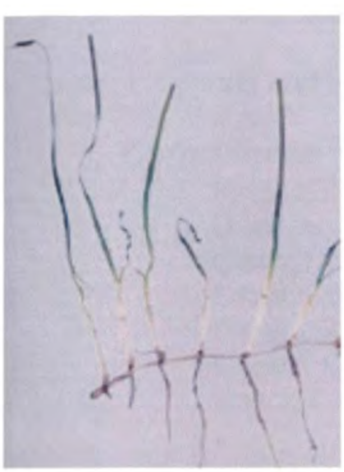
Plate 2

(a) *Thalassia hemprichii*

(b) T. hemprichii with flowers

(c) *Halophila ovalis*

(d) *Syringodium isoetifolium*



(e) *Halodule uninervis*

(f) *Cymodocea serrulata*

Plate 2. Morphology of the seagrass species of Minicoy lagoon

brown in colour. Flowering and fruiting occurs throughout the year. They occur both in marine and backwater areas. Marine forms grow on coarse sands in the sea and on the muddy substratum in tidal and sub tidal zones. This is one of the most common seagrass found in the coastal areas of India

2. *Thalassia hemprichii* (Ehrenb.) Asch.

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Hydrocharitales
Family: Hydrocharitaceae
Genus: *Thalassia*
Species: *T. hemprichii*

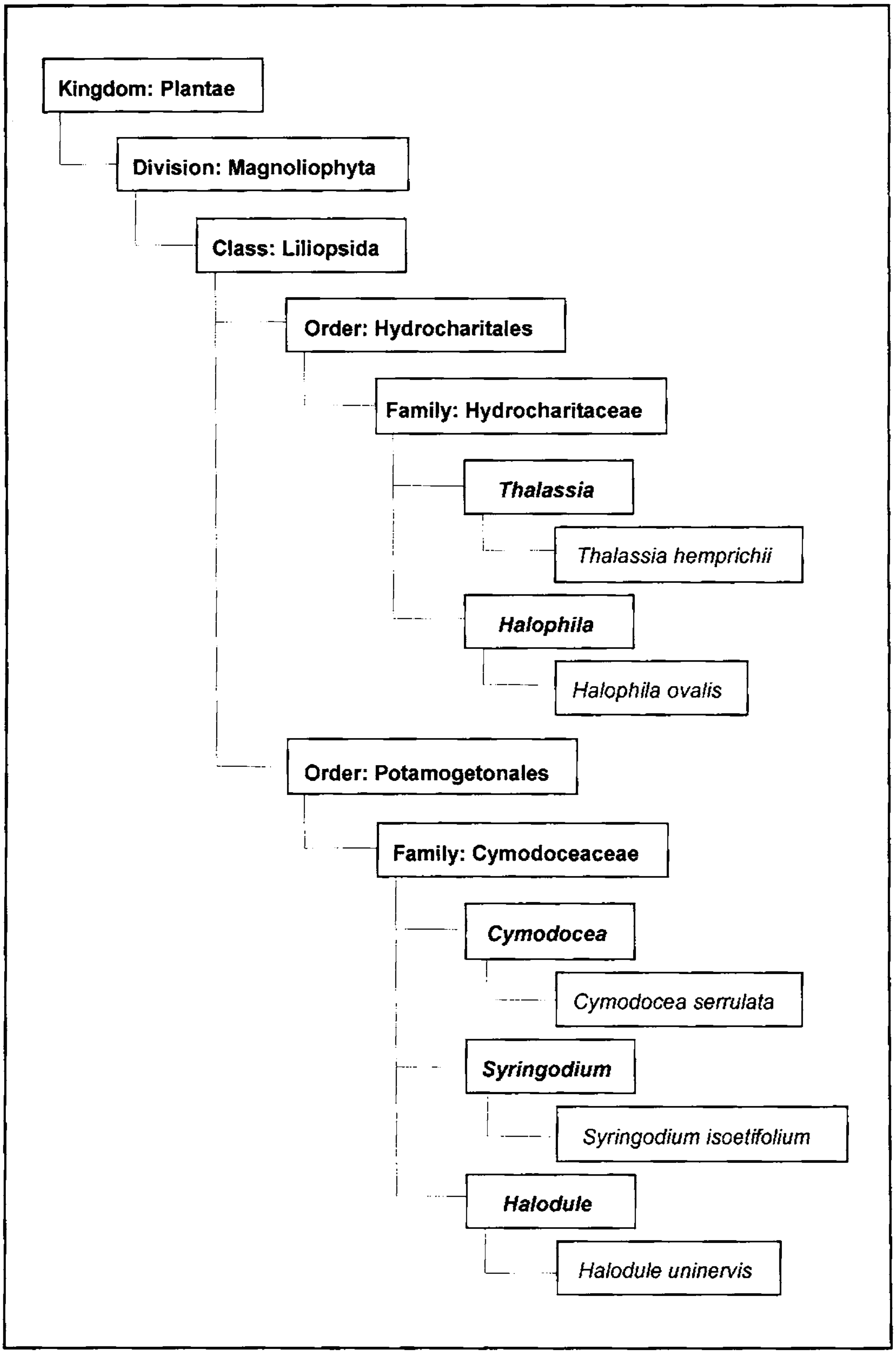
These are perennial plants occur in tidal and sub tidal zones, in black muddy and loose sandy soils. They have thick creeping rhizome with scales and scale scars. Male and female plants are separate. Shoots are erect, with 2-6 leaves, and are covered by old decayed leaves. This is purely a marine form and occurs in tidal and sub tidal zones, in black muddy and loose sandy soils. Common in the coral lagoons of east and west coast of India and it constitute the major share of the seagrass biomass in that ecosystem.

Leaf blades are linear, 3-7 in each shoot and measuring up to 15cm in length. Flowers are single and covered by spathe. Three elliptical tepals are present. Fruits are globose, rough coated and showing three distinct ridges. Flowering and fruiting and flowering occur throughout the year.

3. *Cymodocea serrulata* (R. Br.) Asch. & Magnus

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Potomogetonales
Family: Cymodoceaceae
Genus: *Cymodocea*
Species: *C. serrulata*

Table. 4.1. Systematic position of Seagrass communities of Minicoy lagoon (Lee Long *et al.*, 2000)



Plants grow in shallow water areas up to 1m depth on fine to coarse sand with mud. Both male and female plants are present. They are perennial plants having creeping rhizome with scales and scale scars. Shoots are erect and covered with decayed old leaves. Purely a marine form and grow in shallow water areas up to 1m depth on fine to coarse sand with mud. A common species and usually found in mosaic with *Thalassia*.

In each branch, 2-5 leaves are present and leaf sheaths are broadly triangular. Flowers are solitary, terminal and become lateral in due course, due to the production of successive lateral shoots. There are no organized tepals. Ovary is globose in shape. Flowering and fruiting occurs during March- April and September- October.

4. *Halodule uninervis* (Forsk.) Asch.

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Potomogetonales
Family: Cymodoceaceae
Genus: Halodule
Species: *H. uninervis*

Plants prefer to fine to coarse sand, black mud, rock and coral pebbles. Found to occur in open seas, sheltered localities, backwaters, estuaries and margins of mangrove creeks. It is not an abundant species, but their presence is common in the Indian coastal waters. Male and female plants are separate. Shoots are up to 30 cm long and erect, having 2-4 leaves in each branch. Leaves are linear, narrowed at base with sheath, margin entire and midrib conspicuous. Rhizomes creeping, branched and moniliferous; roots unbranched, 1-6 at each node. Female flowers are sessile and enclosed in leaf sheaths. Ovary is ovoid with terminal styles.

Fruits sub globoid with persistent styles. Flowering and fruiting occurs in June – July.

5. ***Syringodium isoetifolium* (Asch.) Dandy**

Kingdom: Plantae
Division: Magnoliophyta
Class: Liliopsida
Order: Potomogetonales
Family: Cymodoceaceae
Genus: *Syringodium*
Species: *S. isoetifolium*

These are herbaceous plants with creeping rhizomes and grow well on coral flats and sandy to muddy bottoms. Growing usually at a depth of 2-3m. It is purely marine and mainly distributed in the Lakshadweep, Palk Strait, Palk Bay and Gulf of Mannar regions. Shoots erect, branched and bearing 2-3 leaves. Leaves are tubular, narrowed at the base and pointed at the apex. Roots are present at each node and are branched. Flowers are in terminal cymes, growing up to 30cm long. Ovary has one style with bifid stigma. Fruits are ellipsoid with hard pericarp. Flowering and fruiting occurs throughout the year.

4.2.2. Mapping and Distribution

A baseline or control is required to determine seasonal or annual changes in seagrass coverage caused by natural or anthropogenic factors. Seagrass meadow has to be mapped before any statement as to their extent or environmental significance can be made. The seagrass meadow is described as the appearance of strands of seagrasses; having up to 15,000 shoots of the smaller species, with single or several leaves per shoot, may arise from each square metre of sub tidal sand or mudflats (Barnes and Hughes, 1999). Their boundaries must be known for statements about loss or

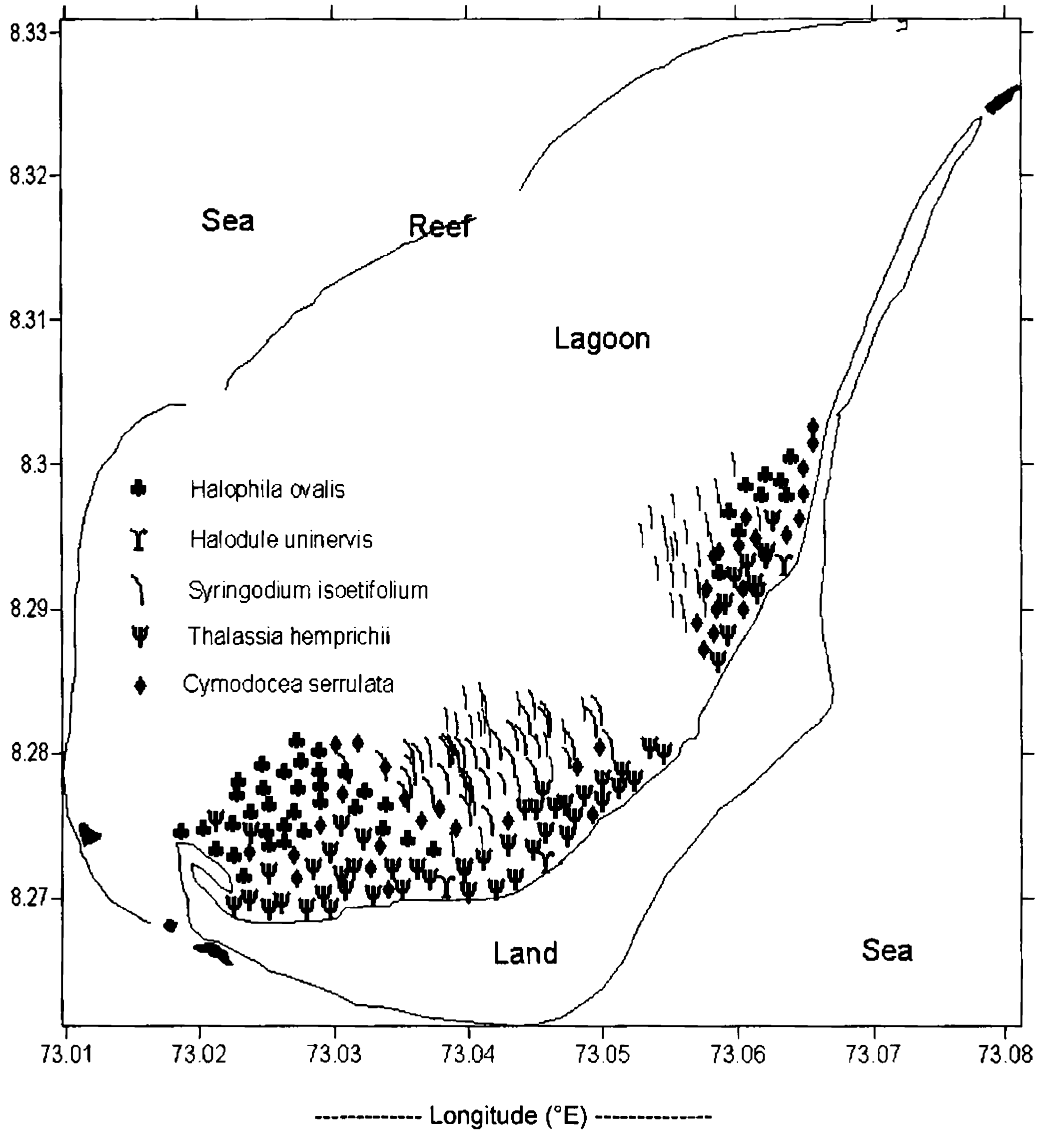


Fig. 4.1. Distribution of seagrasses in Minicoy Lagoon

gain in areas of perturbation. Since, the seagrass meadow in Minicoy Lagoon extends only to few kilometers, transect-line method is used for studying distribution and mapping. First, the seagrass meadow is examined carefully by underwater tows. Transects are fixed at specific intervals. At regular intervals of 100m, a reference point is fixed as permanent markers. Along transects, species composition, abundance and relevant characteristics were noted. Description was included 50m each side of the transect line. The survey carried during low tides. The results were recorded in the form of a profile. Two annual surveys were conducted for detecting any changes in seagrass cover and the results of the surveys were represented (Fig. 4.1) diagrammatically.

4.2.3. Shoot density and Biomass

Seagrass communities make significant contributions to coastal productivity. In addition, the abundance and diversity of animals associated with seagrass communities are strongly related to the species composition, abundance and biomass of the seagrass. In general, the more dense the seagrass, the greater the protection that is offered to a macro-fauna species. The biomass at a given time of a seagrass consists of leaves, rhizomes and roots. In most seagrasses, the roots and rhizomes have a much longer life span, lower growth rate and longer turn over time than do the leaves. Further more, they are devoid of chloroplasts, thus comprising the heterotrophic part of the plant. So for this study only the above ground biomass was estimated.

The seagrass ecosystem of Minicoy lagoon is a mixed meadow, consists of five species, namely, *Thalassia hemprichii, Halophila ovalis, Cymodocea serrulata, Syringodium isoetifolium* and *Halodule uninervis.* The shoot density and biomass were found out independently for each species and the data were pooled together for analysis. This was done because of the mixed nature of the meadow.

The results of the monthly average shoot density and biomass of total seagrass present in square metre were given in the Figs. 4.2 and 4.3. Seasonal and spatial average values were represented in the Figs. 4.4 and

4.5. The correlation between seagrass shoot density and biomass were represented in the Fig. 4.6. ***ANOVA*** were done for finding out the variation in seagrass shoot density and biomass and the results were represented in the table 4.2 and 4.3 respectively. Correlation tables were given in the tables 4.4a to 4.4d. Abundance-Biomass curve (ABC Curve) was plotted for finding out the disturbance level in the ecosystem, based on the monthly (Fig. 4.7) and seasonal (Fig. 4.8) data of seagrass shoot density (abundance) and biomass. ***BEST*** analysis was done to find out the relationship of seagrass shoot density (Fig. 4.9 a&b) and biomass (Fig.4.10 a&b) with environmental variables (Table 4.5 & 4.6). Diversity indices were given in the table 4.7. and plotted in the Fig. 4.11. MDS ordination plot for seagrass shoot density based on monthly and seasonal data were represented in the Figs. 4.12a and 4.12b respectively and that for seagrass biomass, in the Figs. 4.13a and 4.13b. The bubble plot showing the relative abundance of five species of seagrasses based on seasonal data were given in the Fig. 4.14 using the mean values of indices. *SIMPROF test* were conducted for finding out significant similarities of seagrass shoot density based on monthly (Fig. 4.15a and Fig. 4.15b) and biomass (Figs. 4.16a to 4.16b) respectively for both monthly and seasonal patterns. All these analysis were done using ***PRIMER v6.***

Shoot Density

Station I: Highest shoot density of 716 shoots/m^2 was recorded in July and lowest in February, which were contributed by *Halophila ovalis* and *Thalassia hemprichii* respectively. During January and March, no samples

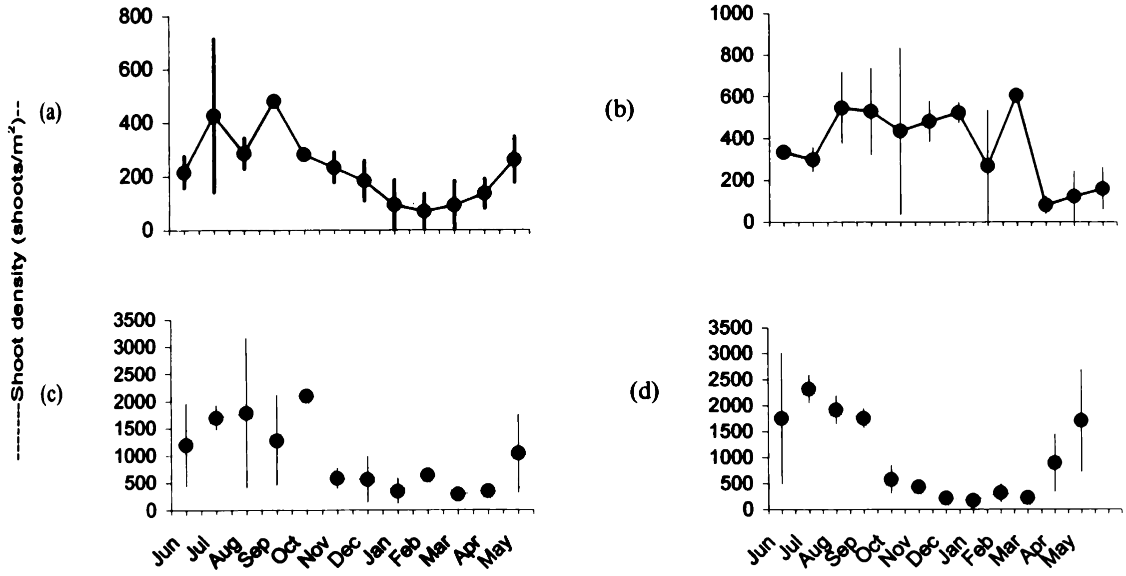


Fig. 4. 2. Monthly variations in seagrass shoot density (shoots/m^2) at (a) Station I (b) Station II (c) Station III and (d) Station IV

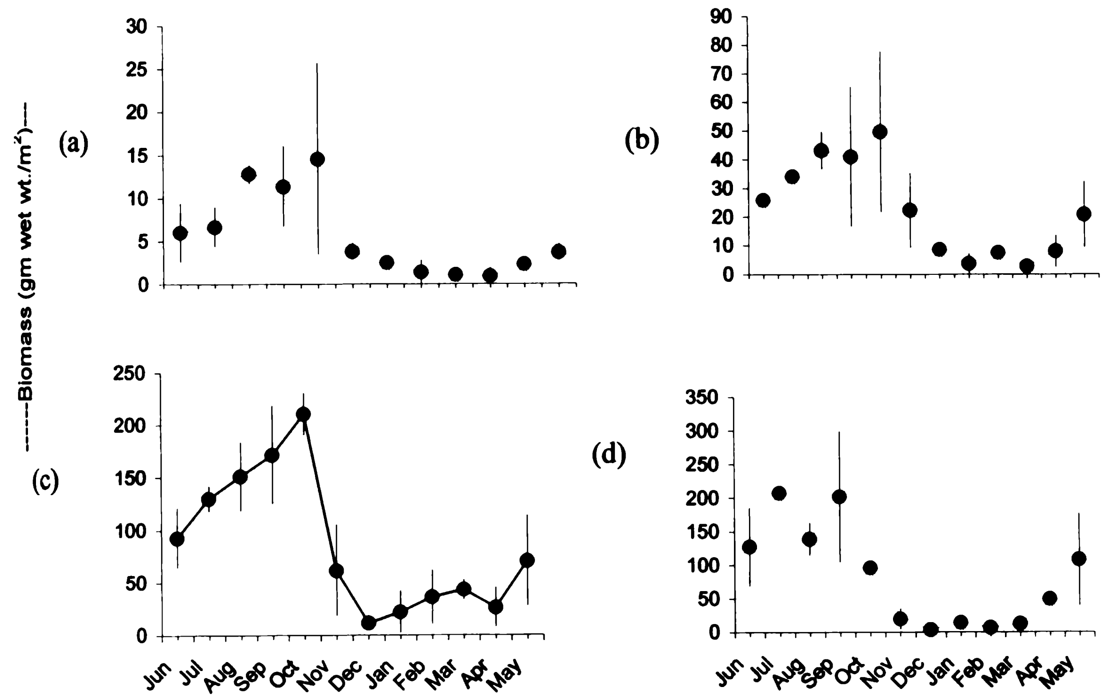


Fig. 4.3. Monthly variations in seagrass biomass (gm dry wt./m^2) at (a) Station I (b) Station II (c) Station III and (d) Station IV

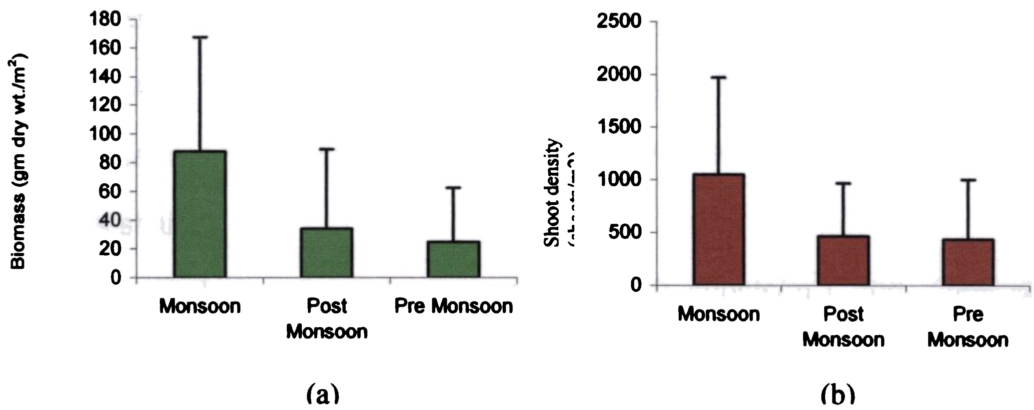


Fig. 4. 4. Seasonal variations in (a) seagrass biomass (gm dry wt./m^2) and (b) seagrass shoot density (shoots/m^2) in Minicoy lagoon

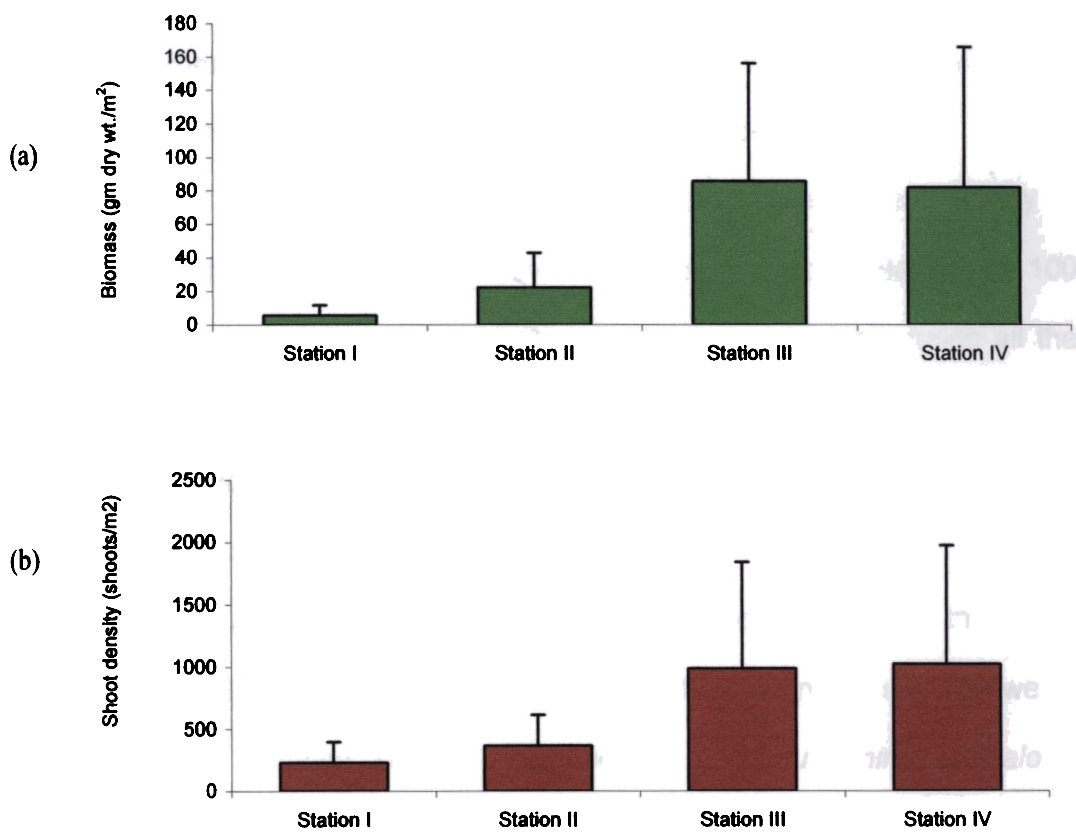


Fig. 4.5. Spatial variations in (a) seagrass biomass (gm dry wt./m^2) and (b) seagrass shoot density (shoots/m^2) in Minicoy lagoon

were obtained. *Halophila ovalis* was the dominant species in this station along with the rare occurrence of *Thalassia hemprichii, Cymodocea serrulata* and *Halodule uninervis. Syringodium isoetifolium* was not present in this station.

Station II: Here, *Cymodocea serrulata* (660 shoots/m^2) and *Thalassia hemprichii* (176 shoots/m^2) together contributed the highest density of 836 shoots/m^2 in October of first year. Lowest density of 32 shoots/m^2 was obtained in October of second year, which was contributed by *Cymodocea serrulata.* Any of the seagrass species were not obtained in January and April. *Thalassia hemprichii* and *Cymodocea serrulata* together constituted the dominant species, followed by *Halodule uninervis. Halophila ovalis* was very rare and only recorded in November, having 580 shoots/m^2.

Station III: *Syringodium isoetifolium* contributed highest shoot density of 3160 shoots/m^2 in August and lowest, in January with a density of 100 shoots/m^2 by *Halodule uninervis.* Seagrasses were obtained during all the months and *Syringodium isoetifolium* formed the dominant species, followed by *Thalassia hemprichii*, *Cymodocea serrulata* and *Halodule uninervis. Halophila ovalis* was totally absent in this station.

Station IV: All the five species of seagrasses were present in this station. Here also *Syringodium isoetifolium* formed the dominant one, followed by *Cymodocea serrulata*, *Thalassia hemprichii* and *Halodule uninervis*. *Halophila ovalis* was recorded only during November and February. Highest density was in June having 3016 shoots/m^2, which was contributed by *Syringodium isoetifolium* and *Cymodocea serrulata*. Lowest density was recorded during January with 48 shoots/m^2 of *Thalassia hemprichii* only.

Spatially highest mean shoot density of 1021.67±949.6 shoots/m^2 was recorded in the station IV and lowest, 230.5±165.7 shoots/m^2 in the Station I. 987.67±850.64 shoots/m^2 and 364.83±248.74 shoots/m^2 in St III and II respectively.

Seasonally highest mean shoot density of 1050.9±921.4 shoots/m^2 was recorded during monsoon and lowest, 435.75±565.56 shoots/m^2 during premonsoon. 466.9±499.85 shoots/m^2 was recorded during post monsoon.

Table 4.2. ANOVA of Seagrass shoot density

Source	df	Mean Square	F	Sig.
Corrected Model	11	748.051	8.211	0
Intercept	1	46631.008	511.864	0
SEASON	2	1326.134	14.557	0
STATION	3	1400.144	15.369	0
SEASON * STATION	6	229.31	2.517	0.027
Error	84	91.1		
Total	95			
R^2 = 0.518				

Table 4.3. ANOVA of Seagrass Biomass

Source	df	Mean Square	F	Sig.
Corrected Model	5	22.757	11.766	0
Intercept	1	444.164	229.641	0
SEASON	2	13.886	7.179	0.002
STATION	1	67.265	34.777	0
SEASON * STATION	2	0.545	0.282	0.756
Error	36	1.934		
Total	41			
R^2 = 0 .620				

Table 4.4a. Correlation between seagrass biomass, seagrass shoot density and hydrographic parameters at Station I

	Seagrass biomass	Seagrass shoot density	Temp	Sal	pH	DO	PO_4	NO_3	NO_2	SiO_4
Seagrass biomass	1									
Seagrass shoot density	.512(*)	1								
Temp	-0.154	-.418(*)	1							
Sal	0.228	0.201	0.163	1						
pH	.775(**)	.490(*)	-0.33	0.108	1					
DO	.874(**)	.534(**)	-0.264	0.269	.916(**)	1				
PO_4	0.156	0.137	-.517(**)	0.31	0.221	0.198	1			
NO_3	-0.318	-0.201	-0.101	-0.15	0.051	-0.12	-0.04	1		
NO_2	-0.226	-0.368	0.248	0.12	-0.128	-0.27	-0.15	0.29	1	
SiO_4	-0.209	-0.268	0.201	-0.32	0.023	-0.09	-0.18	0.37	-0.1	1

* Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Table 4.4b. Correlation between seagrass biomass, seagrass shoot density and hydrographic parameters at Station II

	Seagrass biomass	Seagrass shoot density	Temp	Sal	pH	DO	PO_4	NO_3	NO_2	SiO_4
Seagrass biomass	1									
Seagrass shoot density	.555(**)	1								
Temp	-.487(*)	-.422(*)	1							
Sal	-0.128	0.027	0.175	1						
pH	.757(**)	0.225	-0.253	-0.11	1					
DO	.815(**)	.426(*)	-0.248	-0.05	.814(**)	1				
PO_4	0.236	0.199	-.697(**)	-0.21	0.235	0.208	1			
NO_3	-0.252	0.14	-0.085	-0.24	-0.053	-0.078	0.267	1		
NO_2	-0.186	-0.181	0.041	0.085	-0.091	-0.216	-0.184	0.042	1	
SiO_4	0.182	.529(**)	0.072	-0.02	0.036	0.286	-0.089	0.092	-0.07	1

* Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Table 4.4c. Correlation between seagrass biomass, seagrass shoot density and hydrographic parameters at Station III

	Seagrass biomass	Seagrass shoot density	Temp	Sal	pH	DO	PO_4	NO_3	NO_2	SiO_4
Seagrass biomass	1									
Seagrass shoot density	.742(**)	1								
Temp	-.436(*)	-.414(*)	1							
Sal	0.28	0.112	-0.082	1						
pH	.652(**)	.411(*)	-0.079	0.303	1					
DO	.865(**)	.759(**)	-0.35	0.227	.708(**)	1				
PO_4	0.306	.417(*)	-.563(**)	-0.01	-0.295	0.269	1			
NO_3	-0.287	0.037	-0.076	-0.08	-0.287	-0.03	0.185	1		
NO_2	-0.153	-0.195	0.22	0.106	-0.08	-0.08	-0.13	.434(*)	1	
SiO_4	-0.275	-0.111	0.25	0.08	0.154	-0.08	-0.34	0.111	0.06	1

** Correlation is significant at the 0.01 level

* Correlation is significant at the 0.05 level

Table 4.4d. Correlation between seagrass biomass, seagrass shoot density and hydrographic parameters at Station IV

	Seagrass biomass	Seagrass shoot density	Temp	Sal	pH	DO	PO_4	NO_3	NO_2	SiO_4
Seagrass biomass	1									
Seagrass Shoot density	.853(**)	1								
Temp	-0.064	0.158	1							
Sal	-0.087	-0.089	0.015	1						
pH	.651(**)	.708(**)	0.115	-0.11	1					
DO	.740(**)	.647(**)	-0.016	-0.09	.834(**)	1				
PO_4	-0.077	-0.133	-.640(**)	0.063	-0.177	0.081	1			
NO_3	-0.081	-0.006	-0.157	-0.15	-0.293	-0.27	0.213	1		
NO_2	-0.157	-0.214	-0.072	-0.1	-0.363	-0.28	-0.17	0.166	1	
SiO_4	-0.23	-0.01	.511(*)	-0.03	0.063	-0.14	-0.38	-0.01	-0.23	1

** Correlation is significant at the 0.01 level

* Correlation is significant at the 0.05 level

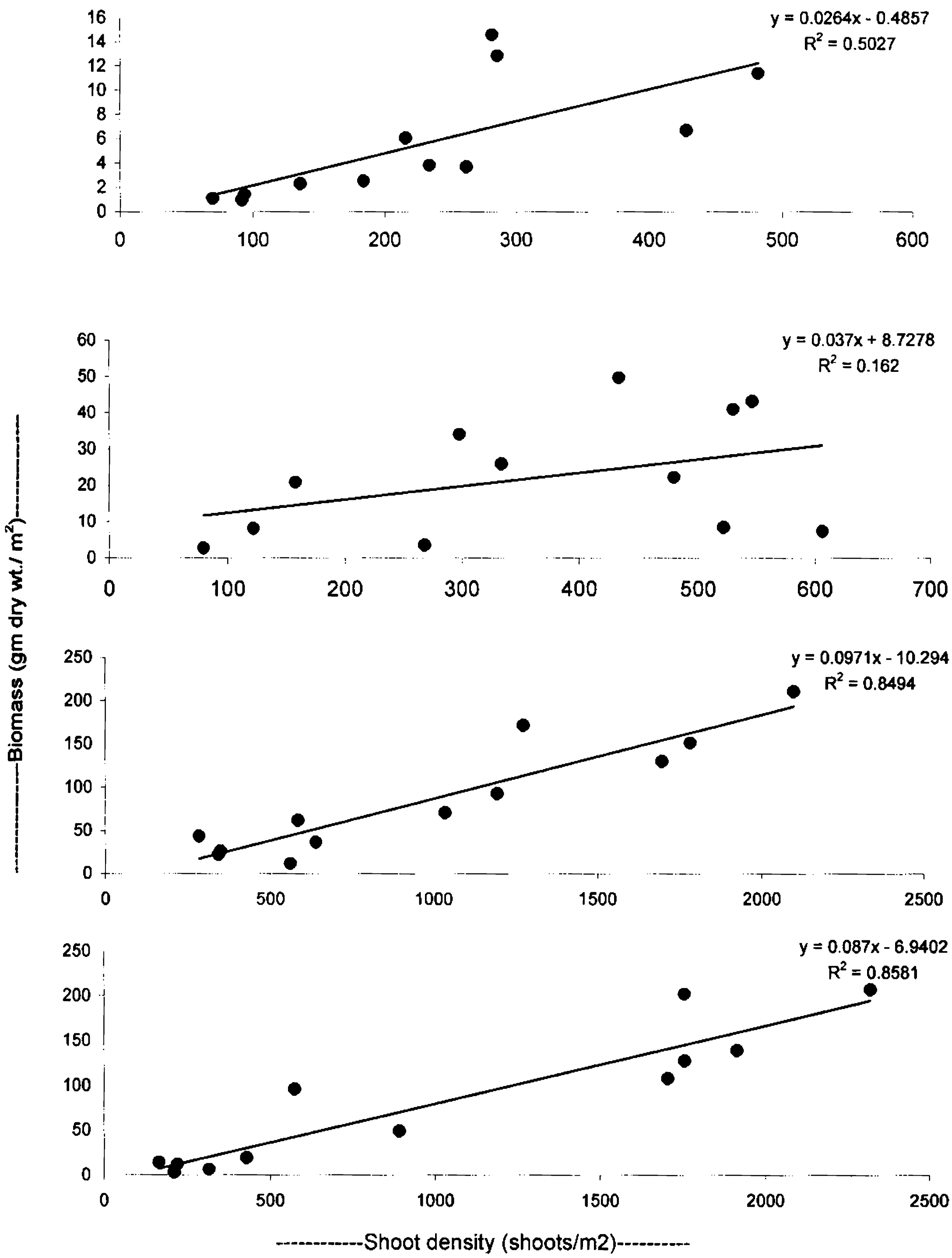


Fig. 4.6. Graph showing the correlation between seagrass shoot density (shoots/m^2) and biomass (gm dry wt./m^2) in (a) station I (b) station II (c) station III and (d) station IV

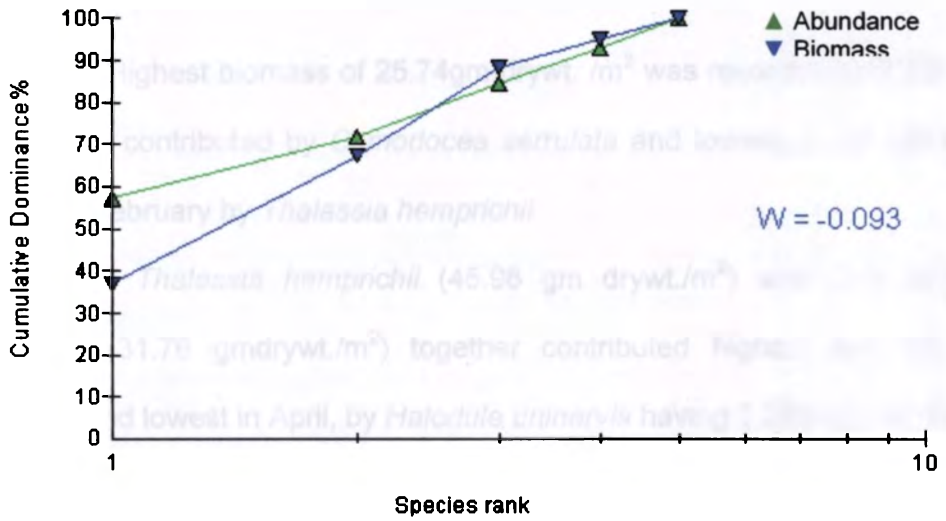


Fig. 4.7. Abundance Biomass Curve (ABC Curve) of seagrass using monthly data

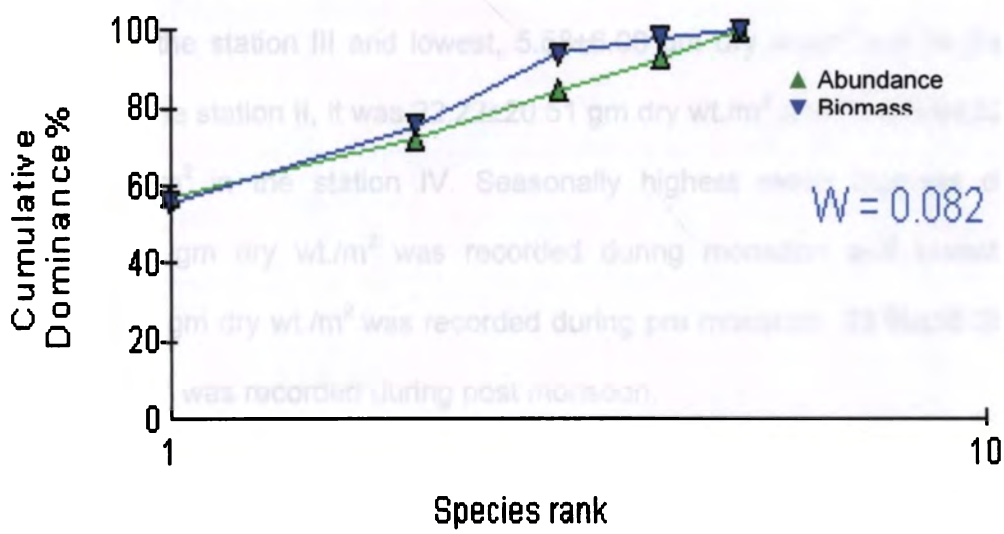


Fig. 4.8. Abundance Biomass Curve (ABC Curve) of using seasonal data

Biomass

Station I: Highest biomass of 25.74gm drywt. /m^2 was recorded in October, which was contributed by *Cymodocea serrulata* and lowest, 0.720 gm dry wt./m^2 in February by *Thalassia hemprichii.*

Station II: *Thalassia hemprichii* (45.98 gm drywt./m^2) and *Cymodocea serrulata* (31.76 gmdrywt./m^2) together contributed highest biomass in October and lowest in April, by *Halodule uninervis* having 2.29gmdrywt. /m^2.

Station III: *Syringodium isoetifolium* contributed highest biomass of 230.69 gm dry wt./m^2 in this station in October and *Halodule uninervis* in January contributed the lowest biomass of 1.80 gm dry wt. /m^2.

Station IV: In this station, highest biomass of 300 gm dry wt./m^2 was recorded in September by *Syringodium isoetifolium* and lowest, 1.33 gm dry wt./m^2 in December by *Halodule uninervis.*

Spatially highest mean biomass of 85.59±70.66 gm dry wt./m^2 was recorded in the station III and lowest, 5.58±6.08 gm dry wt./m^2 was in the station I. In the station II, it was 22.22±20.51 gm dry wt./m^2 and 81.96±84.32 gm dry wt./m^2 in the station IV. Seasonally highest mean biomass of 87.62±79.74 gm dry wt./m^2 was recorded during monsoon and lowest, 24.91±37.61 gm dry wt./m^2 was recorded during pre monsoon. 33.99±55.38 gm dry wt./m^2 was recorded during post monsoon.

BEST analysis:

BEST analysis were done for finding out the relationships between seagrass shoot density (Fig.4.10 & 4.11) and biomass (Fig.4.13 & 4.13), both in monthly and seasonal patterns. The results showed that best correlation coefficient (Rho) for seagrass shoot density for monthly and seasonal patterns were 0.194 (Table 4.5) and 0.32 respectively and that for seagrass biomass (Table 4.6) were 0.237 and 0.333 respectively.

Table 4.5. BEST (Biota and Environment Matching) results for seagrass shoot density

Seagrass shoot density					
		Monthly		Seasonal	
Sl. No.	Variables	Variables selected	BEST correlation values (Rho)	Variables selected	BEST correlation values (Rho)
1	Temperature	**3,4,6,7**	**0.194**	**2,4**	**0.320**
2	Salinity	4,6,7	0.193	2-4	0.319
3	pH	3,4,6	0.191	2,4,7	0.315
4	DO	3-7	0.191	2-4,7	0.315
5	Phosphate	4,6	0.190	2,4,6	0.301
6	Nitrate	4-7	0.189	2-4,6	0.301
7	Nitrite	3-6	0.188	2-4,6,7	0.299
8	Silicate	4-6	0.186	2,4,6,7	0.293

Table 4.6. BEST (Biota and Environment Matching) results for seagrass biomass

Seagrass biomass					
		Monthly		Seasonal	
Sl. No.	Variables	Variables selected	BEST correlation values (Rho)	Variables selected	BEST correlation values (Rho)
1	Temperature	**2-4,7**	**0.237**	**2-4**	**0.333**
2	Salinity	2-4	0.235	2,4	0.331
3	pH	2,4,7	0.235	2-4,7	0.331
4	DO	2-5,7	0.233	2-4,6,7	0.330
5	Phosphate	2,4	0.232	4	0.312
6	Nitrate	2-5	0.230	2,4,6	0.312
7	Nitrite	2,4,5,7	0.230	2-4,6	0.312
8	Silicate	2,4,5	0.227	2,4,6,7	0.309

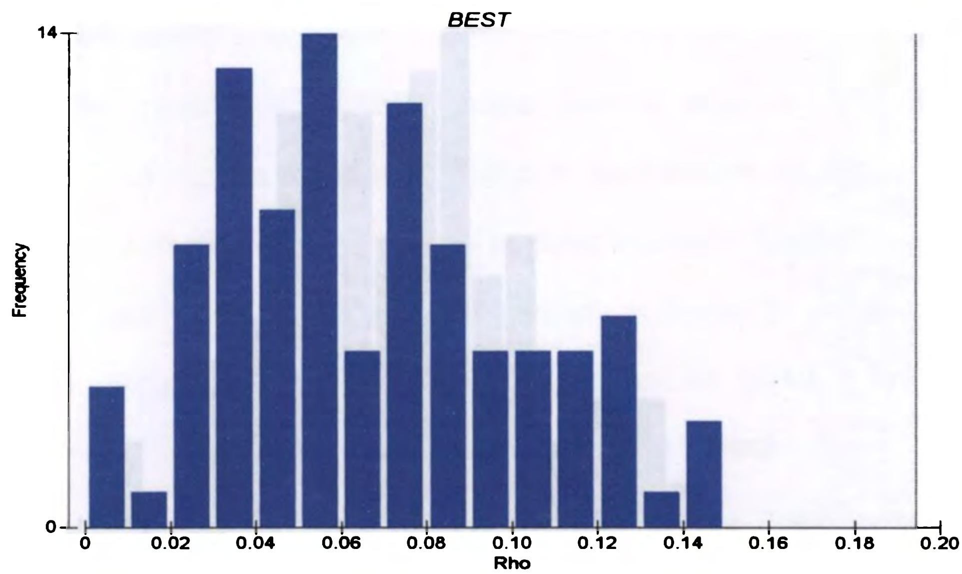


Fig.4.9a. Histogram showing the BEST results of monthly seagrass shoot density distribution (Rho = 0.197)

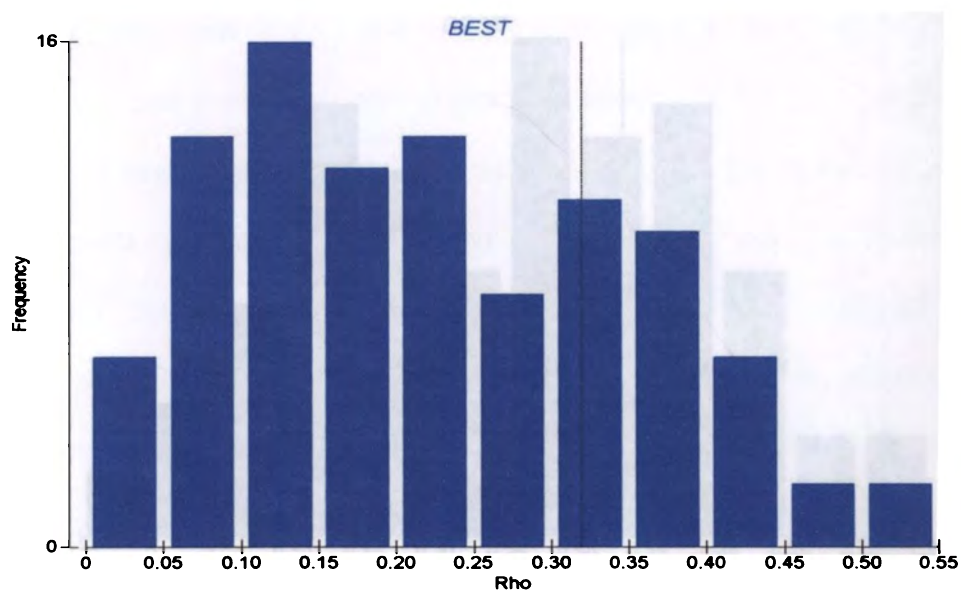


Fig.4.9b. Histogram showing the BEST results of seasonal seagrass shoot density distribution (Rho = 0.32)

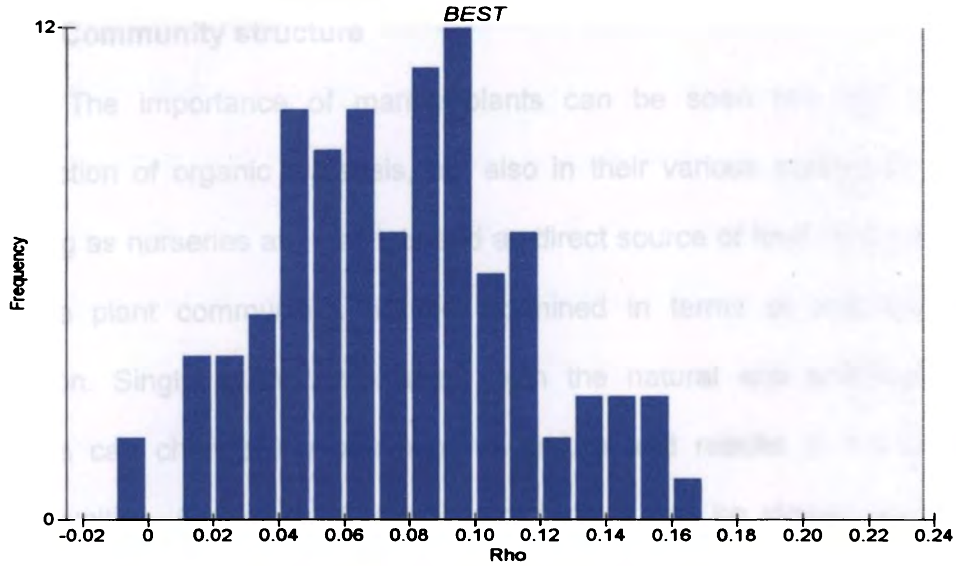


Fig. 4.10a. Histogram showing the BEST results of monthly seagrass biomass distribution (Rho = 0.237)

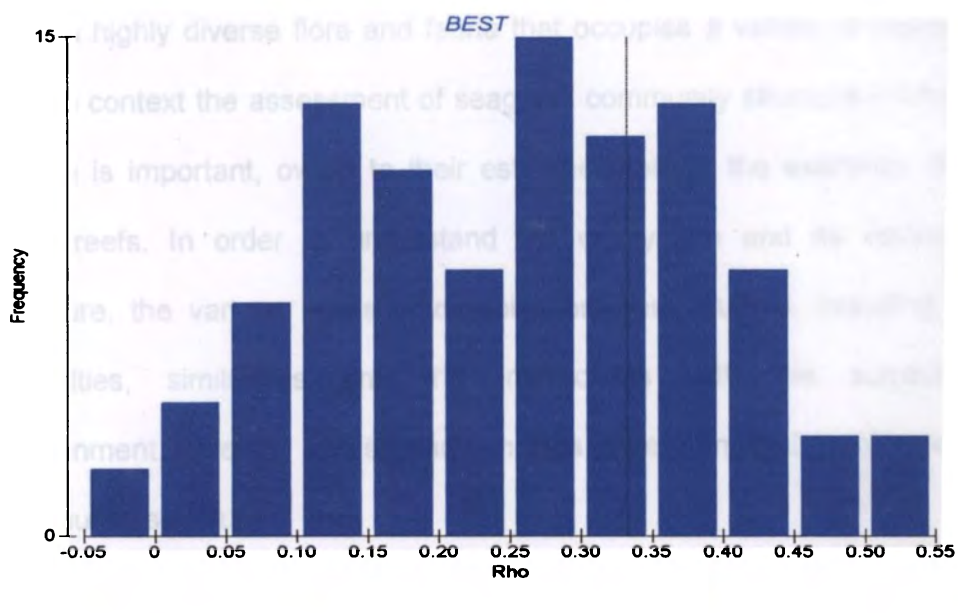


Fig. 4.10b. Histogram showing the BEST results of seasonal seagrass biomass distribution (Rho = 0.333)

4.2.4. Community structure

The importance of marine plants can be seen not only in the production of organic materials, but also in their various ecological roles, serving as nurseries and habitats and as direct source of food. The types of marine plant communities will be examined in terms of structure and function. Singly or in combination, both the natural and anthropogenic factors can change the community structure and results in the shift in communities. A number of marine communities can be viewed as climax communities, including coral reefs, salt marshes, mangroves and seagrass beds. All of these communities show successional stages toward their ultimate development and have a high degree of interaction between physical factors and their biological components. All of these communities have a highly diverse flora and fauna that occupies a variety of niches. In such a context the assessment of seagrass community structure in Minicoy lagoon is important, owing to their esteemed role in the existence of the coral reefs. In order to understand the ecosystem and its community structure, the various levels of organization were studied, including their diversities, similarities and the interactions with the surrounding environment. Diversity and similarity indices were found out to interpret the community structure.

