ECOLOGY OF THE FREE-LIVING MARINE NEMATODES FROM THE CENTRAL WEST COAST OF INDIA

Thesis submitted for the degree of

Doctor of Philosophy

In
The Department of Marine Science
Goa University

By

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2010

DECLARATION

As required under the University Ordinance 0.19.8 (iv), I hereby declare that the present thesis entitled '**ECOLOGY OF THE FREE-LIVING MARINE NEMATODES FROM THE CENTRAL WEST COAST OF INDIA**' is my original work carried out in the National Institute of Oceanography, Dona-Paula, Goa and the same has not been submitted in part or in full elsewhere for any other degree or diploma. To the best of my knowledge, the present research is the first comprehensive work of its kind from the area studied.

Mandar Nanajkar

CERTIFICATE

This is to certify that the thesis entitled ECOLOGY OF THE FREE-LIVING MARINE NEMATODES FROM THE CENTRAL WEST COAST OF INDIA submitted by Mandar Nanajkar for the award of the degree of Doctor of Philosophy in Marine Science is based on original studies carried by him under my supervision.

The thesis or any part thereof has not been previously submitted for any degree or diploma in any Universities or Institutions.

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27.4.11

27/4/2011

ACKNOWLEDGEMENT

Finally, this thesis is a result of four and half years of work whereby I have been accompanied and supported by many people. It is a pleasant aspect that I have now the opportunity to express my gratitude for all of them.

First of all, I express my sincere and deep gratitude to my guide, Dr BS Ingole for being a patient supervisor and for supporting this work with ideas, criticism, encouragement, etc.

I would like to gratefully acknowledge the supervision of Dr PV Dessai as a co-guide during this work.

I am grateful to Dr Satish Shetye, Director, National Institute of Oceanography, Goa and Dr Ehlrich De'Sa, Former Director NIO, Goa, for providing me the necessary facilities to carry out this research work.

I am grateful to Dr H Menon, Head, Marine Science Dept., Goa University, and former head Dr GN Nayak for carrying out my Ph.D officially in the Dept.

I would also like to thank all the members of my PhD committee who monitored my work and took effort in reading my reports and providing me with valuable comments especially Dr Mohandass.

My thanks are due to Dr PA Lokabharati, Dr R Nigam, Dr Nagendernath, Dr R Sharma, Dr AB Valsangkar, Dr AC Anil, Dr Ramaiah, Dr Raghukumar, Dr Verlekar, Dr Dhargalkar, Dr Rathod and Shri RA Shreepada.

I am very thankful, to Mr Chitari for tracing the nematode sketches and drawings.

A special thanks goes to Alba, Kishan, Sini, Sanitha, Sandhya and Reshma to whom I have known for many years now as lab mates and who were kind, helpful and trustful friends. I am deeply indebted to them on this thesis journey. I could not have wished for better friends and colleagues.

My thanks are due to Sabya, Aditya, Rubail, Uday, Indranil, Mythili, Anna, Gobardhan, Ganesh, Caji, Dhillan for their support and help rendered to me in whatever things I wanted.

Being in NIO, gave me an opportunity to meet many good friends and colleagues Samir & Varada, Bhaskar & Jane, Rajiv Saraswat, Jay De, Abhijit, Pawan, Vinod, Chetan, Sanjay Singh, Sanjay Rana, Shantanu, Priya, Sharon, Rouchelle Shamina, Christabelle, Vera, Ravi, Vishwas, Ram, Milind, Anthony, Linshy, Sujata, Uddhav, Janhavi, Aneesh & Joreen, and I thank you all for your help and support and also having shared many experiences and thoughts with me throughout the years.

My apology isn't an excuse and is unacceptable for not remembering names but would like to thank you all for making it a pleasant run.

I am forever indebted to my parents and feel a deep sense of gratitude for teaching me the good things that really matter in life. Manasi and Samrat were immensely supportive with a persistent inspiration for my journey.

THANK YOU ALL!!

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If all the matter in the universe except the nematodes were swept away, our world would still be dimly recognizable, and if, as disembodied spirits, we could then investigate it, we should find its mountains, hills, vales, rivers, lakes and oceans represented by a thin film of nematodes. The location of towns would be decipherable, since for every massing of human beings there would be a corresponding massing of certain nematodes. Trees would still stand in ghostly rows representing our streets and highways. The location of the various plants and animals would still be decipherable, and, had we sufficient knowledge, in many cases even their species could be determined by an examination of their erstwhile nematode parasites.