Diversity indices:

It is the relative abundance of different species at each site or time reduced to a single index. For the analysis of diversity indices Shannon-Wiener diversity index is the most widely used diversity measure. Logarithmic base 2 is used here for the analysis as most of the tropical studies are using this pattern for comparison. The data were selected on the seasonal scale. The highest Margalef species richness index, 0.68 was in the station IV during post monsoon and lowest (0.18) during pre monsoon in the station II. Evenness was more (0.98) in the station II during post monsoon and less (0.23) during monsoon in the station IV. Shannon diversity index was highest (2.04) in the station IV during post monsoon and lowest (0.36) during monsoon in the same station.

Table 4.7. Mean diversity indices of seagrasses in the stations I to IV in Minicoy Lagoon

	Richness (d)	Evenness (J')	Diversity (H')	Dominance (D)
Station I	0.12	0.50	0.50	0.78
Station II	0.16	0.49	0.65	0.73
Station III	0.21	0.54	0.54	0.75
Station IV	0.18	0.47	0.69	0.72

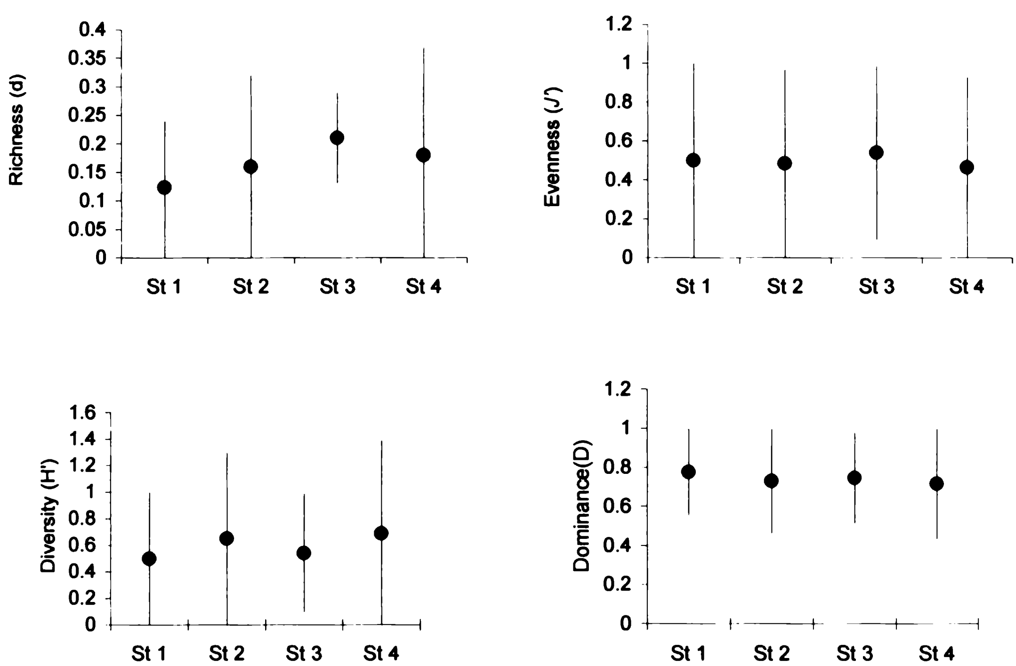


Fig. 4.11. Spatial variations in (i) species richness (*d*) (ii) evenness (*J'*) (iii) diversity (*H'log*$_2$) and (iv) dominance (D)

Species dominance was higher (0.90) in the station IV during monsoon and lower (0.26) during post monsoon in the station II.

Similarity indices:

For finding out the similarities between seasonal and spatial aspects, multi-dimensional scaling (MDS) and *Bray-Curtis* Similarity plots with SIMPROF tests were made for both seagrass shoot density and biomass.

i) Non – metric Multi-Dimensional Scaling Plots:

MDS plot for seagrass shoot density gave a good ordination having the stress value of 0.13 for monthly distribution (Fig.4.12a) and 0.07 (Fig.4.12b) for seasonal distribution and that for biomass; it was 0.15 (Fig. 4.13a) and 0.06 (Fig.4.13b) respectively. Bubble plots were constructed using the abundance data, for showing the relative abundance (Fig. 4.14).

ii) **SIMPROF Test:**

The significance of the clusters created was tested by the Similarity Profile (***SIMPROF***) Test. Based on monthly distribution pattern of seagrass shoot density, five significant clusters were formed (Fig.4.15a) and that on seasonal patterns, no significant groupings (Fig. 4.15b) were formed. The SIMPROF test for seagrass biomass based on monthly distribution patterns showed two significant clusters (Fig.4.16a), while only one was formed (Fig.16b) based on seasonal patterns.

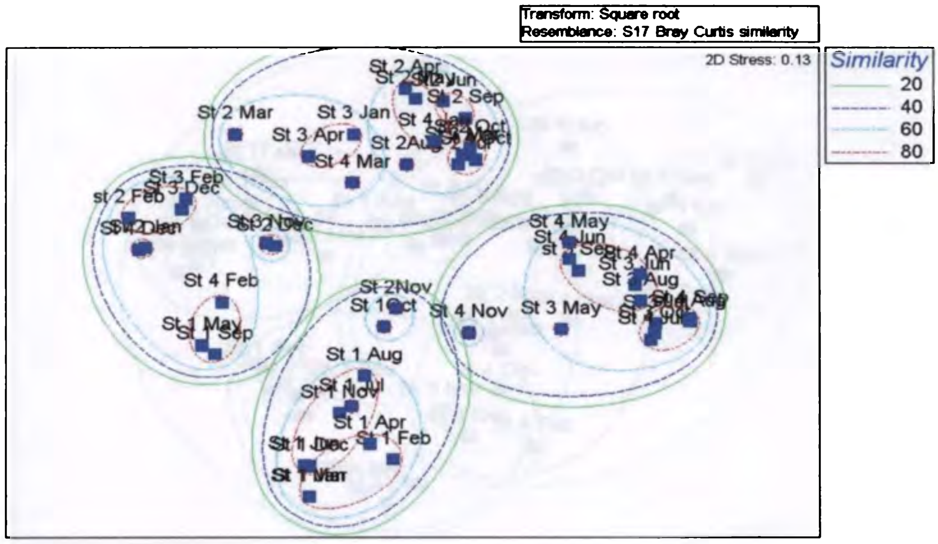


Fig. 4.12a. Non-metric Multi Dimensional Scaling (MDS) ordination plot (stress = 0.13) of samples taken from four stations with monthly distribution patterns of seagrass shoot density (shoots/m^2)

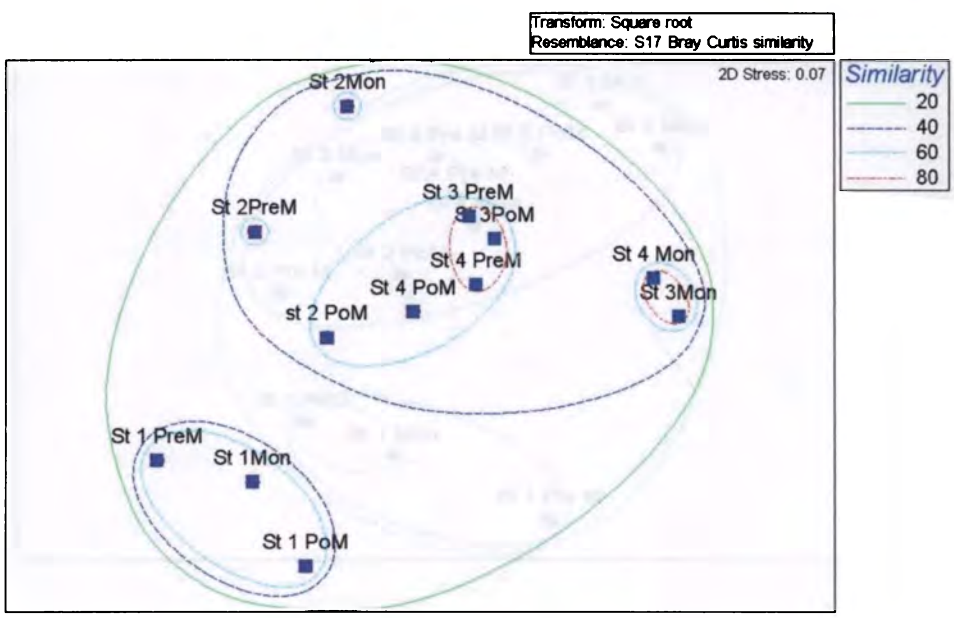


Fig. 4.12b. Non-metric Multi Dimensional Scaling (MDS) ordination plot (stress = 0.07) of samples taken from four stations with seasonal distribution patterns of seagrass shoot density (shoots/m^2)

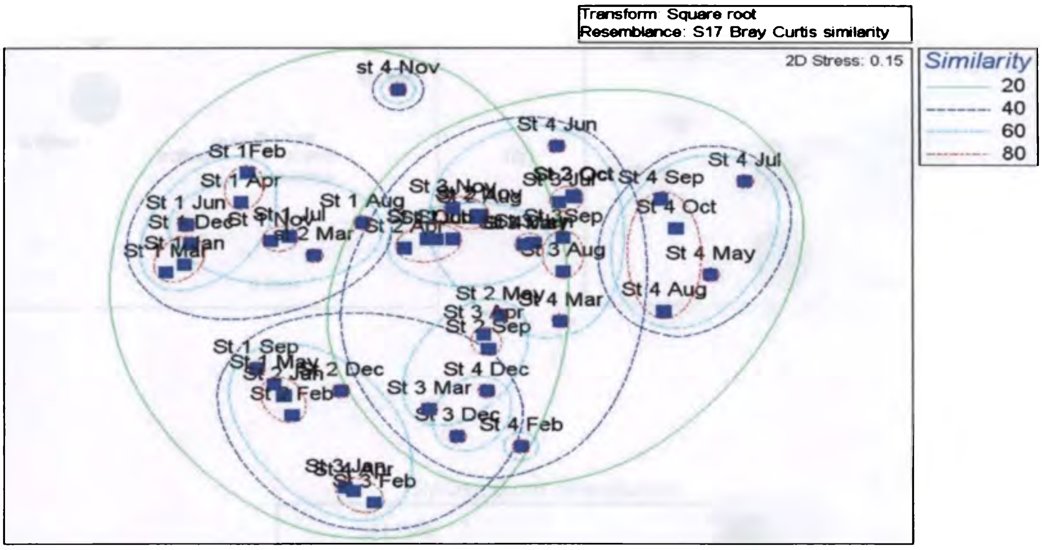


Fig. 4.13a. Non-metric Multi Dimensional Scaling (MDS) ordination plot (stress = 0.15) of samples taken from four stations with monthly distribution patterns of seagrass biomass (gm drywt/m^2)

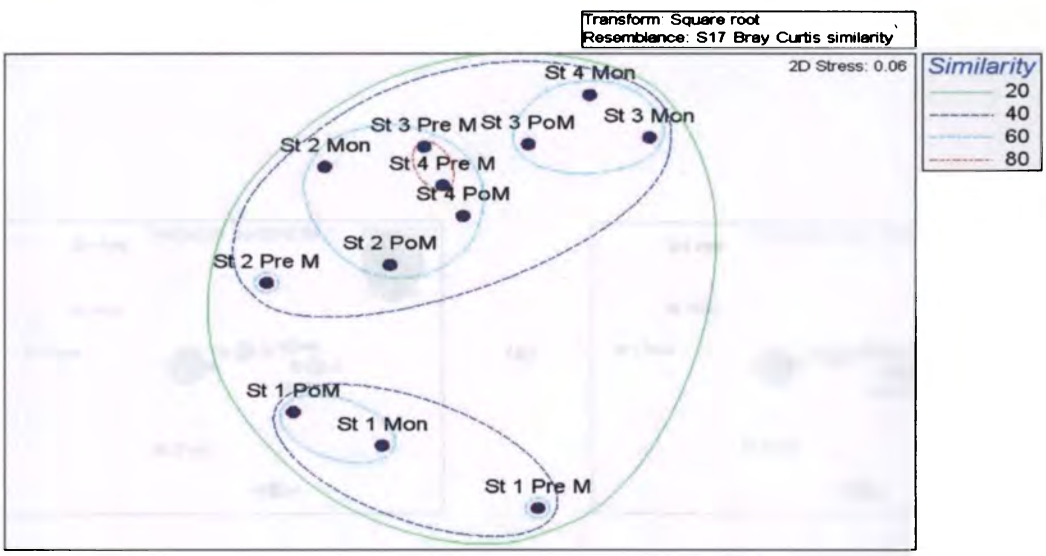


Fig. 4.13b. Non-metric Multi Dimensional Scaling (MDS) ordination plot (stress = 0.06) of samples taken from four stations with seasonal distribution patterns of seagrass biomass (gm drywt/m^2)

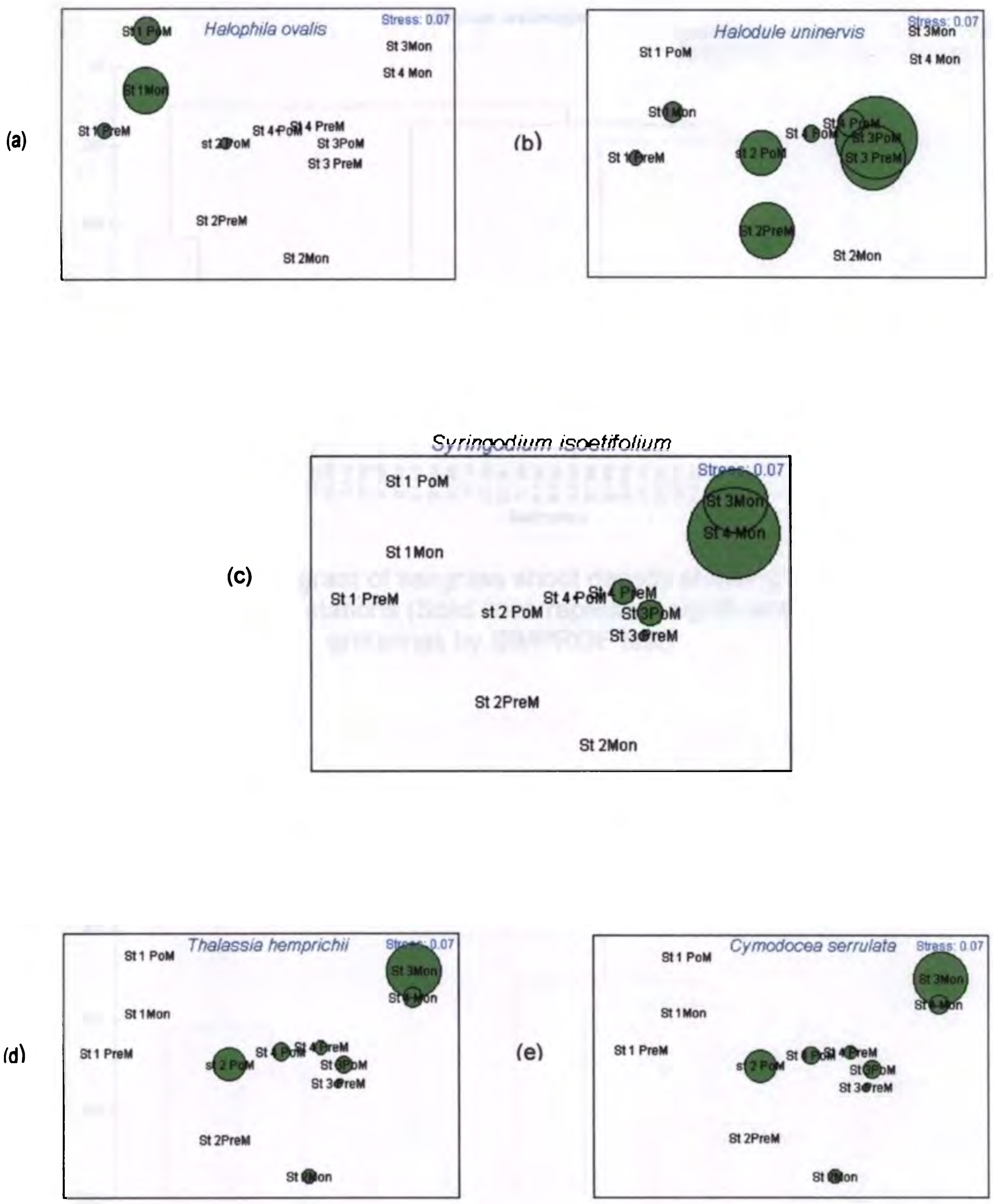


Fig. 4. 14. Bubble plot showing the abundance of (a) *Halophila ovalis* (b) *Halodule uninervis* (c) *Syringodium isoetifolium* (d) *Thalassia hemprichii* and (e) *Cymodocea serrulata*

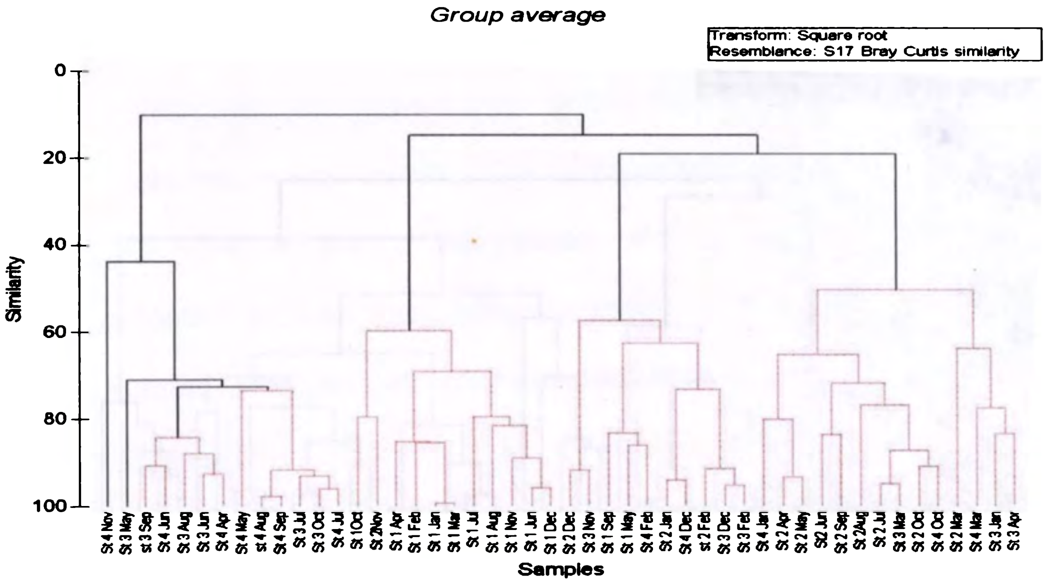


Fig. 4.15a. Dendrogram of seagrass shoot density showing the monthly similarities in the four stations (Solid lines represent significant delineation of groupings by SIMPROF test)

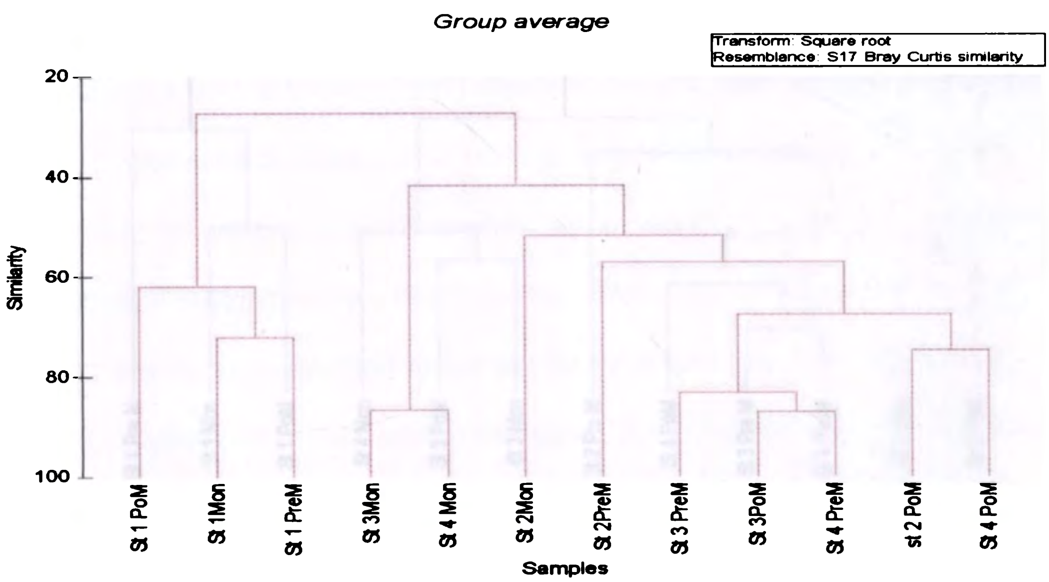


Fig. 4.15b. Dendrogram of seagrass biomass showing the seasonal similarities in the four stations (Solid lines represent significant delineation of groupings by SIMPROF test)

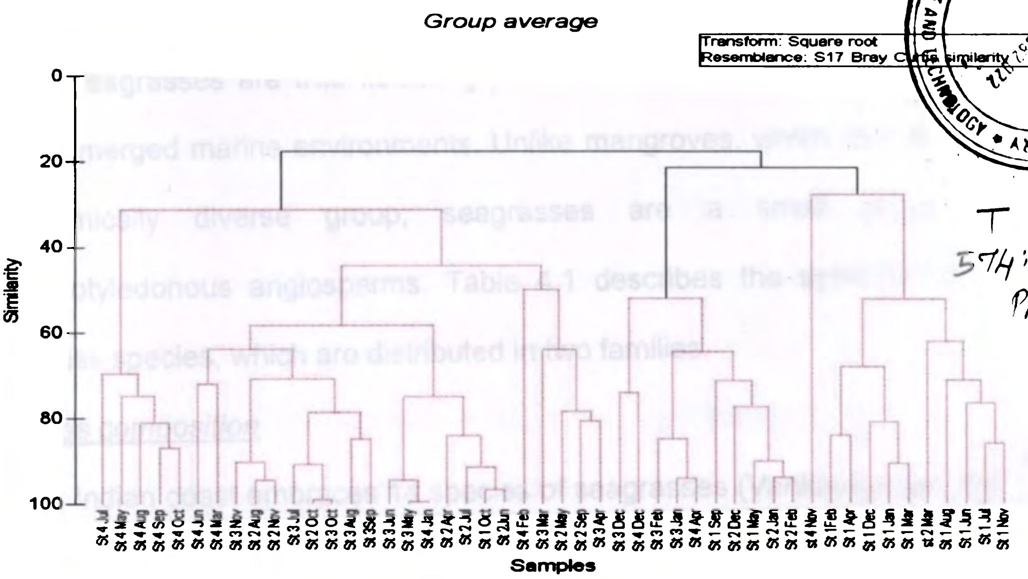


Fig. 4.16a. Dendrogram of seagrass biomass showing the monthly similarities in the four stations (Solid lines represent significant delineation of groupings by SIMPROF test)

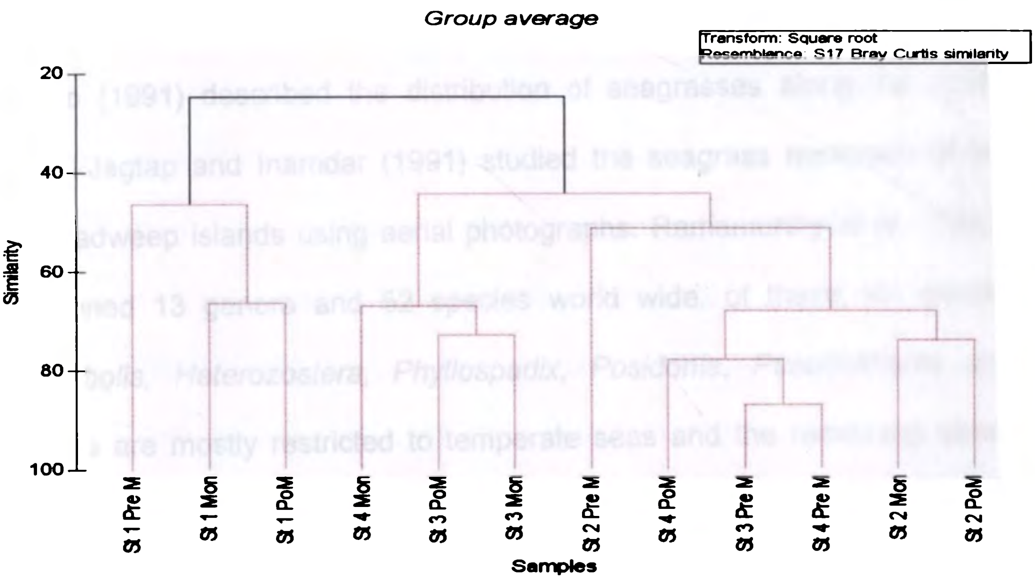


Fig. 4.16b. Dendrogram of seagrass biomass showing the seasonal similarities in the four stations (Solid lines represent significant delineation of groupings by SIMPROF test)

4.3. Discussion

Seagrasses are true flowering plants that have adapted to living in the submerged marine environments. Unlike mangroves, which represent a taxonomically diverse group, seagrasses are a small group of monocotyledonous angiosperms. Table 4.1 describes the systematics of seagrass species, which are distributed in two families.

Species composition

Indian coast embraces 14 species of seagrasses (Venkataraman and Wafar, 2005) and are found often in association with coral reef areas. Studies on seagrasses were started only during 1980s and some of the first reports are available from the southern coast of India. Distribution of seagrasses along the Indian coast varied with varying species diversity. Jagtap (1991) described the distribution of seagrasses along the Indian coast. Jagtap and Inamdar (1991) studied the seagrass meadows of the Lakshadweep islands using aerial photographs. Ramamurthy *et al.*, (1992) mentioned 13 genera and 52 species world wide, of these, six genera *Amphibolis, Heterozostera, Phyllospadix, Posidonia, Pseudalthenia* and *Zostera* are mostly restricted to temperate seas and the remaining seven genera, *Cymodocea, Enhaulus, Halodule, Syringodium, Thalassia and Thalassodendron* are represented in tropical seas. Out of which 6 genera and 14 species are present in Indian waters (Kannan *et al.*, 1999; Venkataraman and Wafar, 2005). Kaliaperumal *et al.*, (1989) reported 6 species of seagrasses from Lakshadweep islands, which include 4 species from Minicoy lagoon. They include *Cymodocea serrulata, C. rotundata, Halodule uninervis, Halophila ovalis, Syringodium isoetifolium* and *Thalassia* *hemprichii* and reported the occurrence in 10 islands. Untawale and Jagtap (1984) reported 5 species of seagrasses from Minicoy lagoon, which include *Thalassia hemprichii, Halophila ovalis, Cymodocea rotundata, Halodule uninervis,* and *Syringodium isoetifolium.* From Lakshadweep, the occurrence of *Thalassia hemprichii, Syringodium isoetifolium, Cymodocea serrulata, Cymodocea rotundata, Halodule uninervis, Halophila ovalis* and *Enhaulus acoroides* were reported (Kannan *et al.*, 1999; Venkataraman and Wafar, 2005). Five species of seagrasses viz., *Halophila ovalis, Thalassia hemprichii, Cymodocea serrulata, Halodule uninervis* and *Syringodium isoetifolium* were observed during the present study.

Mapping and Distribution

Tropical seagrass communities tend to be characterized by complex mixed species and are dynamic on a variety of spatial and temporal scales. The rates of establishment, growth, reproduction and death of individual species within the community differ. At some places, the seagrass composition is mono-specific, while at others many species co-exist (Kirkman, 1985). Light, temperature, salinity, substratum, nutrient levels, epiphytes and diseases have all been found to affect the survival and distribution of seagrasses (Twilley *et al.*, 1986; Short and Burdick, 1996; Moore *et al.*, 1997). Wherever natural and man-made perturbations occur it is necessary to know the extent of changes caused by those perturbations. A baseline or control is required to determine the seasonal or annual changes in seagrass coverage. Detailed studies of such changes in community structure of seagrass communities are essential to understand the role of these communities and the effects of disturbances on their composition, structure and rate of recovery. Seagrass meadows have to be mapped before any statement as to their extent or environmental significance can be made. Their boundaries must be known for statements about loss or gain. Mapped information on the spatial distribution of seagrasses in Minicoy lagoon was derived from the transect line method. There was no detailed report on the mapping of seagrass meadow from Lakshadweep.

Seagrass survive in the intertidal zone especially in sites sheltered from wave action or where there is entrapment of water at low tide, protecting the seagrasses from exposure to heat at low tide. Most tropical and subtropical species are found in water less than 10m deep. Coles *et al.*, (1987) noted three general depth zones of seagrass species composition for tropical waters: a shallow zone less than 6m deep with high species diversity, likely to include all species found in a region; a zone between 6m and 11m where the most commonly found seagrasses were the pioneering *Halodule* and *Halophila* species and a zone deeper than 11m where only species of the Genus *Halophila* were commonly found. The ability of *Halophila* sp., which has a petal shaped leaf to grow in low light intensities, may give this genus advantage over others in deep or turbid waters.

In Minicoy lagoon, uniform meadow of seagrass meadow occurs in the depth zone of less than 5m. Based on results of the survey conducted it has been found that seagrasses are distributed in the intertidal and sub tidal zones of the lagoon, excluding the southern and northern ends and the village area. *Thalassia hemprichii, Halophila ovalis, Halodule uninervis, Cymodocea serrulata* and *Syringodium isoetifolium* are the five species of seagrasses found in the area. There exists stratification in the distribution of seagrasses in the tidal zone. *Halodule* and *Halophila* generally extend from the upper intertidal to the lower sub-tidal zone. Both *Thalassia hemprichii* and *Cymodocea serrulata* are distributed throughout the intertidal zones. *Syringodium isoetifolium* is restricted to sub-tidal habitats, usually in the areas with increased wave action. *Halophila ovalis* is found only in some areas as patches, and found both in upper region and the deeper sub-tidal zones, whereas *Halodule uninervis* is present as a narrow broken stretch, near to the upper intertidal zone. *Halodule* is also found in the regions of the inlets, through which the seawater enters the lagoon, where strong inflow occurs. The meadow is found to be mono-specific and as mixed communities in the lagoon. *Thalassia hemprichii* is the dominant species and found in all the stations as mixed or single species meadows. They existed as mixed community with *Cymodocea serrulata, Syringodium isoetifolium* and *Halophila ovalis.* Abundant growth of these species is observed in the station II and III. Even though less abundant species *Halophila ovalis* is present in all stations, except at station III. *Syringodium isoetifolium* is existed mostly as single species meadow in the intertidal and sub-tidal zones of station III and IV and completely absent from the upper zone of intertidal region. *Halodule uninervis* is the least abundant species and existed as small patches in the upper boundary of the intertidal zone of the stations III and IV. Untawale and Jagtap (1989) reported an area of 0.765km^2 of seagrass meadow in Minicoy lagoon. Later, Jagtap (1991) reported an area of 0.4 km^2. During the present study, it was revealed that the average area of seagrass meadow was declined to 0.396km^2. This minor variation can be attributed to the increased turbidity in the village region (near the station III) due to increased transportation and the changes in the substratum characteristics (near the station II) due to the construction of a small bund across the tidal channel. This increased the sedimentation and the accumulated sediments formed a muddy substratum, which were colonized by mangroves. This feature explains the succession in seagrass meadows and their interactions.

Seagrass and Hydrography

Distribution and abundance of seagrasses is controlled by a range of environmental conditions including light availability (Dennison and Alberte, 1985; Dennison, 1987), nutrient availability (Short, 1987), water motion (Fonseca and Kenworthy, 1987) and grazing (Lanyon *et al.,* 1989). The typically clear, warm and low nutrient waters of tropical seas, together with the predominantly carbonate nature of the sediments where tropical seagrasses grow, led to consider the seagrass growth to be nutrient limited in these environments (Short *et al.*, 1985; Fourqurean *et al.*, 1992), which received experimental support from several *in situ* nutrient experiments in tropical and subtropical seagrass meadows (Agawin, *et al.*, 1996). They thrive well in the waters having the temperature range of 26-31°C. Extreme temperature caused by low tides causes seagrasses to loose their leaves and vast quantities of dead material washed ashore in the beaches of Minicoy Island. The rhizomes appear to be unaffected and new growth of leaves allows the plants to recover. In addition, seagrasses depend on the degree of water clarity to sustain productivity in their submerged environment. Nutrient enrichment can enhance the growth of macroscopic and microscopic algae on seagrass leaf surfaces, which results in the shading of seagrass leaves by up to 65% and reduces photosynthetic rates and leaf densities (Walker and Mc Comb, 1992). Salt tolerance is a highly specialized physiological trait in these angiosperms, which have only a small percentage of halophytes. The lack of salt tolerance may be one of the reason there are only about 60 species of true seagrasses worldwide, distributed in as few as 13 genera (Lee Long, *et al.,* 2000). By contrast, there are an estimated 500-700 freshwater species of angiosperms representing about 50 genera. Factors beyond salinity are important in the comparison of fresh water, estuarine and marine environments. Regular tidal motion and water level changes in lagoons are also influence the distribution of seagrasses. However, macrophytes frequently reduce water velocities enough to accelerate deposition of fine-grained materials in dense grass beds (Fonseca *et al.*, 1982). This sedimentation provides conditions for deeper penetration of light and high specific heat. In addition, there is constant supply of salt the marine environment, which produces less shifting of pH in marine environments. All these factors increase the growing season of seagrasses in the lagoons. In the present observations, *ANOVA* results showed that the variations in shoot density was significant both in spatial and temporal aspects ($R^2 = 0.518$). The variations in seagrass biomass were also significant ($R^2 = 0.620$) both spatially and temporally. From these values, it can be inferred that there is no variation in shoot density and biomass in the same season for all the stations. Many seagrass species have broad tolerances to ranges of substrate conditions, temperature and salinity. Variations in seagrass adaptiveness, morphology and flowering response have been noted for several species as a correlate with environmental variations (Biebl and McRoy, 1971; Kenworthy and Fonseca, 1977; McMillan, 1982). The results of some experimental manipulations, suggest that the broad physiological tolerances characterise each seagrass population, but that local habitat conditions have a selective influence on the pattern of variation within a species (McMillan and Phillips, 1969). Seagrasses abound in oligotrophic and mesotrophic waters, where they develop extensive meadows as observed in the station I and II. The capacity to exploit the nutrient reservoir of the sediment besides that of the water column (McRoy and Barsdate, 1970) does not imply that nutrients are available to seagrasses in excess. On the contrary, nutrient – limited growth appears to be quite a common phenomenon (Orth, 1977). The generally high productivity of seagrasses, which is logically, paralleled by a high nutrient demand, often nutrient-poor environments, has attracted attention since the expansion of seagrass research in the early seventies.

The efficient use of available nutrients depends on specific plant properties. Nutrient resorption from senescing leaves and leaf longevity are the two plant characteristics, which are important in the conservation of nutrients in seagrass ecosystems. Resorption reduces the need for uptake of nutrients from the environment, and hence is a strategy that can be of particular importance to plants growing in nutrient - poor environment (Aerts, 1990). The second characteristic, the longevity is known as an important mechanism to conserve nutrients in evergreen species (Reich *et al.,* 1995). The broken pieces of seagrass leaves, produced as the result of strong wave action during monsoon also provide nutrients when they were decayed. These inferences were supporting the existence of seagrasses in the low nutrient environment of Minicoy lagoon.

The correlation between shoot density and hydrographic parameters showed that in the station I, the pH is significantly correlated (r = 0.490; $p<$ 0.05) and with DO (r = 0.534; $p<$ 0.01). At the same time, temperature showed a negative correlation (r = -0.418; $p<$ 0.05) with shoot density. DO, nitrite, nitrate and silicate were not significant in this station. In the station II, The shoot density was significantly correlated with DO (r = 0.426; $p<$ 0.05) and with silicate at (r = 0.529; $p<$ 0.01). Here also temperature showed a negative correlation (r = 0.422; $p<$ 0.05). A significant correlation of shoot density with DO (r = 0.759; $p<$ 0.01) and with pH (r = 0.411; $p<$ 0.05) was observed in station III. The negative correlation of temperature (r = -0.414, $p<$ 0.05) was noticed in this station also. Temperature is not a significant factor in the station IV where as pH (r = 0.708; p< 0.05) and DO (r = 0.647; p< 0.05) were significant.

From these inferences, it can be concluded that the temperature is a controlling factor in the distribution and abundance of shoot density as they affect during the time of low tide. When the water recedes from the shallow intertidal regions, where the seagrasses grow, they may subject to desiccation. It may leads to the destruction and reduction of seagrass shoots. It was confirmed that nutrients such as nitrite, nitrate, phosphate and silicate were not at all a limiting factor in this region. In Minicoy lagoon, the tidal influence and the depth of the location were also the determining factors of seagrass distribution as evidenced from the field observations and analysis.

The significant correlation with DO indicates that the increased seagrass biomass could increase photosynthesis, thereby the amount of DO in the surrounding environment. In all the four stations, DO (r = 0.874, 0.815, 0.865 and 0.740; $p< 0.01$) and pH (r = 0.775, 0.757, 0.652 and 0.651; $p< 0.01$) were significantly correlated. Temperature is not a significant factor at station I and IV and it may be due to the direct contact with open sea and the resultant mixing due to wave action. The deeper water column so that the desiccation impact on seagrasses would become less. In the station II and III, the significant negative correlation (r = -0.487 and -0.436; $p< 0.05$) were exist, which shows that the shallow nature of these stations may increase the desiccation and resulted in the destruction of seagrass shoots and leaves, which in turn reduced the seagrass biomass. In all the stations, salinity, phosphate, silicate, nitrite and nitrate were not significant.

The biomass of seagrass varies latitudinally, being greatest in tropical waters. In temperate areas mean biomass probably lies close to 500gm dry wt. /m^2 during actively growing season. Comparable average Figures for tropical seagrasses are 800gm dry wt./m^2. In the present study in the Minicoy lagoon, which is tropical in nature, maximum biomass of 300 gm dry wt./m^2 was obtained during the active growing period and the least amount of biomass of 0.7 gm dry wt./m^2 was obtained in February. The biomass of seagrass showed both temporal and spatial variations. The temporal variations were due to the effect of tidal changes and the growth characteristics of the seagrasses and the spatial variations were due to the physical conditions existing in that particular area, including the closeness to the open sea.

Significant correlations (r = 0.502, 0.849 and 0.858 respectively) were found between seagrass shoot density and biomass in the station I, III and IV, while in the station II, the correlation was not significant (r = 0.162). This may be due to the abundance of *Halophila ovalis*, which have very thin rhizome and shoot, where other species of the mixed community contributed major share to the total biomass. In the station I also *Halophila ovalis* present, but comparitively lesser quantity than station II.

From the BEST results, it was inferred that pH, DO, nitrite and nitrate were the best matching variables for seagrass shoot density on monthly patterns, while with seasonal scales, in addition to these factors salinity also became an influencing environmental variable. This indicated that the minor variations in salinity within in a short period (month) were not affecting but the long term (season) changes would affect shoot density. In the case of seagrass biomass, the best matching environmental variables were salinity, pH, DO and nitrite on monthly distribution patterns and for seasonal pattern, nitrite was excluded.

Shoot density in tropical seagrasses is generally influenced by seawater temperature (Fortes, 1986). However, photoperiod or intensity of light seems to be more important (Jagtap and Untawale, 1981; Mazzela and Alberte, 1986) factors for seagrass growth from Lakshadweep islands. In the present study with the BEST analysis, it was revealed that water temperatures is not at all a limiting factor for the growth of seagrasses, where as pH and DO forms the significant variables, along with nutrients.

Community Structure

a)Similarity indices

Multi-dimensional scaling (MDS) plot was constructed for finding out the similarity ranking by using both the seagrass abundance and biomass, which showed good ordination between the samples collected, as indicated by the low stress value of 0.13 and 0.07 for seagrass shoot density and 0.15 and 0.06 for seagrass biomass respectively for monthly and seasonal patterns. Stress value < 0.1 corresponds to a good ordination with no real prospects of a misinterpretation. This showed that the seasonal samplings were excellent in the interpretation of the studies. Samples showing similarities were grouped together and dissimilar ones, far away. MDS plots revealed a clear separation of the samples of station I, where, *Halophila ovalis* was the highly dominant species, than the remaining 3 stations. This difference in species composition made a dissimilar cluster for that station. 11 clusters showed 80% similarities for monthly distribution pattern of seagrass shoot density and 2 clusters for seasonal patterns. 12 clusters with monthly and only one cluster with seasonal distribution for seagrass biomass showed 80% similarities. In most of the cases, station I showed a separation from the other stations.

Bray- Curtis similarity plots were made for both seagrass abundance and shoot density based on the seasonal data. From the cluster plots, it was evident that there are 11 clusters of similarities, having the similarity percentage range of 27-87% for abundance and 50 - 87% for biomass. Highest similarity (87%) in the seagrass abundance was obtained between the post monsoon season in the station III (St 3 PoM) and pre-monsoon season in the station IV (St 4 PreM), followed by 86% between monsoon season in the station III (St 3 Mon) and station IV (St 4 Mon) and 83% between the pre monsoon in the station III (St 3 PreM) and station IV (St 4 PreM). Similarities in seagrass biomass was high (87%) between the pre monsoon in the station III (St 3 PreM) and station IV (St 4 PreM). 82% similarity was obtained between the post- and pre- monsoon seasons in the station IV (St 4 PoM and St 4 PreM). 75% similarity was revealed between the post monsoon in the station II and station IV (St 2 PoM and St 4 PoM). Further analysis by **SIMPROF** for testing the significance of similarity indicated that only five groupings were significant in the case of monthly shoot density, while no significant groupings were obtained for seasonal scales. When considering the seagrass biomass on monthly patterns only two significant clusters were formed, whereas on seasonal pattern, only one significant cluster was formed. These results revealed that though there exist similar significant variations both in shoot density and biomass for short periods, which would be nullified in the long period of time. So the seagrass ecosystem changes are minimum when they are in undisturbed conditions, with its capacity of self-regulation. Further, the different regions of the seagrass ecosystem in Minicoy lagoon have their own characteristics for adjustment.

Abundance-Biomass Curve (ABC) plot include both abundance and biomass *k-dominance* lines on the same plot and have been interpreted as indicating, 'undisturbed' community, if the biomass curve is above the abundance curve; 'gross disturbance' if the abundance curve lies above the biomass curve and 'moderate disturbance', if the two lines are largely separated. *W* - value measures the extent to which biomass curve lies above the abundance curve. The positive value indicates the undisturbed and negative, disturbed condition. In the present interpretation on the seagrass ecosystem of Minicoy lagoon, the ABC plot using monthly data indicated a slightly disturbed condition. The abundance curve lies above biomass curve up to an extent and then attains the reverse condition. The negative *W*- value (*W* = -0. 093) indicated a slight disturbed condition, which can be attributed to the gross disturbances (*e.g.* organic enrichment), resulted by the monsoonal conditions. When considering seasonal aspects, these minor disturbances are nullified and the system showed a perfect undisturbed scenario. Here, the biomass curve lies above the abundance curve with a positive *W*-value of 0.082. So the seagrass community of Minicoy lagoon is an undisturbed system, with the self-regulating capacity to overtake the disturbances.

b) Diversity indices

The number of seagrass species is by no means proportional to their ecological importance. It appears that the structural complexity of these communities is linked with the dominant growth forms of the constituent species. Data generated by such studies provide an understanding of the fundamental processes underlying the dynamics of seagrass communities.

Present concern about the preservation of biological diversity is partially based on the belief that loss of biodiversity would result in the loss of ecosystem functions and the many services they provide to society (Constanza *et al.,* 1997). Moreover, the contribution to ecosystem functions and the viability as harvestable food or raw material of any one species seem to be very much dependent on the development of a significant abundance, for rare species can hardly have a significant impact on their environment. Hence, the link between biodiversity and ecosystem functions and services is not straightforward. Yet the test of these links is essential to demonstrate a significant ecosystem role for biological diversity (Tilman, 1997), which would provide reasons other than ethical for the preservation of biodiversity as a whole, rather than that of target species alone. The demonstration of this link has, therefore, inspired research efforts of many scientists and ranks highest in the agendas of international research programmes on biological diversity (http: / /www.icsu.org/ diversitas /).

Efforts to test the hypothesized positive link between ecosystem services and functions and biodiversity are increasing in order to forecast the consequences of the present erosion of biodiversity on ecosystem functions and to provide an additional basis for the conservation of biodiversity. Studies illustrated strong reasons to expect a strong positive relationship between species diversity and the functions of marine ecosystems and, thereby, the services they yield to humanity.

In Minicoy lagoon, only five species of seagrasses were found. Their abundance and distribution patterns determine the structure and function of the system temporally and spatially. The bubble plot describes the relative abundance of the seagrass species present in the lagoon. This distribution pattern, in turn, influences the species diversity of seagrass itself and its associated communities. Species diversity is the relative abundance of different species at each site of time reduced to a single index (Khan, 2005). Margalef richness index is the indicator of species richness in a specified location or time. Here the average value is higher in the station IV, where

Shannon diversity value was also highest, which means that the species diversity will be higher species richness is more. These two factors together are in turn, inversely related to the dominance of species. In this case, the condition is that where the species dominance was higher, the species diversity will be lower. Here, in the station I, *Halophila ovalis* dominated and this resulted in low diversity in that station and all the five species were present in the station IV, where the diversity was higher. Even though the number of species falls within the range of 2-5 only, the diversity values were on the higher side, having the value of 2.04, in the station IV and it is attributed to the higher evenness value (0.98) recorded here.

Closer examination indicates that the functional variability of mixed-species seagrass assemblages is correlated to the variability in species size, whereas species of similar size tend to show similar functional capacities and, therefore, a greater degree of functional redundancy. In addition, the demonstration of positive interactions in the seagrass communities, which are also dependent on the presence of engineering species in the community that facilitate the growth of other species, provides increasing grounds to expect an enhanced functional performance of mixed communities over that expected from a simple additive contribution of the community members.

An examination of seagrass communities, which are simple assemblages with a limited membership of about 60 species worldwide and, <12 species in any one community, provides a strong evidence for the existence of a positive link between species richness and ecosystem functions. Ecosystem functions are, however, dependent on the particular membership of the community; rather that it's number, for the functions are species-specific properties. Multi-specific communities also hold, within the functional framework they contain, many unrealised functional potentials that may prove instrumental to ensure the sustainability of ecosystem functions in the presence of disturbance or a changing environment.

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Chapter V

Macro algae

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Macro algae

5.1. Introduction

Marine macro algae or seaweeds are an important autotrophic component in many coastal ecosystems such as lagoons and estuaries. Seaweeds are the only source for the production of phytochemicals like agar-agar, algin, carrageenan, *etc.*, which are extensively used in various industries. These are also used as human food, animal feed and as manure in several countries. Most of the seaweeds of the tropical region form very important living renewable resource of the ocean and lagoons. The economic importance of seaweeds is gaining momentum and it has become essential to have first hand knowledge about their availability, ecological distribution and seasonal fluctuations.

Macro algae are one of the marine living resources having no distinguishable roots, stems or leaves and belong to three major classes of classes– Chlorophyceae, Phaeophyceae and Rhodophyceae. Chlorophyceae are one of the larger groups of seaweeds in terms of number of species and are almost widely distributed. There is considerable biochemical, physiological and morphological diversity among species. Except for a few genera the brown algae (Phaeophyceae) are exclusively marine, usually dominating in the rocky, coral reef and seagrass ecosystems of intertidal zone. They are commercially important in a number of ways. Most of the red algae (Rhodophyceae) are macroscopic seaweeds, which share the coastal waters with green and brown algae and seagrasses. Red algae are tend to be more abundant in tropical waters and are exploiting largely for commercial purposes. The potential areas in India for luxuriant growth of seaweeds are south Tamil Nadu Coast, Gujarat coast, Lakshadweep and Andaman and Nicobar islands.

The extensive shallow base coral reefs and lagoons characterized by slow to moderately strong currents and sandy coralline bottoms are ideal habitats for many economically important types of seaweeds. Mixture of algae and vascular plants can often be found growing in or anchored to sand or muddy bottom in shallow waters. Both micro algae and macro algae can be seen as epiphytes in vascular plants like seagrasses. Green, red and brown macro algae are abundant in seagrass meadows of tropical region especially in areas having coral reefs. The extensive seagrass bed creates a stable substratum for the attachment of seaweeds by stabilizing the sediment and by providing large surface areas in the leaf canopy. Since many seagrass meadows are associated with coral reefs, macro algae share both the ecosystems. Coral reefs and associated less turbid water column heavily support calcified red algae (Dawson, 1966), those at times are responsible for a major portion of the reef building activity. The coral reef shows zonation and this in turn influences the distribution pattern of coastal floral communities like seagrasses and seaweeds.

The seasonal control of production cycle of macro algae depends on the available nutrients and light. While seagrass grow on sediments at depths receiving more than 11% of incident light (Duarte, 1991), macro algae can grow down to 0.12 % and less than 0.003% of incident light (Markager and Sand Jensen, 1992). It is important to understand these requirements, interactions and adaptations so that the presence and ecological significance of species in time and space can be explained and predicted. Understanding of the environmental biology of algae can be integrated with the data on the dynamics of other functional components of the ecosystem to yield a more comprehensive assessment of ecosystem structure and function.

The shallow coral reef and lagoons, characterized by sandy coralline bottom having live corals, coral pebbles and seagrass beds are ideal habitats for many economically important seaweeds. The coral lagoons of Lakshadweep have luxuriant growth of seaweeds. In coral reef ecosystems calcareous algae forms the important group in seaweeds, as they are essential in the formation of coral reefs. Much of the sand and lagoon sediment in coral in coral atoll is from these algae. Calcareous algae are most common in tropics and the distribution seems to be related to such physical factors as light, temperature, and wave action (Littler, 1976).

Studies on macro algal biomass in seagrass communities, particularly in lagoons are limited, despite the recognition of their importance by several investigators (Mc Roy and Mc Millan, 1977; den Hartog, 1979). Seaweed resources of Lakshadweep have been assessed partially during 1977-1979 by the combined effort of CSMCRI and Dept. of Fisheries. The survey revealed the biomass of standing crop for all the islands of the group have a potential area of 1334 ha. (Anon, 1979). Studies on seaweeds in Lakshadweep were only a few, which are mainly conducted as part of the survey of marine living resources (Kaliaperumal *et al.,* 1989; Koya *et al.,* 1999; Mohammed, 1999; Koya, 2000). The present study was made with a view to estimate the species composition, abundance and distribution of seaweeds and its influence on seagrass ecosystem.

5.2. Results

In Minicoy lagoon, abundant growth of seaweeds was observed both in reef and lagoon, especially in the seagrass meadows. For this study, seaweeds associated with seagrass meadow are only considered. The available species in all the stations were collected and their morphological features were carefully analyzed for species identification with the aid of pioneer references on taxonomy of seaweeds (Bhandari and Trivedi, 1975; Chennubotla *et al.,* 1987; Gopinathan and Panigrahy, 1983; Jagtap, 1983; Michanek, 1975; Subbaramaiah *et al.,* 1977; 1979; Koya, 2000) and also noted the biomass and distribution patterns, and found out the spatial and temporal variations and the correlations between seaweed biomass and hydrographical parameters.

5.2.1. Species Composition

In Minicoy lagoon all the three major classes of seaweeds *i.e.,* Chlorophyceae, Phaeophyceae and Rhodophyceae were represented. During the study period, 43 species were obtained from the seagrass meadow. They belong to 9 orders, 17 families and 26 genera (Table 5.1). They were grouped into 3 classes, namely Chlorophyceae, Phaeophyceae and Rhodophyceae. The most dominant group is Rhodophyceae, which include 4 orders, 9 families and genera and 20 species. Next dominant group is Chlorophyceae, which comprises 2 orders, 5 families and 8 genera and 16 species, while in Phaeophyceae, 3 orders, 3 families, 5 genera and 6 species were present.

Chlorophyceae

Species of *Enteromorpha compressa, E. tubulosa, Ulva lactuca* (*Plate* 3a), *U. reticulata, Chaetomorpha linoides* (*Plate* 3b), *C. aerea* (*Plate* 4a), *C. antennina, Cladophora fascicularis, Cladophoropsis* sp., *Caulerpa cupresoides, C. taxifolia, C. peltata, C. sertularioides, C. racemosa* (*Plate* 4b), *Codium tomentosum, Halimeda gracilis* and *Boergesenia forbesii* are the members of Chlorophyceae (*Plate* 5a).

Phaeophyceae

The species belong to Phaeophyceae are *Dictyota* sp., *Padina gymnospora, Hydroclathrus clathratus, Sargassum duplicatum, S. whittii* and *Turbinaria ornata* (*Plate* 5b).

Rhodophyceae

Species of *Gelidium pusillum, Gelidiella acerosa, Amphiroa sp., Jania capillacea, Lithothamnion sp., Halymenia floresia, Gracilaria lichenoides, G. crassa* (Plate 6a), *G. edulis* (*Plate* 6b), *G. verrucosa, G. arcuata, G. corticata, G. folifera, Hypnea musciformis, H. valentiae, Sarconema furcellatum, Acanthophora spicifera, Laurencia papillosa, L. obtusata* and *Porphyra indica* constitute the Rhodophyceae.

5.2.2. Distribution

An understanding of the changes in spatial changes in the distribution of seaweed population is an important aspect of their biology and ecosystem functioning. The distribution of seaweeds in all the stations was represented in the Table 5.1 and the percentage contributions of major species were given in

Plate 3

Plate 3a. *Ulva lactuca* in seagrass meadow

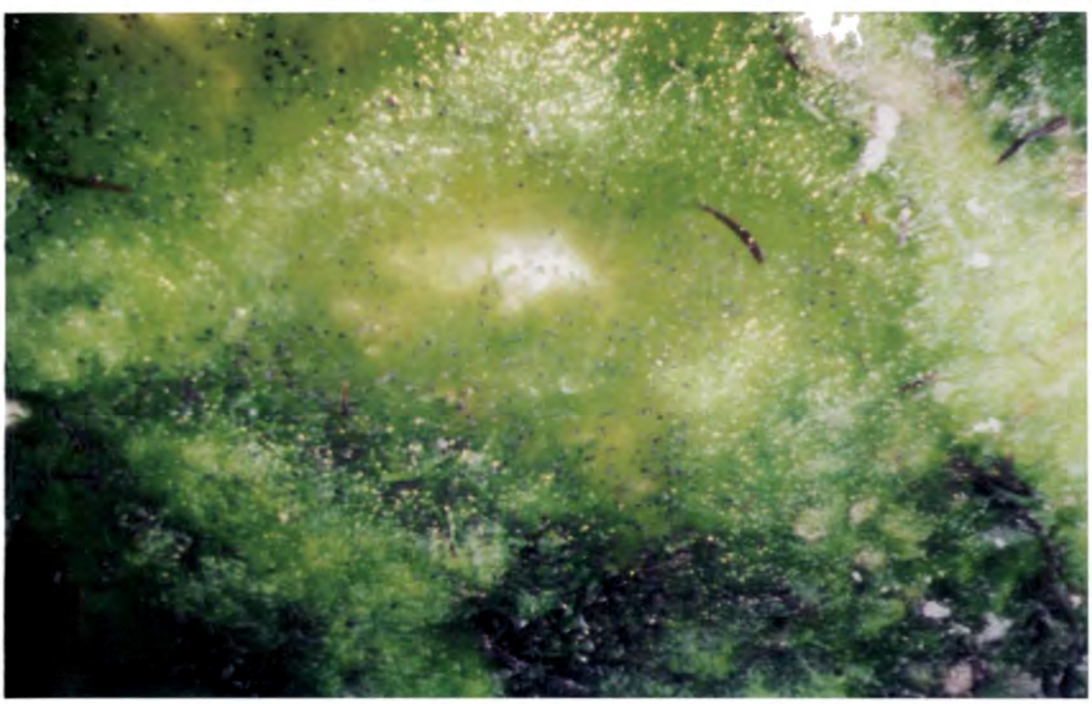

Plate 3b. *Chaetomorpha linoides* in seagrass meadow

Plate 4

Plate 4a. *Chaetomorpha aerea* in seagrass meadow

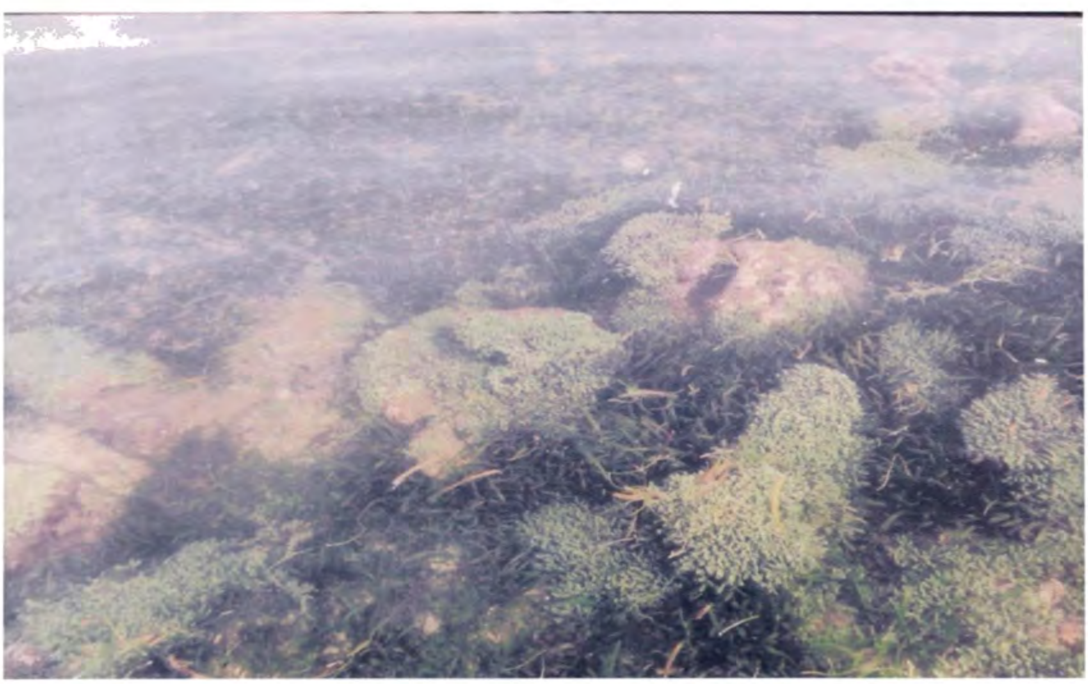

Plate 4b. *Caulerpa racemosa* in seagrass meadow

Plate 5

Plate 5a. Mixed algal mats (chlorophyceae) over seagrass meadow

Plate 5b. *Turbinaria ornata* in the patchy areas of seagrass meadow

Plate 6

Plate 6a. Abundant growth of *Gracilaria crassa* in seagrass meadow

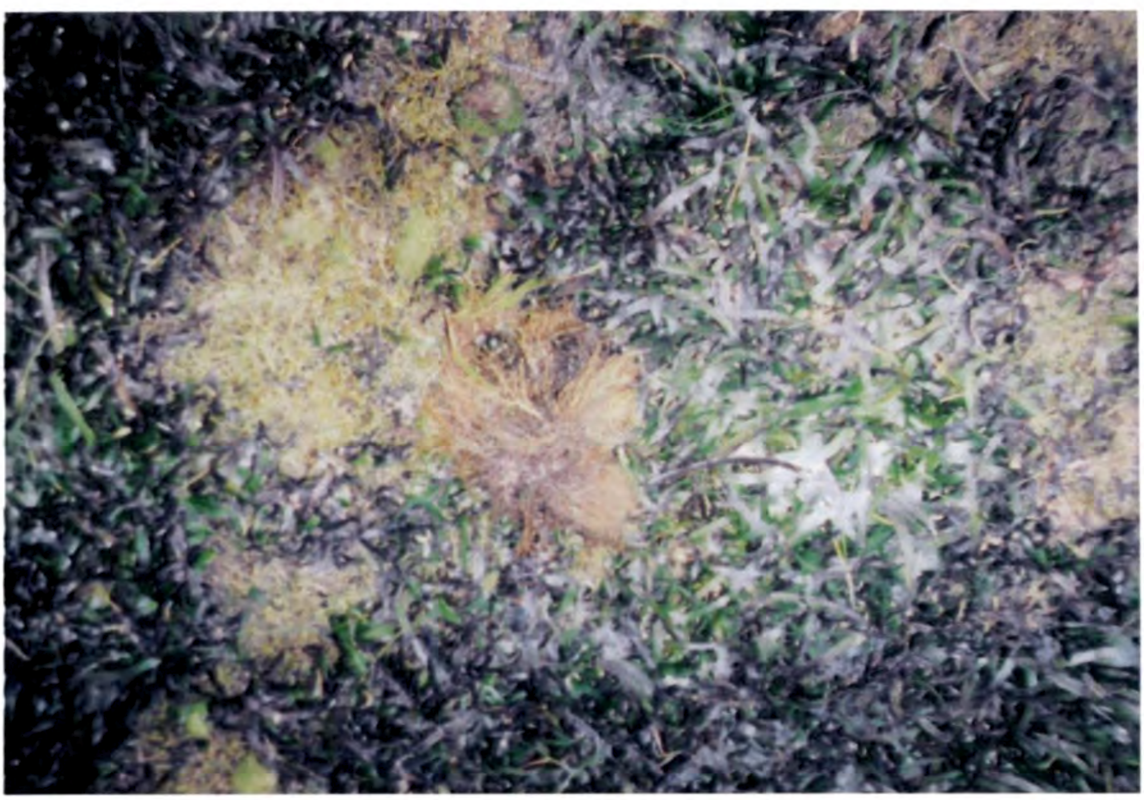

Plate 6b. *Gracilaria edulis* in seagrass meadow

Table 5.1. Station wise distribution of macro algae in the four stations

Species	St I	St II	St III	St IV
Class: Chlorophyceae				
Order: Ulvales				
Family: Ulvaceae				
Enteromorpha compressa	-	-	+	+
Enteromorpha tubulosa	+	+	-	-
Ulva lactuca	-	-	+	+
Ulva reticulata	+	-	+	-
Order: Cladophorales				
Family: Cladophoraceae				
Chaetomorpha aerea	+	+	+	+
Chaetomorpha antennina	+	+	-	-
Chaetomorpha linoides	+	+	+	+
Cladophora fascicularis	+	+	+	+
Cladophoropsis sp.	+	+	+	-
Family: Siphonocladaceae				
Boergesenia forbesii	-	+	+	+
Order: Caulerpales				
Family: Caulerpaceae				
Caulerpa cupresoides	+	+	-	+
Caulerpa taxifolia	+	-	-	+
Caulerpa peltata	-	-	+	+
Caulerpa sertularioides	+	+	-	+
Caulerpa racemosa	-	-	+	+
Family: Codiaceae				
Codium tomentosum	-	-	+	-
Family: Udoteaceae				
Halimeda gracilis	+	+	+	+
Class: Phaeophyceae				
Order: Dictyotales				
Family: Dictyotaceae				
Dictyota sp.	+	-	-	-
Padina gymnospora	+	+	-	+
Order: Dictyosiphonales				
Family: Punctariaceae				
Hydroclathrus clathratus	-	-	-	+
Order: Fucales				
Family: Sargassaceae				
Sargassum duplicatum	-	+	-	+
Sargassum whittii	-	-	-	+

Contd...

Turbinaria ornata	+	+	-	+
Class: Rhodophyceae				
Order: Gelidiales				
Family: Gelidiaceae				
Gelidium pusillum	-	-	+	+
Family: Gelidiellaceae				
Gelidiella acerosa	+	-	+	+
Order: Cryptomemiales				
Family: Corallinaceae				
Amphiroa sp.	-	-	-	+
Jania capillaceae	+	+	-	-
Lithothamnion sp.	+	-	-	+
Family: Grateloupiaceae				
Halymenia floresia.	+	+	+	+
Order: Gigartinales				
Family: Gracilariaeeae				
Gracilaria lichenoides	-	-	+	-
Gracilaria edulis	-	-	+	+
Gracilaria crassa	+	+	+	-
Gracilaria verrucosa	-	-	-	+
Gracilaria arcuata	-	-	+	-
Gracilaria corticata	-	-	+	+
Gracilaria folifera	-	-		+
Family: Hypneaceae				
Hypnea musciformis	+	+	+	+
Hypnea valentiae	+	+		-
Family: Solieriaceae				
Sarconema furcellatum	-	-		+
Family: Rhodomelaceae				
Acanthophora spicifera	+	+	+	+
Laurencia papillosa	+	+	+	+
Laurencia obtusata	+	+	+	+
Order: Bangiales				
Family: Bangiaceae				
Porphyra indica	+	-	-	-

Table 5.2. Percentage composition of first ten dominant species of macro algae in the (a) Station I (b) Station II (c) Station III and (d) Station IV

(a)

Station I	
Species	% Composition
Halimeda gracilis	33.75
Acanthophora spicifera	11.70
Gracilaria crassa	9.70
Laurencia papillosa	8.08
Turbinaria ornata	4.68
Chaetomorpha aerea	3.97
Hypnea musciformis	3.48
Caulerpa sertularioides	3.40
Padina gymnospora	2.92
Porphyra indica	2.47

(b)

Station II	
Species	% Composition
Halimeda gracilis	60.90
Chaetomorpha aerea	10.48
Chaetomorpha linoides	7.08
Gracilaria crassa	5.94
Laurencia papillosa	3.58
Acanthophora spicifera	2.10
Laurencia obtusata	2.07
Boergesenia forbesii	1.70
Jania capillaceae	1.38
Cladophora fascicularis	1.12

(c)

Station III	
Species	% Composition
Gracilaria crassa	31.18
Halimeda gracilis	23.93
Caulerpa peltata	17.78
Gelidiella acerosa	6.38
Gracilaria edulis	4.94
Chaetomorpha aerea	2.91
Caulerpa racemosa	2.82
Halymenia floresia.	2.60
Laurencia papillosa	2.44
Hypnea musciformis	1.27

(d)

Station IV	
Species	% Composition
Gracilaria edulis	17.40
Acanthophora spicifera	16.63
Gelidiella acerosa	14.82
Laurencia papillosa	13.17
Hypnea musciformis	8.77
Caulerpa peltata	8.30
Caulerpa racemosa	6.93
Halimeda gracilis	2.72
Halymenia floresia.	2.39
Sargassum duplicatum	1.15

table 5.2. The number of species in each group was highlighted in the Fig.5.1 and the percentage composition of biomass of each group was represented in the Fig. 5.2.

Station I: In the station I, 25 species of seaweeds were present. They were grouped into 19 genera, 13 families, 8 orders and 3 classes. 11 species, 7 genera, 4 families and 2 orders represented Class Chlorophyceae. Phaeophyceae consists of 3 species, 3 genera, 2 families and 2 orders. Class Rhodophyceae consists of 11 species, 9 genera, 7 families and 4 orders. The dominant species that contributed highest biomass (33.75%) was *Halimeda gracilis*, followed by *Acanthophora spicicfera* (11.70%) and *Gracilaria crassa,* (9.7%).

Station II: A total of 21 species were obtained and belongs to 16 genera, 12 families, 6 orders and 3 classes. In the class chlorophyceae, 10 species, 7 genera, 5 families and 2 orders were present. 3 species, 3 genera, 2 families and 2 orders represented Phaeophyceae. Class Rhodophyceae consisted of 8 species, 6 genera, 5 families and 2 orders. *Halimeda gracilis* formed the dominant species, which contributed 60.9% of the total biomass of the total biomass, followed by *Chaetomorpha aerea* (10.48%) and *C. linoides* (7.08%).

Station III: 24 species of seaweeds were recorded from the station III. They were grouped into 16 genera, 11 families, 5 orders and 2 classes. Class Chlorophyceae was represented by 12 species, 9 genera, 5 families and 2 orders. Rhodophyceae consists of 12 species, 7 genera, 6 families and 3 orders. Class Phaeophyceae was totally absent in this station. Here, *Gracilaria crassa* formed the dominant species, having 31.18% contribution to

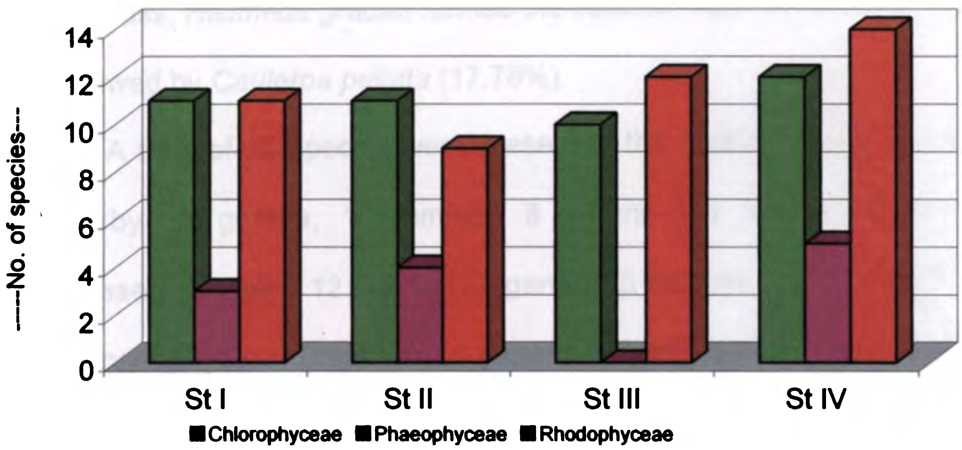

Fig. 5.1. Number of species of Chlorophyceae, Phaeophyceae and Rhodophyceae in all the stations

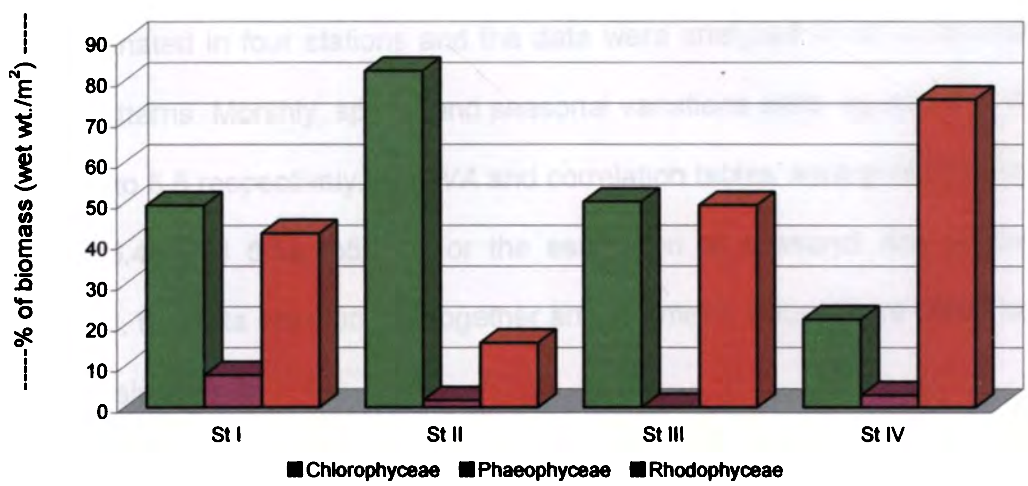

Fig. 5.2. Percentage composition of Chlorophyceae, Phaeophyceae and Rhodophyceae in all the stations

the total biomass. *Halimeda gracilis* formed the second major contribution with 23.93% followed by *Caulerpa peltata* (17.78%).

Station IV: A total of 32 species were present in the station IV, which were constituted by 21 genera, 16 families, 8 orders and 3 classes. Class Chlorophyceae comprises 12 species, 7 genera, 5 families and 2 orders. In the class Phaeophyceae, 6 species, 4 genera, 3 families and 3 orders were present. 14 species, 10 genera, 8 families and 3 orders constitute the class Rhodophyceae. *Gracilaria edulis* was the dominant species in this station, which contributed 17.40% of the total biomass. *Acanthophora spicifera* is the second major species with 16.63%, followed by *Gelidiella acerosa* (14.82%). *Halimeda gracilis* was very less (2.72%) in this station.

5.2.3. Biomass

The biomass of Chlorophyceae, Phaeophyceae and Rhodophyceae were estimated in four stations and the data were analysed in temporal and spatial patterns. Monthly, spatial and seasonal variations were represented in Figs. 5.3 to 5.5 respectively. *ANOVA* and correlation tables were given Tables 5.4a to 5.4c and 5.5a to5.5d. For the estimation of seasonal and spatial variations, the data were pooled together and the mean values were taken for the analysis.

Chlorophyceae: During the entire study period, the biomass of chlorophyceae varied from 0.4 in November to 1568 gm wet wt./m^2 in July. In the station I, it ranged between 1.2 in November to 168 gm wet wt./m^2 in May. In the station II, it varied from 2.4 in March to 1568 gm wet wt./m^2 in July and in station III, the range was 2.4 in August to 908 gm wet wt./m^2 in Jun. In the

Table. 5.3a. ANOVA of Chlorophyceae

CHLOROPHYCEAE			
Source	**df**	**Mean Square**	**F**
Corrected Model	11	295.698	10.114
Intercept	1	5533.166	189.264
SEASON	2	564.351	19.304
STATION	3	444.293	15.197
SEASON * STATION	6	131.851	4.51
Error	84	29.235	
Total	96		
$R^2 = 0.570$			

Table 5.3b. ANOVA of Phaeophyceae

PHAEOPHYCEAE			
Source	df	Mean Square	F
Corrected Model	11	5.205	2.111
Intercept	1	55.606	22.546
SEASON	2	12.992	5.268
STATION	3	6.302	2.555
SEASON * STATION	6	2.062	0.836
Error	84	2.466	
Total	96		
$R^2 = 0.217$			

Table 5.3c. ANOVA of Rhodophyceae

RHODOPHYCEAE			
Source	**df**	**Mean Square**	**F**
Corrected Model	11	126.44	4.299
Intercept	1	4184.322	142.258
SEASON	2	276.072	9.386
STATION	3	170.053	5.781
SEASON * STATION	6	54.756	1.862
Error	84	29.414	
Total	96		
$R^2 = 0.360$			

Table 5.4a. Correlation of seaweed biomass (group wise) in Station I

	Seagrass biomass	Seagrass shoot density	Chloro	Phaeo	Rhodo	Temp	Sal	pH	DO	PO_4	NO_3	NO_2	SiO_4
Seagrass biomass	1.000												
Seagrass shoot density	.512(*)	1.000											
Chloro	0.117	0.340	1.000										
Phaeo	.596(**)	-0.033	-0.181	1.000									
Rhodo	0.177	0.258	.837(**)	-0.151	1.000								
Temp	-0.154	-.418(*)	-0.158	0.157	-0.016	1.000							
Sal	0.228	0.201	-0.147	0.249	-0.070	0.163	1.000						
pH	.775(**)	.490(*)	0.299	0.293	0.401	-0.330	0.108	1.000					
DO	.874(**)	.534(**)	0.165	0.343	0.263	-0.264	0.269	.916(**)	1.000				
PO_4	0.156	0.137	0.022	0.341	-0.036	-.517(**)	0.310	0.221	0.198	1.000			
NO_3	-0.318	-0.201	-0.118	-0.292	-0.039	-0.101	-0.151	0.051	-0.117	-0.040	1.000		
NO_2	-0.226	-0.368	-0.140	-0.096	0.194	0.248	0.120	-0.128	-0.267	-0.147	0.289	1.000	
SiO_4	-0.209	-0.268	0.090	-0.007	0.081	0.201	-0.315	0.023	-0.093	-0.176	0.373	-0.098	1.000

* Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Table 5.4b. Correlation of seaweed biomass (group wise) in Station II

	Seagrass biomass	Seagrass shoot density	Chloro	Phaeo	Rhodo	Temp	Sal	pH	DO	PO_4	NO_3	NO_2	SiO_4
Seagrass biomass	1.000												
Seagrass shoot density	.555(**)	1.000											
Chloro	0.261	0.048	1.000										
Phaeo	-0.186	0.031	-0.223	1.000									
Rhodo	0.025	0.128	0.002	-0.176	1.000								
Temp	-.487(*)	-.422(*)	-0.205	0.029	-0.210	1.000							
Sal	-0.128	0.027	-0.159	0.309	0.096	0.175	1.000						
pH	.757(**)	0.225	0.315	-0.077	-0.211	-0.253	-0.105	1.000					
DO	.815(**)	.426(*)	0.236	-0.144	-0.054	-0.248	-0.054	.814(**)	1.000				
PO_4	0.236	0.199	0.281	-0.094	-0.069	-.697(**)	-0.214	0.235	0.208	1.000			
NO_3	-0.252	0.140	-0.109	0.146	-0.301	-0.085	-0.239	-0.053	-0.078	0.267	1.000		
NO_2	-0.186	-0.181	-0.203	.672(**)	-0.131	0.041	0.085	-0.091	-0.216	-0.184	0.042	1.000	
SiO_4	0.182	.529(**)	-0.044	0.149	0.204	0.072	-0.019	0.036	0.286	-0.089	0.092	-0.067	1.000

* Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Table 5.4c. Correlation of seaweed biomass (group wise) in Station III

	Seagrass biomass	Seagrass shoot density	Chloro	Phaeo	Rhodo	Temp	Sal	pH	DO	PO_4	NO_3	NO_2	SiO_4
Seagrass biomass	1.000												
Seagrass shoot density	.742(**)	1.000											
Chloro	0.053	0.001	1.000										
Phaeo	.(a)	.(a)	.(a)	.(a)									
Rhodo	0.151	0.108	-0.141	.(a)	1.000								
Temp	-.436(*)	-.414(*)	0.171	.(a)	-0.128	1.000							
Sal	0.280	0.112	0.046	.(a)	0.222	-0.082	1.000						
pH	.652(**)	.411(*)	-0.046	.(a)	0.374	-0.079	0.303	1.000					
DO	.865(**)	.759(**)	-0.016	.(a)	0.365	-0.350	0.227	.708(**)	1.000				
PO_4	0.306	.417(*)	0.103	.(a)	-0.014	-.563(**)	-0.010	-0.295	0.269	1.000			
NO_3	-0.287	0.037	-0.071	.(a)	0.321	-0.076	-0.075	-0.287	-0.033	0.185	1.000		
NO_2	-0.153	-0.195	-0.066	.(a)	.501(*)	0.220	0.106	-0.080	-0.076	-0.132	.434(*)	1.000	
SiO_4	-0.275	-0.111	-0.251	.(a)	.455(*)	0.250	0.080	0.154	-0.076	-0.339	0.111	0.057	1.000

** Correlation is significant at the 0.01 level

* Correlation is significant at the 0.05 level

a Cannot be computed because at least one of the variables is constant.

Table 5.4d. Correlation of seaweed biomass (group wise) in Station IV

	Seagrass biomass	Seagrass shoot density	Chloro	Phaeo	Rhodo	Temp	Sal	pH	DO	PO_4	NO_3	NO_2	SiO_4
Seagrass biomass	1.000												
Seagrass shoot density	.853(**)	1.000											
Chloro	.448(*)	.445(*)	1.000										
Phaeo	-0.280	-0.378	-0.116	1.000									
Rhodo	.451(*)	0.357	0.261	-0.247	1.000								
Temp	-0.064	0.158	-0.198	-0.234	0.095	1.000							
Sal	-0.087	-0.089	-0.352	-0.244	-0.089	0.015	1.000						
pH	.651(**)	.708(**)	0.210	-0.252	0.137	0.115	-0.108	1.000					
DO	.740(**)	.647(**)	.418(*)	-0.246	0.276	-0.016	-0.090	.834(**)	1.000				
PO_4	-0.077	-0.133	0.289	0.234	0.100	-.640(**)	0.063	-0.177	0.081	1.000			
NO_3	-0.081	-0.006	0.104	0.062	-0.042	-0.157	-0.150	-0.293	-0.269	0.213	1.000		
NO_2	-0.157	-0.214	-0.111	0.091	-0.176	-0.072	-0.103	-0.363	-0.283	-0.172	0.166	1.000	
SiO_4	-0.230	-0.010	-0.127	-0.161	-0.192	.511(*)	-0.028	0.063	-0.141	-0.383	-0.011	-0.233	1.000

** Correlation is significant at the 0.01 level

* Correlation is significant at the 0.05 level

Chloro – Chlorophyceae; Phaeo – Phaeophyceae; Chloro – Chlorophyceae; Temp – Temperature; Sal - Salinity; DO - Dissolved Oxygen

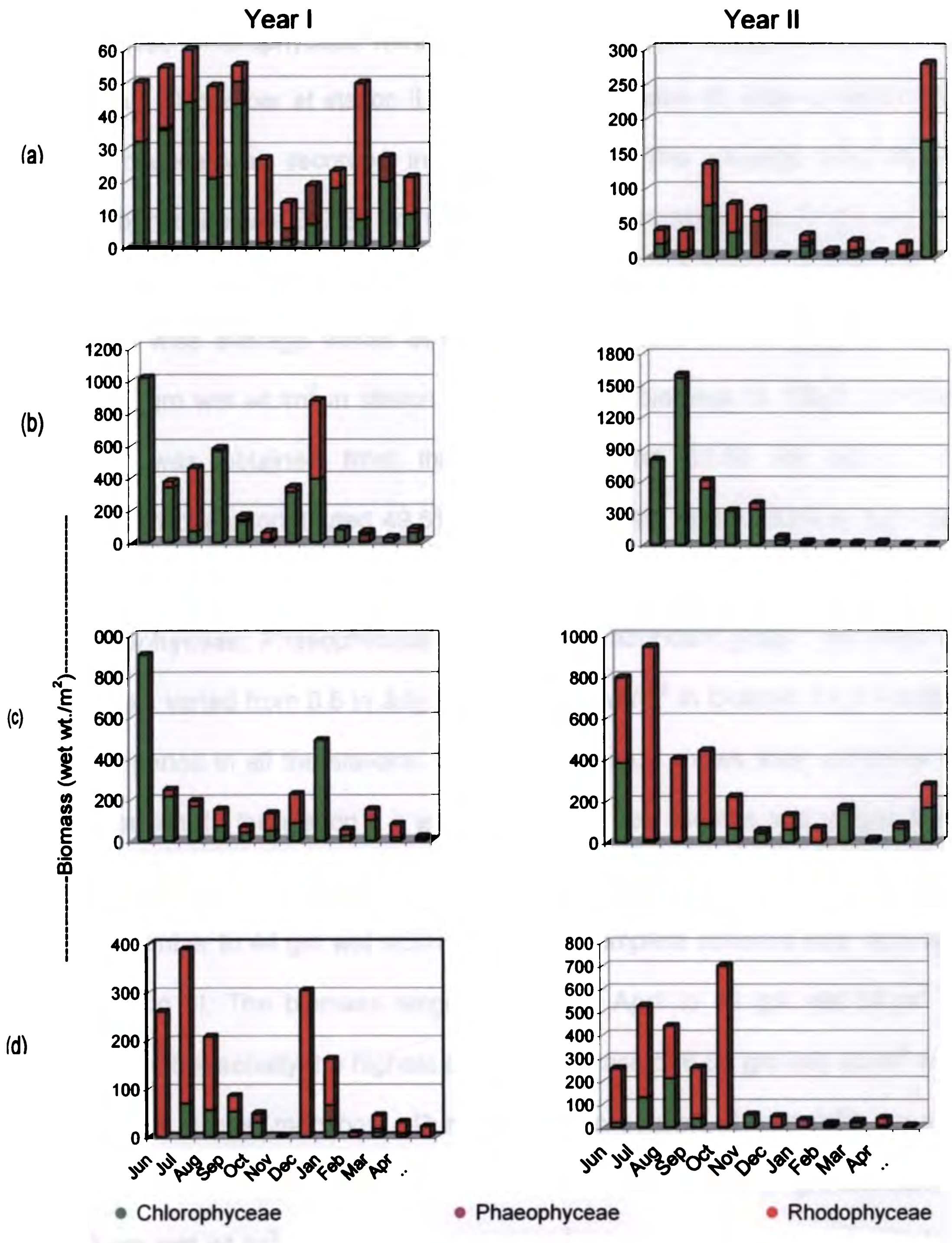

Fig.5.3. Group wise distribution of macro algal biomass (gm wet wt./m^2) in the four stations of Minicoy lagoon

station IV, the range of biomass was 0.4 in November to 213.2 gm wet wt./m^2 in August. Chlorophyceae were present in all months except in October at station I, December at station II and January in station III, while in station IV, the absence was recorded in a few months. The average biomass of Chlorophyceae was 247.34 gm wet wt./m^2 during monsoon, 71.07 gm wet wt. /m^2 during post monsoon and 32.89 gm wet wt./m^2 during pre monsoon. Station wise average values of Chlorophyceae were 24.3 in station I, and 278.18 gm wet wt./m^2 in station II. The average biomass of 135.31 gm wet wt./m^2 was obtained from the station III and 31.58 for station IV. Chlorophyceae contributed 49.5%, 82.48%, 50.44% and 21.53% of the total biomass in the stations I, II, III and IV respectively.

Phaeophyceae: Phaeophyceae was the least abundant group. The monthly biomass varied from 0.8 in July to 52 gm wet wt./m^2 in October for the entire study period in all the stations. Spatially this group shows wide variations in distribution. In the station I, it was present in a few months and ranges from 0.8 in July to 52 gm wet wt./m^2 in October and in station II, it was between 9.4 in December to 44 gm wet wt./m^2 in March. Complete absence was recorded in station III. The biomass range was 1.2 in April to 34 gm wet wt./m^2 in January. Seasonally the highest average biomass of 6.82 gm wet wt./m^2 was recorded in post monsoon. During monsoon season, it was 0.53 gm wet wt./m^2 and 2.66 during pre monsoon. Average biomass of 3.89 gm wet wt./m^2, 5.3 gm wet wt./m^2 and 4.15 gm wet wt./m^2 was obtained in the stations I, II and IV, respectively. Phaeophyceae was totally absent in station III. In the station I the contribution of biomass by Phaeophyceae was 7.81%, while it was 1.73% in station II and 2.93% in station IV. No contribution was in the station III.

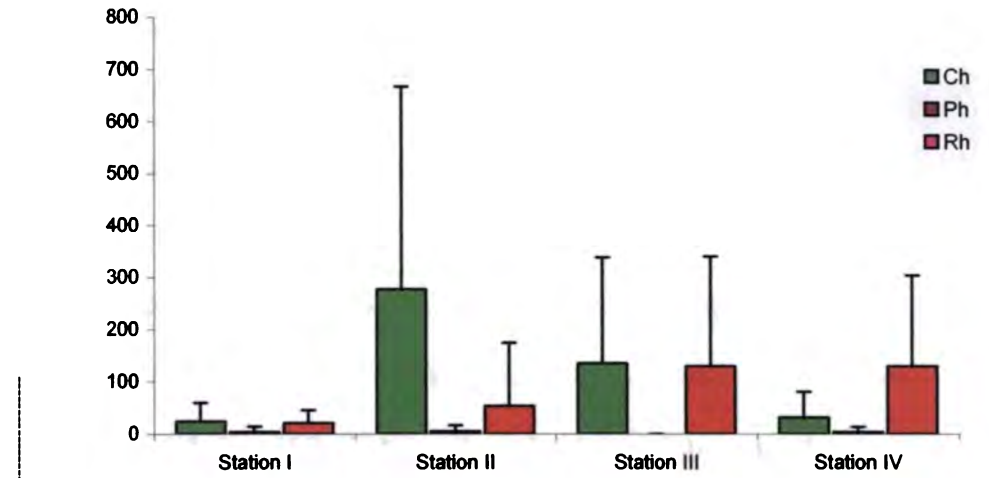

Fig.5.4. Spatial variations in biomass (gm wet wt./m^2) of Chlorophyceae, Phaeophyceae and Rhodophyceae in the four stations of Minicoy lagoon

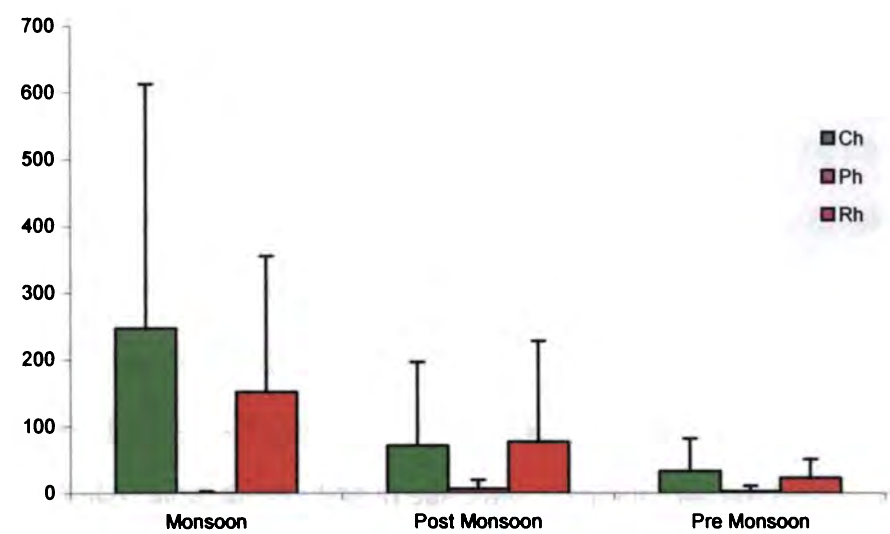

Fig. 5.5. Seasonal variations in biomass (gm wet wt./m^2) of Chlorophyceae, Phaeophyceae and Rhodophyceae in the four stations of Minicoy lagoon

Rhodophyceae: Rhodophyceae contributed a major share in the total seaweed biomass and distributed almost uniformly in all the stations. During the entire study period, the biomass of Rhodophyceae varied from 0.8 in November to 936 gm wet wt./m^2 in July. It ranges from 0.8 in November to 112.4 gm wet wt./m^2 in May in the station I, while in station II, it was 2 in May to 484gm-wet wt./m^2 in January. In the station III, the biomass varied from 11.2 in May to 936 gm wet wt./m^2 in July and in station IV, it was 1 in November to 699.2 gm wet wt./m^2 in October. Average biomass of Rhodophyceae during monsoon was 151.93 gm wet wt./m^2, while it was 76.82 gm wet wt./m^2 and 22.68 gm wet wt./m^2 during post monsoon and pre monsoon respectively. Rhodophyceae have the average biomass value of 21.01, 53.66, 130.25 and 130.25 gm wet wt./m^2 in the stations I, II, III and IV respectively. 42.6% of the total biomass of seaweeds in the station I was contributed by Rhodophyceae and in the station II, it was 15.8% only. In the station III and IV, it was 49.56% and 75.54% respectively.

5.3. Discussion

Marine algae are one of the potential renewable living resources of the littoral vegetation along Lakshadweep islands. Though considerable work has been undertaken to estimate the seaweed resource potential of the Indian coast, surprisingly, the major group of islands around India largely remain unexplored due to their remoteness and other different constraints. Data on macro algal distribution in seagrass communities are limited, despite recognition of their importance by several investigators (Mc Roy and Mc Millan, 1977; den Hartog, 1979). However, Subbaramaiah *et al.,* (1979) surveyed the major group of Lakshadweep islands and reported about algal species belonging to Chlorophyceae, Phaeophyceae and Rhodophyceae. Among the Lakshadweep islands, the maximum resources of marine algae were found in Minicoy Island though the economically important species were not fully represented (Anon, 1979). Jagtap (1987) reported 34 species of marine algae from Lakshadweep atolls belonging to Chlorophyceae (10 species), Phaeophyceae (5 species) and Rhodophyceae (19 species). Kaliaperumal *et al.*, (1989) surveyed the seaweed resources of 12 islands and reported 54 species of Rhodophyceae, 14 species of Phaeophyceae and 43 species of Chlorophyceae. In Minicoy, 52 species were recorded out of which 21 species belong to Chlorophyceae, 6 species to Phaeophyceae and 23 species to Rhodophyceae. Koya, (2000) recorded 38 algal species from lagoon and reef flat, which include 14 species of Chlorophyceae, 5 species of Phaeophyceae and 18 species of Rhodophyceae. Maximum number of (10 species) brown algae was found in Kalpeni Island. In all Lakshadweep islands, Rhodophyceae was more (Jagtap, 1987) and Phaeophyceae was less (Kaliaperumal, *et al.,* 1989). At present Lakshadweep islands harbours 114 species of marine algae, coming under various genera (Koya, 2000).

In marine coastal habitats, biotic and abiotic factors combine to determine patterns of species distribution (Underwood and Jernakoff, 1984; Andrew and Viejo, 1998; Beendetti-Cecchi, *et al.,* 2000). The importance of these factors on the maintenance of benthic macro algae has been widely stressed (Schiel and Foster, 1986; Kautsky and van der Maarel, 1990; Paine, 1990; Sala and Boudouresque, 1997; Middelboe *et al.,* 1997; Baynes, 1999). In fact, the knowledge of factors influencing the growth and distribution of species may allow forecasting the ecosystem dynamics and it represents an instrument for the management of these ecological emergencies (Bax *et al.*, 2001).

The macro algae grow well in habitat characterized by true marine waters, where the salinity is moderately high. Some species such as the genera *Gracilaria, Chaetomorpha, Cladophora* and *Enteromorpha* grow well in slightly brackish waters. Under both levels of salinity, clear water with moderate currents and good nutrient loading will be favourable for the growth (Rabanal and Trono *Jr.,* 1983). Shepherd and Womersley (1981) found that species richness and dominance were related to the degree of water movement, substratum characteristics and depth. Water movement is a major factor determining the local distribution and abundance of marine organisms (Gurjanova, 1968). The seaweeds have colonized a zone, which reaches from about high water mark down to a maximum depth of 200m. They were abundant in enclosed bays and lagoons with suitable substratum and attached to rocks, coastal structures, etc. Seagrasses provide a suitable substratum for seaweeds directly (as epiflora) and indirectly. In this study it was found that Chlorophyceae biomass was found to be higher in station II, which almost like a bay with less influence of water (tidal) movement. Rhodophyceae was higher in the station III, which is characterised by abundant growth of *Syringodium isoetifolium* in the deeper waters having high shoot density. This high shoot density provides a suitable stable water column and substratum for the abundant growth of red algae and green algae. Phaeophyceae was found to be more in the stations I and IV, which were adjacent to the open sea regions, and completely absent in the station III, which is away from the open sea area. In the station II, Phaeophyceae was comparitively less. This may be due to the absence of massive corals, which provide firm substratum for attachment of holdfast. Unavailability of suitable substratum may thus form a factor in determining the distribution of macro algae.

In the present study a total of 43 species of seaweeds were recorded. Chlorophyceae was represented by 17 species, Rhodophyceae by 20 and Phaeophyceae by 7 species. Chlorophyceae comprises 2 orders, namely Ulvales and Chladophorales. Family Ulvaceae of the order Ulvales include *Enteromorpha compressa, E. tubulosa, Ulva lactuca* and *U. reticulata.* Order Cladophorales include 4 families - Cladophoraceae, Caulerpaceae, Codiaceae and Valoniaceae. *Chaetomorpha aerea, C. antennina, C. linoides* and *Cladophora fascicularis* belong to the family: Cladophoraceae; *Caulerpa cupresoides, C. taxifolia, C. peltata, C. sertularioides* and *C. racemosa* belong to the family Caulerpaceae, *Codium tomentosum* and *Halimeda gracilis* belong to the family Codiaceae and *Boergesenia forbesii* form the single representative of the family: Valoniaceae.

Class: Phaeophyceae comprises 3 orders, namely, Dictyotales, Dictyosiphonales and Fucales. Single families, Dictyotaceae, Punctariaceae and Sargassaceae, represent each of these 3 orders respectively. *Dictyota* sp. and *Padina gymnospora* represented Dictyotaceae. *Hydroclathrus clathratus* is the only representative of the family: Punctariaceae. Order: Fucales include the family: Sargassaceae, which consists of 3 species, namely *Sargassum duplicatum, S. whitii* and *Turbinaria ornata.*

Class: Rhodophyceae include 4 orders such as Gelidiales, Cryptonemiales, Gigartinales and Bangiales. Order: Gelidiales consists of two families namely Gelidiaceae and Gelidiellaceae, which are represented by *Gelidium pusillum* and *Gelidiella acerosa* respectively. Order Cryptonemials include 2 families Corallinaceae and Grateloupaceae *Amphiroa* sp., *Jania capillaceae* and *Lithothamnion* sp. represent the family Corallinaceae and *Halimnea floresia* represents the family: Grateloupaceae 4 families constitute the Order Gigantinales namely Gracilariaceae, Hypneaceae, Solieraceae and Rhodomelaceae. Family Gracilaraceae comprises 7 species of *Gracilaria,* namely *Gracilaria lichenoides, G. edulis, G. crassa, G. verrucosa, G. arcuata, G. corticata* and *G. folifera*. The economically important seaweed, *Gracilaria edulis* was prominent in the seagrass meadow. Earlier Jagtap (1998) reported the dominance of this species in the lagoons of Lakshadweep islands.

Family: Hypneaceae is represented by *Hypnea musciformis* and *H. valentiae*. *Sarconema furcellatum* forms the sole member of the family: Solieraceae. *Acanthophora spicifera, Laurencia papillosa* and *L. obtusata* represents the family: Rhodomelaceae. Order: Bangiales include single family Bangiaceae, which consists of a single species, *Porphyra indica.*

Among Chlorophyceae, *Caulerpa* form the dominant genus and was represented by 5 species, followed by *Chaetomorpha* with 3 species. *Boergesenia forbesii* of the family Valoniaceae is the rare species. Among Phaeophyceae, *Sargassum* was the dominant genus having 3 species. *Gracilaria* was the dominant genus among Rhodophyceae and represented by 7 species.

An understanding of the occurrence of seasonal and spatial changes in macro-algal population is an important aspect of their biology as their distribution and abundance in the lagoon were quite variable from one location to another. Macro algae may be present in seagrass beds as large clumps of detached drift algae (Josselyn, 1977; Williams-Cowper, 1978; Benz *et al.,* 1979; Virnstein and Carbonara, 1985; Bell and Hall, 1997). Species of drift algae found commonly in the seagrass meadow of Minicoy lagoon include *Hypnea, Laurencia, Chaetomorpha,* etc. In the station I *Hypnea musciformis* and in station II different species of *Chaetomorpha* were abundant. High biomass was observed during post monsoon season and less during late pre monsoon and early monsoon periods. Abundant detached bundle of *Turbinaria ornata* and *Sargassum duplicatum* were observed during post monsoon season. Such seasonal variations in algal biomass associated with seasonal changes were observed by Josselyn (1977). However the factors that control drift algal distribution and abundance are not fully known and need to be studied further. Drift algae like *Laurencia* sp. have been found to be important contributors to primary production and have also been recognized as important habitat for numerous invertebrate species (Virnstein and Carbonara, 1985).

Benthic or rhizophytic macro algae such as *Caulerpa* and *Halimeda* are important in stabilizing sediments and adding organic matter, thereby facilitating seagrass succession (Williams, 1990; Thayer *et al.,* 1994). Rhizophytic algae have been intensively studied in South Florida as producers of carbonate sediments (Wefer, 1980; Drew, 1983). Williams (1990) found rhizophytic algae in the genera *Halimeda* and *Caulerpa* to be the primary colonizers invading empty plots within a few months. These algae stabilized the unconsolidated sediments and were found to increase nutrients in the sediment upon their demise, thereby facilitating the ability of seagrass to recolonize the bare patches. *Halimeda gracilis* inhabit shallow coasts and coral atolls. This calcareous alga is the integral part of the coral reef ecosystem and produce huge quantities of calcareous material, which can be useful in the formation of reefs (Siddiquie, 1980; Krishnamurthy and Jayagopal, 1995). Productivity was higher in the monsoon season and reduced productivity or even absence during pre monsoon. Where there is a limited amount of suitable substrate, the macro algal community is rather sparse. *Halimeda gracilis* forms the dominant contributor of biomass in most of the stations. This species was found to be the first colonizer in the bare sandy areas in Minicoy lagoon, the abundant growth of which trap and stabilize sediments and creates a nutrient rich stable area for the colonization of seagrass and macro algae (Jagtap, 1998). They also provide calcareous material for the reef building. The genus *Caulerpa* forms one of the strong competitors in the seagrass community and interferes with the existing communities (Verlaque, *et al.,* 2000) and they were not limited by grazing because of the production of toxic substances (Boudouresque, *et al.,* 1996). The effect of sedimentation on the spread of *Caulerpa* species has yet to be considered, although the influence of sediment deposition and burial on macroalgal assemblages has been evaluated in sub tidal habitats worldwide (Chapman and Fletcher, 2002; Airoldi, 2003). Along the Tuscany coast (northwestern Mediterranean Sea), correlative and experimental studies showed that high sedimentation rates could damage Mediterranean macroalgal assemblages and increase the competitiveness of filamentous species (Airoldi, *et al.,* 1995; Piazzi and Cinelli, 2001). These algae were characterized by an efficient vegetative growth that allows them to reconstitute assemblages quicker than species reproducing sexually (Airoldi and Virgilio, 1998). Moreover filamentous species form turfs that may trap sediment increasing their competitiveness (Kendrick, 1991). Large mats of filamentous algae were observed in the seagrass areas in the station II, where large scale sedimentation results due to the coastal constructions. Caulerpales show high vegetative growth and capacity to trap sediment through mechanisms similar to turf species. A synergism between the increase of sedimentation and invasions of *Caulerpa* is likely to occur in the coastal habitats. The abundance of *Caulerpa* was observed in the station III. The studies of Piazzi *et al.,* (2005), revealed that the growth of *Caulerpa racemosa* was not affected by an increase of sedimentation rate. Thus it showed a high adaptability to physical and biotic factors. In fact, it may spread on all types of substrate, in sheltered and exposed areas, at depths ranging from the intertidal down to 70m (Argyrou, *et al.,* 1999); more over it may colonize both macroalgal and seagrass meadows (Ceccherelli and Campo, 2002). In view of these facts a multifactorial studies are necessary to understand the mechanisms involved in the effects of *Caulerpa* and *Halimeda* on the sedimentation, when more disturbances co-occur and the long-term effects on benthic assemblages.

Epiphytic macro algae, especially filamentous and sheet like green (*Enteromorpha* and *Ulva*) and red algae (*Gelidiella acerosa*) grow attached to the seagrass blades (Humm, 1964). Epiphytes shade light to the seagrass blades and thereby reduce productivity of the seagrasses (Zieman, 1975; Bulthuis and Woelkerling, 1983; Jensen and Gibson, 1986). Nutrient enrichment as occurs around sewage outfall areas greatly stimulates epiphytic growth (Lapointe *et al.,* 1994). This situation leads to the destruction of seagrasses from the village areas of Minicoy. Mohammed *et al.,* (1999) reported the abundance of *Caulerpa* in the polluted site of Minicoy lagoon where the seagrasses gradually decreasing. The dominance of green alga *Caulerpa racemosa* was reported by Piazzi, *et al.* (2005) in the Mediterranean Sea. There, it is widely colonized and interfering the natural seagrass population. This area is characterized by the dumping of domestic wastes, tuna fish cleaning and harbour activities. Epiphytes have been identified as important contributors of primary production in seagrass systems and may dominate total primary production in some systems (Jensen and Gibson, 1986; Moncreiff, *et al.,* 1992). This is in part caused by the ephemerality of seagrass blades, causing the epiphytes to have a rapid turnover rate (Zieman, 1982). Numerous species of drift algae may contribute as it senesces (Benz *et al.,* 1979). Calcareous epiphytes can contribute to biogenic carbonate production along with the rhizophytic algae (Frankovich and Zieman, 1994). The number of associated macro algae from the study area was relatively less compared to the marine algae from the seagrass meadows from southeast coast of India (Jagtap, 1996).

Biomass: Data on the macro algal biomass in seagrass communities, particularly in coastal lagoons are limited despite the recognition of their importance (Mc Roy and Mac Millan, 1977; den Hartog, 1979; Bologna and Heck, 1999; Mohamed *et al.*, 1999; Koya, 2000; Eklof, *et al.*, 2005). The algae typical of these communities include forms, which can anchor in the sediments and unattached entanglements of green and red algae, especially *Chaetomorpha, Cladophora, Enteromorpha* and *Gracilaria* (Dillon, 1971). It ahs been suggested that environmental parameters influence the seasonal and spatial abundance of macro algae in the tropics (De Wreede, 1976). Light and water temperature in the warmer months were the important facteros determining then variations in the biomass and abundance of algal vegetation (Conover, 1964). Santelices (1977) stressed the importance of water movement as a seasonally significant factor in the tropics. Stephenson and Stephenson (1972) described the tropical and subtropical shores by its sea surface temperatures, which does not fall below 20°C and commonly exceeds 23.5°C. This study on the population of Tihuara reef showed that the environment affects the morphology and biology of the macro algae. Density and biomass as well as the abundance of the holdfast increased in the exposed sites while on the contrary, branching, plant size and individual species biomass decreased (Pyari, 1984). Banaimoon (1988) studied the marine algal resources of Khalf, PDR Yemen, and found that the growth of algae was most active from July to September. In the present study it was found that the Chlorophyceae was abundant during the monsoon season; Rhodophyceae, during both monsoon and post monsoon seasons and Phaeophyceae, only during post monsoon. The studies of Richard Mc Curt (1984) revealed that *Sargassum* spp. were most abundant during winter in tropical regions and during summer months in temperate zone.

From the *ANOVA* results, it was seen that the variations of Chlorophyceae biomass between season as well as station were significant at 1% level with a significant R^2 value (R^2 = 0.570), indicating that the overall variations in Chlorophyceae were considerably significant with regard to the spatial and temporal distribution of Phaeophyceae and Rhodophyceae. It was also observed that variations in Rhodophyceae between season and station were also significant. The variation in Phaeophyceae was not very significant.

The computation results of Pearson's correlation between total seaweed biomass and hydrographical parameters, revealed that at station I, pH is significantly correlated (r = 0.492; $p < 0.05$). It is also observed that temperature and nitrite showed negative relationship with the total seaweed biomass in this station, where as with other parameters such as salinity, DO, phosphate, nitrite and silicate, a positive relationship was emerged. The negative correlation indicates an inverse relationship with total biomass at station I, signifying that temperature as well as nitrite had influences on the overall seaweed biomass in this zone. In the station IV, pH and DO were significantly correlated (r =0.599 and 0.694; $p < 0.01$). Station I and IV were characterised by the direct influence of open sea. These indicate that pH and DO influences the distribution and biomass of seaweeds of all groups in the seagrass ecosystem of Minicoy lagoon. From the correlation values, it was found that the biomass of Chlorophyceae and Rhodophyceae determines the amount of total seaweed biomass in station I, III and IV, where both of this group co-exist. In the station II, the Chlorophyceae alone determines the amount of total seaweed biomass.

The results of Pearson's correlation analysis of seaweed groups (Chlorophyceae, Phaeophyceae and Rhodophyceae) revealed that in the station I, no significant correlation with hydrographic parameters was existed. In the station II, biomass of Phaeophyceae was significantly correlated (r = 0.672; $p < 0.01$). In the station III, the biomass of Rhodophyceae was significantly correlated with nitrate and nitrite (r = 0.501 and 0.455; $p < 0.01$) at

1% level. In the station IV, only the significant correlation was observed between Chlorophyceae and DO (r = 0.418; $p <$ 0.05). So, in general, the nutrient status of the water column is not at all a limiting factor for the distribution and abundance of macro algae in the seagrass ecosystem of Minicoy lagoon. From the results it was found that the biomass of Chlorophyceae and Rhodophyceae at station I were interdependent and have a tendency to co- exist. From the field observations, it can be assumed that the topographical and physical factors have more influence on the distribution and abundance of macro algae in the seagrass ecosystem of the lagoon.

Seaweed – Seagrass Interactions

The functional roles of algae in seagrass ecosystem are numerous. They include increased habitat complexity, primary production and trophic cycling as well as sediment stabilization and potential successional facilitation in the case of rhizophytic algae (Zieman, 1982). Habitat complexity is increased by the presence of all three groups of algae, but especially in the case where aggregations of drift algae occur. This increases the potential number of niches available, leading to greater species richness and abundance (Stoner and Graham-Lewis, 1985). Drift algae have been found to support an abundant benthic fishes and invertebrates (Heck and Thoman, 1981; Smith and Herrnkind, 1992). Juvenile of numerous benthic species, including the commercially important spiny lobster, preferentially settle and then spend a large portion of the juvenile stage amongst drift algae (Herrkind and Butler, 1986). Holmquist (1994) further demonstrated the ability of benthic fauna to disperse using clumps of drifting algae, which may be beneficial especially to species without extended planktonic larval stages. Seagrass community primary production is enhanced in the presence of algae, especially epiphytes. Up to 90% of the materials assimilated by grazers are algae rather than seagrass (Dimberger and Kitting, 1988). This has been shown by the feeding preference studies by Gleason, (1986) as well as research using stable isotopes, which have been used to follow trophic utilization of algal vs. seagrass detritus (Fry *et al.,* 1982; Kitting *et al.,* 1984). This may be in large part because algae can be assimilated by the herbivores with greater efficiency than seagrass (Moore *et al.,* 1963; Zimmerman, *et al.*, 1979). Algae contain less refractory matter and have been found to break down quicker under microbial action, with subsequent nitrogen enrichment of the breakdown particles (Odum and Haeld, 1972). The structural complexity of the seagrass community includes species of algae (Zieman, 1982; Biber and Irlandi, 2006) that can be grouped into drift algae (eg: *Laurencia* sp.) rhizophytic algae (*eg*: *Caulerpa* sp., *Halimeda* sp.) and epiphytes (eg: *Enteromorpha* sp.) The algae typical of these communities include forms, which can anchor in sediments and unattached entanglements of green and red algae, especially *Chaetomorpha, Cladophora and Gracilaria* (Dillon, 1971; den Hartog, 1979) and epiphytes attached to the leaves of the seagrasses. The physical structure of seagrasses and algae combined together not only provides shelter for larger organisms such as fish, but also provide a large surface area for the growth of epiphytes, there by supporting invertebrate grazers, which in turn provide food for higher trophic levels (Schwarz, *et al.*, 2006). Both the drifting and rhizophytic macro algae in the seagrass ecosystem increases the structural complexity as they acts as food source for numerous organisms and as a shelter. The rhizophytic algae in addition, trap and stabilize sediments. The decay of macro algae supplies nutrients to the system, which in turn enhances the seagrass colonization. The seagrasses, in turn provides a stable substratum and moderately calm water column. Seagrass leaves also acts as the substratum for epiphytic algae. In the station I, seagrass biomass is well correlated (r = 0.596) with the biomass of Phaeophyceae. This station is adjacent to the reef and by the presence of massive corals and bare sand, both enhances the growth of brown algae, such as *Turbinaria* and *Padina.* The most abundant seagrass in this station is *Halophila ovalis,* which form the first colonizer of the seagrass community in the bare sand and have small thallus and less shoot density. So the sedimentation was also less, which enhances the coral growth.

In the station II and III, no specific correlations were observed between seaweed biomass and seagrass biomass and shoot density. These stations were characterised by the shallow enclosed topography, which may influence the growth of Chlorophyceae, which is comparatively abundant in this station. Water movement is less in this station, so that the seaweeds can grow well in this station. In the station IV, Chlorophyceae and Rhodophyceae were well correlated (r = 0.448 and 0.451 respectively) with the seagrass biomass and Phaeophyceae, negatively correlated. The seagrass shoot density was influenced the biomass of Chlorophyceae only in this station. Other groups were not related to the shoot density. This station is characterised by strong wave action and occupied with massive corals in the sub littoral zone. The presence of high shoot density provided a stable calm area for the growth of seaweeds; meanwhile the massive corals provided the substratum for the attachment of holdfasts of brown algae such as *Turbinaria, Sargassum,* *Padina, etc.* Numbers of species of seaweeds were highest in the station IV, followed by station I, where the corals and seagrass co-exist and they mutually enhance the growth and abundance of seaweeds. In the station I, massive corals were less abundant and correspondingly the brown algae were comparatively less and totally absent in the station III. In this station Phaeophyceae was completely absent. In short, the changes on the tidal emergence and submergence, topography of the coast, surf action, levels at which the plants grow contribute much to the fluctuations in the growth, abundance and behaviour of macro algae (Chennubotla. *et al.*, 1987).

From the results it is concluded that the potential for changes in the distribution and abundance of macro algal communities of seagrass habitats can be correlated with changes in environmental regime, especially pH and DO. Availability of suitable substratum is also a major factor in the abundance and distribution of seaweeds. In this context, studies on their distribution, abundance, seasonality and production of seaweeds are important and the basic studies are essential in the conservation of these important renewable resources.

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Chapter VI

Macro invertebrate fauna

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6. 1. Introduction

Tropical coastal zones support a high diversity of seagrass species and respective associations, having different factors contribute to their distribution and production variability. Seagrass beds are characteristics of estuarine and marine coastal environments and known to enhance species diversity (Pihl, 1986; Heck *et al.*, 1989; Edgar, 1990). The root rhizome system of seagrasses forms a dense matrix, which penetrates the substratum and anchoring the plant. Seagrass meadows constitute areas of high productivity, providing habitat, feeding and breeding ground for a variety of fauna (Larkrum *et al.,* 1989; Heck *et al.*, 1995). These meadows support a high diversity and abundance of associated fauna and other biological assemblages such as micro-phyto benthos and microorganisms (Ansari, 1984; Schneider and Mann, 1991). Seagrass affect sediment stability, current speed (Orth, 1977; Fonseca and Bell, 1998; Terrados *et al.*, 1998), provide complexity (Ansari *et al.*, 1991) and modify biotic interactions (Orth *et al.*, 1984; Summerson and Peterson, 1984) or food availability.

The faunal assemblages associated with seagrasses can be sub divided into several structural subunits (Kikuchi and Peres, 1977) as follows: (1) Species living on the leaves including micro and meiofauna, sessile, mobile creeping and swimming epifauna, (2) species attached to stems and rhizomes (3) mobile species under and over the leaf canopy and (4) infauna including burrowers and the tube dwellers as well as those animals creeping or crawling at the sediment – water interface, according to their distribution within the meadow. Mobile epifauna consists of amphipods, gastropods, isopods, and free-living polychaetes. Sessile epi-fauna are mainly hydrozoans, bryozoans and tubicolous polychaetes; infauna is mainly burrowing amphipods and a variety of bivalves, polychaetes and decapod crustaceans, and epi-benthic species are mainly resident and transient fishes (Howard, *et al.*, 1989).

The macro invertebrate faunal groups present in the seagrass meadow of Minicoy lagoon include sponges, cnidarians, platyhelminthes, annelids, crustaceans, molluscs and echinoderms.

i) Sponges: The members of this group are mainly plant like immobile animals have a body structure unlike that of ant other group of invertebrates. The majority of them are marine, but a few species occur in fresh water. Their body from is extremely variable, being influenced by the type of substratum and the amount of water movement. Where water movements are strong, they may often grow as round or flattened clumps, but in calmer waters they may assume branching tree-like shapes. Sponges are found in all seas, living mainly in shallow waters although some occur at great depths. The majority of them attach themselves to any suiTable substratum such as rock, hard-shelled animals, seaweeds and seagrasses. A few species bore into rocks and shells. The growth of sponges varies according to the habitat conditions.

ii) Cnidarians: Representatives of this group, which includes jellyfishes, hydroids sea anemones and corals, are found on the sea bottom from the seashore to abyssal depths and also as floating in plankton community. Cnidarians include 3 classes, namely, Hydrozoa, Scyphozoa and Anthozoa. Majority of the hydroids are marine, while scyphozoans and anthozoans are totally marine.

iii) Platyhelminthes: Only two classes, the Turbellaria and the Gnathostomulida contain free-living marine species.

iv) Annelids: Includes a large group of worms, the majority of which are marine, but includes a substantial proportion of terrestrial and freshwater forms. Polychaetes were the dominant group in this category.

v) Crustaceans: Most crustaceans are marine. The majority of the planktonic animals are crustaceans and is well represented on the sea-bottom from the shore to abyssal depths. They range in size from microscopic planktonic forms to the large bottom living spider crabs, massive lobsters, etc.

vi) Molluscs: Molluscs are one of the largest and the most successful groups of invertebrate animals, includes the snails, mussels, oysters and octopuses. Many molluscs are found in the sea.

vii) Echinoderms: Echinoderms are common in the Lakshadweep waters from the shallow inter tidal region to deeper areas. They include holothurians, brittle stars and sea urchins.

In this section, species composition, abundance, distribution and community structure of macro-invertebrate fauna were analysed in relation to the hydro-biological parameters of the seagrass ecosystem.

6.2. Results

A total of 217 species of macro-invertebrate fauna were identified from the seagrass meadow (Table 6.1) during the study period. The station wise distribution of all the species was listed in this Table. The whole animals were grouped into 7 categories. The percentage composition and number of species of fauna in each group were represented in the Fig. 6.1. and 6.2.

6.2.1. Species composition

The faunal community constitutes 22 species of sponges, 19 species of cnidarians, 4 species of platyhelminthes and annelids, 48 species of crustaceans, 100 species of molluscs and 20 species of echinoderms.(Plate 7-17)

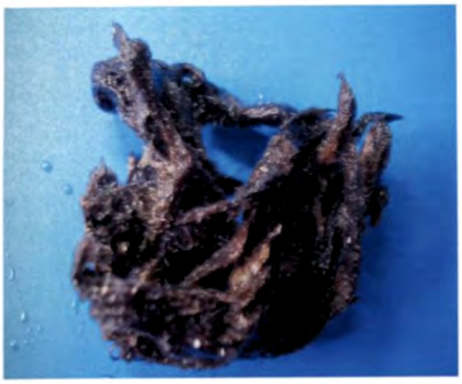
(i) Sponges: *Clathrina* sp., *Scypha ciliata, Dysidea fragilis, Fasciospongia cavernosa, Ircinia compana, Aurora globostellata, Cliona* sp, *Spirastrella inconstans, Suberites* sp., *Tethya diploderma, Xenospongia* sp., *Halichondria* sp., *Haliclona pigmentifera, Haliclona tenuiramosa, Callispongia* sp., *Gelliodes cellaria, Sigmadocia fibulata, Hyatella cribriformis, Spongia officianalis, Echinodictyum longistylum, Thalysias reinwardti* and *Psammaplysilla purpurea.*

(ii) Cnidarians: *Alcyonium palmatum, Anthopleura* sp., *Gyrostoma* sp., *Ilyanthus* sp., *Stychodactyla helianthus, Stychodactyla* sp., *Favia* sp., *Goniastrea retiformis, Fungia* sp., *Psammocora* sp., *Heliopora coerulea, Tubipora* sp., *Zoanthus sociatus, Zoanthus* sp., *Millepora complanata, Zanclea* sp., *Stylaster elegans, Physalia physalis* and *Porpita porpita.*

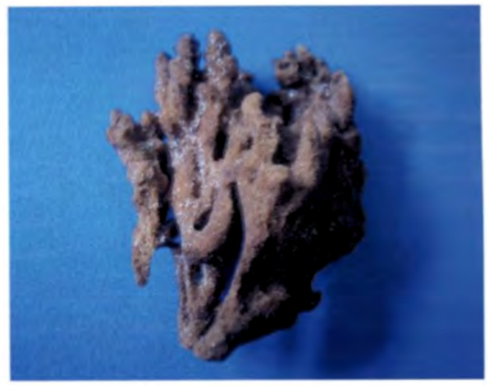
(iii) Platyhelminthes: *Pseudoceros corallophilus Pseudoceros dimidiatus Pseudoceros hancokonus* and *Pseudoceros* sp.

(iv) Annelids: *Glycera* sp., *Glycera tesselata, Neries* sp. and *Spirobis spirobis*

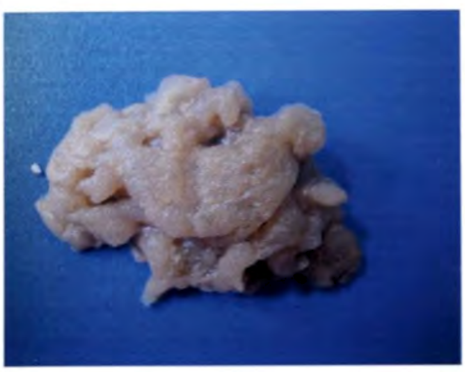
Plate 7



(a) *Echinodictyum longistylum*



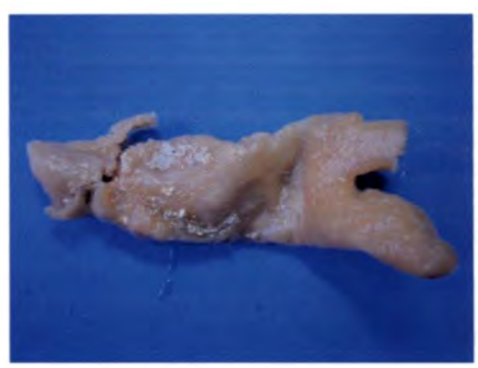
(b) *Hyatella cribriformis*



(c) *Haliclona tenuiramosa*

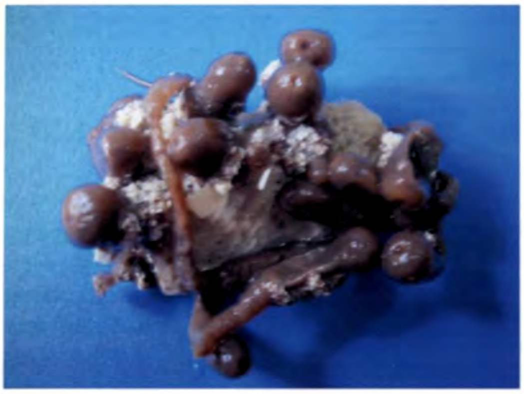
(d) *Sigmodocea fibulata*

(e) *Psammaplysilla purpurea*



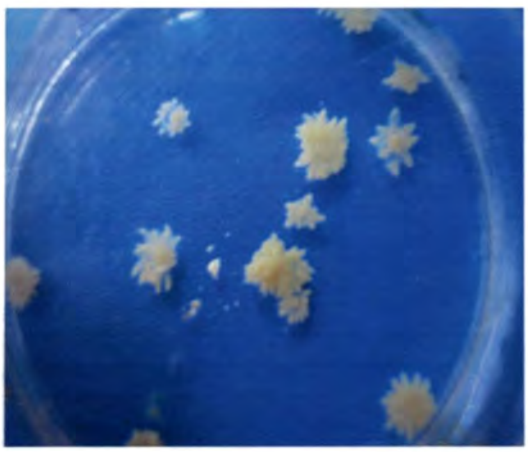
(f) *Spirastrella inconstans*

Plate 7. Sponges obtained during the study period from the seagrass meadow of Minicoy lagoon



(a) *Zoanthus sociatus*

(b) *Zoanthus* sp.



(c) *Stylaster elegans*

(d) *Physalia physalis*

(e) *Pseudoceros* sp.

(f) *Spirobis spirobis*
(attached to the shell)

Plate 8. Cnidarians (a to d), Platyhelminthes (e) and Annelid (f) obtained during the study period from the seagrass meadow of Minicoy lagoon

(v) Crustaceans: *Cymadusa imbroglio, Gammarus locusta, Maera pacifica, Mallacoota insignis, Stenothoe kaia, Gonodactylus* sp., *Squilla* sp., *Alpheus* sp., *Calappa calappa, Calappa lophos, Calappa* sp., *Clibanarius* sp., *Dardanus arrosar, Dardanus* sp., *Dromia* sp., *Emerita* sp., *Eriphia* sp., *Graspus strigosus, Lomis hirta, Maja* sp., *Pagurites squamosus, Pagurus calidus, Pagurus handreckii, Pagurus* sp., *Strigopagurus elongatus, Strigopagurus* sp., *Macropipus* sp., *Portunus* sp., *Thalamita crenata, Ocypoda ceratophthalma, Uca* sp., *Pinnotherus* sp., *Etisus* sp., *Actaea savingneyi, Platypodia cristata, Ixa* sp., *Coenobita* sp., *Parapandalus* sp., *Acetes* sp., *Panulirus ornatus, Panulirus versicolor, Palaeomon elegans, Penaeus latisulcatus, Penaeus* sp., *Metapenaeopsis* sp., *Lepas anatifera, Lepas* sp. and *Cypridina* sp.

(vi) Molluscs: *Codakia* sp., *Codakia tigerina, Gaffrarium disper, Gaffrarium divaricatum, Gaffrarium* sp., *Mesodesma* sp., *Tellina* sp., *Tridacna* sp., *Pinctada fucata, Pinctada margaritifera, Pinctada* sp., *Pinna muricata, Modiolus* sp., *Arca barberata, Atys cylindrica, Melo* sp., *Batillaria* sp., *Cerithidea cingulata, Cerithidea rhizophorarum, Terebralia palustris, Cerithium asperum, Cerithium carbonarium, Cerithium pfefferi, Cerithium sinensis, Cerithium* sp., *Rhinoclavis asper, Cymatium clandestinum, Cymatium* sp., *Cypraea arabica, Cypraea corica, Cypraea monita, Cypraea* sp., *Cypraea tigris, Cypraea xanthonotus, Fusitriton* sp., *Lambis crocata, Lambis* sp., *Lambis truncata, Strombus erythrinus, Strombus fasciatus, Strombus gigas, Strombus* sp., *Strombus urceus, Littorinopsis* sp., *Littorinopsis pintado, Littorinopsis undulata, Littorina scabra, Natica* sp., *Polinices melanostoma, Planaxis* sp., *Conus arenatus, Conus episcopus, Conus excavatus, Conus*

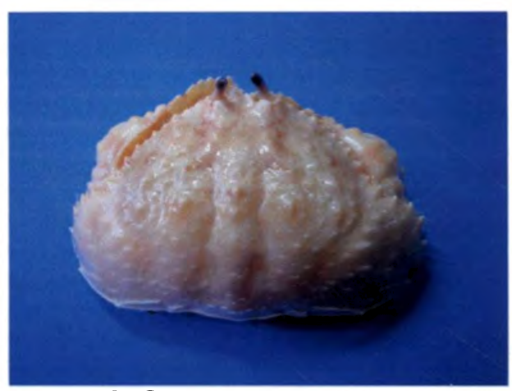
(a) *Cymadusa imbroglio*

(b) *Gammarus locusta*

(c) *Mallacoota insignis*

(d) *Stenothoe kaia*

(e) *Alpheus* sp.



(f) *Calappa calappa*

(g) *Ixa* sp.

(h) *Pinnotherus* sp.

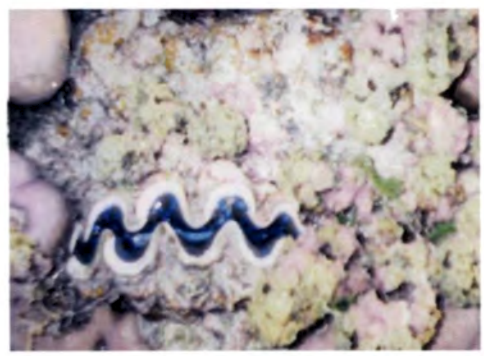
Plate 9. Crustaceans obtained during the study period from the seagrass meadow of Minicoy lagoon

Plate 10

(a) *Codakia tigerina*

(b) *Gaffrarium disper*

(c) *Tellina* sp.



(d) *Tridacna* sp.

(e) *Pinctada fucata*

(f) *Pinna muricata*

Plate 10. Bivalves obtained during the study period from the seagrass meadow of Minicoy lagoon

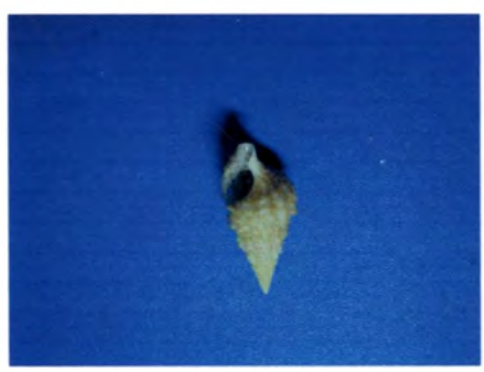
(a) *Batillaria* sp.

(b) *Cerithidea cingulata*

(c) *Cerithidea rhizophorarum*

(d) Terebralia palustris

(e) *Cerithium asperum*



(f) *Clipeomorus bifasciatus*

Plate 11. Gastropods obtained during the study period from the seagrass meadow of Minicoy lagoon

(a) Cerithium sinensis

(b) *Cerithium* sp.

(d) Cymatium clandestinum

(e) Cymatium sp.

(f) *Cypraea monita*

(g) *Cypraea* sp.

(h) *Fusitriton* sp.

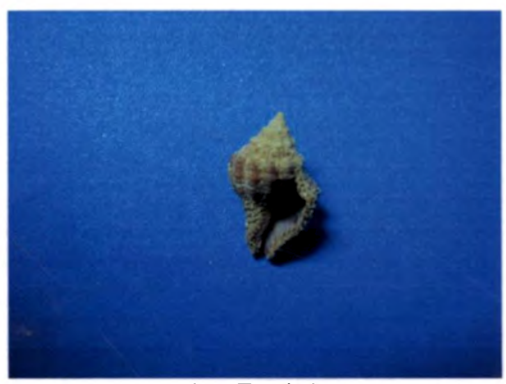
(i) *Conus* sp.

Plate 12. Gastropods obtained during the study period from the seagrass meadow of Minicoy lagoon

(a) *Lambis truncata*

(b) *Lambis* sp.

(c) *Columbella versicolor*



(d) *Fusitriton* sp.

(e) *Strombus urceus*

(f) *Strombus* sp.

Plate 13. Gastropods obtained during the study period from the seagrass meadow of Minicoy lagoon

Plate 14

(a) *Littorinopsis pintado*

(b) *Littorinopsis scabra*

(c) *Natica* sp.

(d) *Planaxis* sp.

(e) *Conus* sp.

(f) *Morula* sp.

(g) *Pyrene misera*

(h) *Pyrene* sp.

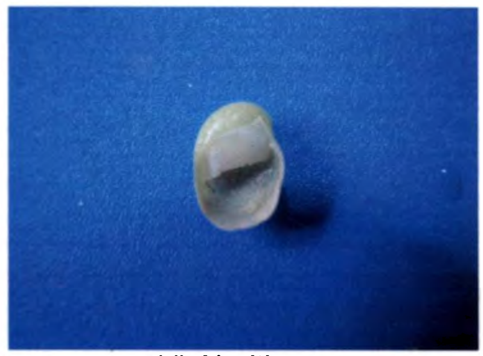
Plate 14. Gastropods obtained during the study period from the seagrass meadow of Minicoy lagoon

Plate 15

(a) *Drupa granulata*

(b) *Drupa spathulifera*

(c) *Drupa* sp.



(d) *Neritina* sp.

(e) *Olivia episcopalis*

(f) *Nassa* sp.

(g) *Nerita polita*

(h) *Nerita turrita*

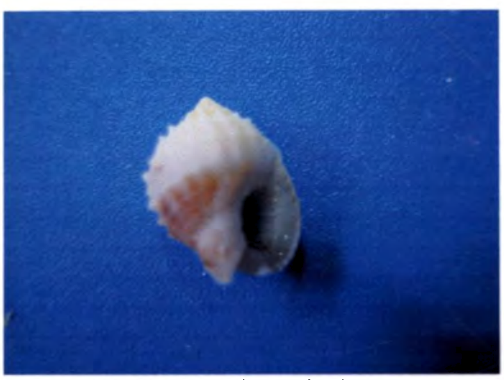
Plate 15. Gastropods obtained during the study period from the seagrass meadow of Minicoy lagoon

(a) *Nerita plicata*

(b) *Nerita chameleon*

(c) *Nerita* sp.

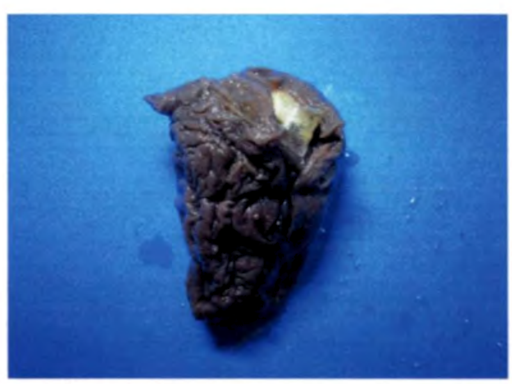
(d) *Neritopsis radula*



e) *Nassarius clathratus*

(f) *Nassarius* sp.

(g) *Turbo* sp.



(h) *Aplysia* sp.

Plate 16. Gastropods obtained during the study period from the seagrass meadow of Minicoy lagoon

planorbis, Conus sp., *Conus taeniatus, Conus textile, Conus virgo, Diodora rupelli, Drupa granulata, Drupa* sp., *Drupa spathulifera, Morula* sp., *Murex* sp., *Fasciolaria* sp., *Columbella* sp., *Harpa* sp., *Pyrene misera, Pyrene* sp., *Pyrene versicolor, Mitra* sp., *Nassa* sp., *Nassarius clathratus, Nassarius* sp., *Hemifusus ternatanus, Terebra strigata, Vasum turbinellus, Nerita albicilla, Nerita chameleon, Nerita plicata, Nerita polita, Nerita* sp., *Nerita turrita, Neritina* sp., *Smaragdia rangiana, Clithon sowerbianus, Puperita* sp., *Neritopsis radula, Olivia porphyria, Olivia* sp., *Tectus dentatus, Trochus erythraeus, Trochus* sp., *Turbo* sp., *Hexabranchus imperialis, Aplysia* sp., *Stylocheilus longicaudus, Acanthopleura* sp., *Loligo sp. and Octopus* sp.

(vii) Echinoderms: *Asterina* sp., *Oreaster* sp, *Echinometra mathaei, Echinothrix diadema, Echinothrix* sp., *Arbacia* sp., *Actinopyga mauritiana, Actinopyga miliaris, Bohadschia* sp., *Holothuria atra, Holothuria nobilis, Holothuria scabra, Holothuria spinifera, Euapta lappa, Ophiocnemus* sp., *Ophiocoma dentata, Ophiocoma* sp., *Ophiocoma texturata, Ophiomastrix* sp. and *Ophiomastrix annulosa.*

6.2.2. Distribution

Except in the station III, where platyhelminthes were absent, all the seven groups of macro- invertebrate fauna were present in the stations selected for the study. In the station I, 8 species of sponges, 6 species of cnidarians, 2 species of platyhelminthes, 3 species of annelids, 24 species of crustaceans, 51 species of molluscs and 8 species of echinoderms were present. In the station II, 6 species of sponges, 3 species of cnidarians, 1 species of platyhelminth, 2 species of annelids, 17 species of crustaceans, 42 species of molluscs and 9 species of echinoderms were present.

Table 6.1. Station wise distribution of macro invertebrate fauna in Minicoy lagoon

	Station I	Station II	Station III	Station IV
Clathrina sp.	+	+	+	-
Scypha ciliata	-	-	-	+
Dysidea fragilis	-	-	-	+
Fasciospongia cavernosa	-	-	-	+
Ircinia compana	+	-	-	-
Aurora globostellata	+	-	-	-
Cliona sp	-	+	+	+
Spirastrella inconstans	-	+	+	+
Suberites sp.	-	-	-	+
Tethya diploderma	+	+	+	-
Xenospongia sp.	+	-	-	-
Halichondria sp.	-	-	+	-
Haliclona pigmentifera	-	-	+	-
Haliclona tenuiramosa	-	-	-	+
Callispongia sp.	+	-	-	-
Gelliodes cellaria	-	-	-	+
Sigmadocia fibulata	+	+	+	+
Hyatella cribriformis	-	-	-	+
Spongia officianalis	-	+	-	-
Echinodictyum longistylum	-	-	-	+
Thalysias reinwardti	-	-	-	+
Psammaplysilla purpurea	+	-	-	-
Alcyonium palmatum	-	-	-	+
Anthopleura sp.	-	+	-	-
Gyrostoma sp.	-	+	-	-
Ilyanthus sp.	-	+	-	-
Stychodactyla helianthus	-	-	+	-
Stychodactyla sp.	-	-	-	+
Favia sp.	-	-	-	+
Goniastrea retiformis	-	-	-	+
Fungia sp.	-	-	-	+
Psammocora sp.	+	-	-	-
Heliopora coerulea	-	-	-	+
Tubipora sp.	+	-	-	-

Contd...

Zoanthus sociatus	+	-	-	-
Zoanthus sp.	-	-	-	+
Millepora complanata	+	-	-	-
Zanclea sp.	-	-	-	+
Stylaster elegans	+	-	-	-
Physalia physalis	-	-	+	-
Porpita porpita	+	-	-	-
Pseudoceros corallophilus	-	-	-	+
Pseudoceros dimidiatus	+	-	-	-
Pseudoceros hancokonus	+	-	-	+
Pseudoceros sp.	-	+	-	+
Glycera sp.	+	-	-	+
Glycera tesselata	-	+	-	-
Neries sp.	+	+	+	+
Spirobis spirobis	+	-	+	+
Cymadusa imbroglio	+	-	-	-
Gammarus locusta	-	-	+	-
Maera pacifica	+	-	+	+
Mallacoota insignis	+	+	+	+
Stenothoe kaia	+	+	+	+
Gonodactylus sp.	-	+	-	-
Squilla sp.	+	-	-	-
Alpheus sp.	+	+	+	+
Calappa calappa	+	-	-	-
Calappa lophos	+	-	-	-
Calappa sp.	-	+	+	-
Clibanarius sp.	+	-	+	+
Dardanus arrosar	-	+	-	-
Dardanus sp.	-	+	+	-
Dromia sp.	-	+	-	-
Emerita sp.	-	+	-	-
Eriphia sp.	+	-	+	+
Graspus strigosus	-	-	+	-
Lomis hirta	+	-	-	-
Maja sp.	-	-	-	+
Pagurites squamosus	-	-	-	+
Pagurus calidus	+	-	-	-

Contd...

Pagurus handreckii	-	-	-	+
Pagurus sp.	+	+	+	-
Strigopagurus elongatus	+	+	+	-
Strigopagurus sp.	-	+	-	-
Macropipus sp.	-	-	-	+
Portunus sp.	-	+	+	-
Thalamita crenata	+	+	+	+
Ocypoda ceratophthalma	+	-	-	-
Uca sp.	+	-	-	-
Pinnotherus sp.	-	+	+	-
Etisus sp.	+	-	+	-
Actaea savingneyi	+	-	-	+
Platypodia cristata	+	-	-	-
Ixa sp.	-	-	-	+
Coenobita sp.	-	+	-	-
Parapandalus sp.	+	-	-	-
Acetes sp.	-	+	-	-
Panulirus ornatus	-	-	+	-
Panulirus versicolor	-	-	-	+
Palaeomon elegans	+	-	-	-
Penaeus latisulcatus	-	-	+	+
Penaeus sp.	-	-	+	-
Metapenaeopsis sp.	-	-	-	+
Lepas anatifera	+	-	-	-
Lepas sp.	+	-	-	-
Cypridina sp.	+	-	-	-
Codakia sp.	+	+	-	-
Codakia tigerina	-	+	-	+
Gaffrarium disper	+	+	+	+
Gaffrarium divaricatum	-	-	+	-
Gaffrarium sp.	+	+	+	+
Mesodesma sp.	+	-	-	-
Tellina sp.	+	+	-	+
Tridacna sp.	+	-	-	+
Pinctada fucata	-	-	+	+
Pinctada margaritifera	-	+	-	+
Pinctada sp.	+	+	+	-

Contd...

Pinna muricata	+	+	-	+
Modiolus sp.	+	-	+	-
Arca barberata	-	+	-	-
Atys cylindrica	+	+	-	-
Melo sp.	-	+	+	-
Batillaria sp.	-	+	+	+
Cerithidea cingulata	-	+	-	+
Cerithidea rhizophorarum	-	+	+	+
Terebralia palustris	+	+	-	-
Cerithium asperum	-	+	+	+
Cerithium carbonarium	+	-	-	-
Cerithium pfefferi	+	+	+	-
Cerithium sinensis	+	-	-	-
Cerithium sp.	+	+	+	+
Rhinoclavis asper	+	-	-	-
Cymatium clandestinum	-	-	-	+
Cymatium sp.	+	-	+	-
Cypraea arabica	-	+	-	-
Cypraea corica	-	+	-	-
Cypraea monita	+	+	+	-
Cypraea sp.	+	+	-	-
Cypraea tigris	+	+	+	+
Cypraea xanthonotus	-	+	-	-
Fusitriton sp.	+	-	-	+
Lambis crocata	-	-	+	-
Lambis sp.	+	-	-	+
Lambis truncata	-	-	-	+
Strombus erythrinus	+	-	-	-
Strombus fasciatus	+	-	-	-
Strombus gigas	+	-	-	-
Strombus sp.	+	+	+	+
Strombus urceus	-	+	+	-
Littorinopsis sp.	+	+	+	+
Littorinopsis pintado	-	+	-	+
Littorinopsis undulata	-	-	-	+
Littorina scabra	-	+	+	-
Natica sp.	+	-	-	-

Contd...

Polinices melanostoma	+	-	-	-
Planaxis sp.	-	+	+	-
Conus arenatus	+	-	-	-
Conus episcopus	+	-	-	-
Conus excavatus	+	-	-	-
Conus planorbis	-	-	-	+
Conus sp.	+	+	-	+
Conus taeniatus	-	-	-	+
Conus textile	+	-	-	-
Conus virgo	-	+	-	-
Diodora rupelli	+	-	-	-
Drupa granulata	-	+	-	+
Drupa sp.	+	-	+	+
Drupa spathulifera	-	-	+	-
Morula sp.	-	-	-	+
Murex sp.	-	-	+	-
Fasciolaria sp.	-	-	-	+
Columbella sp.	+	+	+	-
Harpa sp.	-	-	-	+
Pyrene misera	+	-	-	+
Pyrene sp.	+	+	+	+
Pyrene versicolor	-	-	-	+
Mitra sp.	-	-	-	+
Nassa sp.	-	-	+	+
Nassarius clathratus	+	+	+	+
Nassarius sp.	-	-	+	+
Hemifusus ternatanus	-	-	+	+
Terebra strigata	-	+	-	-
Vasum turbinellus	-	-	-	+
Nerita albicilla	-	-	+	-
Nerita chameleon	-	-	+	-
Nerita plicata	+	-	-	-
Nerita polita	+	-	+	-
Nerita sp.	-	-	+	+
Nerita turrita	+	+	-	-
Neritina sp.	+	+	-	+
Smaragdia rangiana	-	-	+	+

Contd...

Clithon sowerbianus	-	+	+	-
Puperita sp.	+	-	-	-
Neritopsis radula	+	-	-	+
Olivia porphyria	-	-	-	+
Olivia sp.	-	-	-	+
Tectus dentatus	-	-	-	+
Trochus erythraeus	+	-	-	-
Trochus sp.	+	-	-	-
Turbo sp.	-	-	-	+
Hexabranchus imperialis	-	-	-	+
Aplysia sp.	+	+	-	-
Stylocheilus longicaudus	-	-	-	+
Acanthopleura sp.	+	-	+	-
Loligo sp.	-	-	+	-
Octopus sp.	+	-	-	-
Asterina sp.	+	-	-	-
Oreaster sp.	-	-	-	+
Echinometra mathaei	+	+	-	-
Echinothrix diadema	+	-	-	-
Echinothrix sp.	-	-	+	-
Arbacia sp.	-	+	-	-
Actinopyga mauritiana	-	-	-	+
Actinopyga miliaris	+	-	-	-
Bohadschia sp.	-	-	+	-
Holothuria atra	-	+	+	-
Holothuria nobilis	-	+	-	+
Holothuria scabra	-	-	+	-
Holothuria spinifera	+	-	-	-
Euapta lappa	+	-	-	-
Ophiocnemus sp.	+	+	-	-
Ophiocoma dentata	-	+	+	-
Ophiocoma sp.	+	+		+
Ophiocoma texturata	-	-	+	-
Ophiomastrix sp.	-	+	-	-
Ophiomastrix annulosa	-	+	-	-

\+ present - absent

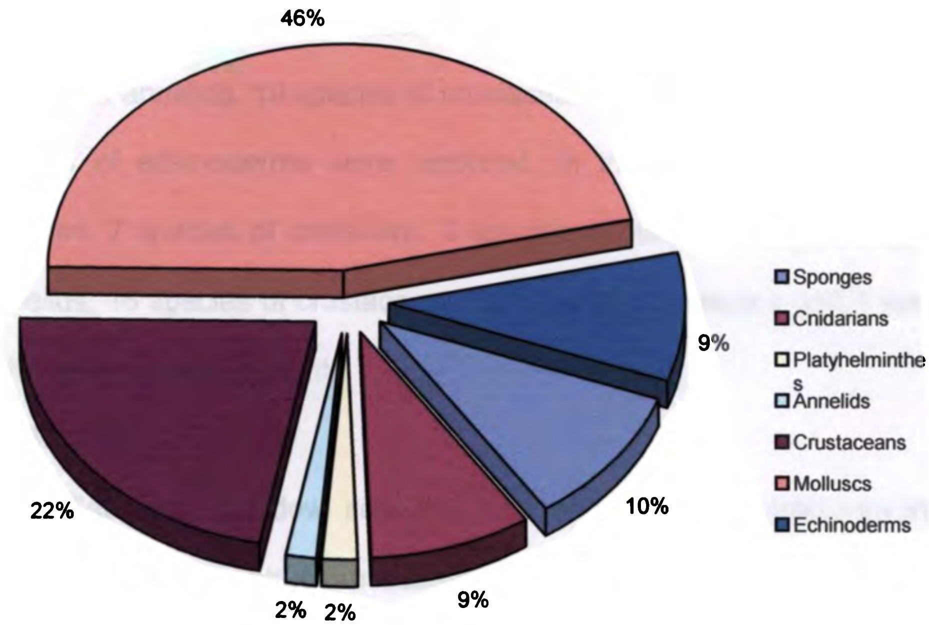


Fig. 6. 1. Percentage composition of faunal group recorded during the study period from the four stations of Minicoy lagoon

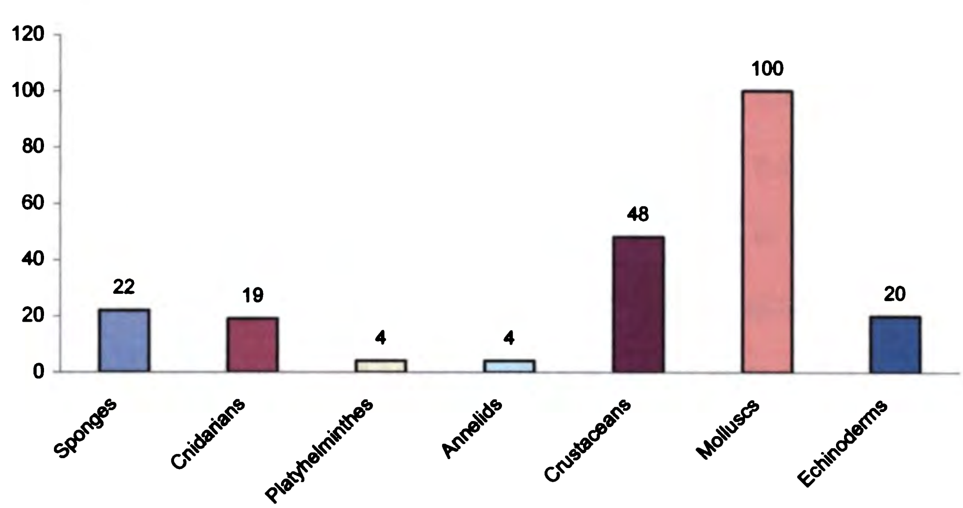


Fig.6.2. Number of species in each faunal group recorded during the study period from the four stations of Minicoy lagoon

In the station III, 7 species of sponges, 2 species of cnidarians, 2 species of annelids, 19 species of crustaceans, 38 species of molluscs and 6 species of echinoderms were recorded. In the station IV, 11 species of sponges, 7 species of cnidarians, 3 species of platyhelminthes, 3 species of annelids, 16 species of crustaceans, 56 species of molluscs and 4 species of echinoderms were present.

6.2.3. Abundance

Seagrass meadow supports high abundance of macro-invertebrate fauna. The complex structural habitat provides a suitable habitat for the faunal groups as food source, shelter and nursery grounds. The abundance of fauna is mainly controlled by the environmental, physical and biological parameters. In this study, the variations in faunal density were studied in relation to hydro-biological parameters. Monthly mean variations in total faunal density were represented in the Fig. 6.3. and seasonal variations in total faunal density were given in Fig. 6.4. The mean seasonal and spatial variations of faunal groups were given in the Figs. 6.5 and 6.6 respectively. List of 10 dominant species in each station were presented in the Table 6.2 and number of species in each group in the four stations were shown in the Table 6.3. *3-WAY ANOVA* was done to find out the variations in the abundance of faunal groups between stations and seasons and the results were given in the Table 6.4. For finding out the relationships of faunal groups with various hydro-biological parameters, Pearson's correlations were found out and the results were depicted in the Table 6.5a to 6.5d. Draftsman scatter plot showed no significant correlation (Fig. 6.7) between various groups (Table 6.6) of fauna.

Station I: Highest monthly mean density of total fauna recorded in this station was 142 no. /m^2 in September (68 to 216 no. /m^2), which was mainly

Table 6.2. Percentage composition of dominant species of fauna in the four stations of Minicoy lagoon

Station I	
Species	**%**
Cerithium sp.	25
Pyrene sp.	9.3
Spirobis spirobis	4.2
Stenothoe kaia	3.8
Neritina sp.	2.2
Cerithium pfefferi	2.2
Terebralia palustris	2.2
Strombus sp.	2.0
Nerita turrita	1.7
Gaffrarium disper	1.7

Station II	
Species	**%**
Cerithium sp.	24
Batillaria sp.	9.4
Cerithidea cingulata	6.7
Neries sp.	5.1
Neritina sp.	5.1
Cerithium pfefferi	4.9
Pagurus sp.	4.8
Pyrene sp.	3.7
Gaffrarium sp.	3.0
Acetes sp.	2.4

Station III	
Species	**%**
Cerithium sp.	28.1
Cerithium asperum	4.7
Littorinopsis sp.	4.5
Pyrene sp.	4.3
Gaffrarium sp.	4.3
Gammarus locusta	3.2
Strombus sp.	3.0
Spirobis spirobis	2.8
Gaffrarium disper	2.0
Spirastrella inconstans	1.8

Station IV	
Species	**%**
Cerithium sp.	22.3
Pyrene sp.	5.3
Stychodactyla sp.	4.9
Pinctada margaritifera	4.7
Neries sp.	3.7
Littorinopsis undulata	3.4
Pyrene misera	3.4
Batillaria sp.	3.3
Alpheus sp.	2.5
Stenothoe kaia	2.2

Table 6.3. Distribution of number of species in the faunal group

Faunal Group	No. of species			
	Station I	Station II	Station III	Station IV
Sponges	8	6	7	11
Cnidarians	6	3	2	7
Platyhelminthes	2	1	0	3
Annelids	3	2	2	3
Crustaceans	24	17	19	16
Molluscs	51	42	38	56
Echinoderms	8	9	6	4

Table. 6.4. ANOVA of density of fauna of Minicoy lagoon during the study period

Source	df	Mean Square	F	Sig.
Corrected Model	47	90.042	25.776	0
Intercept	1	2686.234	768.981	0
SEASON	2	21.35	6.112	0.002
STATION	3	12.762	3.653	0.012
FAUNA	6	657.018	188.083	0
SEASON * STATION	6	3.189	0.913	0.485
SEASON * FAUNA	12	3.224	0.923	0.523
STATION * FAUNA	18	8.393	2.403	0.001
Error	624	3.493		
Total	671			
$R^2 = 0.660$				

Table 6.5a. Correlation of faunal groups with hydro-biological parameters in the Station I

	Sg biomass	Sg shoot density	Chloro	Phaeo	Rhodo	Spng	Cnd	Platy	Annld	Crusta	Molsc	Echinod	Temp	Sal	pH	DO
Sg biomass	1															
Sg shoot density	.512(*)	1														
Chloro	0.117	0.34	1													
Phaeo	.596(**)	-0.033	-0.181	1												
Rhodo	0.177	0.258	.837(**)	-0.151	1											
Spng	**.405(*)**	**.626(**)**	0.157	0.027	0.13	1										
Cnd	0.165	0.08	0.2	-0.089	-0.025	-0.024	1									
Platy	-0.116	0.036	-0.02	-0.112	0.253	-0.176	-0.14	1								
Annd	**.440(*)**	0.201	0.15	-0.063	0.267	0.122	0.161	-0.118	1							
Crusta	-0.01	-0.124	-0.025	0.336	-0.219	0.132	0.035	-0.185	-0.098	1						
Molsc	-0.051	0.344	0.022	-0.161	-0.199	0.156	0.162	-0.113	0.177	-0.029	1					
Echinod	0.191	**.425(*)**	-0.02	-0.162	0.128	0.074	-0.18	**.487(*)**	0.179	-0.259	0.167	1				
Temp	-0.154	-.418(*)	-0.158	0.157	-0.016	-0.218	-0.17	0.043	-0.102	0.216	-0.055	-0.317	1			
Sal	0.228	0.201	-0.147	0.249	-0.07	0.038	0.096	0.237	0.014	0.364	-0.181	0.082	0.163	1		
pH	.775(**)	.490(*)	0.299	0.293	0.401	0.293	0.084	0.064	**.510(*)**	-0.122	-0.123	0.356	-0.33	0.11	1	
DO	.874(**)	.534(**)	0.165	0.343	0.263	**.405(*)**	0.193	-0.085	**.539(**)**	-0.03	-0.145	0.351	-0.264	0.27	.916(**)	1

* Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Table 6.5b. Correlation of faunal groups with hydro-biological parameters in the Station II

	Sg biomass	Sg shoot density	Chloro	Phaeo	Rhodo	Spng	Cnd	Platy	Annld	Crusta	Molsc	Echinod	Temp	Sal	pH	DO
Sg biomass	1															
Sg shoot density	.555(**)	1														
Chloro	0.261	0.048	1													
Phaeo	-0.186	0.031	-0.223	1												
Rhodo	0.025	0.128	0.002	-0.176	1											
Spng	-0.165	-0.133	-0.029	-0.29	0.399	1										
Cnd	0.177	-0.075	**.427(*)**	-0.143	0.402	0.185	1									
Platy	-0.008	-0.285	0.03	-0.099	0.01	-0.13	-0.063	1								
Annld	-0.106	-0.101	-0.118	-0.13	-0.158	-0.25	-0.104	-0.11	1							
Crusta	**.468(*)**	0.344	-0.096	-0.032	0.224	-0.01	-0.15	-0.21	-0.171	1						
Molsc	0.239	0.273	0.153	0.017	0.178	-0.25	0.083	-0.11	-0.057	0.29	1					
Echinod	**.593(**)**	0.388	0.069	0.027	-0.056	-0.15	0.089	-0.11	0.155	0.393	-0.073	1				
Temp	-.487(*)	-.422(*)	-0.205	0.029	-0.21	-0.38	-0.238	0.265	0.266	-0.371	-0.342	-0.397	1			
Sal	-0.128	0.027	-0.159	0.309	0.096	-0.36	-0.4	0.159	0.231	0.276	0.366	-0.107	0.175	1		
pH	.757(**)	0.225	0.315	-0.077	-0.211	-0.37	0.141	-0.07	0.125	0.333	0.261	**.494(*)**	-0.253	-0.11	1	
DO	.815(**)	.426(*)	0.236	-0.144	-0.054	-0.23	0.185	0.135	0.056	0.364	0.272	**.410(*)**	-0.248	-0.05	.814(**)	1

** Correlation is significant at the 0.01 level

* Correlation is significant at the 0.05 level

Table 6.5c. Correlation of faunal groups with hydro-biological parameters in the Station III

	Sg biomass	Sg shoot density	Chloro	Phaeo	Rhodo	Spng	Cnd	Platy	Annld	Crusta	Mollsc	Echin od	Temp	Sal	pH	DO
Sg biomass	1															
Sg shoot density	.742(**)	1														
Chloro	0.053	0.001	1													
Phaeo	.(a)	.(a)	.(a)	.(a)												
Rhodo	0.151	0.108	-0.141	.(a)	1											
Spng	0.181	0.028	-0.025	.(a)	-0.114	1										
Cnd	0.163	-0.2	**.550(**)**	.(a)	0.067	0.041	1									
Platy	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)	.(a)								
Annld	0.095	-0.121	-0.134	.(a)	0.262	-0.026	-0.1	.(a)	1							
Crusta	0.349	0.147	0.073	.(a)	0.01	**.411(*)**	0.102	.(a)	0.125	1						
Mollsc	**.603(**)**	**.536(**)**	0.076	.(a)	-0.072	-0.241	-0.02	.(a)	0.045	0.021	1					
Echinod	-0.007	0.115	0.229	.(a)	-0.015	-0.062	-0.15	.(a)	0.344	0.034	-0.044	1				
Temp	-.436(*)	-.414(*)	0.171	.(a)	-0.128	-0.262	-0.01	.(a)	0.035	-0.222	-0.144	0.201	1			
Sal	0.28	0.112	0.046	.(a)	0.222	0.162	0.187	.(a)	0.216	0.217	**.474(*)**	-0.09	-0.082	1		
pH	.652(**)	.411(*)	-0.046	.(a)	0.374	0.273	0.26	.(a)	0.059	0.238	0.256	-0.121	-0.079	0.3	1	
DO	.865(**)	.759(**)	-0.016	.(a)	0.365	0.064	0.12	.(a)	0.064	0.255	**.538(**)**	-0.028	-0.35	0.23	.708(**)	1

** Correlation is significant at the 0.01 level

* Correlation is significant at the 0.05 level

a Cannot be computed because at least one of the variables is constant.

Table 6.5d. Correlation of faunal groups with hydro-biological parameters in the Station IV

	Sg biomass	Sg shoot density	Chloro	Phaeo	Rhodo	Spng	Cnd	Platy	Annld	Crusta	Molsc	Echinod	Temp	Sal	pH	DO
Sg biomass	1															
Sg shoot density	.853(**)	1														
Chloro	.448(*)	.445(*)	1													
Phaeo	-0.28	-0.378	-0.116	1												
Rhodo	.451(*)	0.357	0.261	-0.247	1											
Spng	-0.055	-0.054	0.002	-0.232	0.056	1										
Cnd	0.235	0.356	-0.094	-0.004	-0.161	0.049	1									
Platy	0.083	0.144	**.476(*)**	-0.069	0.012	0.239	-0.07	1								
Annld	0.04	0.041	**.613(**)**	-0.021	-0.053	0.078	0.033	0.304	1							
Crusta	0.313	0.382	0.126	-0.195	0.151	-0.11	0.044	0.228	-0.144	1						
Molsc	-0.093	-0.109	-0.314	-0.036	0.149	-0.06	-0.29	-0.07	-0.225	-0.055	1					
Echinod	-0.28	-0.343	-0.188	-0.179	0.127	-0.16	-0.18	0.073	0.1	-0.263	0.05	1				
Temp	-0.064	0.158	-0.198	-0.234	0.095	0.001	0.322	-0.04	-0.068	0.053	-0.016	0.246	1			
Sal	-0.087	-0.089	-0.352	-0.244	-0.089	0.038	0.008	-0.34	-0.041	0.099	0.317	0.301	0.015	1		
pH	.651(**)	.708(**)	0.21	-0.252	0.137	0.115	0.322	0.161	-0.171	**.567(**)**	-0.131	**-.410(*)**	0.115	-0.11	1	
DO	.740(**)	.647(**)	.418(*)	-0.246	0.276	-0.07	0.187	0.247	0.056	**.576(**)**	-0.141	-0.24	-0.016	-0.09	.834(**)	1

** Correlation is significant at the 0.01 level

* Correlation is significant at the 0.05 level

Sg – Seagrass; Chloro – Chlorophyceae; Phaeo – Phaeophyceae; Rhodo – Rhodophyceae; Spng – Sponges; Cnd – Cnidarians; Platy – Platyhelminthes; Annld – Annelids; Crusta – Crustaceans; Molsc – Molluscs; Echinod – Echinoderms; Temp – Temperature; Sal - Salinity

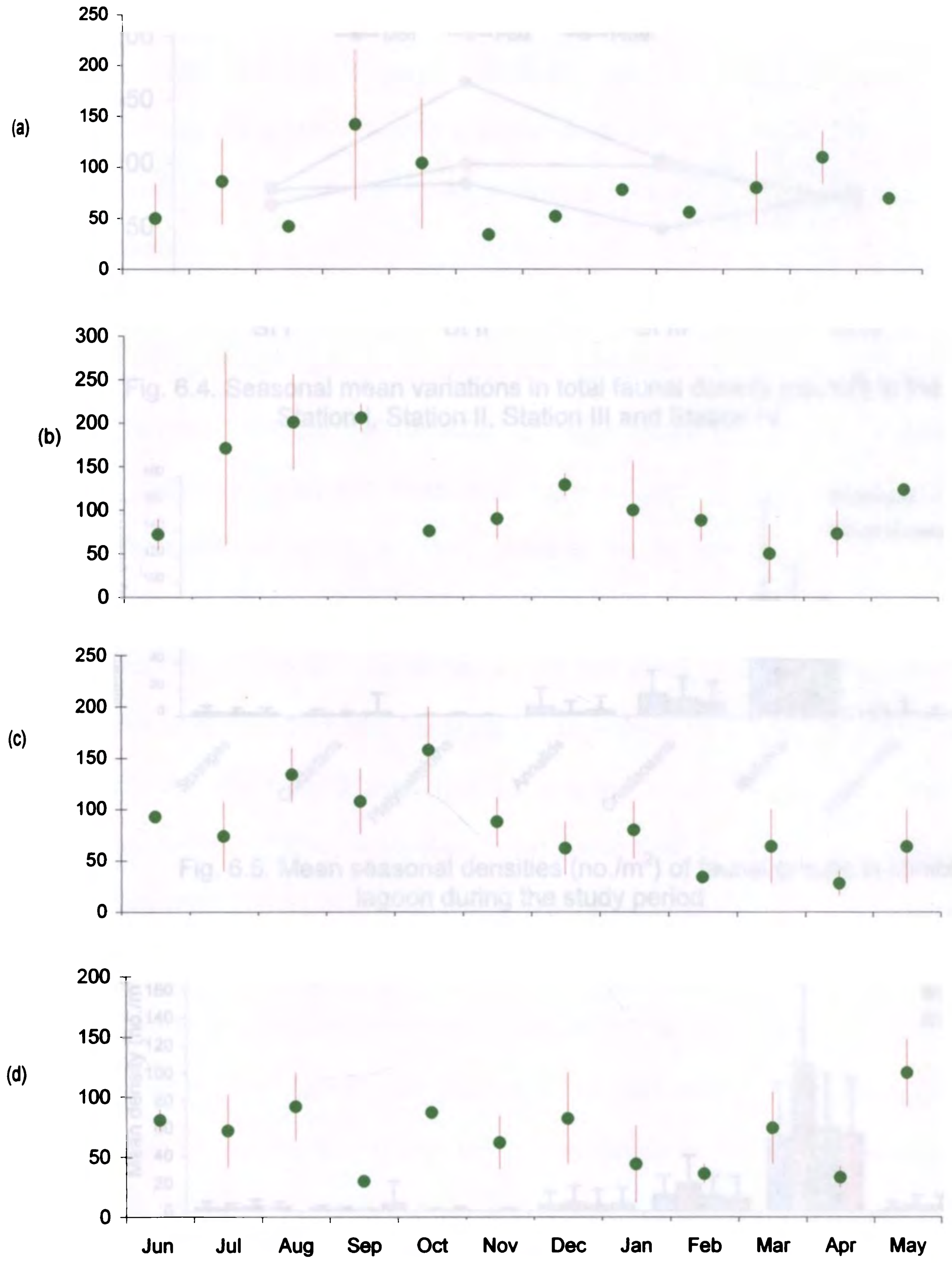


Fig. 6.3. Monthly mean variations in total faunal density (no./m^2) in the (a) Station I (b) Station II (c) Station III and (d) Station IV

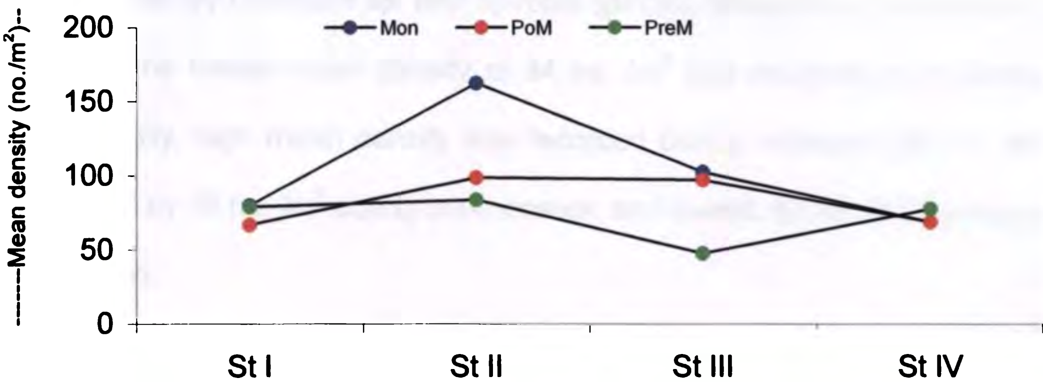


Fig. 6.4. Seasonal mean variations in total faunal density (no./m^2) in the Station I, Station II, Station III and Station IV

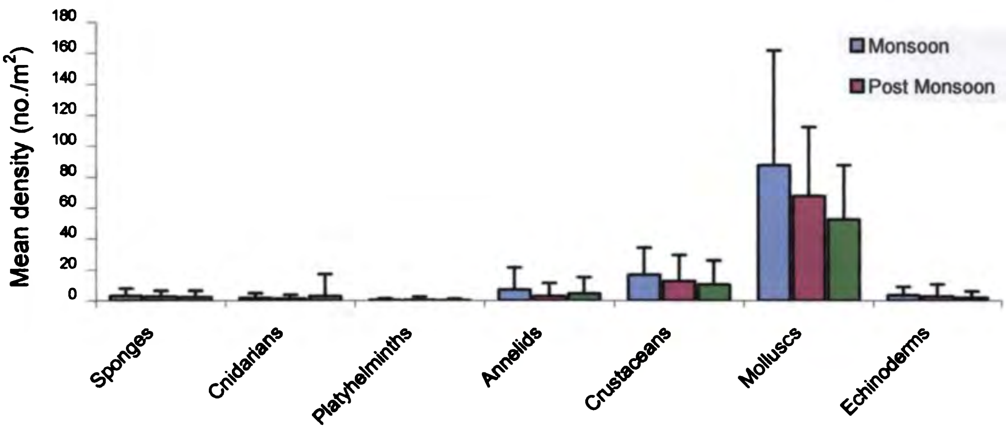


Fig. 6.5. Mean seasonal densities (no./m^2) of faunal groups in Minicoy lagoon during the study period

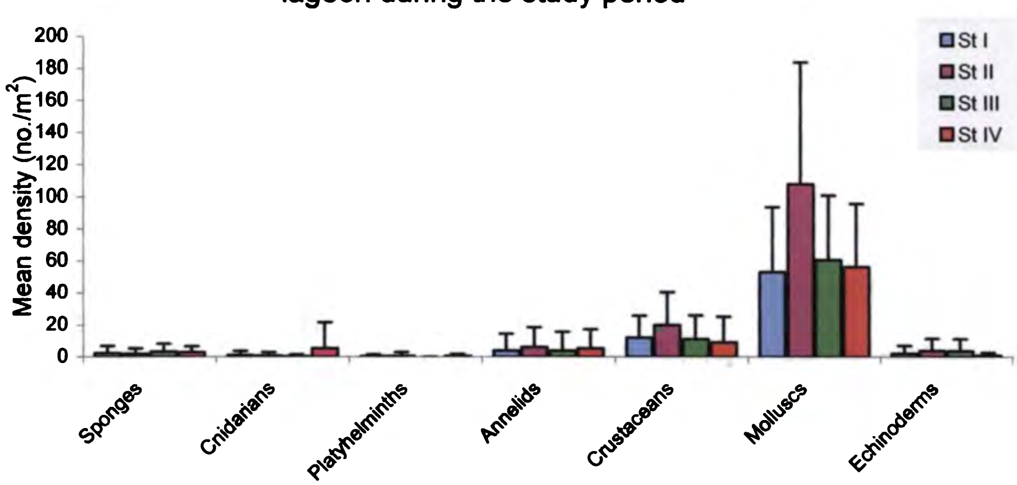


Fig. 6.6. Mean spatial densities (no./m^2) of faunal groups in Minicoy lagoon during the study period

contributed by *Cerithium* sp. and *Spirobis spirobis,* followed by 110 no./ m^2 in April . The lowest mean density of 34 no. /m^2 was recorded in November. Seasonally, high mean density was recorded during monsoon (89 no. /m^2), followed by 79 no. /m^2 during pre-monsoon and lowest, 67 no. /m^2 during post monsoon.

Station II: In this station, highest monthly mean density of 206 no. /m^2 (190 to 222 no. /m^2) was observed in September, followed by 201 no. /m^2 in August. The dominant species was *Cerithium* sp. The lowest mean density, 50 no. /m^2 was recorded in March. Seasonally highest mean density was observed during monsoon (162.5 no. /m^2), followed by 98.75 no. /m^2 during post monsoon and 83.75 no. /m^2 during pre monsoon.

Station III: 158 no. /m^2 was the mean monthly average density of total fauna in this station, which was observed in October (116 to 200 no. /m^2) and contributed mainly by *Cerithium* sp. followed by 134 no. /m^2 in August. Lowest mean density of 28 no. /m^2 was recorded during April. Highest seasonal mean density of 102.25 no. /m^2 in this station was recorded during monsoon season. It was 97 no. /m^2 during premonsoon and 77.75 no. /m^2 during pre monsoon.

Station IV: Highest monthly mean density of 120 no. /m^2 was recorded during May (92 to 148 no. /m^2), followed by 92 no. /m^2 during August. The most abundant species in this station was *Stychodactyla* sp. The lowest density of 30 no. /m^2 was observed in September. Seasonally during monsoon and post monsoon, the faunal density was same (68.75 no. /m^2) and during premonsoon, it was 77.75 no. /m^2.

6.2.4. Seasonal Variations in faunal group density

Mean seasonal density of sponges was highest (3.13±4.63 no. /m^2) during monsoon and lowest during pre monsoon (2.38±4.05 no. /m^2). Cnidarians were highest (2.88±14.12 no. /m^2) during pre monsoon and lowest (1.13±2.54 no. /m^2) during post monsoon. The mean density of platyhelminthes was similar during monsoon and post monsoon (0.38±1.18 and 0.38±2.12 no. /m^2). During pre monsoon it was 0.25±0.98 no. /m^2. The mean density of annelids was highest during monsoon (7±14.55 no. /m^2) and lowest (3±8.25 no. /m^2) during post monsoon. Crustaceans have the highest mean density during monsoon (16.56±17.59 no. /m^2) and lowest during pre monsoon (10.19±15.72 no. /m^2). Highest seasonal mean density of molluscs was recorded during monsoon (87.5±74.35 no. /m^2) and lowest (52.44±35.29 no. /m^2) during pre monsoon. Echinoderms were highest during monsoon (3.5±5.35 no. /m^2) and lowest (2±4.06 no. /m^2) during pre monsoon.

6.2.5. Spatial Variations in faunal group density

Highest mean density of sponges (3.33±4.46 no. /m^2) was found in the station III and lowest (2±3.34 no. /m^2) in the station II. Cnidarians were highest in the station IV (5.5±16.12 no. /m^2). Platyhelminthes were very less and the highest density was only 0.5±1.35 no. /m^2) in the station IV and totally absent in the station III. The mean density of annelids were highest in the station IV (6.17±12.31 no. /m^2) and lowest (3.83±11.76 no. /m^2) in the station III. Crustaceans were highest (20±20.53 no. /m^2) in the station II and lowest (9.17±16.06 no. /m^2) in the station IV. Molluscs were highest (107.5±76.02 no. /m^2) in the station II and lowest (52.83±40.47 no. /m^2) in the station I. Highest mean density of echinoderms (3.83±7.5 no. /m^2) was observed in the station II and lowest (1±1.77 no. /m^2) in the station IV.

6.2.6. Interactions of fauna

i) Hydrography and fauna:

Temperature, salinity, pH and DO were the hydrographic parameters selected for analysis. Significant correlations were obtained for annelids with pH and DO and sponges with DO in the station I; while, in the station II, echinoderms showed significant correlation with pH and DO. In the station III, molluscs were significantly correlated with salinity and DO, whereas in the station IV, crustaceans showed significant correlation with pH and DO.

ii) Seaweed biomass and fauna:

Associated macro algae have some influence on the distribution of macro fauna in the seagrass meadow. In the station I, no significant correlation was obtained between fauna and macro algae and in the station II and III, cnidarians were significantly correlated with chlorophyceae. In the station IV, platyhelminthes and annelids were significantly correlated. Rhodophyceae and Phaeophyceae have no influence on the distribution of macro-fauna.

iii) Seagrass and fauna:

Sponges and echinoderms showed significant correlations in the station I and molluscs in the station III, with seagrass shoot density. No significant correlation in this regard was obtained in the station II and IV.

In the station I, sponges and annelids; in the station II, crustaceans and echinoderms and in the station III, only molluscs were significantly correlated with seagrass biomass. In the station IV, no significant correlation was existed.

Draftsman Scatter Plot:

Draftsman plot gives a scatter plot for multiple variables. Here, the scatter plot for the groups of fauna showed no significant correlation between different groups of fauna.

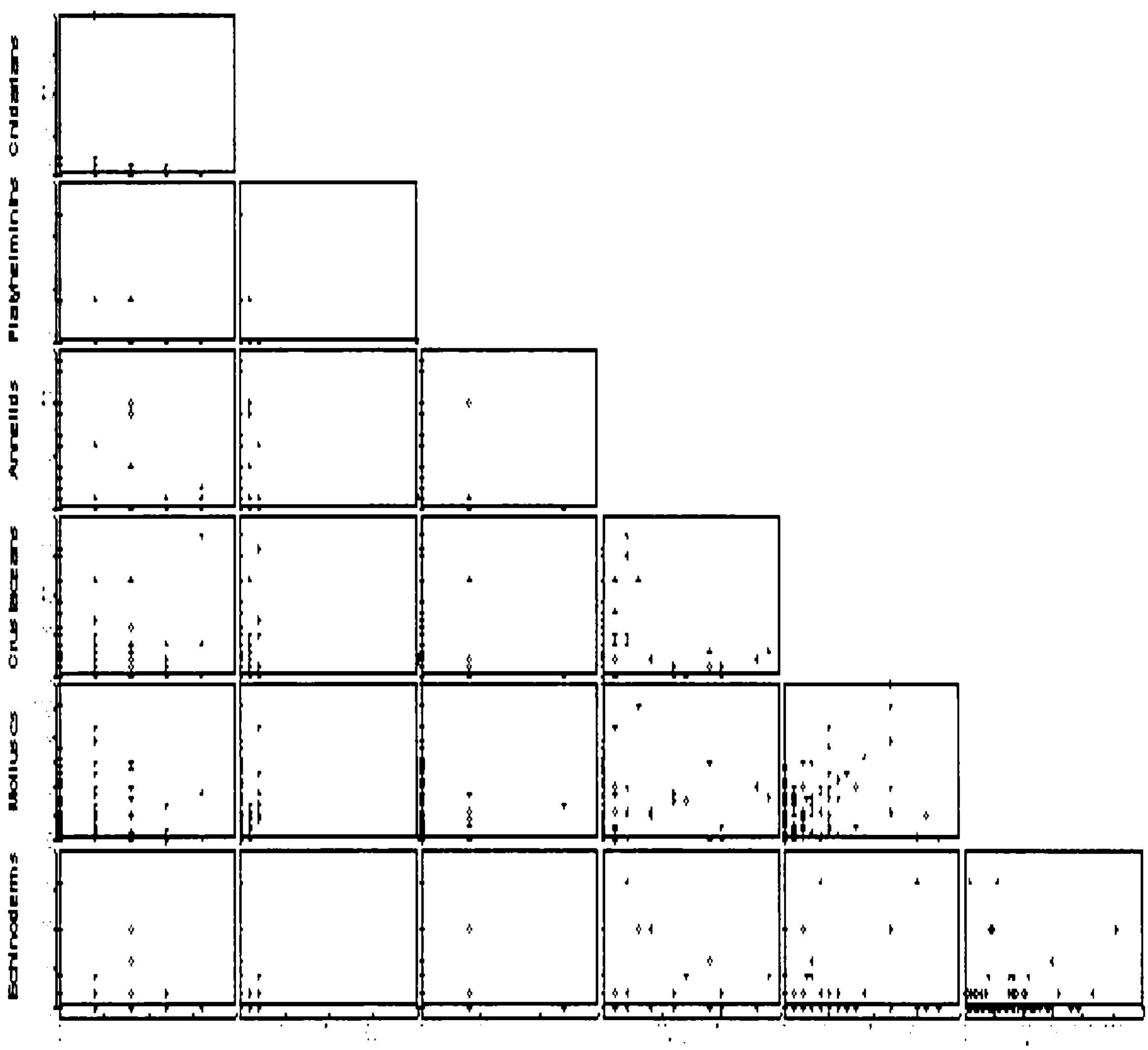


Fig. 6.7. Draftsman plot showing the correlations between faunal groups for all the stations of Minicoy lagoon

Table 6.6. Correlation results of Draftsman scatter plot analysis for the macro invertebrate faunal groups of all the four stations

Variables	Variables	Correlation
Sponges	Cnidarians	0.038
Sponges	Platyhelminths	-0.039
Sponges	Annelids	-0.020
Sponges	Crustaceans	0.084
Sponges	Molluscs	-0.135
Sponges	Echinoderms	-0.062
Cnidarians	Platyhelminths	-0.025
Cnidarians	Annelids	0.022
Cnidarians	Crustaceans	-0.021
Cnidarians	Molluscs	-0.120
Cnidarians	Echinoderms	-0.078
Platyhelminths	Annelids	0.013
Platyhelminths	Crustaceans	-0.068
Platyhelminths	Molluscs	-0.064
Platyhelminths	Echinoderms	0.011
Annelids	Crustaceans	-0.065
Annelids	Molluscs	0.003
Annelids	Echinoderms	0.199
Crustaceans	Molluscs	**0.203**
Crustaceans	Echinoderms	0.129
Molluscs	Echinoderms	0.035

BEST Analysis: The results of the biota-environmental matching (BEST) revealed that the correlation coefficient (Rho) is 0.107 (Fig. 6.8) for monthly pattern of species distribution and 0.161 (Fig. 6.9) for seasonal pattern.

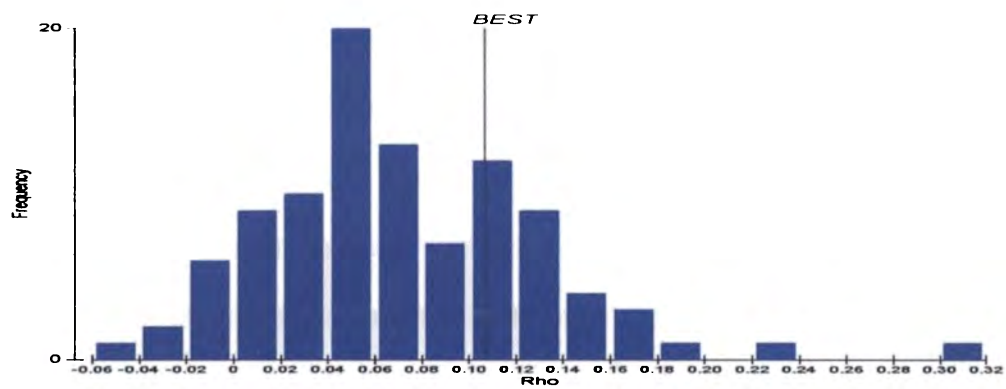


Fig. 6.8. Histogram showing the BEST results of monthly distribution of species of fauna (Rho = 0.107)

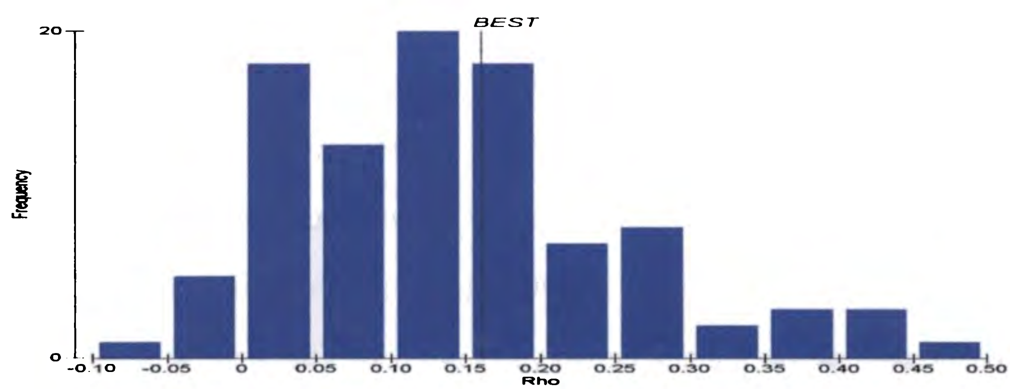


Fig. 6.9. Histogram showing the BEST results of seasonal distribution of species of fauna (Rho = 0.161)

Table 6. 7. BEST (Biota and Environment Matching) results for faunal density

Faunal density					
		Monthly		Seasonal	
Sl. No.	Variables	Variables selected	BEST correlation values (Rho)	Variables selected	BEST correlation values (Rho)
1	Temperature	**3,4**	**0.107**	**2,3**	**0.161**
2	Salinity	4	0.104	2	0.155
3	pH	2-4	0.098	1-3	0.059
4	DO	3	0.098	1,2	0.057

6.2.7. Community structure

The community concept is one of the important principles in ecological thought and practice, because it emphasizes the fact that diverse organisms usually live in an orderly manner, not just haphazardly strewn over the earth as independent beings (Odum, 1971). Communities not only have a functional unity with the characteristic trophic structure and patterns of energy flow but they also have a compositional unity in that there is a certain probability that certain species will occur together. However, species are to a large extent replaceable in time and space so that functionally similar communities may have different species composition (Odum, 1971). The purpose of measuring community indices is usually to judge its relationship either to other community properties such as productivity and to stability or to environmental conditions to which the community is exposed (Pielou, 1975).

In the present study, the community structure of the macro invertebrate fauna of the seagrass meadow was analysed. The indices were calculated by using the data collected during the study period and the results were given in the table 6.8. and the spatial variations were given in the Fig. 6.10.

(i) Diversity Indices:

Station I: Highest richness of 4.87 was recorded in October and lowest, 2.28 was in January. Evenness was highest (0.98) in August and November and lowest (0.92) in January. Highest species diversity of 4.11 was recorded in October and lowest, 2.77 in January. Dominance index was highest (0.91) in October and lowest (0.73) in December.

Table 6.8. Mean diversity indices of fauna in the stations I to IV in Minicoy lagoon

	Richness (d)	Evenness (J')	Diversity (H'log$_2$)	Dominance (D)
Station I	2.75	0.82	2.97	0.83
Station II	2.58	0.81	2.98	0.83
Station III	2.45	0.80	2.78	0.80
Station IV	2.70	0.82	2.92	0.81

Station II: Highest richness of 4.76 was recorded in August and lowest, 2.41was in March. Evenness was highest (0.98) in October and lowest (0.93) in July. Highest species diversity of 4.08 was recorded in August and lowest, 2.68 in March. Dominance index was highest (0.93) in October and lowest (0.76) in February.

Station III: Highest richness of 4.47 was recorded in June and lowest, 1.65 was in April. Evenness was highest (0.97) in April and May and lowest (0.92) in October. Highest species diversity of 3.94 was recorded in June and lowest, 2.75 in April. Dominance index was highest (0.90) in May and lowest (0.73) in March.

Station IV: Highest richness of 4.53 was recorded in October and lowest, 2.64 was in September. Evenness was highest (0.98) in January and February and lowest (0.91) in May. Highest species diversity of 3.92 was recorded in October and lowest, 2.89 in September. Dominance index was highest (0.89) in February and August and lowest (0.67) in March.

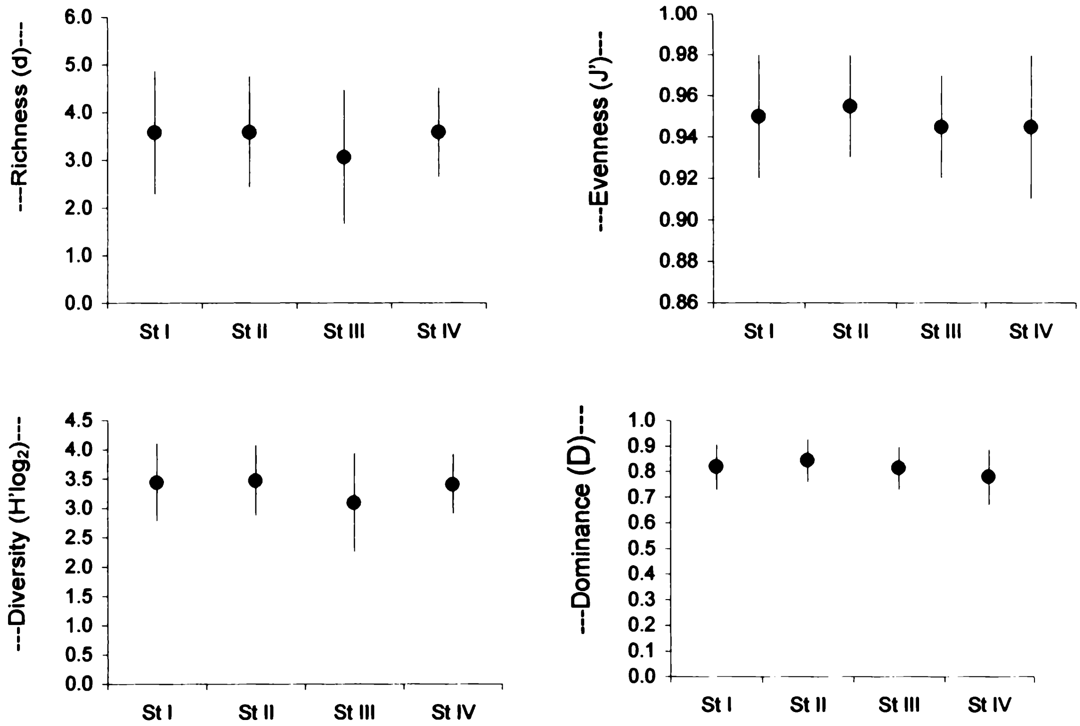


Fig. 6.10. Spatial variations in (i) species richness (*d*) (ii) evenness (*J'*) (iii) diversity (*H'log₂*) and (iv) dominance (D)

Taxonomic Distinctness:

All of the species recorded throughout the study were assigned to their respective genera, families, orders, classes and to their common phyla and the average taxonomic distinctness (AvTD, Δ+) and variation in taxonomic distinctness (VarTD, λ+), both of which are measures of species relatedness, were calculated using the DIVERSE routine in the PRIMER statistical package. AvTD (Δ+) and VarTD, (λ+) were represented in the Figs. 6. 11 and 6.12. Joint comparison of both Δ+ and λ+ was represented in the Fig. 6.13. Joint average taxonomic distinctness and variation in taxonomic distinctness analyses the relationship between the average taxonomic distinctness and variation in taxonomic distinctness of samples collected from different sites,

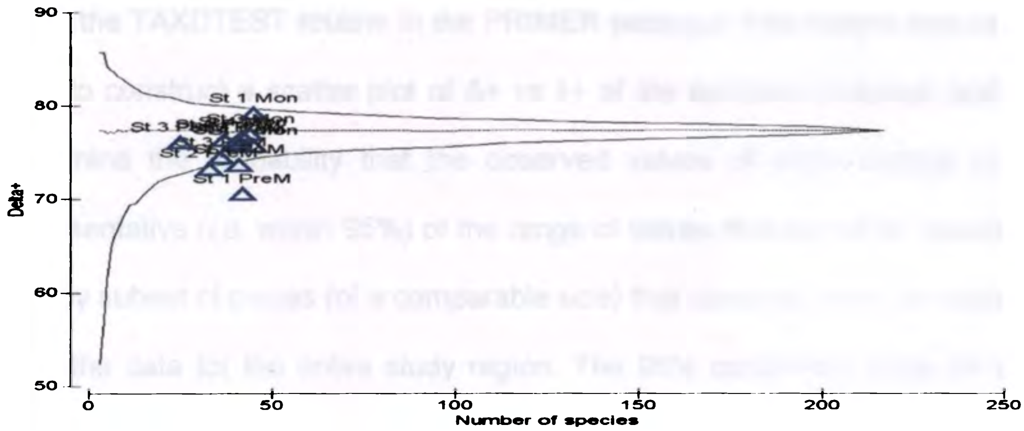


Fig. 6. 11. The 95% probability funnel for the average taxonomic distinctness (Δ+) values. Expected average indicated by the dotted line in the middle of the funnel

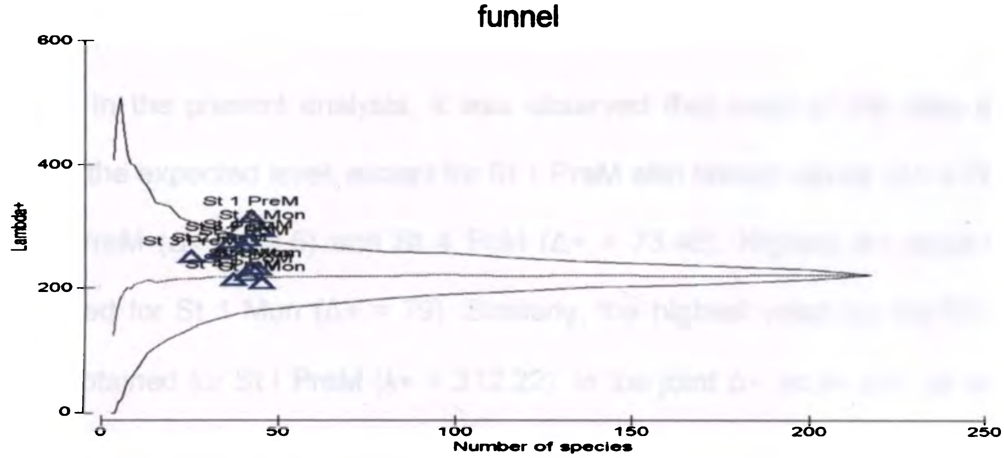


Fig. 6. 12. The 95% probability funnel for the variation in taxonomic distinctness (λ+) values. Expected average indicated by the dotted line in the middle of the funnel

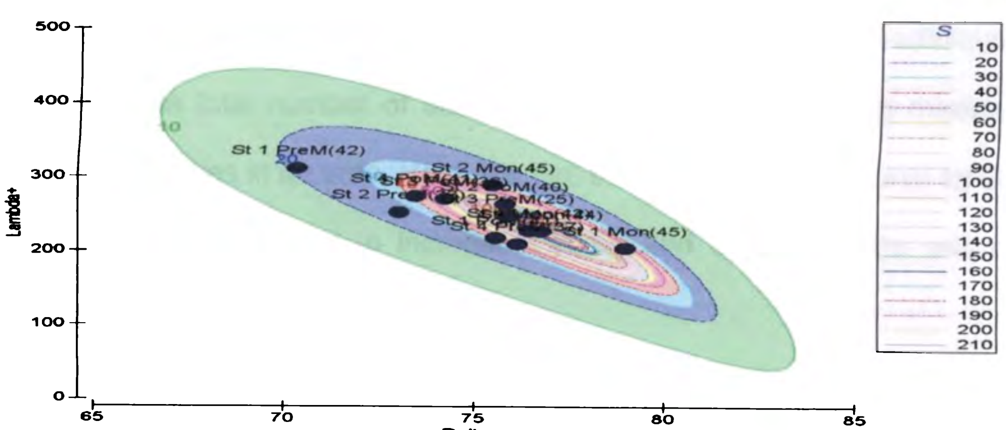


Fig. 6. 13. Ellipse plot showing the comparison of AvTD (Δ+) and VarTD (λ+) for the macro invertebrate fauna

using the TAXDTEST routine in the PRIMER package. This routine was used both to construct a scatter plot of Δ+ *vs* λ+ of the samples collected, and to determine the probability that the observed values of these indices were representative (*i.e.* within 95%) of the range of values that would be expected for any subset of pecies (of a comparable size) that could be drawn at random from the data for the entire study region. The 95% confidence limits for the different-sized subsets of species were represented as concentric "ellipses" on the scatter plots, and were calculated from 1000 random simulations of Δ+ and λ+.

In the present analysis, it was observed that most of the sites were within the expected level, except for St 1 PreM with lowest values (Δ+ = 70.7), St 2 PreM (Δ+ = 73.5) and St 4 PoM (Δ+ = 73.48). Highest Δ+ value was obtained for St 1 Mon (Δ+ = 79). Similarly, the highest value for VarTD (λ+) was obtained for St I PreM (λ+ = 312.22). In the joint Δ+ *vs* λ+ plot, all of the samples were within the expected 95% confidence level.

Species Area Plot:

Species area curve plotting the cumulative number of different species observed as new sample is added. The advantage of plotting this technique is to predict the total number of stations to be sampled for setting maximum number of species in an area. Here, the Fig. 6.14 represents the curve for 217 species, which continued to increase steadily and the asymptote was not reached.

Geometric Class (GC) Plot:

The geometric class (GC) plots are essentially frequency polygons, plotted for each sample (or a pooled set of samples) of the number of species that fall into a set of geometric (x2) abundance classes. It plots the number of species represented in the sample by a single individual (class 1), 2 or 3 individuals (class 2), 4-7 individuals (class 3), 8-15 individuals and so on. It has been suggested that impact on assemblages tends to change the form of this distribution, lengthening the right tail of the graph (some species become very abundant and many rare species disappear) and giving a jagged curve. The Fig. 6.15 illustrates the species abundance class curve for macro invertebrate fauna in the four stations of Minicoy lagoon with nine geometric class plots having steep curve.

Dominance Plot:

Diversity profiles are also presented using *k*-dominance curves (Lambshead *et al.*, 1983). The purpose of this distributional representation is to extract information on patterns of relative species abundance and dominance. This technique can be considered as intermediate between *univariate* summaries and full *multivariate* analyses (Clarke, 1990). The curves presented are cumulative ranked abundance plotted against species rank (logged axis). Shallow curves tend to correspond to communities with high levels of dominance, whereas steep curves reflect a more balanced, diverse community. Here, the percentage dominance of the organisms were plotted against their rank individually and cumulatively. In this section, the Fig. 6.16 represents the dominance plot for the stations and Fig. 6.17 represents that for seasons. In the ***k***-dominance curve for seasons showed an almost similar pattern with **'S'** shaped curve. Station wise also, ***k***-dominance curve showed the similar pattern with gently slopping **'S'** shaped curve.

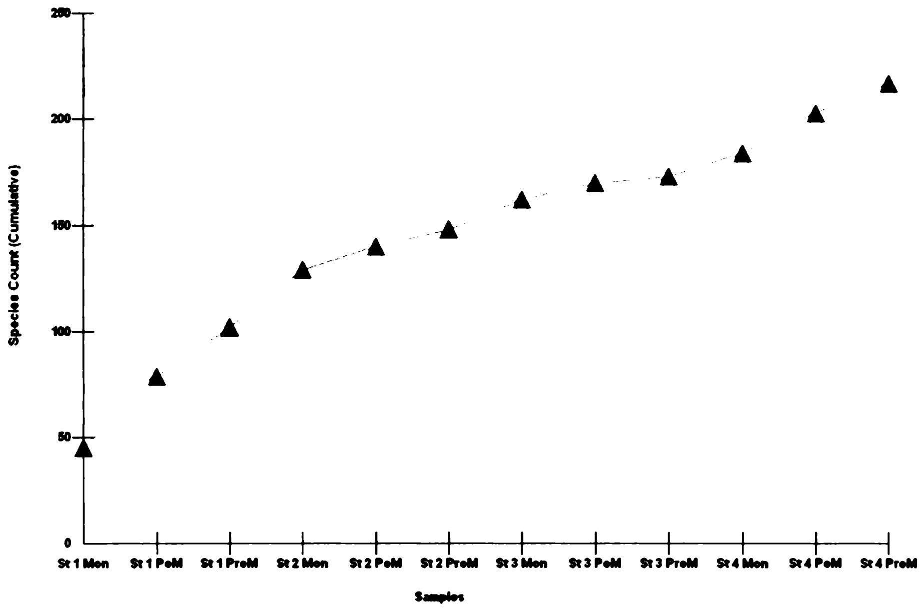


Fig. 6.14. Species area plot showing the cumulative species count of macro invertebrate fauna using seasonal data sets

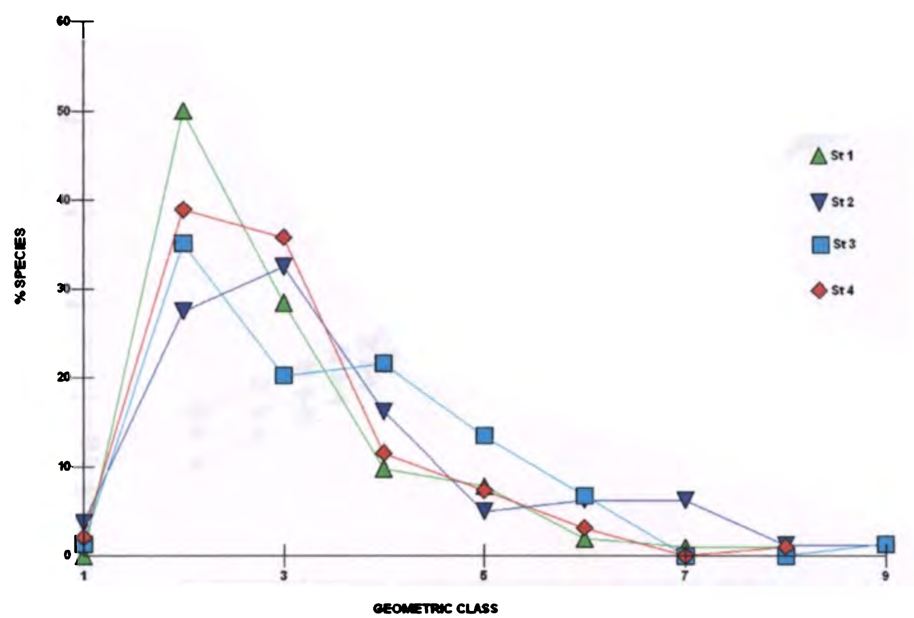


Fig. 6.15. Geometric class plot for species abundance of macro invertebrate fauna in the four stations of Minicoy lagoon.

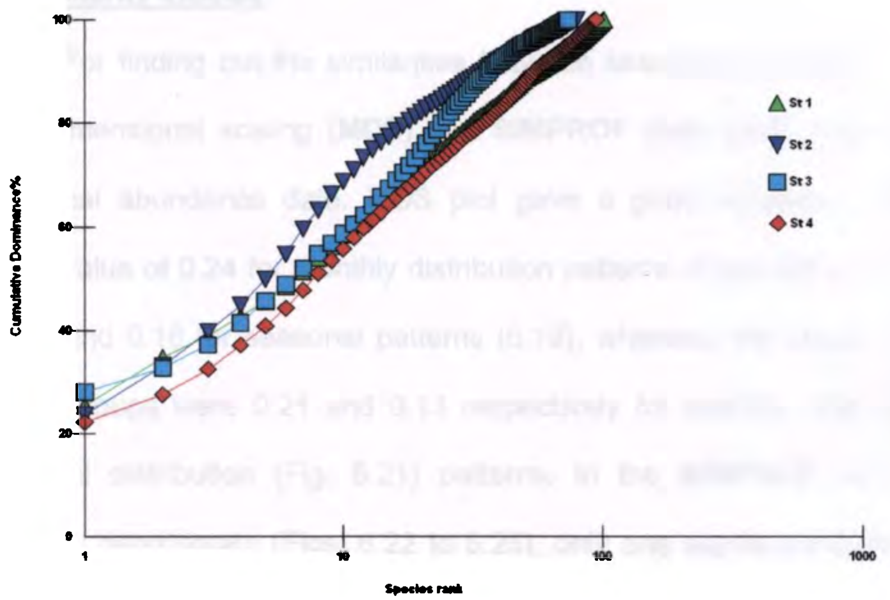


Fig. 6.16. *k*-dominance ranked curves for the samples from four Stations (▲St 1, ▼St 2, ■St 3 and ♦St 4) of Minicoy lagoon

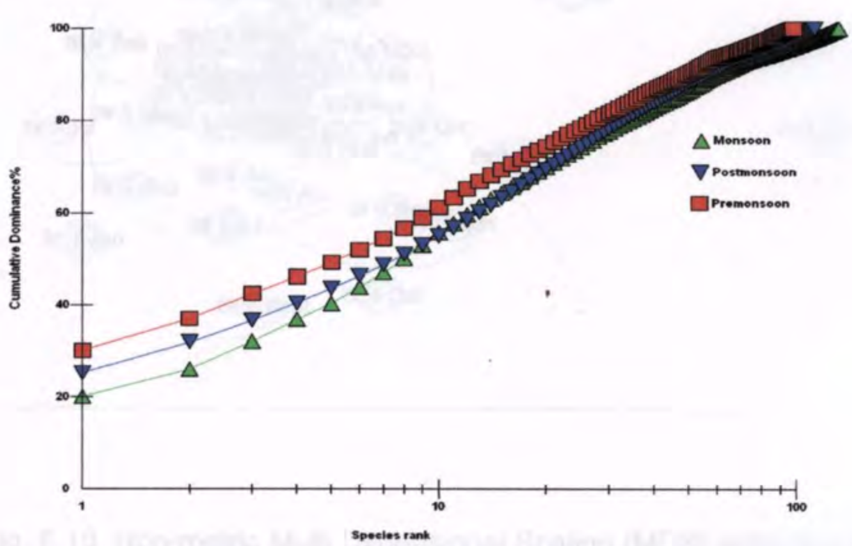


Fig. 6.17. *k*-dominance ranked curves for the samples for Monsoon (▲), Post Monsoon (▼) and Pre Monsoon (■)

(ii) Similarity indices:

For finding out the similarities between seasonal and spatial aspects, multi-dimensional scaling (**MDS**) and **SIMPROF** *tests* were done using the numerical abundance data. MDS plot gave a good ordination having the stress value of 0.24 for monthly distribution patterns of species of fauna (Fig. 6. 18) and 0.16 for seasonal patterns (6.19), whereas, the stress values for faunal groups were 0.21 and 0.13 respectively for monthly (Fig. 6.20) and seasonal distribution (Fig. 6.21) patterns. In the **SIMPROF** *test* and the resultant dendrogram (Figs. 6.22 to 6.25), only one significant similarity was observed.

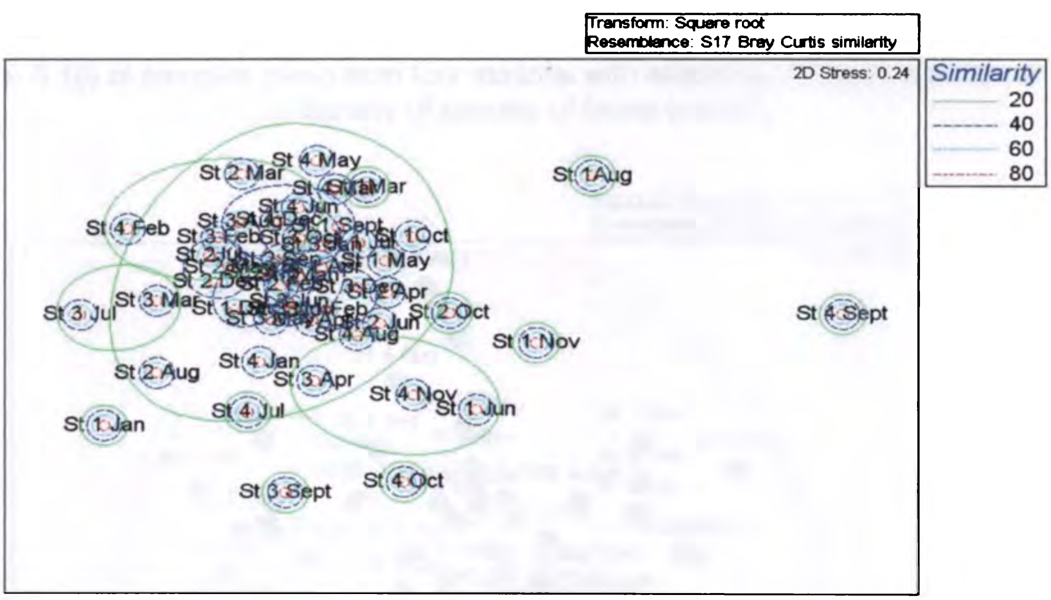


Fig. 6.18. Non-metric Multi Dimensional Scaling (MDS) ordination plot (stress = 0.24) of samples taken from four stations with monthly distribution patterns of density of species of fauna (no./m^2)

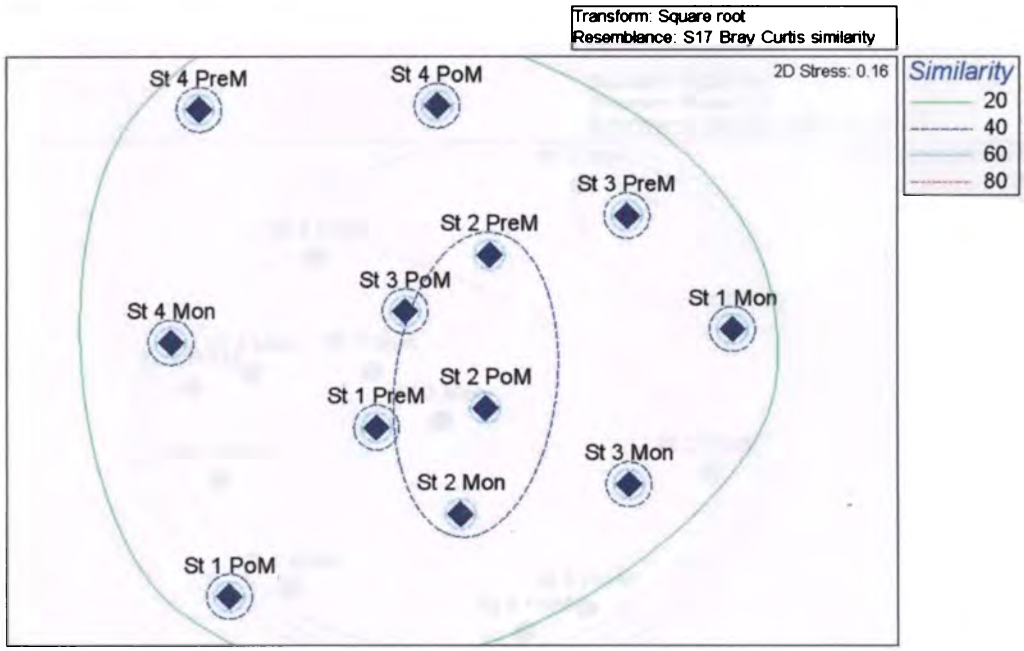


Fig. 6.19. Non-metric Multi Dimensional Scaling (MDS) ordination plot (stress = 0.16) of samples taken from four stations with seasonal distribution patterns of density of species of fauna (no./m^2)

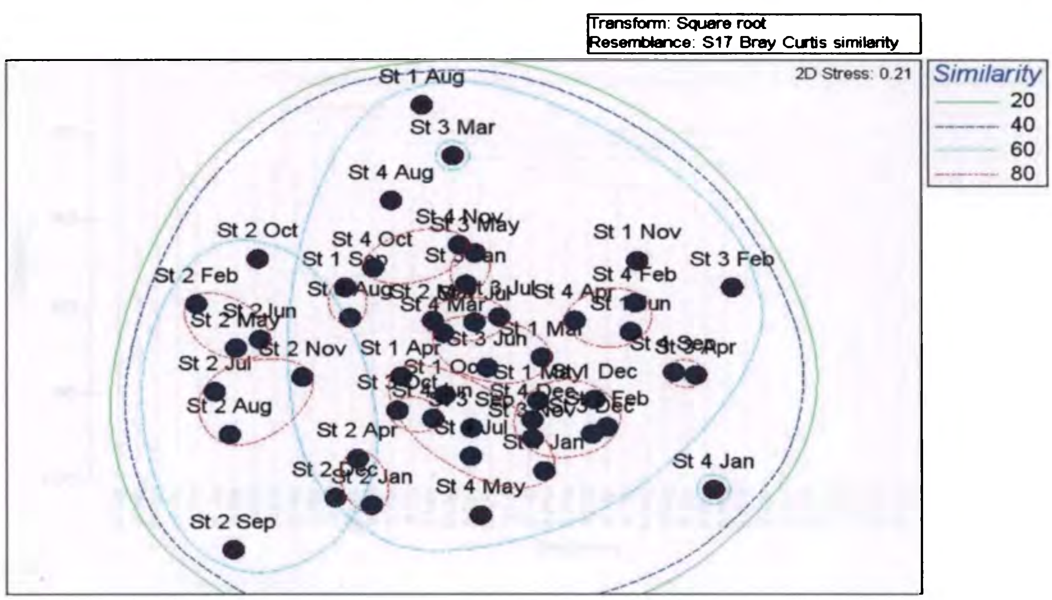


Fig. 6.20. Non-metric Multi Dimensional Scaling (MDS) ordination plot (stress = 0.21) of samples taken from four stations with monthly distribution patterns of density of faunal groups (no./m^2)

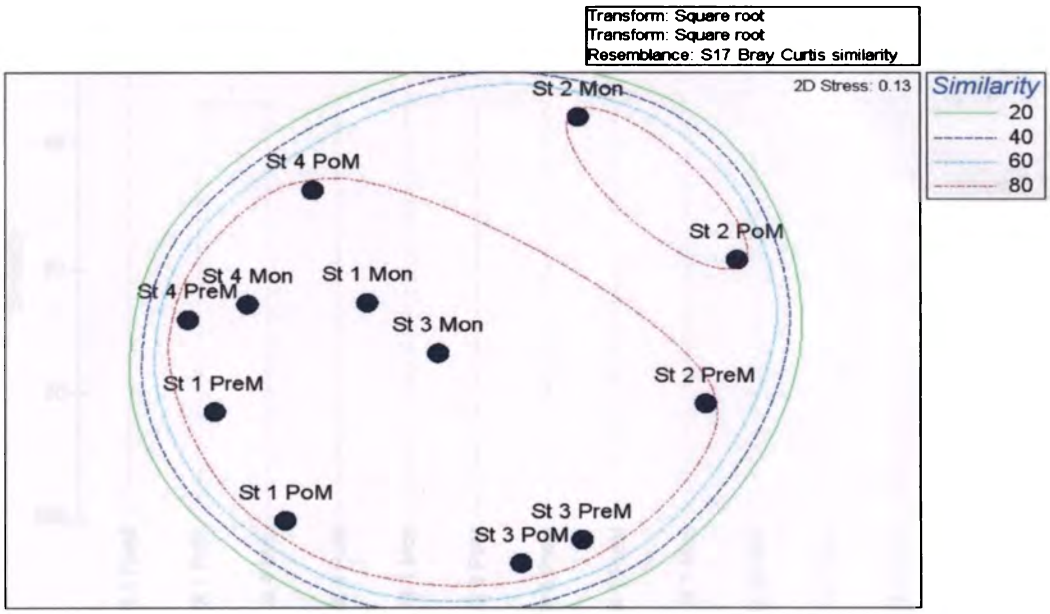


Fig. 6.21. Non-metric Multi Dimensional Scaling (MDS) ordination plot (stress = 0.13) of samples taken from four stations with seasonal distribution patterns of density of faunal groups (no./m^2)

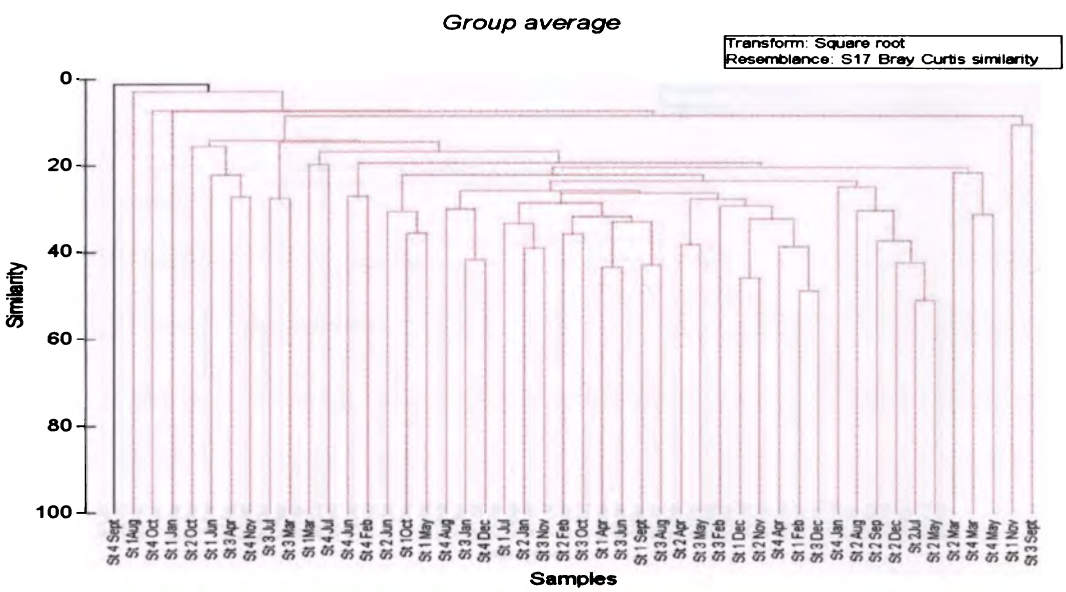


Fig. 6.22. Dendrogram of macro faunal species density showing the monthly similarities in the four stations (Solid lines represent significant delineation of groupings by SIMPROF test)

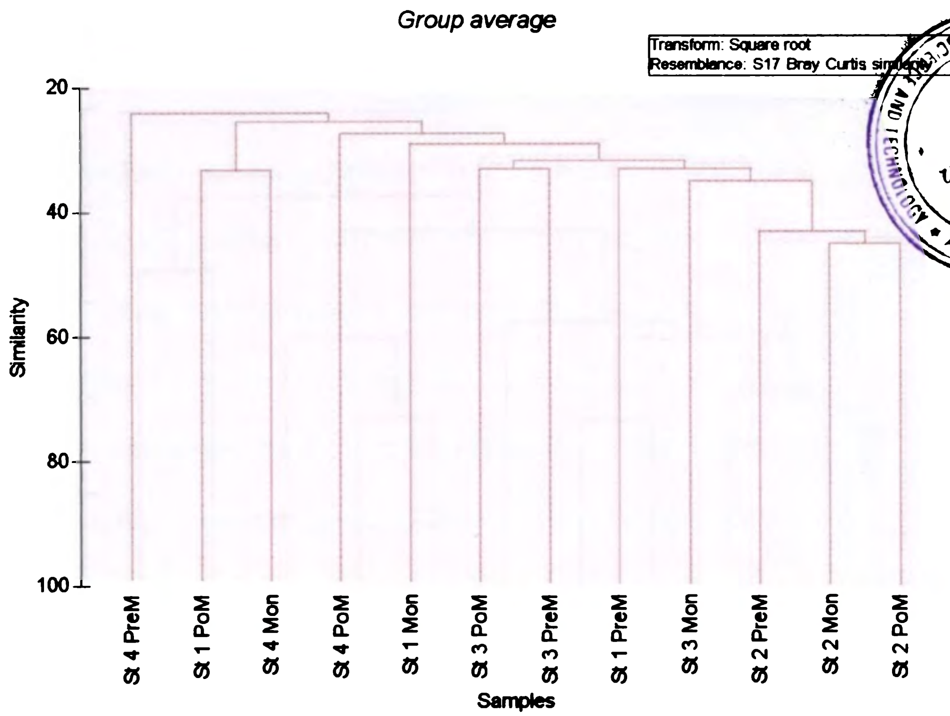


Fig. 6.23. Dendrogram of macro faunal species density showing the seasonal similarities in the four stations (Solid lines, if present represent significant delineation of groupings by SIMPROF test)

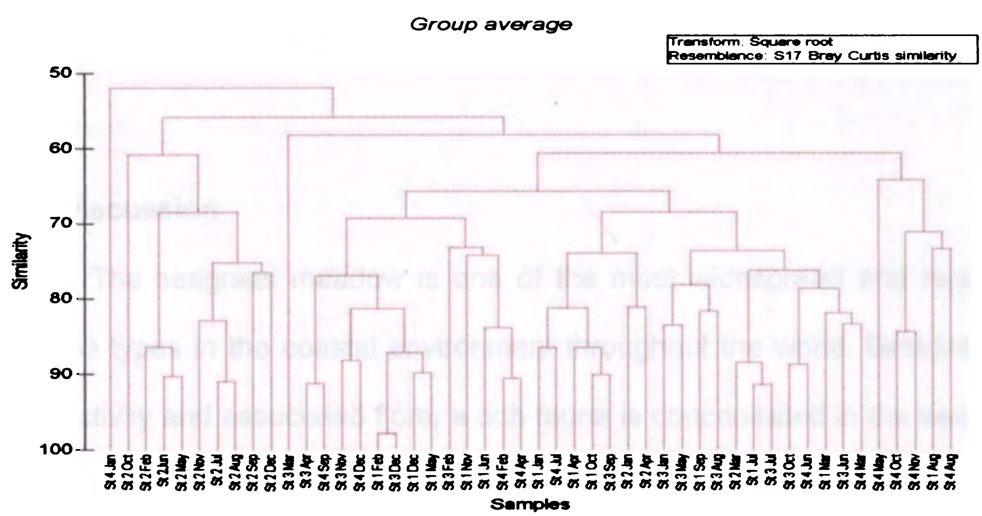


Fig. 6.24. Dendrogram of macro faunal group density showing the monthly similarities in the four stations (Solid lines, if present represent significant delineation of groupings by SIMPROF test)

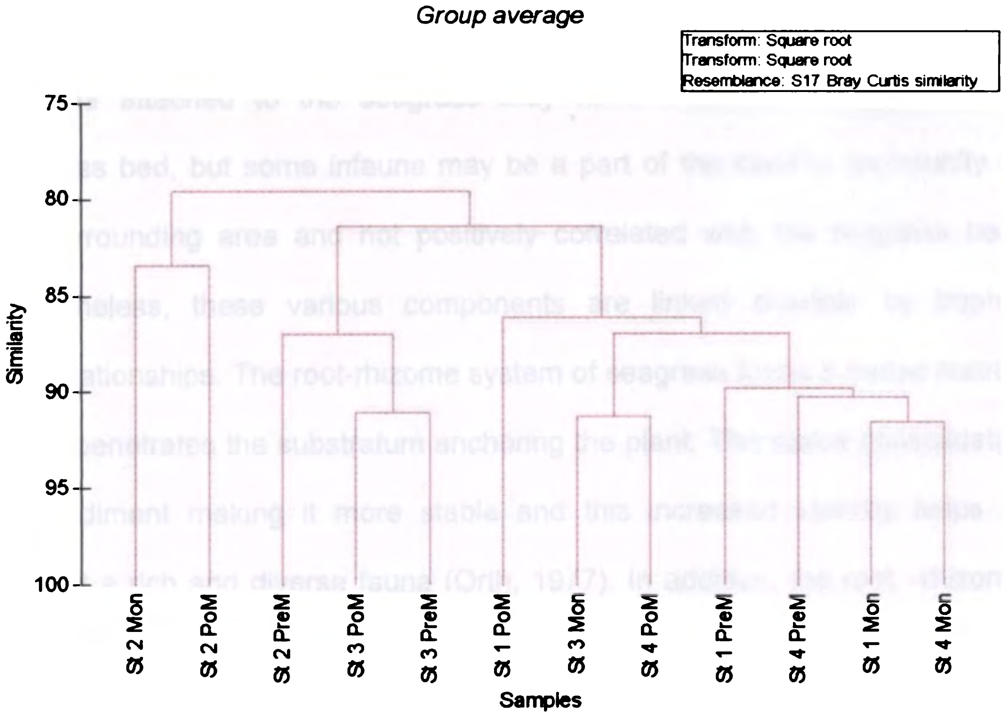


Fig. 6.25. Dendrogram of macro faunal group density showing the seasonal similarities in the four stations (solid lines, if present, represent significant delineation of groupings by SIMPROF test)

6.3. Discussion

The seagrass meadow is one of the most widespread and recurrent biotope types in the coastal environment throughout the world. Besides high productivity and associated flora, a rich fauna is concentrated in the seagrass bed. Among their most important attributes are their ability to serve as nursery areas containing high densities and diversities of macro-invertebrate and fishes. A dense vegetation of seagrasses produces a great quantity of organic material, and offers a good substrate for epiphytic algae, micro-flora and sessile fauna. The vegetation plays the role of sediment trap and creates unique microhabitats for small animals. In the case of an animal assemblage, epifauna attached to the seagrass may have close correlation with the seagrass bed, but some infauna may be a part of the benthic community of the surrounding area and not positively correlated with the seagrass bed. Nevertheless, these various components are linked together by trophic interrelationships. The root-rhizome system of seagrass forms a dense matrix, which penetrates the substratum anchoring the plant. The matrix consolidates the sediment making it more stable and this increased stability helps to support a rich and diverse fauna (Orth, 1977). In addition, the root –rhizome system and the leaves of the seagrass provide horizontal and vertical complexity. This structural complexity and the interaction with the neighbouring ecosystems such as mangroves and coral reefs are responsible for the dramatic rise in species diversity, when compared with local unvegetated areas. Many studies have demonstrated the difference in macrofaunal community structure between seagrass bed and surrounding bare areas. (Castel *et al*, 1989). Organisms interact with one another as well as with the physical and chemical components of the environments in which they live. Such interactions influence their distribution and abundance. Based on the existing data, the biota inhabiting seagrass meadows has been subdivided into several structural subunits (Kikuchi and Peres, 1977), according to their habitat preferences and functional aspects. The macro fauna on the green leaves include epiphytic forms such as hydrozoans, sessile fauna attached to leaves such as sponges, mobile epifauna creeping or crawling on the leaves such as gastropods and as a variation of epifauna, which rest on the leaves, such as squids. Mobile epifauna on leaves are the most characteristic component of seagrass bed communities. Macro-invertebrate fauna attached to stems and rhizomes form the second category of the fauna of the seagrass beds. Some nest building polychaets and sponges included in this group. In this microhabitat, a very rich fauna inhabits the complicated rhizome network; various kinds of decapod crustaceans (alpheid shrimps, crabs of Majidae, hermit crabs, *etc.*), molluscs (Arcidae, Venerid bivalves, Mytilidae, snails of Trochidae, Muricidae, Nassaridae, *etc*), echinoderms and polycheates. Small crustaceans such as Amphipods, Isopods, *etc.* also occur in high density. A considerable portion of the fauna found in this layer in the daytime seemed to migrate to the upper leaf layer or at least outside of the rhizome network at night. The third category is the highly mobile animals swimming under the leafage, such as cephalopods and some crustaceans. This group is not restricted to the seagrass beds; length of the residing period and biological significance of the bed must differ with the species. There is another category among the fauna of the seagrass beds, which can live both as infauna in the sediment and as epifauna occasionally. They include some bivalves and polychaets. They may not be the components of typical seagrass faunal community, but are an extension of the benthic community of the neighbouring systems. The genera such as *Gaffrarium*, Codackia, *etc.* obtained in the present study, belong to this category. The organic debris deposited in the seagrass beds becomes a food source and the structural complexity sustains a rich faunal assemblages and diversity. In short, the abundance and diversity of fauna in seagrass beds are higher than those in the neighbouring areas. The fauna mentioned above are all closely linked with the presence of seagrass vegetation. Dependence of fauna on the seagrasses was clearly shown with the decline of *Zostera marina,* due to wasting disease occurred on the coasts of Atlantic Ocean (Kikuchi, 1974). During the present study, a total of 217 species of macro-invertebrate fauna were recorded, which belongs to 151 genera, 119 families, 52 orders, 18 classes and 7 phyla. The detailed composition is described as follows.

Sponges are found in all seas, living mainly in shallow waters although some occur at great depths. The majority attach themselves to any suitable substratum such as rock, hard-shelled animals, seaweeds and seagrasses. A few species bore into rocks or shells. Sponges feed on microscopic plants and animals and on detritus, which they filter from the water current passing through the body. Many other animals use sponges as a surface on which to settle. So far, 486 species of sponges have been described in India (Venkataraman and Wafar, 2005). The sponge fauna of India is dominated by species of Demospongiae. A total of 82 species were reported from Lakshadweep, out of which 18 species were coral boring sponges. There are no reports on the sponges of the seagrass meadow of Minicoy lagoon. The rhizome and leaves of seagrasses provide suitable substratum for the attachment of sponges. In addition, the reduced water movement and shading also created an ideal habitat for sponges in the seagrass ecosystem. In the present observations, sponges formed the third largest faunal group in the seagrass meadow. The group included the 22 species, which, belongs to 21 genera, 19 families, 10 orders and 3 classes. Sponges constituted 10% of the total faunal population of the seagrass meadow and highest (4% of the total faunal population) in the station III and IV.

The cnidarians were the fist multi-cellular animals with true tissues. The body is radially symmetrical with an opening at the top forming the mouth. Most cnidarians are marine and prefer warm tropical shallow waters. In India, 212 species of Hydrozoa, 25 species of Scyphozoa and 600 species of Anthozoa were present. As in the case of sponges, the seagrass structural and functional aspects created a suitable substratum for the cnidarians. They constituted 9% of the total population, which comprise, 19 species, 17 genera, 15 families, 11 orders and 2 classes. Highest percentage of this group (7% of the total population of the fauna) was recorded in the station IV.

Platyhelminthes group includes 4 species of free-living forms. They belong to 1 genus, 1 family, 1 order and 1 class and constitute 2% of the total population. Annelids were also a smallest group recorded during the study period. Only 4 species were present, which were included in 3 genera, 3 families, 3 orders and 1 class. Only 2% of the faunal population is constituted by the annelids. They were negligible in the station I, II and IV and totally absent in the station IV.

In India, as many as 139 species of stomatopods, 26 species of lobsters, 162 species of hermit crabs, 705 species of brachyuran crabs and 84 species of shrimps and prawns have been reported so far (Venkataraman and Wafar, 2005). Crustaceans were the second largest group of fauna in the seagrass beds of Minicoy lagoon. 48 species of crustaceans were observed during the study and they belong to 39 genera, 29 families, 5 orders and 3 classes. Crustaceans constitute 22% of the total population. They form the second dominant group in all the stations and recorded highest (16%) in the station I.

Molluscs include a diverse assemblage of deposit and suspension feeders that inhabit ecosystems from the upper intertidal zone to hydrothermal vents and cold seeps in the deep ocean (Paul and Heck, 2000). From the Lakshadweep region, 424 species of molluscs were recorded. Seagrass ecosystems, which form the part of intertidal zone, provide a good habitat for molluscs. Seagrass ecosystem has an important impact on physical environment by stabilizing sediments, dampening wave energy, altering turbulence and changing water flow velocity (Gambi *et al.,* 1990; Fonseca and Cahalan, 1992). As a result, the larvae of molluscs may settle in greater densities in seagrasses than in unvegetated substrates (Wilson, 1990). Gastropods form a considerable subset of epifauna and they are important grazers of seagrass epiphytes (Howard, 1987; van Montfrans *et al.*, 1984; Virnstein and Howard, 1987). In Minicoy lagoon the seagrass ecosystem supplies considerable amount of detritus and it forms a suitable source of food for the grazers such as gastropods and other molluscs. The present observation reveals that the most dominant group of fauna in the seagrass meadow was the molluscs, which contribute 46% of the total faunal population and dominated in all the stations. It was 71% in the station I, 77% in the station II, 74% in the station III and 69% in the station IV.

Nearly 200 species of echinoderms were known from the seas around India, of which about 75 species are from the shallow waters within 20 m depth (James, 1994). Of these about 10 species are of commercial value. The lagoons in the Lakshadweep offer an excellent habitat for the echinoderms. Here the waters are calm with very little disturbances. Among echinoderms, holothurians were the dominant family. The holothurians collected by Gardiner from Maldives and Minicoy Islands have been dealt in a cursory manner by Pearson (1914). James (1969) listed 14 species of holothurians from Lakshadweep. Nagabhushanam and Rao (1972) recorded 16 species from Minicoy lagoon. Daniel and Haldar (1974) recorded 23 species of holothurians from Lakshadweep. A general account on the ecology of intertidal holothurians from the Indian region was given by James (1982). Mukhopadhyay and Samanta (1983) reported 12 species of holothurians from the islands of Androth, Kalpeni and Minicoy. The holothurian resources of the Lakshadweep have been studied in greater detail after conducting a planned survey to the 10 islands in the Lakshadweep by James (1989a; 1989b) and reported 25 species of holothurians. *Holothuria atra* is the most common holothurians of the area. *Bohadschia argus* is a common species found in the seagrass bed in the southern side of the lagoon. *Holothuria nobilis* is a characteristic of the *Thalassia* bed. *Stichopus chloronotus* was found near the coral - seagrass boundary area. Echinoderms were contributed 9% of the total faunal population and highest percentage (4% of the total population) was in the station III.

The *3-WAY ANOVA* analysis was done for finding out the variations in faunal density. The results showed that the total contribution was found to be highly significant (R^2 = 0.660). The two interactions of season-station and season-fauna were not found to be significant; where as station wise faunal variations were found to be significant. Among the group of fauna, molluscs dominated in all the stations. At species level, *Cerithium* sp. contributed the major share in the total faunal density of fauna. It was 25% in the station I, 24% in the station II, 28.1% in the station III 22.3% in the station IV.

Interactions of fauna

i) Hydrography and fauna

The living things in an environment are so intimately linked up with their surroundings that they form part of the environment itself. This interaction offers both ways in that the environment is modified by the activities of the biota. A basic knowledge about the needs of the various organisms can be useful to the ecologist. An assessment of the available materials in the environment will indicate the kinds of organisms one can expect in it. In nature, the distribution of animals and plants is controlled by the quantity and variability of materials necessary for the organisms, the physical factors and the limit of tolerance of the organisms to these components of the environment. Environmental components do not exert equal influence on an organism in a particular situation. An environmental factor, which is critical or limiting to one organism, may leave another in the same environment completely unaffected. It is therefore necessary to isolate those factors, which affect the growth and distribution of an organism at any time during life cycle. Once this is done it will be possible to discover those factors, which are critical to an organism, by means of observations and analysis of information, so obtained. So the hydrographical studies viz., physical, chemical and biological parameters of the marine environment are inevitable for the studies of the flora and fauna of the ecosystem. Seagrass beds are highly structure habitats with a morphology that can vary with the constituent seagrass species and the complex interactions between numerous biotic and abiotic factors (Atrill *et al.*, 2000; Hemminga and Duarte, 2000). Minicoy lagoon is the best example for a self-regulating ecosystem. Hydrographic and biological parameters showed a little variation. Organic matter produced in the lagoon is recycled and is utilized by organisms of different trophic levels. This organic matter is the main factor, which controls the nutrient status of the system and thereby influencing the floral and faunal components.

The results of Pearson's correlation between faunal groups and hydrographic parameters showed that, sponges and annelids were significantly correlated with DO ($r = 0.405$, $p< 0.05$; $r = 0.539$, $p< 0.01$) and annelids alone with pH ($r = 0.510$, $p< 0.05$) at station I. In the station II, only the echinoderms showed a significant correlation with DO and pH ($r = 0.494$, $p< 0.01$; $r = 0.410$, $p< 0.01$), while in the station III, the molluscans only showed the significant correlation and it was with salinity ($r = 0.474$, $p< 0.01$) and DO ($r = 0.538$, $p< 0.05$). In the station IV, crustaceans showed significant correlation with pH ($r = 0.567$, $p< 0.05$) and DO ($r = 0.576$, $p< 0.05$) and echinoderms with pH ($r = -0.410$, $p< 0.01$). From the results, it was clear that the less mobile and sedentary forms are strongly influenced by the hydrographical parameters such as pH and DO, rather than the actively moving species. Temperature and salinity is not at all influencing the faunal density, as there are no wide fluctuations in these parameters in the lagoon. **BEST** (Biota and Environment Matching) analysis showed that pH and DO forms the most influential combinations of environmental variables on monthly pattern with the global R value (Rho) of 0.167, while in seasonal distribution pattern, the best results was illustrated by the combinations of salinity and pH, with the Rho value of 0.161. These results showed that temperature is not at all an influencing factor in the distribution of macro invertebrate fauna in the lagoon. The cumulative changes in salinity on seasonal scale have some influence on the distribution of fauna along with pH.

ii) Seaweed biomass and fauna

The seaweeds in the seagrass ecosystem are of three types, viz., rhizophytic, epiphytic and drifting. These algae can change the nature of a seagrass community by providing food and habitat for associated fauna (Bologna and Heck, 1999). However, understanding of these interacting effects is difficult, because both presence of food and increase in structural complexity can increase the density of organisms. The biomass of three groups of seaweeds such as chlorophyceae, phaeophyceae and rhodophyceae were not significantly correlated with density of any of the faunal groups in the station I, whereas in the station II and III, cnidarians showed a significant correlation with chlorophyceae ($r = 0.427$, $p < 0.01$ and $r = 0.550$, $p < 0.05$). Platyhelminthes and annelids were significantly correlated with chlorophyceae ($r = 0.476$, $p < 0.01$ and $r = 0.613$, $p < 0.05$). This relationship may be due to the presence of drift algal mats in these stations. The other groups commonly did not form drifting mats. Thorhaug and Rossler (1977) have produced quantitative evidence that areas with drift algae contain significantly higher animal densities than do areas with seagrasses alone. The two most likely explanations for these higher densities are (i) that large food supplies by algae attract animals and (ii) that algal masses serve as refuges in which small organisms may escape their predators. Certain amphipods associated with drift algal masses do utilize the algae for food (Zimmerman, 1978) and small fishes such as pipefishes and gobies are abundant in the drift algae, actively feed on the associated amphipods. This suggests that at least for amphipods, drift algae may serve primarily as a food source and not a site of reduced predator effectiveness. However, it seems unlikely that these animals are attracted by food alone, since species of the drift algae are also present on individual grass blades and other food in the form of detritus is widely distributed throughout seagrass beds. For large invertebrates, such as shrimps, gastropods and echinoderms, it seems that the masses of drift algae serve as sites of reduced predator effectiveness. The rhizophytic and epiphytic macro algae also provide protection for invertebrates from predators.

A calcareous alga, *Halimeda gracilis*, forms another green alga, which makes the seagrass habitat of Minicoy lagoon, more complex. This species was abundant in the station II and III. This may also influenced the strong correlations of fauna with Chlorophyceae. They form thick mats, even expelling the seagrasses from the area and seems to exert a strong influence on the invertebrates, especially in the *Thalassia hemprichii* dominated beds. *H. gracilis,* when present in dense, it forms an understorey beneath the seagrass canopy. Within this and beneath this many species of animals that normally use coral rubble or rocks for shelter can be found (Heck and Westone, 1977). Members of Rhodophyceae such as *Gracilaria crassa and G. edulis* forms thick mats on the substratum, also harbours many species of fauna. The brown algae are not at all showed any relationship with the faunal community. This may be due to their morphological characteristics. Brown algae such as *Turbinaria ornata* and *Sargassum* sp. present in Minicoy lagoon have hard thallus, which prevent the fauna from taking it as food source. So the chlorophyceae group of seaweeds in the seagrass meadow forms both as food source and shelter for the fauna of the system, which in turn, add habitat complexity and diversity to the ecosystem.

iii) Seagrass and fauna

Seagrass meadows support high densities of animals and are considered fundamentally important in providing habitat for commercially or recreationally harvested aquatic animals (Jackson, *et al.,* 2001). Plants structure the habitat and provide food and shelter to animals in direct or indirect ways (Silvertown, 2004). The rhizomes and roots of the grasses bind sediments on the bottom, where nutrients are recycled by microorganisms back into the marine ecosystem. The leaves of the grasses slow water flow, allowing suspended material to settle on the bottom. This creates a clam habitat for many species. Seagrass beds are characteristic of estuarine and marine coastal environments (Rasmussen, 1977). The presence of these meadows is known to enhance species diversity (Heck *et al.,* 1989; Edgar, 1990). The influence of these seagrass beds on the fauna is both structural by enhancing habitat complexity, allowing different species to occupy various ecological niches in a same area (Orth *et al.,* 1984), and trophic by supporting epiphytes, a resource for many grazers (van Montfrans *et al.,* 1984; Duffy *et al.,* 2003). The presence of seagrass is also known to enhance organic matter content by increasing sedimentation through a reduction of current velocity (Fonseca and Fisher, 1986) and by in situ degradation of plant material. This organic matter represents an important food source for deposit feeders (Edgar, 1999) although this plant material is refractory and consumed after several decomposition phases (Fenchel, 1977). Another factor favouring faunal abundance in seagrass beds is a reduced predation pressure in seagrass-vegetated area (Orth *et al.,* 1984) compared to unvegetated tidal flats (Reise, 1978). Many studies on macrobenthic seagrass beds communities have focused on the comparison of seagrass bed faunal assemblages with that of adjacent non-vegetated areas (Heck *et al.,* 1989; Bostro¨m and Bonsdorff, 1997; Connolly, 1997) or areas with different kind of vegetation (Schneider and Mann, 1991; Paula *et al.,* 2001; Sfriso *et al.,* 2001). Nevertheless, studies on heterogeneity of macrobenthic communities within seagrass beds are scarce (Jacobs *et al.,* 1983; Webster *et al.,* 1998). They have highlighted the heterogeneity of communities' structure within these meadows. These differences have been related to environmental constraints such as duration of emersion (Jacobs *et al.,* 1983), sediment characteristics (Jacobs and Huisman, 1982) or vegetation parameters such as shoot density (Webster *et al.,* 1998).

From the Pearson's correlation analysis it was found that, the density of sponges was significantly correlated ($r = 0.405$, $p< 0.01$) with seagrass biomass and with seagrass shoot density ($r = 0.626$, $p< 0.01$) at station I. The density of annelids with seagrass biomass ($r = 0.440$, $p< 0.01$) and the density of echinoderms with seagrass shoot density ($r = 0.425$, $p< 0.01$) were also significantly correlated at station I. Other significant relationships with seagrass biomass were with crustaceans ($r = 0.468$, $p< 0.01$), with echinoderms ($r = 0.593$, $p < 0.05$) at station II and with molluscs at station III ($r = 0.603$, $p< 0.05$). The density of molluscs was also showed a significant correlation ($r = 0.536$, $p < 0.05$) with seagrass shoot density at station III. No significant relationships were found in the station IV. The fluctuating correlations of faunal community in different stations are most likely to be caused by the differences in the seagrass habitat structure rather than its biomass or algal components. This is supported by the results from other studies (Eklof *et al.,* 2005). The molluscans contributed maximum faunal density form the grazers of the seagrass community. Among molluscs gastropods form the dominant group, which are important grazers. The high quantity of detritus produced by the seagrasses, especially by, *Thalassia testudinum* forms the major source of food for them. The rhizome and leaves form a suitable substratum for the completely sedentary forms like sponges. The shoot density and biomass is thus directly influences the population of these groups. The comparitively calm water column, created by the seagrass canopy is an ideal condition for the benthic adaptation of the platyhelminthes, annelids and echinoderms. So these organisms have good correlation with seagrass shoot density and biomass.

Ecological systems like seagrass meadows encompass spatial heterogeneity in habitat types and processes (Turner, *et al.,* 2001). Such studies incorporate patch attributes such as size and shape and the spatial or temporal relationship among habitats. Studies at this provide a better understanding of the spatial and temporal requirements for population persistence (Debinski and Holt, 2001) and because of the scale, at which habitat perturbations by humans often occur, for management of species (Freemark, *et al.,* 1995). Increased understanding of how the arrangement and areal extent of habitats influence assemblages of animals can improve conservation of human interactions with ecosystems.

Seagrass systems are ideal for the application of landscape-scale ideas because of their natural propensity to form variable sized patches

(Robbins and Bell, 1994). This study forms the first of this kind in Minicoy lagoon. The coral atolls of Lakshadweep group of islands harbour rich vegetation of seagrass in its lagoons. Seagrass meadows can be considered as the marine counterpart of the vegetated landscapes (Robins and Bell, 1994), supporting highly speciose and productive ecosystems (Hemminga and Duarte, 2000).

Seagrass communities are one of the most productive and dynamic ecosystems (Larkum *et al.*, 1989; Bortone, 2000). They provide habitats and nursery grounds for many marine animals and act as substrate stabilizers. In some coastal areas, entire fisheries may depend on the productivity of these seagrass beds. Seagrass meadows are a major food source for a number of grazing animals. The green turtle and dugongs feed on seagrass. In the lagoon of Minicoy, the seagrass meadow is highly productive and forms an ecologically important habitat in the island ecosystem. The dominant species of seagrass include *Thalassia hemprichii* and *Syringodium isoetifolium*, while *Cymodocea serrulata* and *Halophila ovalis* are dominant only in some areas. *Halodule uninervis* is the early colonizer of disturbed areas as found in the station III near to the canning factory waste disposal site and near the village waste disposal site at station IV. It is very much reduced in their presence. It was also found that in such areas, *Thalassia* and *Syringodium* were excluded because of the prevailing environmental conditions. Zieman (1982) reported the same condition in the seagrass meadows. The relationship between faunal abundance and seagrass biomass only holds within a seagrass species and when comparing the faunal communities of different seagrass species, plant morphology has greatest influence (Stoner, 1980).

Consequently, comparisons of the fauna of different seagrass species are difficult to make.

iv) Interactions of faunal groups

The interactions between and within the communities determine the dynamics of any ecosystems. In some ecosystems many species or group of organisms interact each other and for their healthy survival and are inter-dependant. While existing such interactions, direct dependence with each other does not occur in some ecosystems or within communities of a particular region. Such systems are commonly seen in undisturbed areas. The seagrass ecosystem of Minicoy lagoon belongs to such category. The communities have their own niche either for feeding or breeding. The community structure is self-regulating and themselves maintain the seasonal fluctuations. The Draftsman scatter plot clearly illustrated the independent nature of different groups of fauna in the four stations of the study site. The analysis using pooled data showed that all the correlations (interactions) between the faunal groups were not significant as shown in the Draftsman plot.

Community structure

It has been widely documented that seagrasses, through habitat modification and associated changes in local biological, chemical and physical conditions, may strongly influence the structure and functioning of associated macro-invertebrate communities (Orth, 1992; Polte *et al.*, 2005). In practice, the distribution and abundance of fauna varies spatially and temporally (Howard, 1987). Many studies have shown that the abundance and diversity of fauna tend to change according to the abundance of macrophytes in the meadows (Lewis, 1987; Heck *et al.*, 1995, Lee *et al.*, 2001). Many studies have explored the effects of habitat complexity on the abundance and diversity of seagrass associated macrofauna (Blanchet, 2004). Much of the existing information on macro-invertebrate community diversities in seagrass beds is limited to small spatial scales.

While, direct comparisons between studies are difficult due to different sampling methods (core, sieve or quadrat) and differences in the component of fauna sampled (intertidal or sub-tidal; dense or sparse beds; meadows or patches), many studies have showed high macro-invertebrate species diversities in seagrass ecosystem (Heck *et al.,* 1995; Edgar and Barrett, 2002). Indeed, many studies have now convincingly demonstrated the difference in macro-invertebrate community structure between seagrass bed and surrounding bare sand (Castel *et al.*, 1989; Bostro¨m & Bonsdorff, 1997). Seagrass is thus considered a ' structural species ' and because aspects of its complexity can vary, it is considered an ideal system for investigating the role of habitat heterogeneity in structuring communities in the marine environment (Mazzella *et al.*, 1992).

The coastal marine environments have some of the richest biodiversity areas (Khan, *et al.,* 2005). Seagrass ecosystem form one of such coastal marine habitat. Studies on the community structure of macro invertebrate fauna in the seagrass meadow of Minicoy lagoon was almost nil, except some survey reports. This study forms the first one dealing with the community structure of the seagrass ecosystem of the region. Shannon-Wiener diversity index was highest in the station I, where, highest number of species (102) was observed. This in turn, resulted in the highest species richness (Margalef index) in this station. The interactions with neighbouring ecosystems such as coral reefs and open-ocean are more in this station. Even though high biomass and shoot density of seagrasses occurred in the station III and IV, low diversity was observed in these stations. In the Station III, lowest number of species was recorded. Howes, *et al.,* (2004), in his studies showed that macro-invertebrate diversity does not differ consistently between seagrass and unvegetated areas and at high seagrass biomass sampling locations, macro-invertebrate diversity was much lower than that of unvegetated locations. Seagrass beds did not always have the highest biodiversity and abundance compared to adjacent areas with different ecosystems. Furthermore, boundaries between these habitats appeared to have distinctive community compositions. Station III have no direct interactions with neighbouring habitats directly, so the species number become less. Simpson dominance index, which indicating the abundance of a particular species or group in sample, showed lower values in the station I where the species diversity was highest.

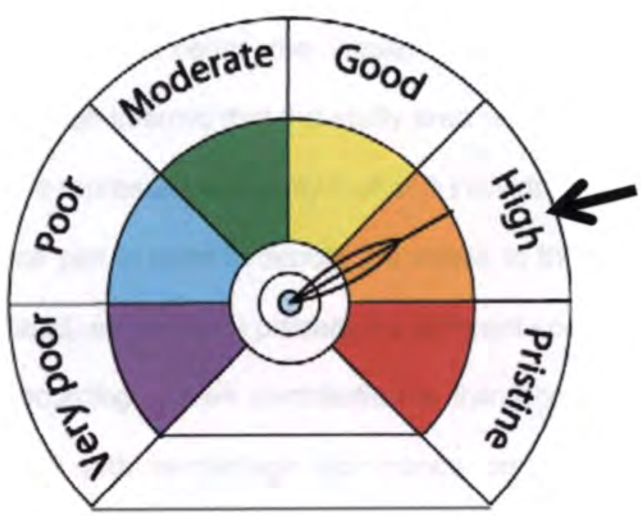
Taking into consideration, the demerits of the routinely used conventional diversity indices, new indices have been recently introduced. They include average taxonomic distinctness (AvTD, $\Delta+$) and variation in taxonomic distinctness (VarTD, $\lambda+$). Average taxonomic distinctness is a measure of species diversity or "taxonomic breadth", and represents the average phylogenetic path length (Δ) between every pair of species in a sample, traced through the levels of a Linnaean taxonomic tree (Warwick and Clarke 2001). Variation in taxonomic distinctness reflects the "evenness" of the distribution of species across the taxonomic tree by determining the variance between each pair of species in a sample (Warwick and Clarke 2001).

In the funnel plot for both Av TD (Δ+) and Var TD (λ+) for all the stations together, the points were clustered together within the 95% confidence level, except for 3 points. Values of both taxonomic diversity indices fell more or less within the 95% limits of the probability funnel indicating that taxonomic diversity of both the assemblages did not vary significantly from the regional species pool. According to the Δ+ values, all of the areas are as diverse as expected (expectation refers to the values produced by simulation and located in the funnel). High Λ+ (low taxonomic evenness) values indicate the presence of a phylogenetically closely related species. This variation is distinctly shown by Λ+, as the variation in taxonomic distinctness index is sensitive to variations in taxonomic evenness of the assemblage and the presence of speciose genera reduces the taxonomic evenness of the assemblage, which is reflected as higher Λ+ values.

A taxonomic diversity index is a measure of biodiversity that indicates how different the species in a habitat are from each other (Harper and Hawksworth, 1994). The taxonomic relatedness diversity indices have appealing sampling properties: non-dependence on quantitative data and consideration of the relatedness of species in an assemblage that are of great practical utility in diversity analysis and are considered as being most promising for biodiversity assessments (Warwick and Clarke 2001; Price 2002; Warwick *et al.,* 2002; Magurran, 2003).

The relationship between the average taxonomic distinctness and variation in taxonomic distinctness of samples collected from the sites was determined using the ellipse plot using TAXDTEST routine to determine the probability that the observed values of these indices were representative (*i.e.* within 95%) of the range of values that would be expected for any subset of species that could be drawn at random from the data for the entire study region. The 95% confidence limits for the different-sized subsets of species were represented as concentric "ellipses" on the scatter plots, and were calculated from 1000 random simulations of $\Delta+$ and $\lambda+$. Any sites that fell outside their corresponding 95% probability ellipse were considered to represent those at which Av TD ($\Delta+$) and Var TD ($\lambda+$) exhibited significant departure from the values expected for these indices over the entire study region. These plots showed that the points for the various sites were particularly tightly grouped at the center of the ellipse indicating that the values for both $\Delta+$ and $\lambda+$ at each of the sites were relatively similar. All of the sites in each season lay within their respective 95% confidence ellipses, except for one site representing the moderately exposed habitat. This was due to the particularly low $\Delta+$ of samples collected at that site.

Based on the expectation, which is used as a novel measure of marine biodiversity, it has wide applications in conservation management. Clarke and Warwick (2001) made a descriptive assessment of the quality of sampling sites. According to this description, the areas are categorized into (i) Pristine - having the abundance of native species, no non-native species and no significant source of contaminants (applicable to Marine Protected Areas), (ii) High – the abundance of native species as expected according to the geographical and physiographical conditions and some disturbance favoured species are present. Non-native species may be present. The area have no significant source of contaminants and would not be subject to damaging human activities, although environmentally benign fisheries may be pursued, (iii) Good - species diversity below than expected, several non-native species may present and contaminants are more from coastal modifications, (iv) Moderate – more disturbed condition and species diversity may be below than expected, (v) Poor – species diversity lower than expected and non-native species abundant and (vi) Very poor – species diversity is very low and some areas are azoic. Based on this description the seagrass meadow of Minicoy lagoon is a high quality site, as shown below, which has small coastal developments such as villages, jetties, etc. Such a condition is applicable to remote area of coast, distant from sources of contamination where small-scale fisheries occur that are not destructive and environment friendly. Minicoy Atoll is such type of an oceanic island away from the mainland of India.



The species area plot is used to predict the total number of stations to be sampled for setting maximum number of species in an area. Here, in the Figure, the curve continued to increase steadily and the asymptote was not reached. An asymptote is reached, if no more species is to occur in the study area. This indicates that more species can be encountered in the sampling sites selected for the present study.

The geometric class plot curves based on station wise abundance of macro invertebrate fauna were gently steep in Figure and they extend across very few abundance classes. Higher number of classes occurs in the samples with more dominant species and rare species are very low. In the present investigation, for all the stations, except station III, only 8 abundance classes were present. 9 abundance classes were recorded in the station III. Highest percentage of species abundance class was recorded in the station I and lowest in the station III, which followed the same trend in Shannon - Wiener diversity index. Second order abundance class has the highest representation class in the present investigation. This means that conservative species were more and opportunistic species were less. The lower the number of abundance classes, the better the health of the system. From these observations it can be inferred that the study area is relatively unpolluted with many rare species represented by only 1, 2 or 3 individuals.

Dominance plot is used to denote the stress to the biota. *k*-dominance curves (Lambshead, *et al.*, 1983) present the different species ranked in order of dominance according to their contribution to living coverage on the x-axis (logarithmic scale) with percentage dominance on the y-axis (cumulative scale). Here the percentage dominance of the organisms was plotted against their rank individually and cumulatively. In the stressed environment, the curve is **'J'** shaped, showing the dominance of opportunistic species. In the unimpacted situation, the cumulative dominance curve is **'S'** shaped and drops gradually showing the presence of conservative species. The starting point of the curve and its inclination are indicative of the diversity profile of the examined community; a steep slope with a high starting point reflects low diversity. In the dominance curve plotted based seasonal pattern showed an **'S'** shaped curve, which indicated an unpolluted (unimpacted) habitat. **'S'** shaped curve indicated the gradual increase in species diversity, where as the curves showing steep elevation indicated more dominance and less diversity. In the case of station wise species distribution pattern, highest percentage of cumulative dominance was recorded in station III and highest species rank goes to station I. The slope of the *k*- dominance curve for station I is more, which indicated a high species diversity. Station III experiences a minor rate of pollution due to human activities (transportation of goods and tuna fishing activities). These disturbances are reduced by the working holidays during monsoon season and the health of the ecosystem is maintained in good condition. *k*-dominance curve for seasons also showed an **'S'** shaped curve with almost similar gentle slope for all the seasons and showed clear separation from each other. Highest percentage of cumulative dominance and in turn, lowest diversity was recorded for pre monsoon and highest for monsoon. Highest species rank was also recorded for monsoon season.

Multi-dimensional scaling (MDS) used to construct a "map" of the sampling sites, in which the more similar samples are in terms of species abundance, the nearer they are to each other on the map (Clarke and Green, 1988). MDS depends only on rank information rather than quantitative values, using the interpretation- points that are close together represent samples that are very similar in species composition, points that are far apart correspond to very different communities. The extent to which these relationships can be adequately represented on a two-dimensional map is expressed as the stress coefficient statistic, with low values indicating success (e.g., <0.1). The 'stress' indicates how faithfully the high-dimensional relationships among the samples are represented in the 2D ordination plot. Multivariate techniques, such as MDS, are now considered the most sensitive measures in terms of detecting changes in community structure, especially compared to conventional univariate biodiversity measures. However, these procedures by themselves do not indicate deleterious changes. This is usually achieved by linking community structure to univariate environmental measures (Clarke and Warwick, 2001), such as by superimposing values of variables that indicate disturbances to the ecosystem. In the present analysis, species and group wise data of macro invertebrate fauna were used for MDS analysis both on monthly and seasonal scale. The red lines represent 80% similarity contour, blue line 40% and green, 20%.

Based on the finding that samples from this study area showed good similarity seasonally, while on monthly pattern, greater variability in community structure was observed. 40% similarity contours were dominated in the species wise abundance of fauna both in monthly and seasonal patterns. The stress coefficient in the case of monthly distribution pattern is 0.24 and 0.21 both in species and group wise patterns, while; the stress coefficient is 0.16 and 0.13 in the case of seasonal pattern. 80% similarity was observed in this case of seasonal pattern of faunal groups, whereas, 60% of similarity was recorded for seasonal pattern of species distribution. This difference differences in similarity indicated in the stress value as 0.16 for those with 80% similarity and 0.13 for those with 60% similarity. Stress value <0.2 gave potentially useful 2D picture with a good ordination between samples, and that between 0.2 - 0.3 should be treated with a great deal of scepticism. In Fig. 6.9., St 1 PreM, St 2 PreM, St 2 Mon, St 2 PoM and St 3 Po M showed similarities in the species abundance and composition, where in the Fig. 6.11., 2 separate clusters with St 2 Mon and St 2 PoM were formed. All the other samples formed as separate cluster. From the whole MDS analysis, it was confirmed that seasonal samplings are best fro the interpretation of the faunal composition of the seagrass meadow of Minicoy lagoon.

For the clear interpretation and cross checking of the association and similarities of any samplings it is better to alternative multivariate analyses. In order to find out the significant similarities, Similarity Profile (**SIMPROF**) Test was done using PRIMER v6. From the similarity dendrogram it was evident that no significant similarities were obtained for either faunal species of group wise distribution pattern, except a minor significant clustering in the case of monthly distribution pattern of faunal species as indicated by the bold line in the Fig. 6. 12.

Out of 34 phyla, 32 are reported from the marine ecosystems of the world. However, in India, major studies have been conducted only on commercially important organisms. Seagrass ecosystem provides a good habitat for both commercially and taxonomically important species of fauna. The lower abundance of fauna could itself have substantial effects at the system level, as benthic macro-fauna perform a number of important functions in seagrass beds, (*e.g.* Detritivory and filtration). Further, many macro- and meio- faunal taxa constitute important food for benthic fish in seagrass beds implying that a reduction in abundance of macro-fauna could result in altered fish community residing in seagrass beds.

The results of this study demonstrate that the role of seagrass habitat in influencing macro-invertebrate communities is complex and variable. The presence of seagrass was found to have an influence on macro-invertebrate community composition, and this influence was found to change with spatial conditions and seagrass species composition. The presence of seagrass bed may not always result in increased macro-invertebrate abundance and diversity. This does not preclude seagrass from providing important coastal habitat, but emphasizes the significance of context dependence and the need to understand the linkage between different habitats in heterogeneous conditions and their effects on the abundance and diversity of macro-invertebrate communities over different spatial and temporal scales. The results from this study also suggest that the influence of seagrass on macro-invertebrate communities may vary as a result of site, which can be related to the characteristics of the seagrass bed itself as well as environmental conditions, underlining the importance of long term sampling in wide geographical area, in order to understand the macro-invertebrate distribution patterns. This study forms a comprehensive base for the faunal composition of the seagrass meadow of Minicoy lagoon and will be useful in future for the assessment of the ecosystem to find out any changes in community structure and conservation management.

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Chapter VII

Ichthyofauna

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Ichthyofauna

7.1. Introduction

Most of the marine fishes are found on or near the edges of the continental shelf with wide varieties of habitats and each inhabited by a distinctive set of fishes. As a consequence of the high productivity, the seagrass meadow supports large populations of fishes, which find both food and shelter in the grass. Several studies have documented the importance of seagrass beds as habitats for fishes, (Kikuchi, 1980; Orth, *et al.*, 1984; Edgar, 1990; Blaber *et al.*, 1992; Coles *et al.*, 1993; Gray *et al.*, 1998; Nagelkerkan *et al.*, 2000; Paula *et al.*, 2001; Gell *et al.*, 2002; Luczkovich *et al.*, 2002; Dorenbosch *et al.*, 2004; Jones and West, 2005). These fishes are principally either juveniles of large species or species with small adult sizes. This habitat enhances the growth and survival of juvenile fishes because they provide high food availability, low predation risk, and protection from adverse weather conditions. This fact was supported by the studies of Heck *et al.*, (1989); Gray *et al.*, (1996; 1998); Jenkins *et al.*, (1997) and compared the relative abundance both in vegetated and unvegetated areas. They found that vegetated and unvegetated areas, support different and more diverse fish assemblages than adjacent bare sand, as well as being considered more important as nursery areas for juveniles of many economically important species.

There are four basic feeding types that can be found in the sea grass beds: detritivores, carnivores, planktivores and omnivores. The most abundant fishes are carnivores, which feed on the abundant invertebrates and small fishes associated with the grasses. Direct herbivory by fishes on sea grass is rare (Bell and Pollard, 1989) except in the hemiramphids and monocanthids as well as some kyphosids and sparids have been reported to eat epiphytic algae in seagrass meadows. Most of these fishes appear to be feeding mainly on the associated epi-fauna (Klumpp *et al.,* 1989). They suggested that direct grazing of seagrass by fishes probably insignificant in terms of seagrass removal. There is evidence that the ingestion of seagrass may be incidental, with the preferred diet being epifauna and epiphytes living on the sea grass leaves (Bell *et al.*, 1987) and monacanthids and hemirhamphids gain some nutrition from the plant material (Klumpp and Nichols, 1983).

Research on the fishes in seagrass beds has mostly taken place in temperate to warm temperate areas such as southern Australia (Bell and Pollard, 1989) and North America (Thayer *et al.,* 1975). Fishes in tropical seagrass meadow have only been studied in the Caribbean (Baelde, 1990; Heck and Weinstein, 1989; Robblee and Zeiman, 1984), the Papua New Guinea, tropical Northern Australia and isolated parts of the Pacific (Blaber *et al.*, 1992; Brouns and Heijs, 1985). Seagrass areas in these studies were small beds, usually within coral reef lagoons.

Detailed studies on the species composition, distribution, and abundance of fishes in seagrass beds of Lakshadweep lagoons were lacking. Only the details of survey on fishes of the lagoon and surrounding waters were available (Jones, 1964; Jones, *et al.*, 1969). This is the first attempt for studying the distribution, species composition and abundance of ichthyofauna in the seagrass meadow of Minicoy lagoon.

7.2. Results:

7.2.1. Species composition and Distribution

During the study period, a total of 203 species of fishes were obtained from the seagrass meadow of Minicoy lagoon, by using beach seine (Plate 18a&b; Plate 19a&b). They belong to 2 classes, 11orders, 43 families and 93 genera. Out of this, 6 species belong to the class Chondreichthyes and 197 species belong to Osteichthyes. Total list of species was given in the table 7.1 and the station wise list was given in the table 7.2. In the Station I, 129 species of fishes were recorded and they were included in 74 genera, 37 families, 10 orders and 2 classes. 52 species of fishes were obtained from the station II, which belong to 34 genera, 23 families, 8 orders and 2 classes. In the station III, 83 species, which constitute 53 genera, 31 families, 8 orders and 2 classes were recorded. 72 species of fishes were obtained from the station IV, which belong to 46 genera, 30 families, 8 orders and 2 classes. Numbers of species in the dominant families, having the species number 5 and above were shown in the Fig. 7.1. Percentage composition of the number of species in dominant families, having the percentage of species number higher than 10 were represented in the Fig. 7.2.

Plate 18

Plate 18 a & b. Beach Seine operation in Minicoy lagoon

Plate 19a. Net used for fishing in Minicoy lagoon

Plate 19b. A collection of fishes obtained from Minicoy lagoon

Table 7.1. Systematic list of fishes obtained during the study period from the four stations in Minicoy lagoon

Class: Chondreichthyes
Order: Rajiformes
Family: Dasyatidae
Dasyatis uarnak
Dasyatis sp.

Family: Carcharinidae
Carcharinus melanopterus
***Carcharinus* sp.**

Order: Lamniformes
Family: Lamnidae
Alopius vulpinus
Isurus glaucus

Class: Osteichthyes
Order: Perciformes
Family: Apogonidae
Apogon leptacanthus
A. coccineus
A. nigrosfasciatus
A. bandanensis
A. quadrifasciatus
A. apogonides
A. exostigma
A. sp.
Apogonichthyes ocellatus
Archaemia fucata
A. sp.
Pristiapogon snyderi
Ostorhynchus savayensis
O. endekataenia
O. sp.

Family: Pomacentridae
Amphiprion nigripes
Dascyllus trimaculatus
D. aruanus
Chromis dimidiatus
C. opercularis
C. ternatensis
Pomacentrus lividus
P. nigricans
P. sp.
P. albicaudatus
P. taeniurus
Abudefduf sexfasciatus
A. bengalensis
A. septemfasciatus
A. zonatus
A. glaucus
A. sp.
A. lacrymatus
A. saxatilis

Family: Serranidae
Cephalopholis argus
C. miniata
C. pachycentron
Epinephelus areolatus
E. fuscoguttatus
E. miliaris
E. flavocaeruleus
E. hexagonatus
E. elongatus
E. malabaricus
E. melanostigma
E. caeruleopunctatus
Gnathodentex aurolineatus
Monotaxis grandoculis
M. sp.

Family: Lethrinidae
Lethrinus harak
L. mahsena
L. conchyliatus
L. elongatus
Lethrinella microdon

Family: Labridae
Thalassoma purpureus
T. hardwickii
T. janseni
T. lunare
T. quinquevittatus
Halichoerus marginatus
H. kawarin
H. argus
H. scapularis
H. sp.
Labroides dimidiatus
Gomphosus caeruleus
Chelinus trilobatus
C. undulatus
Stethojulis sp.
S. strigiventer
Coris Formosa

Family: Carangidae
Caranx sexfasciatus
C. ignobilis
C. ferdau
Carangoides malabaricus
C. chrysophrys
Selar crumenothalmus
Trachinotus sp.

Family: Lutjanidae
Lutjanus kasmira
L. gibbus
L. fulviflammus

L. ruselli
L. bohar
L. fulvus
L. sp.
L. quinquelineatus

Family: Mullidae
Upeneus tragula
U. vittatus
U. arge
Parupeneus indicus
P. barberinus
P. pleurostigma
P. macronemus
P. bifasciatus
Mulloides samoensis
M. vanicolensis

Family: Chaetodontidae
Chaetodon lunula
C. melannotus
C. collare
C. bennetti
C. xanthocephalus
C. auriga
C. vagabundus
C. unimaculatus
C. decussatus
Heniochus acuminatus
H. monoceros

Family: Caesionidae
Caesio xanthonotus
C. caerulaureus
C. sp.
C. lunaris
Pterocaesio tile

Family: Theraponidae
Therapon jarbua
T. puta
T. theraps

Family: Kuhlidae
Kuhlia mugil

Family: Gerreidae
Gerres oblongus
G. lucidus

Family: Kyphosidae
Kyphosus cinerascens

Family: Acanthuridae
Acanthurus triostegus
A. nigricans
A. mata
A. sp.
A. leucosternon
Ctenochaetus sp.
Paracanthus heptatus
Acanthurus lineolatus
Naso lituratus

Family: Ephippidae
Platax orbicularis
P. teira

Family: Blennidae
Petroscrites pindae
Cirripectus sebae
Entomacorodus straitus
Salarius fasciatus

Family: Siganidae
Siganus rostratus
S. javus

Family: Scorpaenidae
Pterois volitans
Scorpaena sp.

Family: Zanclidae
Zanclus cornuatus

Family: Leognathidae
Leiognathus sp.

Family: Pempheridae
Pempheris sp.

Family: Haemulidae
Plectorhinchus albovittatus
P. pictus
P. polytaenia
P. orientalis

Family: Grammistidae
Grammistes sexlineatus
Diploprion bifasciatus

Order: Clupeiformes
Family: Clupeidae
Spratelloides delicatulus
S. gracilis
S. japonicus
Sardinella sp.
S. melanura
Dussumeira sp.
Amblygaster sp.
Herklotsichthyes quadrimaculatus

Family: Albulide
Albula vulpes

Family: Engrulidae
Engaulis japonicus

Order: Anguilliformes
Family: Muraenidae
Gymnothorax pictus
G. sp.
G. flavimarginatus
G. javanicus
G. meleagris
Echidna delicatula

Order: Beloniformes
Family: Belonidae
Albennes hians
Thalassosteus sp.

Family: Hemiramphidae
Hyporhampus unifasciatus
H. dussumieri

Order: Beryciformes
Family: Holocentridae
Sargocentron diadema
Myripristis murdjan
Neoniphon samara
Holocentrus lacteoguttaus

Order: Mugiliformes
Family: Sphyraenidae
Sphyraenia barracuda
S. fosteri
S. obtusata

Family: Atherinidae
Atherina forskalii
A.duodecimalis

Order: Pleuronectiformes
Family: Bothidae
Bothus pantherinus
B. sp.

Order: Tetradontiformes
Family: Balistidae
Odonus niger
Canthidermis rotundatus
Balistoides viridescens
Psuedobalistes flavimarginatus
Rhinecanthus aculeatus
R. sp.
Sufflamen chrysopterus

Family: Diodontidae
Diodon hystrix
Lophodiodon calori

Family: Ostraciidae
Ostracion tuberculatus
O. mileagris
Rhynchostracion nasus
Canthigaster margarittatus
C. janthinuropterus

Family: Tetraodontidae
Arothron nigropunctatus
A. stellatus

Order: Sygnathifomes
Family: Fistularidae
Fistularia commersoni
F. petimba

Family: Sygnathidae
Hippocampus kuda
Hippocampus sp.

Table 7.2. Station wise distribution of fishes in Minicoy lagoon

	Station I	Station II	Station III	Station IV
Dasyatis uarnak	+	+	-	-
Dasyatis sp.	-	+	-	-
Carcharinus melanopterus	+	+	+	-
Carcharinus sp.	+	+	-	+
Alopius vulpinus	-	-	+	-
Isurus glaucus	-	-	+	-
Apogon leptacanthus	+	-	-	-
Apogon coccineus	+	-	-	-
Apogon nigrofasciatus	+	-	-	+
Apogon bandanensis	+	-	-	-
Apogon quadrifasciatus	+	-	-	-
Apogon apogonides	+	-	-	-
Apogon exostigma	+	-	-	+
Apogon sp.	+	-	-	-
Apogonichthyes ocellatus	+	-	-	-
Pristiapogon snyderi	+	-	-	-
Archaemia fucata	-	-	-	+
Archaemia sp.	+	-	-	-
Ostorhinchus savayensis	+	-	-	-
Ostorhinchus endekatenia	+	-	-	-
Ostorhinchus sp.	+	-	-	-
Amphiprion nigripes	+	-	-	-
Dascyllus trimaculatus	+	-	-	-
Dascyllus aruanus	+	-	-	-
Chromis dimidiatus	+	-	+	-
Chromis opercularis	+	-	-	-
Chromis ternatensis	-	-	-	+
Pomacentrus lividus	+	+	-	-
Pomacentrus nigricans	+	-	-	+
Pomacentrus sp.	+	+	-	-
Pomacentrus albicaudatus	-	-	+	-
Pomacentrus taeniurus	-	-	-	+
Abudefduf bengalensis	+	-	-	+
Abudefduf glaucus	-	+	-	-
Abudefduf lacrymatus	+	-	-	+
Abudefduf saxatilis	-	-	+	-
Abudefduf septemfasciatus	-	-	-	+
Abudefduf sexfasciatus	+	+	+	+
Abudefduf sp.	+	-	-	+
Abudefduf zonatus	-	-	-	+
Cephalopholis argus	+	-	-	-
Cephalopholis miniata	+	-	-	+
Cephalopholis pachycentron	+	-	+	-
Epinephelus areolatus	+	+	+	-
Epinephelus fuscoguttatus	+	-	-	-
Epinephelus miliaris	-	-	-	+
Epinephelus flavocaeruleus	+	-	-	-
Epinephelus hexagonatus	-	-	-	+
Epinephelus elongatus	+	+	-	+
Epinephelus malabaricus	+	-	-	-
Epinephelus melanostigma	-	-	-	+
Epinephelus caeruleopunctatus	-	-	+	-

Contd...

Gnathodentex aurolineatus	+	-	+	-
Monotaxis grandoculis	+	+	+	-
Monotaxis sp.	-	-	+	-
Lethrinus harak	+	+	+	-
Lethrinus mahsena	+	+	+	+
Lethrinus conchyliatus	+	+	+	-
Lethrinus elongatus	+	-	+	-
Lethrinella microdon	+	-	-	+
Thalassoma purpureus	+	+	-	-
Thalassoma hardwickii	+	-	-	-
Thalassoma janseni	+	-	+	-
Thalassoma lunare	+	-	-	+
Thalassoma quinquevittatus	-	+	+	-
Halichoerus marginatus	-	+	+	-
Halichoerus kawarin	-	-	-	+
Halichoerus argus	-	+	-	-
Halichoerus scapularis	-	-	+	-
Halichoerus sp.	+	-	+	-
Labroides dimidiatus	+	-	-	-
Gomphosus caeruleus	+	-	-	+
Chelinus tnilobatus	-	+	+	-
Stethojulis sp.	-	-	+	-
Stethojulis strigiventer	+	-	-	-
Coris formosa	-	-	-	+
Caranx sexfasciatus	+	+	+	+
Caranx ignobilis	+	+	+	+
Caranx sp.	-	-	+	-
Carangoides ferdau	+	+	+	-
Carangoides malabaricus	+	+	-	-
Carangoides chrysophrys	+	+	-	+
Selar crumenothalmus	+	-	-	-
Trachinotus sp.	+	-	-	-
Lutjanus kasmira	+	+	+	+
Lutjanus gibbus	+	+	+	+
Lutjanus fulviflammus	-	-	+	-
Lutjanus ruselli	+	-	+	-
Lutjanus bohar	+	+	+	+
Lutjanus fulvus	+	-	-	-
Lutjanus quinquelineatus	+	-	-	-
Lutjanus sp.	+	-	-	-
Upeneus tragula	+	+	+	-
Upeneus vittatus	+	+	+	+
Upeneus arge	+	+	-	-
Parupeneus indicus	+	+	+	+
Parupeneus barberinus	+	-	-	-
Parupeneus pleurostigma	-	-	+	-
Parupeneus macronemus	-	-	+	-
Parupeneus bifasciatus	+	+	-	+
Mulloides samoensis	+	-	+	+
Mulloides vanicolensis	+	+	+	+
Chaetodon lunula	+	-	+	+
Chaetodon melannotus	-	-	-	+
Chaetodon collare	-	-	-	+
Chaetodon bennetti	-	-	-	+

Contd...

Chaetodon xanthocephalus	+	-	-	-
Chaetodon auriga	+	-	-	+
Chaetodon vagabundus	-	-	-	+
Chaetodon unimaculatus	-	-	+	-
Chaetodon decussatus	-	-	+	-
Heniochus acuminatus	-	-	+	+
Heniochus monoceros	-	-	+	-
Caesio xanthonotus	+	+	-	-
Caesio caerulaureus	-	+	-	-
Caesio lunaris	+	-	-	-
Caesio sp.	+	-	-	-
Pterocaesio tile	+	-	-	-
Therapon jarbua	+	-	+	+
Therapon puta	-	-	+	-
Therapon theraps	+	-	+	+
Kuhlia mugil	+	+	+	-
Gerres oblongus	+	+	+	+
Gerres lucidus	+	+	-	
Kyphosus cinerascens	+	-	+	+
Acanthurus triostegus	+	-	+	+
Acanthurus nigricans	+	-	-	+
Acanthurus mata	-	-	-	+
Acanthurus leucosternon	-	-	-	+
Acanthurus lineolatus	+	-	-	+
Acanthurus sp.	-	-	-	+
Paracanthus heptatus	+	-	+	+
Ctenochaetus sp.	+	-	-	-
Naso lituratus	+	-	-	-
Platax orbicularis	+	-	-	+
Platax teira	+	-	-	-
Petroscrites pindae	-	+	-	-
Cirripectus sebae	-	+	-	-
Entomacrodus straitus	+	-	-	-
Salarius fasciatus	+	-	-	-
Siganus rostratus	-	-	+	-
Siganus javus	-	+	+	-
Pterois volitans	-	-	+	-
Scorpaenia sp.	+	-	+	-
Zanclus sp.	+	-	-	-
Leiognathus sp.	-	-	-	+
Pempheris sp.	+	-	-	-
Plectorhinchus albovittatus	-	-	-	+
Plectorhinchus pictus	-	-	+	-
Plectorhinchus maculatus	-	-	+	-
Plectorhinchus polytaenia	+	-	-	-
Plectorhinchus orientalis	+	-	-	-
Grammistes sexlineatus	-	-	-	+
Diploprion bifasciatus	+	-	-	-
Spratelloides delicatulus	-	-	+	-
Spratelloides gracilis	-	-	+	-
Sardinella sp.	-	-	+	-
Sardinella melanura	-	+	+	+
Dussumeira sp.	-	-	+	-
Amblygaster sp.	-	-	+	-

Contd...

Herklotsichthyes quadrimaculatus	-	-	+	-
Albula vulpes	-	-	+	+
Engraulis japonicus	-	-	+	-
Gymnothorax pictus	-	-	-	+
Gymnothorax sp.	+	-	-	+
Gymnothorax flavimarginatus	+	-	-	+
Gymnothorax javanicus	+	-	-	-
Gymnothorax meleagris	+	-	-	-
Echidna delicatula	+	-	-	+
Albennes hians	+	+	+	+
Thalassosteus sp.	-	-	-	+
Hyporhamphus unifasciatus	+	-	-	-
Hyporhamphus dussumieri	-	+	+	-
Sargocentron diadema	+	-	+	+
Myripristis murdjan	-	-	-	+
Neoniphon sammara	-	-	-	+
Holocentrus lacteoguttatus	+	-	+	-
Sphyraenia barracuda	+	+	+	+
Sphyraenia fosteri	-	+	-	-
Sphyraenia obtusata	-	+	-	-
Atherina forskalii	+	-	-	-
Atherina duodecimalis	+	-	-	-
Bothus pantherinus	+	-	-	-
Bothus sp.	+	+	-	-
Odonus niger	+	+	+	+
Canthidermis rotundatus	+	-	+	+
Balistoides viridescens	+	-	+	-
Pseudobalistes flavimarginatus	+	+	+	+
Rhinecanthus aculeatus	+	+	-	+
Sufflamen chrysopterus	+	+	+	-
Diodon hystrix	+	+	+	-
Lophodiodon calori	+	-	-	-
Ostracion mileagris	-	-	+	-
Ostracion tuberculatus	-	-	+	-
Rhynchostracion nasus	+	-	-	-
Canthigaster margarittatus	+	-	-	+
Canthigaster janthinuropterus	-	-	-	+
Arothron nigropunctatus	+	-	+	-
Arothron stellatus	-	-	-	+
Fistularia commersonii	+	-	-	-
Fistularia petimba	+	+	-	-
Hippocampus kuda	+	-	-	-
Hippocampus sp.	-	-	+	-

\+ present - absent

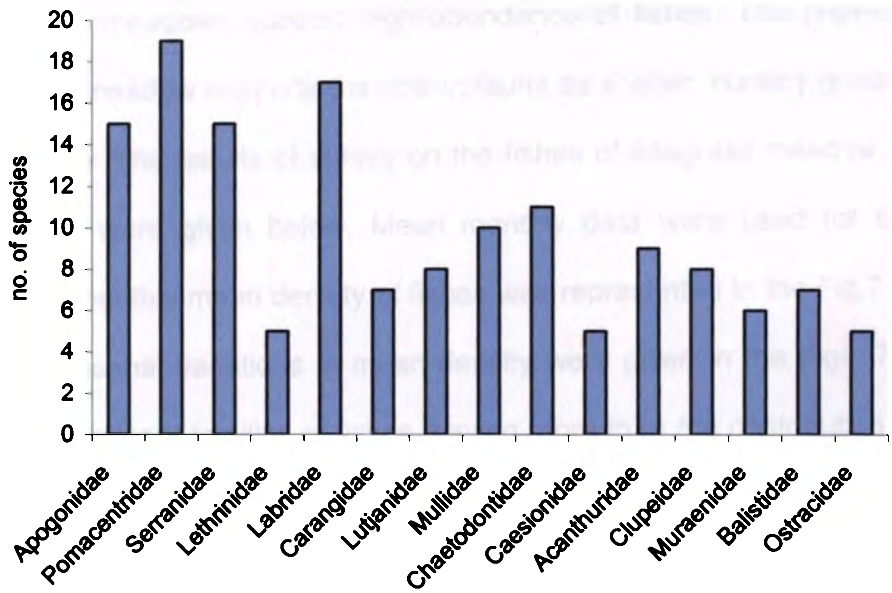

Fig. 7.1. Number of species in the families observed in all the stations in the Minicoy lagoon

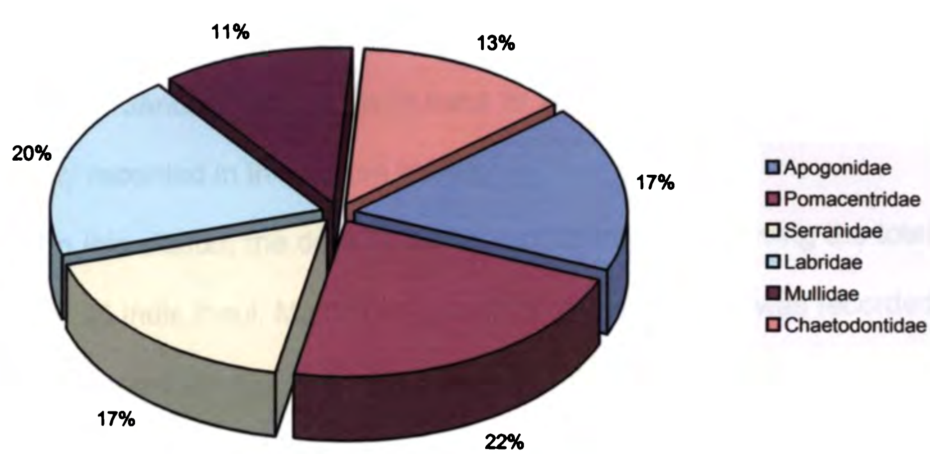

Fig. 7.2. Percentage composition of number of species in dominant families of all the stations

7.2.2. Abundance:

Seagrass meadows support high abundance of fishes. The physical structure of the meadow supports the ichthyofauna as shelter, nursery ground and food source. The results of survey on the fishes of seagrass meadow of Minicoy lagoon were given below. Mean monthly data were used for the analysis. The monthly mean density of fishes was represented in the Fig.7.3. Spatial and seasonal variations in mean density were given in the Figs. 7.4 and 7.5. The dominant families of fishes, having more than 5% contribution to the total abundance in each station were given in the Fig. 7.6.

Spatial variations:

Station I: Mean density of fishes in this station was 33 indls./haul. Highest density of fishes (54 indls./haul) was recorded during December, followed by 53 indls./haul in March and 46 indls./haul in October. Lowest density of 13 indls./haul was observed in May.

Station II: Total mean density of fishes in this station was 31 indls./haul. Highest mean density of 53 indls./haul was recorded in February, followed by 49 indls./haul in January and 48 indls./haul in April. 12 indls./haul was the lowest density recorded in this station in May.

Station III: In this station, the density was comparitively high, having the total mean density 95 indls./haul. Maximum density of 197 indls./haul was recorded in October, followed by 137 indls./haul in December and 130 indls./haul in June. Lowest density of 41 indls./haul was recorded in November.

Station IV: The total mean density recorded in this station was 23 indls./haul. Highest density of 39 indls./haul was recorded in Jun, followed by 33

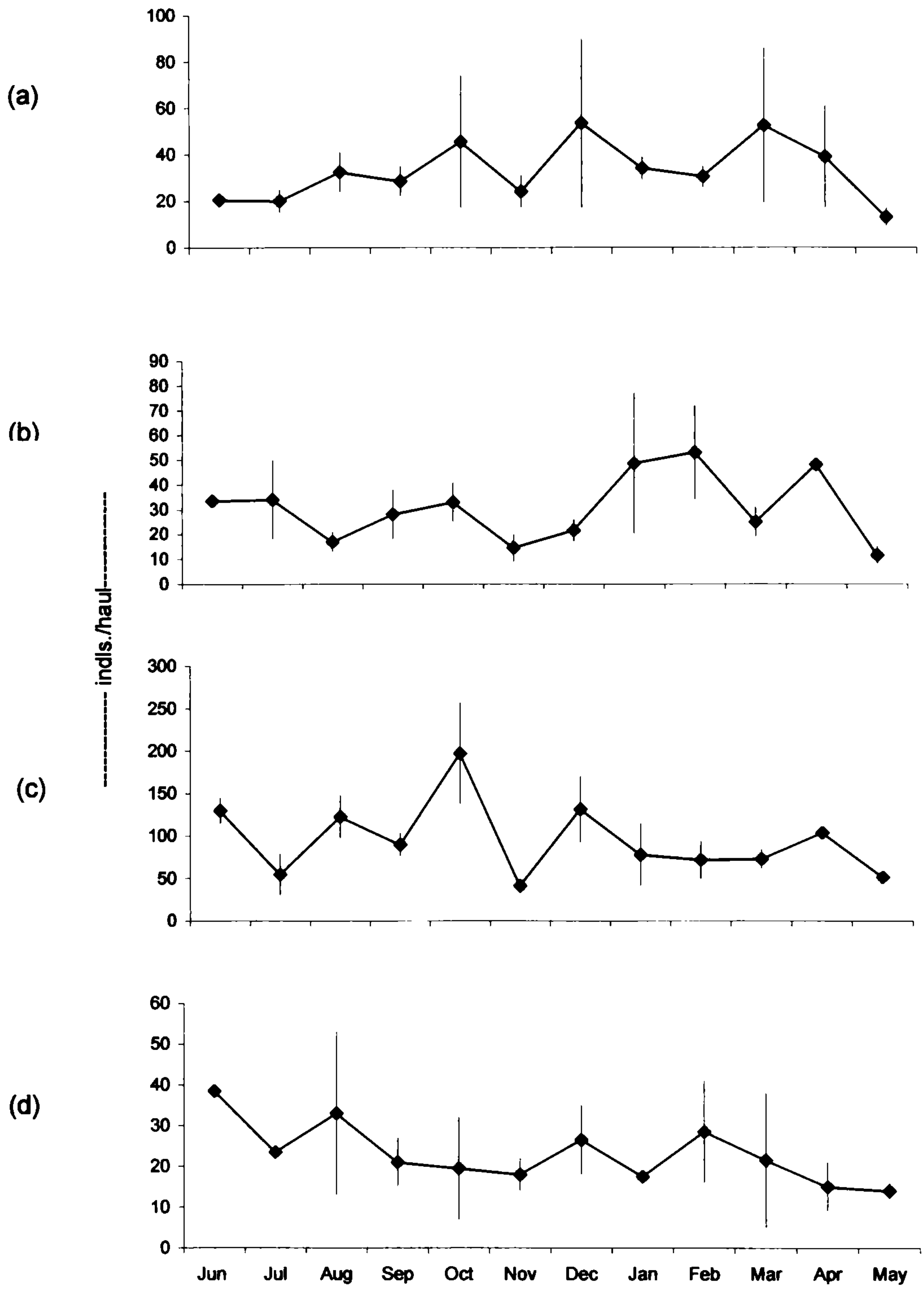

Fig. 7.3. Monthly variations in fish density (indls./haul) in (a) station I (b) station II (c) station III and (d) station IV

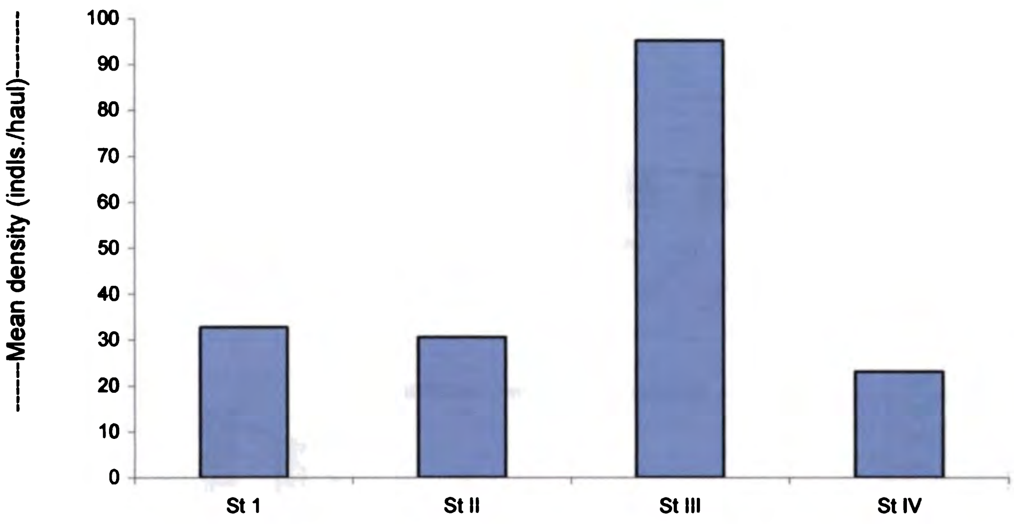

Fig. 7.4. Spatial variations in mean fish density (indls./haul) at four stations of Minicoy lagoon

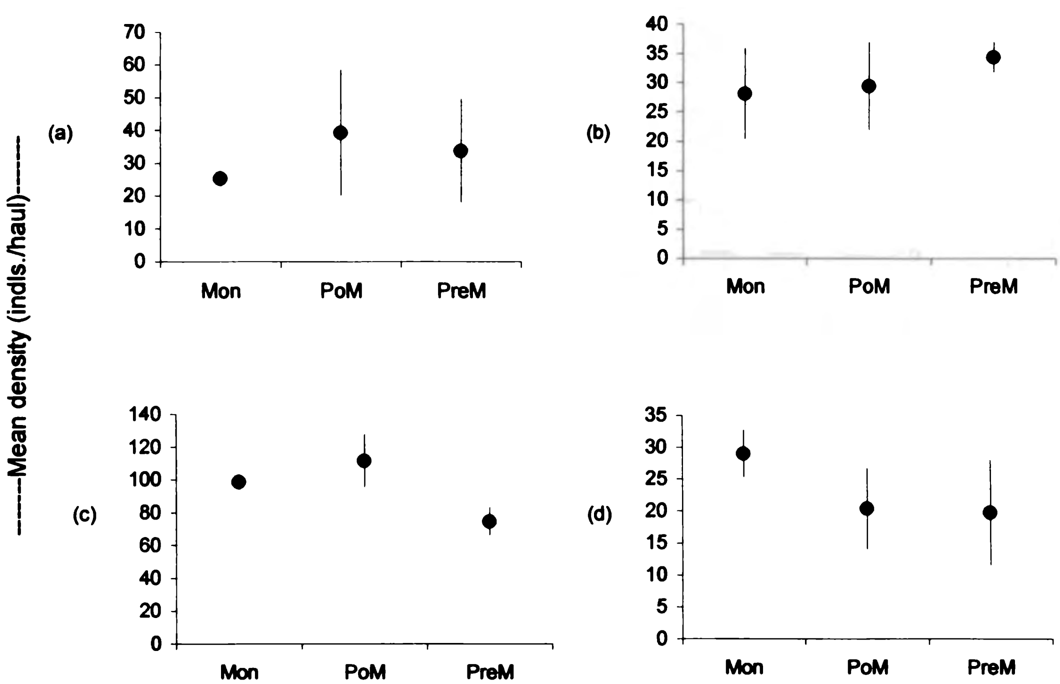

Fig. 7.5. Seasonal variations in mean fish density (indls./haul) in the four stations of Minicoy lagoon

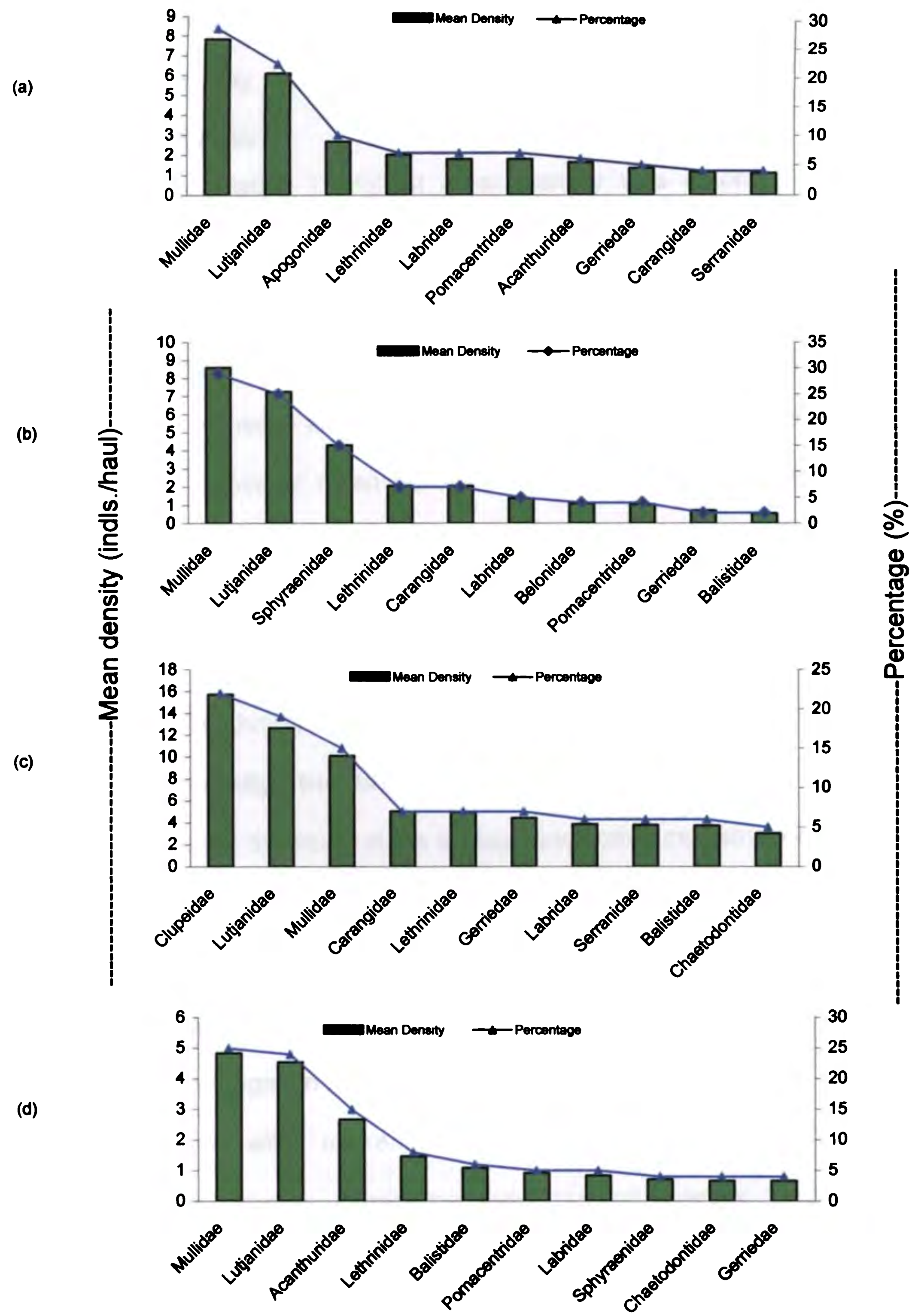

Fig. 7.6. Mean densities (indls./haul) and the percentage composition of dominant families of fishes in (a) Station I (b) Station II (c) Station III and (d) Station IV

indls./haul in August and 29 indls./haul in February. Lowest density of 14 indls./haul, in May.

Seasonal variations:

In the station I, highest mean density was recorded during post monsoon (39 indls./haul) and lowest (25 indls./haul) during monsoon. During pre monsoon it was 34 indls./haul. In the station II, highest mean density was 34 indls./haul, which was recorded during pre monsoon. It was 29 indls./haul during post monsoon and 28 indls./haul during monsoon. 112 indls./haul was the highest seasonal mean density in the station III, which was observed during post monsoon, followed by 99 indls./haul during monsoon and 75 indls./haul during pre monsoon. Highest seasonal mean density (29 indls./haul) in the station IV was recorded during monsoon. 20 indls./haul were recorded during pre- and post monsoon.

7.2.3. Community Structure

Although the study of the ecology and community structure of fishes of the atolls have made (Pillai *et al.*, 1986; Vijayanand and Pillai, 2005) earlier, the community structure of the fishes of seagrass meadow was not yet made in the lagoons of Lakshadweep. This is a first attempt in this regard. The present investigation provides a basis on seagrass fish community organizations with reference to the abundance, similarity, species composition, richness, dominance, evenness and diversity. Similarity indices for seasons and families were represented in the Fig. 7.7and 7.8. The results of the community structure analysis were given in the table 7.3a to 7.3d. and the mean spatial variations were represented in the Fig. 7.9.

Similarity indices:

For finding out the similarities between temporal and spatial patterns, multi dimensional scaling (MDS) and SIMPROF test were done, using the numerical abundance data, both in monthly and seasonal patterns. MDS plot exhibited a good ordination between the samples having stress value of 0.28 for monthly (Fig 7.7) distribution patterns and 0.15 for seasonal (Fig. 7.8) patterns.

Dendrogram were made for the monthly (Fig. 7.9) and seasonal (Fig. 7.10) abundance data and the significance of similarities were found out using **SIMPROF** test. 47 clusters were formed for the monthly data having highest similarity of 60.73%, out of which 4 clusters showed minor significance of similarity. 11 clusters were formed for seasonal data, which showed good significance in similarity as indicated by the bold lines in the Figs.

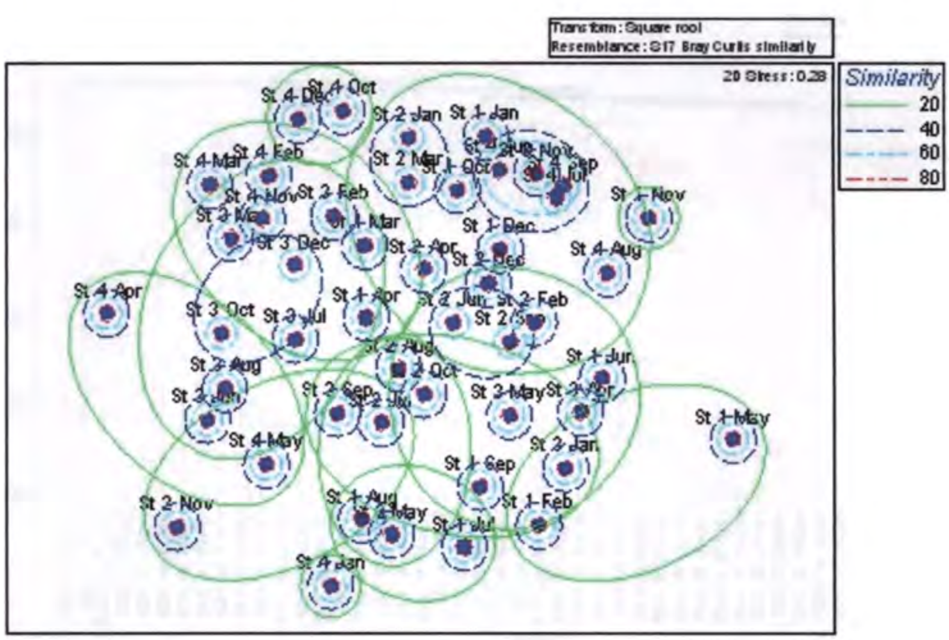

Fig.7.7. Non-metric Multi Dimensional Scaling (MDS) ordination plot (stress = 0.28) of samples taken from four stations with monthly distribution patterns of density of fish (indls. /haul)

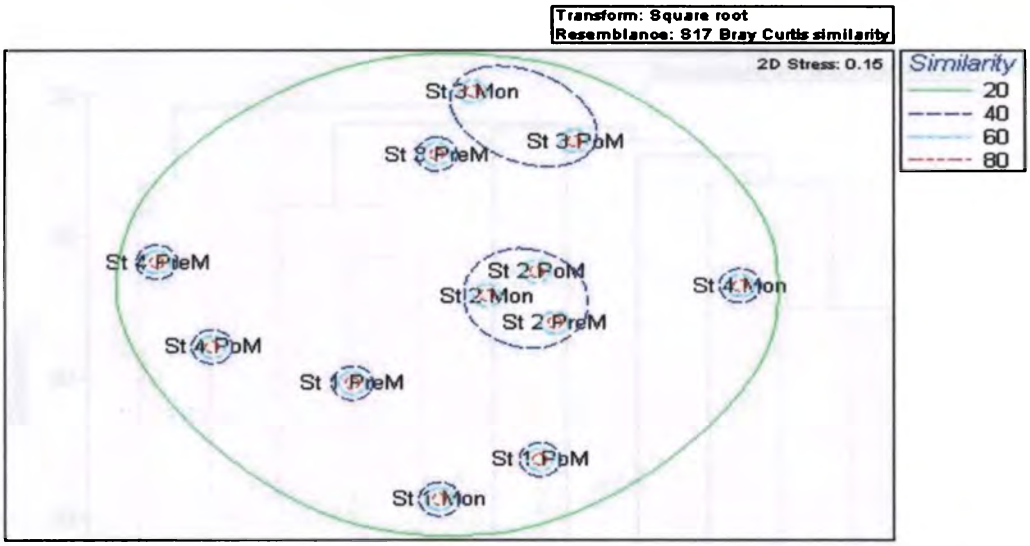

Fig.7.8. Non-metric Multi Dimensional Scaling (MDS) ordination plot (stress = 0.15) of samples taken from four stations with seasonal distribution patterns of density of fish (indls. /haul)

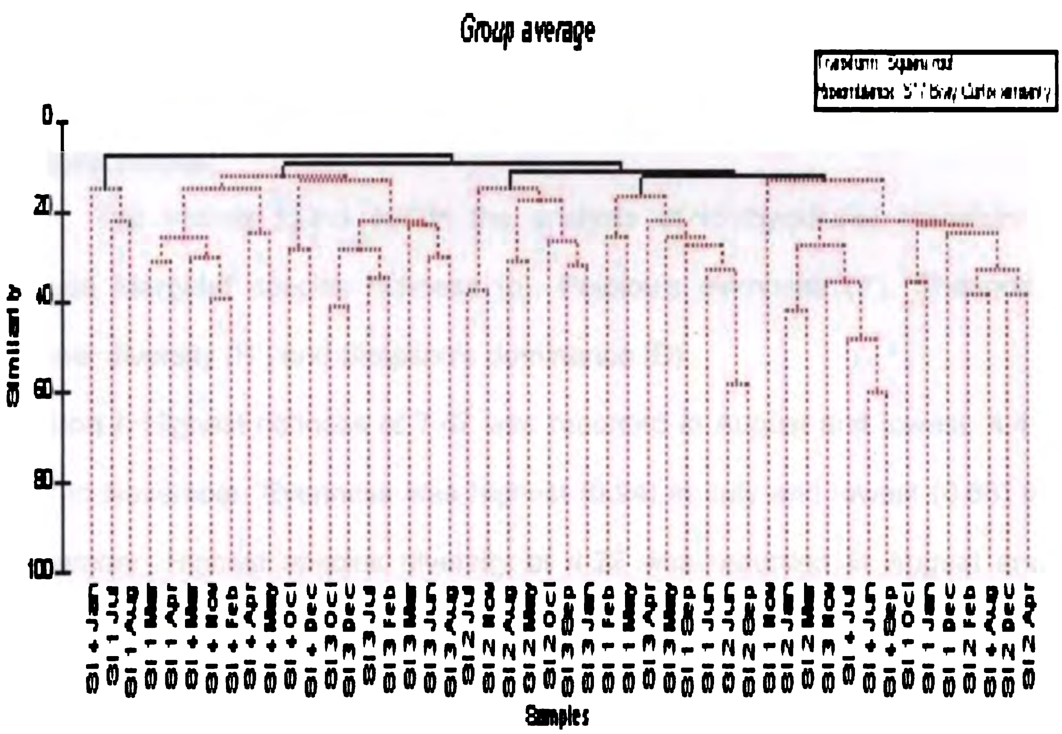

Fig. 7.9. Dendrogram of fish density (indls. /haul) showing the monthly similarities in the four stations (Solid lines represent significant delineation of groupings by SIMPROF test)

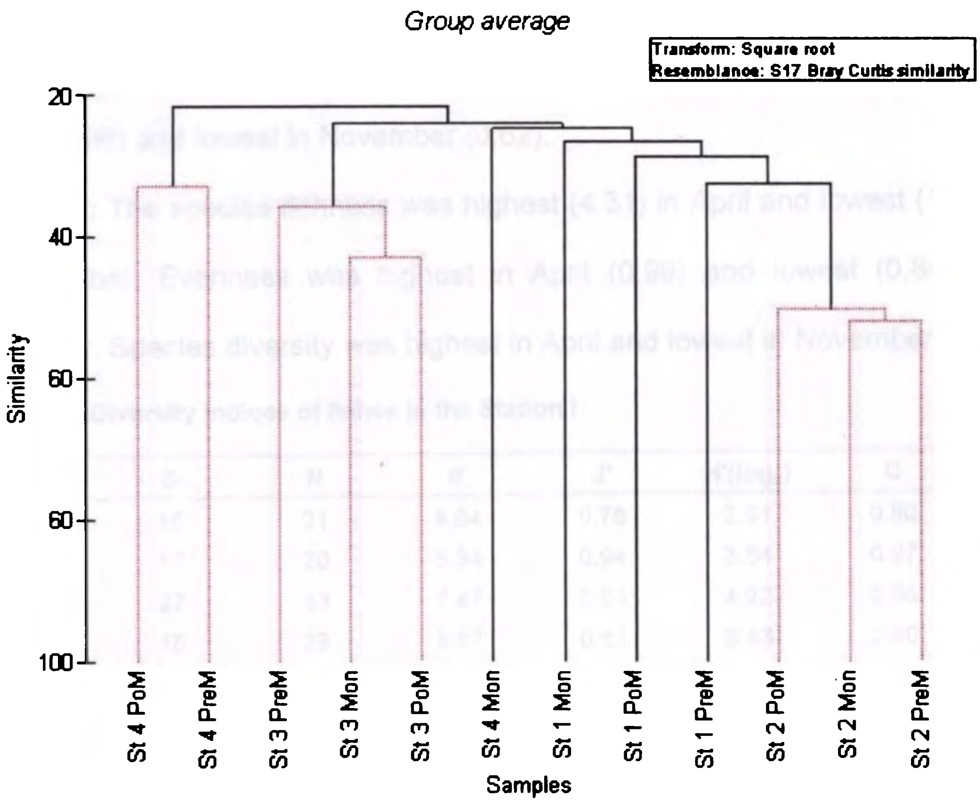

Fig. 7.10. Dendrogram of fish density (indls./haul) showing the seasonal similarities in the four stations (Solid lines represent significant delineation of groupings by SIMPROF test)

Diversity indices:

The indices found out in the analysis of ichthyofaunal community include Margalef species richness (d), Peiolou's evenness (J'), Shannon-Wiener diversity (H') and Simpson's dominance (D).

Station I: Highest richness of 7.47 was recorded in August and lowest, 4.41 was in November. Evenness was highest (0.94) in July and lowest (0.66) in December. Highest species diversity of 4.22 was recorded in August and lowest, 2.91, in June. Dominance value was highest (0.97) in July and low in December.

Station II: The richness value was highest (4.82) in July and lowest (2.17) in March. Highest evenness value of 0.94 was recorded in September and lowest, 0.58 was recorded in October. Species diversity was highest (3.7) in July and lowest (1.80) in November. Highest dominance value was recorded in May (0.96) and lowest in November (0.62).

Station III: The species richness was highest (4.31) in April and lowest (1.35) in November. Evenness was highest in April (0.99) and lowest (0.84) in November. Species diversity was highest in April and lowest in November,

Table 7.3a. Diversity indices of fishes in the Station I

	S	N	d'	J'	H'(log_2)	D
Jun	15	21	4.64	0.75	2.91	0.80
Jul	17	20	5.34	0.94	3.84	0.97
Aug	27	33	7.47	0.89	4.22	0.95
Sep	18	29	5.07	0.82	3.43	0.90
Oct	20	46	4.98	0.69	2.98	0.79
Nov	15	24	4.41	0.90	3.52	0.93
Dec	22	54	5.28	0.66	2.92	0.76
Jan	20	34	5.39	0.76	3.31	0.85
Feb	21	31	5.85	0.86	3.77	0.92
Mar	26	53	6.31	0.84	3.96	0.93
Apr	25	39	6.55	0.87	4.04	0.94
May	13	13	4.68	0.81	3.01	0.86

Table 7.3b. Diversity indices of fishes in the Station II

	S	N	d'	J'	H'(log_2)	D
Jun	15	34	3.99	0.86	3.36	0.89
Jul	18	34	4.82	0.89	3.70	0.93
Aug	13	17	4.24	0.89	3.31	0.93
Sep	10	28	2.70	0.94	3.13	0.91
Oct	13	33	3.43	0.58	2.14	0.64
Nov	7	15	2.24	0.64	1.80	0.62
Dec	11	22	3.26	0.85	2.94	0.88
Jan	10	49	2.32	0.77	2.57	0.80
Feb	10	53	2.27	0.85	2.82	0.85
Mar	8	25	2.17	0.88	2.65	0.84
Apr	13	48	3.10	0.62	2.30	0.67
May	11	12	4.09	0.93	3.20	0.96

Table 7.3c. Diversity indices of fishes in the Station III

	S	N	d'	J'	H'(log_2)	D
Jun	18	130	3.50	0.92	3.84	0.92
Jul	12	55	2.75	0.93	3.33	0.90
Aug	16	123	3.12	0.91	3.63	0.90
Sep	14	89	2.89	0.87	3.31	0.86
Oct	21	197	3.79	0.94	4.11	0.94
Nov	6	41	1.35	0.84	2.16	0.74
Dec	17	131	3.28	0.91	3.72	0.91
Jan	15	78	3.22	0.96	3.77	0.93
Feb	13	72	2.81	0.95	3.51	0.91
Mar	17	72	3.74	0.97	3.95	0.94
Apr	21	104	4.31	0.99	4.33	0.96
May	9	51	2.03	0.93	2.95	0.87

Table 7.3d. Diversity indices of fishes in the Station IV

	S	N	d'	J'	H'(log_2)	D
Jun	12	39	3.01	0.85	3.05	0.88
Jul	8	24	2.22	0.83	2.49	0.80
Aug	12	33	3.15	0.64	2.30	0.66
Sep	8	21	2.30	0.75	2.26	0.77
Oct	14	20	4.38	0.90	3.44	0.93
Nov	10	18	3.11	0.77	2.57	0.79
Dec	14	27	3.97	0.88	3.34	0.91
Jan	16	18	5.24	0.93	3.74	0.97
Feb	9	29	2.39	0.82	2.59	0.83
Mar	12	22	3.59	0.78	2.80	0.84
Apr	9	15	2.95	0.88	2.80	0.89
May	10	14	3.41	0.97	3.21	0.95

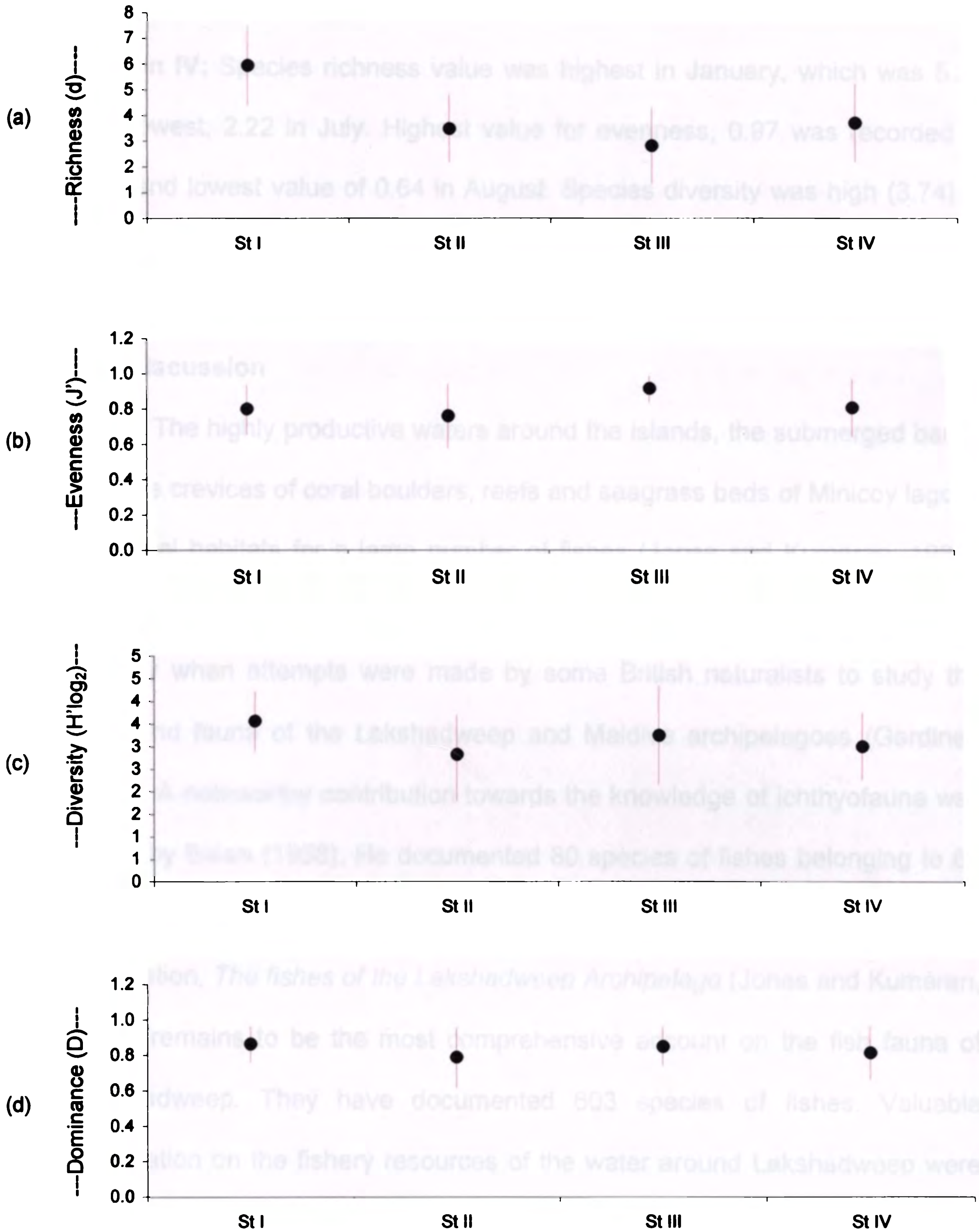

Fig. 7.11. Diversity indices (a) Margalef richness (d) (b) Simpson's evenness (J') (c) Shannon diversity (H'log_2) and (d) Dominance (D) in the four stations of Minicoy lagoon

which were 4.33 and 2.16 respectively. Highest dominance value was 0.96 in April and lowest, 0.74 in November.

Station IV: Species richness value was highest in January, which was 5.24 and lowest, 2.22 in July. Highest value for evenness, 0.97 was recorded in May and lowest value of 0.64 in August. Species diversity was high (3.74) in January and low (2.26) in September. Highest dominance value of 0.97 was recorded in January and lowest value of 0.66 in August.

7.3. Discussion

The highly productive waters around the islands, the submerged banks and the crevices of coral boulders, reefs and seagrass beds of Minicoy lagoon are ideal habitats for a large number of fishes (Jones and Kumaran, 1980). The fisheries research in this area dates back to the latter half of the 19th century when attempts were made by some British naturalists to study the flora and fauna of the Lakshadweep and Maldive archipelagoes (Gardiner, 1903). A noteworthy contribution towards the knowledge of ichthyofauna was made by Balan (1958). He documented 80 species of fishes belonging to 65 genera. Later Jones *et al.,* (1970) elaborated the list of ichthyofauna. The publication, *The fishes of the Lakshadweep Archipelago* (Jones and Kumaran, 1980) remains to be the most comprehensive account on the fish fauna of Lakshadweep. They have documented 603 species of fishes. Valuable information on the fishery resources of the water around Lakshadweep were collected during the surveys conducted by erstwhile Madras Fisheries Department, CMFRI and fisheries department of Lakshadweep Administration. Vijayanand and Pillai (2005) studied the community structure of reef fishes of Kavaratti Atoll. There is no detailed study on the ichthyofauna of the seagrass ecosystem of Minicoy lagoon.

Seagrass meadow of Minicoy lagoon supports rich and diverse composition of ichthyofauna. A number of commercially important species have been linked to seagrass at some stage of their life cycle, although a few such species use seagrass throughout their life. Non-commercial species within seagrass meadows may be an important food source for commercial species, forming trophic linkages (Bell, *et al.,* 2001). This habitat enhances the growth and survival of juvenile fish because they provide high food availability, low predation risk, and protection from adverse weather condition. This is supported by the studies of Heck *et al.,* (1989); Gray *et al.,* (1996); Jenkins *et al.*, (1997); Gray *et al.*, (1998) and compared the relative abundance both in vegetated habitats and adjacent bare areas. They found that the vegetated areas, support different and more diverse fish assemblages than adjacent bare sand, as well as being considered more important as nursery areas for juveniles of many economically important species. Within seagrass meadows, fish fauna have been shown to be influenced by varying sea grass cover and leaf height (Orth, 1992; Jenkins and Surtherland, 1997). However, there have been few accounts of fish assemblages in meadows comprising different sea grass species (Bell and Pollard, 1989; Howard *et al*; 1989), even though the structural complexity of sea grass habitats can very considerably (Kuo and Mc Comb, 1989). It is therefore, likely that, as in other coastal environments, where closely related species of fish often occupy different habitats on both small and large scales (Hyndes *et al.*, 1996; Munday *et al.*, 1997; Sala and Ballesteros, 1997). Such partitioning is likely to occur in sea grass biotope have also influenced by the adjacent ecosystems such as mangroves and coral reefs. Many fish species show ontogenic shifts in habitat utilization and migrate from their nursery grounds to an intermediate life stage habitat, or to the coral reef (Ogdon and Ehrlich, 1977; Weinstein and Heck, 1979; Rooker and Dennis, 1991). This shift in habitat has not been accurately described for many species. Seagrass beds support a rich ichthyofauna of permanent residents including pipefishes, eels, wrasses and sprats. The ichthyofaunal composition in the sampling sites varies according to the interactions with the adjacent systems. Stations I and IV are directly interact with open sea and coral reef systems; station II interact with mangroves and station III is away from the direct influence of these systems.

Species composition and distribution

In the present study, a total of 203 species of fishes were recorded from the four stations. Both Chondrichthyes and Osteichthyes represented the ichthyofaunal community, dominant being the Osteichthyes in all the stations. Highest number of species was belonging to the family Pomacentridae (19 species), which constitute 22 % of the total population. Other dominant families having more number of species are Labridae (17 species), Apogonidae (15 species) and Serranidae (15 species). In the station I, which is near to the coral reefs, observed maximum number of families (37 families) and species (129 species) and minimum number in the station II (23 families and 52 species). The highest number of species in station I can be attributed to proximity to the reef. This highly mobile group moves between reef or mangrove habitats and seagrass beds often in a diel cycle. Chief among these are surgeon fishes (Acanthuridae), which feeds directly on the seagrasses and epiphytes. Many fishes, such as surgeon fishes, puffers and snappers present in grass beds as juveniles taking both food and shelter from the dense leaf canopy. In the station II, the seagrass canopy height was comparitively less as observed during the study and this created a least successful habitat for many fishes. The predator fishes like sharks (*Carcharinus* sp.) and rays (*Dasyatis* sp.) were commonly found in this station, due to the easy availability of prey in the less dense meadow. Clupeiform fishes (*Clupeidae, Engraulide and Albulidae*) are completely absent from the station I, which is highly influenced by the open sea and reef systems. The important among these are the permanent residents of the dense mixed seagrass meadow, which include *Spratelloides delicatulus, S. gracilis, Sardinella melanura, Albula vulpes* and *Engraulis japonicus.* The dense meadow of mixed seagrass communities in the station III, supports high densities of these fishes, which form the baits for tuna fishing. The major live baits of the lagoon belong to the families Clupeidae, Apogonidae and Atherinidae (Jones, 1964).

Ogden and Zieman (1977) described the patterns of exploitation of seagrass beds by fishes. The migrating schools, especially that of Pomacentridae, Lutjanidae and Holocentridae, breakup and the fishes feed individually on seagrass associated invertebrates through the night, gathering and returning to the reef on the same pathways at dawn. In the station I, which lies near to the reef, more number of families were represented than the other stations. Out of 43 families only six families – Lamnidae, Siganidae, Leiognathidae, Clupeidae, Albulidae and Engraulidae – were not recorded during the study period. In the station II, which has lowest number of families, 22 families were absent. They include Lamnidae, Apogonidae, Chaetodontidae, Theraponidae, Gerriedae, Kyphosidae, Acanthuridae, Ephippidae, Blennidae, Scopaenidae, Zanclidae, Leiognathidae, Pempheridae, Haemulidae, Grammistidae, Albulidae, Muraenidae, Holocentridae, Acanthuridae, Ostraciidae, Tetraodontidae and Sygnathidae. In the station III, Apogonidae, Caesionidae, Ephippidae, Blennidae, Zanclidae, Leiognathidae, Pempheridae, Grammistidae, Muraenidae, Atherinidae, Bothidae and Fistularidae were not recorded. In the station IV, Caesionidae, Kuhlidae, Siganidae, Zanclidae, Pempheridae, Engraulidae, Belonidae, Hemiramphidae, Atheirnidae, Diodontidae, Fistularidae and Sygnathidae were not represented.

Abundance

Since, the sea grass beds are located in shallow coastal areas; the water is subject to both seasonal and daily changes in temperature and salinity, although the salinity changes are seldom as dramatic as the temperature changes. The number of fishes in a sea grass bed fluctuates both diurnally and seasonally. Adams (1976) found that densities of fish in eelgrass beds in the summer were highest at night. The movement out of the beds in the daytime permitted the fish, particularly large individuals, to avoid potentially stressful temperatures. On a seasonal basis, densities of fishes are highest in the summer, when the waters are warm. So, the temperature seems to be the key factor regulating the movement of fish into and out of beds. Some fishes are permanent residents, some reside there only seasonally, and for some the seagrass bed is only a part of their daily foraging area. Mobile fauna or nekton are not randomly distributed in seagrass habitats; the abundances of most species are correlated with macro-phytic biomass (Brook, 1977; Heck & Orth, 1980; Lewis & Stoner, 1983), and abundances of different species also vary markedly between adjacent patches with different microhabitat structure (Lewis, 1984).

In the present study, highest mean density of fishes (95 indls./haul) was found in the station III and lowest in the station IV. This highest density in the station III can be due to the high abundance of seagrass shoot density. In the stations I, II, and IV, Mullidae family contributed major share in the abundance of fishes of the seagrass meadow, where as in the station III, the major share was contributed by Clupeidae. In all the stations, Lutjanidae formed the second dominant contributor of abundance of fishes. Seasonally, in the station I and III, highest mean density was recorded during post monsoon, while in the station II, it was during pre monsoon and in the station IV, during monsoon. The bright calm weather conditions and abundant availability of food (as epiphytic algae, seagrasses and invertebrates) during post and pre monsoon periods will increase the number of occasional visitors of fishes, which forms a major part of the ichthyofauna of the seagrass ecosystem. The abundant growth of massive corals, having crevices as observed during the field study, in the station IV, gives a calm shelter for the fishes during the stormy weather conditions of monsoon season. This favourable condition leads to comparatively higher abundance of fishes in the station IV during monsoon. Other stations are highly disturbed by the monsoon winds and waves during this season and the shelter, which can reduce these effects, are less in these stations. On monthly aspects same trend was also noticed, having highest density in the month of December and

October in the stations I and III respectively. In the station II, maximum density was recorded in the month of February, while in the station IV, it was in June. These variations are mainly attributed to the physical structure of the habitat rather than the food source, life cycle or predation.

Five hypotheses provide likely explanations for this ichthyofaunal reduction amongst seagrasses: (i) seagrass plants are more isolated from each other, hence, even with no change in mortality or emigration rates, immigration rates of animals and overall densities may decline in accordance with island biogeographic theory (MacArthur and Wilson, 1967); (ii) seagrass plants are no longer locked together to form a coherent canopy, with the consequence that plant movement greatly increases and animals belonging to the more susceptible species are dislodged by wave action; (iii) animals are negatively affected by the increased solar radiation associated with the disruption to the plant canopy; (iv) predators have greater access and forage with greater efficiency amongst more open seagrass patches; and (v) epifaunal species respond behaviourally to undefined changes in the environment by emigrating after plant thinning. Considerable effort has been expended during the past decade in trying to understand the causes of these patterns, and, in particular, in attempting to determine whether species actively select particular microhabitats, or whether predators or other factors cause variable mortality of animals between microhabitats, thus causing the nonrandom patterns (Bell and Westoby, 1986). These conceptual problems are still not fully resolved, probably largely because the relative importance of predation and habitat selection to animals differs between species (Leber, 1985) and between animals of different sizes (Edgar, 1990) and because two or more factors may interactively influence a species' abundance. The physical factors responsible for spatial or temporal differences in seagrass structure also are directly responsible for the abundance and distribution patterns of fishes.

Similarity indices:

Bray-Curtis similarity indices calculated by using the monthly abundance data revealed that highest similarity of 60.73% occurred between the St 4 June and St 4 September. SIMPROF test showed a significant similarity of 54.6% ($p<0.05$) occurred between the cluster formed by the St 1 January and St 1 July - St 1 August. Among 11 clusters formed on seasonal scale, highest similarity of 51.95% was observed between St 2 Mon and St 2 PreM. Six clusters were significant ($p< 0.05$) with highest significance of 99.8%. All the seasons of the station I and monsoon season of the station IV showed significant similarities. These stations were in the direct contact with the reef and characterised by patchy seagrass meadows. Arrivillaga and Baltz, (1999) suggested that only 20% of species in the seagrass meadow were permanent residents. A number of species that are abundant on coastal reefs may also occur in low numbers in seagrass meadows (Bell and Worthington, 1993). Majority of the species only use seagrass for a small part of their life history as a temporary foraging area or as a temporary refuge from predation (Jackson, *et al.,* 2001). Besides fish that are resident (either temporary or permanent) in seagrass beds, fishes of the families Haemulidae and Lutjanidae may migrate to seagrass beds to feed. Studies have found that the abundance of organisms does not differ between different seagrass species (Rooker and Holt, 1997; Loneragan, *et al.,* 1998), but it may vary between the adjacent non-vegetated areas, where it was found to be higher and showed a decreasing trend with increasing distance from the edge of seagrass bed. Nagelkerkan, *et al.,* (2001) also found that fish abundance and species richness were high in non-vegetated habitats near seagrass and mangroves. These conditions increased the abundance and species diversity in the stations I and IV and showed significant similarities in composition.

MDS also revealed a similar pattern of similarity as that of Bray-Curtis dendrogram. In the monthly distribution pattern, only 20% and 40% similarity groupings were more. In the seasonal two major groupings were formed at 40% similarity. Only the seasonal pattern showed good ordination between the samples. Spatial and temporal variations in fish assemblages has been attributed to a variety of factors, such as patch size of seagrass meadow, edge effects, proximity to other neighbouring ecosystems, orientation of the meadow in response to currents, physical structure, *etc.* (Conolly and Hindell, 2006). Here in this study, the stations I and IV were most influenced by these factors and showed corresponding impacts on fish abundance and distribution. Temporal variability in distribution was another factor. Most taxa responded differently at different times. A few studies reported sampling at the same time of year in different years (Bell, *et al.*, 2002) so that true seasonal differences could be ascertained. As a general trend, from these indices, it can be assumed that the highest similarities occurred between the different seasons of the same station and showed the differences between stations.

<u>Diversity indices</u>

The sub-tidal seagrass habitat often reveals a higher biodiversity of individuals compared to adjacent substrate without vegetation (Orth *et al.,* 1984; Murphy and Fonseca, 1995). Hundreds of species are found living epiphytic on the leaves at any one meadow, and there is a large number of species that live in the refuge offered by the plant's canopies. Hence seagrass meadows are important habitats for ichthyofauna, thereby contributing to maintain marine biodiversity and the production of potential food for humans.

Species richness per se should have no direct relationship to the functional performance of the community, so that high species richness is not necessarily associated to a broad functional aspect. Yet, high species richness is likely to be correlated with a greater performance by the community, and therefore, functional system present within the community to increase with increasing species richness. The functioning of mixed seagrass meadows leads to the conclusion that the link between species richness and ecosystem functions and services is not a direct one. The reason is that the functional performance of the community is a property of the species present therein and not of their number. In the seagrass meadow of Minicoy lagoon, in the case of ichthyofaunal community, highest species richness of 7.47 was found in the station I. This high species richness was due to the proximity to the reef system, as many fishes migrate between the reef and seagrass beds. Lowest species richness (4.31) in the station III, attributed to its distance from the adjacent systems, but the high abundance of the some species, especially that of Clupeiformes reduced the species richness, in addition to the homogeneity of the habitat. The evenness in the species distribution was also associated with the habitat structure. Pielou's index (J') was used to evaluate the evenness of species distribution. Highest value for this index was recorded in the Station III, which have low species richness.

Species diversity forms the important aspects of community structure. Of the total number of species in a system, a relatively small percent are usually abundant and a large percent are rare. It is the large number of rare species that largely determine the species diversity. The diversity of fishes in the seagrass meadows are influenced by the factors related to life cycles, such as spawning, recruitment, death, immigration and emigration (Hall and Werner, 1977; Ross *et al.,* 1987). Other factors that can also influence are seasonal patterns in abundance, which include predation, food availability and movement among different habitats. Additionally, the hydrological regime can have a significant influence across multiple scales on habitat use of fishes in macrophytes. Even though, the seagrasses are less in species level, their role in increasing the faunal diversity are well known, especially the mixed, dense communities increases the species richness and diversity of fishes, which utilize the meadow as the source of food, shelter and nursery ground. Shannon-Weiner index ($H'log_2$) was used to evaluate the diversity of fishes in the seagrass meadow. Highest species diversity was recorded in the station III, which is characterized by the abundant growth of seagrasses, which provides a suitable habitat for both herbivorous and carnivorous fishes and also forms an ideal nursery ground.

Communities include all types of trophic levels. Among these groups some groups or species, which largely controls the structure of the system and strongly influence the environment of the other species or groups are known as ecological dominants. The degree to which dominance is concentrated in one or several species can be expressed by the index of dominance (D). The dominance value showed least variations among four stations. This means that there were not many variations in the composition of ichthyofauna, which influence the total community structure.

With the aid of these indices, it can be assured that the station III, which is away from the direct effect of other ecosystems, showed the influence of seagrass meadow on the species diversity and the community structure of fishes and as a whole, to the total functioning of the seagrass ecosystem. Further research is needed to understand the role of macro consumers such as fishes both in structuring the seagrass community and the higher trophic levels. The close association of the three major tropical communities – coral reefs, mangroves and seagrasses – can be seen as part of the dynamics of the ecosystem. These links will further illuminate the close dependence of these and their central role in the composition of ichthyofauna of tropical coastal zone.

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Conclusion

Conclusion

Seagrass and coral reef ecosystems are commonly associated with lagoon ecosystems. Lagoon ecosystems are maintained by a balance of nutrient loads within the system and tidal flushing from the sea. Since the marine inputs of nutrients to coastal lagoons are low and the low freshwater inflow and tidal exchanges make marine ecosystems of coastal embayment, nutrient poor and dominated by seagrasses. The water quality is dominated by the sediment-water column exchange. It has been widely documented that, seagrasses through habitat modification and associated changes in biological, chemical, and physical conditions, may strongly influence the structure and functioning of associated communities, such as coral reefs and mangroves. The investigations conducted at Minicoy lagoon during the period, June 2000 to May 2002 can be concluded as given below.

The seagrass meadow of Minicoy lagoon, which is associated with the oceanic coral atoll, experiences the tropical climatic conditions. In coastal ecosystems, salinity and temperature variations impose patterns in the temporal and spatial distributions of biological communities. In the Minicoy lagoon there is no direct impact of salinity and temperature on the distribution of organisms, as the lagoon is located far away from the freshwater inputs. Tidal influx is the only one factor which directly influencing the hydrographic conditions. Temperature patterns in the lagoon indicated a more or less homogenous condition. Salinity variation was also minor, except in the station I, where low salinity was observed during the pre monsoon due to the influx of low saline water from Bay of Bengal. Only the DO and pH were found to have greater influence on biota. Various combinations of these parameters will permit, encourage, or eliminate seagrass and associated organisms from a specific location. Nutrient levels showed a clear seasonal variation, but the variations in space were insignificant. Even though the coral reef and associated ecosystems are highly productive, the nutrient status of the lagoon was oligotrophic.

Seagrass meadows vary seasonally and between years. The potential for widespread seagrass loss has been reported from many parts of the world, some times due to natural causes. Anthropogenic impacts on seagrass meadows are continuing to destroy or degrade these coastal ecosystems and decrease their yield of natural resources. In order to detect such changes, it is necessary to first map the distribution and density of existing seagrass meadows. The mapping and survey of distribution of seagrass species conducted as part of this study can be used by coastal management agencies. Detailed studies of changes in community structure of seagrasses are essential to understand the role of these communities and the effects of disturbances on their composition, structure and rate of recovery. In Minicoy lagoon, five species of seagrasses were recorded during the study, which covered an area of 0.396km^2 of the lagoon. The present survey revealed a decrease of 0.004 km^2 in the seagrass cover within the last 10 years. Genus *Halophila ovalis* was common throughout the region, even though less in biomass. *Thalassia hemprichii and Cymodocea serrulata* formed dense meadows both in reef and muddy areas. *Syringodium isoetifolium* formed the thick bed in the stations III and IV. *Halodule uninervis* was found only in the coastal margins as patches in specified locations. The distribution and abundance of seagrasses in Minicoy lagoon were greatly influenced by temperature. Salinity showed minor influence when considering the seasonal aspects. It was also confirmed that nutrient status was not at all a limiting factor for the distribution and abundance of seagrasses in Minicoy lagoon. The tidal influence and the depth of the location were the other factors influencing the distribution of seagrasses.

Living seagrass leaves provide an attachment site for numerous types of epiphytic algae and other algae occur between seagrass shoots and in the surface layers of the sediment. Seagrass-algae beds are rated third most valuable ecosystem of the world, only preceded by estuaries and wet lands. In the present study, 43 species of macro-algae were recorded from the seagrass meadow of Minicoy lagoon. Rhodophyceae formed the dominant group with 20 species. The distribution and abundance of macro algae in seagrass meadow were correlated with the environmental regime, especially with pH and DO. The availability of suitable substratum is also a major factor in the distribution of macro-algae.

In many studies, seagrass habitat has been reported to support increased faunal species diversities, abundance, biomass and productivity compared to adjacent unvegetated soft sediment habitat. Macro faunal composition inside and outside seagrass habitats involves responses to seagrass bed structure at series of hierarchical levels, ranging from individual shoot groups to discrete patches of seagrass to landscapes. The softer, more digestible algae, which support the abundant grazers associated with the meadows. The infauna and epifauna of seagrass beds are known to serve as prey for larger invertebrates and fishes. During this investigation a total of 217 species of macro-invertebrate fauna were recorded, out of which molluscs were the dominant group in all the stations and seasons. The abundance curves, geometric class plots and diversity indices showed a less disturbed condition in the ecosystem. Species richness, abundance and distribution varied spatially, but these differences were due to physical complexity of seagrass and not due to temperature or salinity gradients.

In the survey for fishery resources in seagrass meadows, 203 species of fishes were obtained, out of which Pomacentrids contributed the major share. High abundance of fishes were recorded in the station I, which is in close proximity to reef and oceanic ecosystems. There is no specific pattern in distribution and abundance. Only the physical complexity of seagrass meadow was the key factor influencing the distribution.

The need for conservation and management of coastal seagrass meadows is evident when their complex ecology and multiple roles were considered. Further, these submerged flowering plants can be used to monitor the health of coastal communities. Their declines, which have occurred worldwide, have been linked to natural and human induced disturbances. As a result of their shallow sub-littoral and intertidal existence, seagrasses are subjected to many of the stresses imposed by man's use of coastal environment. Human induced impact on seagrasses include dumping of sewage, silt discharge, fishing activities, oil pollution and dredging and filling operations. Although not on a large scale, some of these human interferences are noticed on the seagrass beds of Lakshadweep.

Dredging and filling activities are potentially having the most damaging impact to seagrass beds and have resulted in the destruction of more grass bed habitats than any other form of stress imposed by man. The resulting sedimentation also leads to turbid waters that affect the productivity of the seagrass bed and its associated communities. The input of sewage into the lagoons in the vicinity of seagrass beds has both the positive and negative impacts, depending on the degree and duration of the stress. The inputs not only alter nutrient availability, but also increase the turbidity of overlying waters. Sewage input has been implicated in species shift from *Thalassia* to other seagrasses or filamentous algae. The intertidal area near the villages of Minicoy Island is completely devoid of seagrasses, because of the dumping of domestic wastes and tuna fish wastes. The presence of excessive organic matter provides nutrients, which enhance the abundant growth of phytoplankton. Both these conditions result in the reduction of light penetration, which is unfit for the growth of submerged plants like seagrasses. Construction of boat channels is noticed in some islands of Lakshadweep. Fishermen dig out intertidal flat area, ranging from 10 - 20m long and 1 - 2m wide. This facilitates the easy beaching of boats prior to the arrival of the monsoon. Seagrasses in such area are uprooted and whole plants are removed. Boat propellers cut the leaves and shoots of seagrasses in shallow waters, leaving the area barren and susceptible to erosion. Beach seining and cast netting for small fishes are also found to be destructive to seagrasses. Even though small-scale damages are taking place in the seagrass meadow of Minicoy lagoon, the overall observation and analysis revealed that the site is a high quality one.

In view of the importance of seagrass beds in the lagoon ecosystem of an oceanic island, their conservation should be necessary for the very existence of the island. The conservation strategies should include –

(i) The assessment and maintenance of healthy environmental status for the growth and surveillance of seagrasses,

(ii) Mapping of seagrass meadow to identify their location and abundance in various islands of Lakshadweep. Identification and initiation of studies in this natural ecosystem should be encouraged to obtain base line data

(iii) Techniques for transplanting seagrasses should be developed to restore degraded seagrass habitats. Investigations on the growth, reproduction, occurrence of seeds and seedlings are required

(iv) Education of local population about the importance of seagrasses. Direct human impacts, such as destruction of seagrasses and indirect actions like dumping of wastes into the lagoon, should be discouraged. The loss of seagrass habitat from intertidal environments will increase the velocity of waves and thus accelerating the coastal erosion. This will in turn, threaten the very existence of islands and also affects the tourism industry

(v) In the ecosystem of seagrass meadow, an effort must be made to evaluate the energy from the beds to surrounding biotopes such as estuaries, shelves, coral reefs and the adjacent oceanic regions. The trophic relationships of this energy export to the secondary production in the surrounding biotopes should be evaluated.

For the protection and management of seagrass meadows, information about their ecosystem services is essential. It is important to document floral and faunal species diversity, distribution and abundance in seagrass meadow to identity the areas requiring conservation measures. In such a point of view, this study forms the baseline information about the seagrass meadow of Minicoy lagoon. Responsive management based on adequate information will help to prevent any further significant areas or species being lost.