-----------Nathan Cobb
Father of Nematology

Chapter 1:

Introduction

1.1 What are nematodes?

Nematodes are structurally simple organisms. Adult nematodes are comprised of approximately 1,000 somatic cells, and potentially hundreds of cells associated with the reproductive system. Nematodes have been characterized as a *tube within a tube*; referring to the alimentary canal which extends from the mouth on the anterior end, to the anus located near the tail. Nematodes possess digestive, nervous, excretory, and reproductive systems, but lack a discrete circulatory or respiratory system. In size, they range from 0.3 mm to over 8 meters.

Nematodes are free-living as well as parasitic and the literature shows a rise in nematode studies in animal and plant parasitic ones but a bottleneck till the late 19th century for their freshwater and marine counterparts. The possible reason for it can be the lack of knowledge about their role as free-living individual. Nematodes today form a large biomass on the whole planet barely leaving a habitat where they do not thrive. The parasitic nematodes have gained enormous importance, as they are economically important. Their numbers can be overwhelming and do possess the ability to destroy the agricultural yield, if not taken care off. Many agricultural universities today have separate 'Department of Parasitology' or 'Nematology Research Divisions', which do find out control measures, either chemical or biological. Parasitic nematodes have the potential to damage worth billions of dollars of crops. Apparently, nematodes possess a considerable importance in other areas now such as soil science where they play a major role in the mineral cycling and fertilization of soil. I restrict the literature for terrestrial, soil and parasitic nematodes here as the present study deals exclusively with free-living marine nematodes.

The most important and beyond belief aspect of nematodes is their abundance and the number of species, as they occur in all different type of habitats they conceive. The species number estimates have reached 1 million for the marine nematodes based on the present number in description, mathematical derivations and statistical analysis.

Nematodes make up 90% of all life on the seafloor, and are found in the deepest ocean trenches, where the pressure is 100 times greater than at the surface. Three species of nematode are found in the McMurdo Dry Valleys of Antarctica which undergo unhydrobiosis, one of the harshest environments on Earth, where temperatures reach -60°C (-76°F) in the winter and wind speeds exceed 320 km/h (200 mph), stripping away almost all moisture (Treonis et al. 2000).

Marine nematodes have apparently evolved to continue in benthic habitats due to lack of swimming ability. The nematodes being exclusively benthic have almost entirely covered all adverse habitats and have been reported from the anoxic region [OMZ] (Levin 2003), hydrothermal vents (Flint et al. 2006), cold seeps (Jensen 1986), and deep-sea trenches (Tietjen 1989). The studies on nematodes from freezing environments of pole have been done by Wharton et al. (2003) from the arctic and Vanhove et al. (2002) from Antarctica. The marine areas are well investigated for nematode diversity and ecology from Atlantic, Pacific, Mediterranean, Arctic and Southern Ocean.

Looking at the quantum of literature available on nematodes in general, the type of studies that have been documented and the area that remain to be explored, it seems ambiguous to recognize marine Nematology as an evolved field or is it still in its infancy?

1.2 History of Nematology

Nematodes have left very little fossil evidence and only some have been found preserved in insects of 120-135 million year old amber (Poinar et al. 1994).

The oldest written record of nematodes is thought to be the intestinal roundworm Ascaris in China 4,690 years ago. This same nematode and the Guinea worm (*Dracunculus medinensis*) are thought to be referred to in a book written in Egypt 3,500 years ago (called the Ebers' Papyrus). The following ancients made references to roundworms in their writings: Hippocrates (430 BC, the pinworm *Enterobius vermicularis*), Aristotle (384-322 BC), Pliny (27-79 AD), Albertus Magnus (1200-1280, nematodes of falcons), Aldrovandus (1602 AD), and Redi (164 AD) (Nguyen 2011 and references therein).

Many scientists have contributed to the science of Nematology during medieval times. During 17th and 18th centaury many workers dedicatedly studied nematodes and formed a firm basis of this field. Rudolphi is often named the "Father of Helminthology" while Aldrovandus studied nematodes in grasshoppers and erected the name *Vermes*. Reaumur described a worm (later named as *Sphaerularia bombi*) in the mid 18th centaury and Needham referred to a nematode, later called *Anguina tritici*. Gould described a mermithid found in ants while Linnaeus listed eight genera in the *VermesIntestini* and Goeze made the first serious study of nematodes under a microscope and described the vinegar eelworm. During this era the availability of microscope brought about increased interest in the smaller, free-living nematodes and their structure. This era experienced great contribution from Tyson (Morphology of *Ascaris*), Borellus (discovered the first free-living nematodes, the vinegar eelworm *Turbatrix aceti*) and Robert Hooke (discovered the paste eelworm). Baker, Leeuwenhoek, and Spallanzani all studied free-living nematodes. The first plant-parasitic nematode, wheat gall nematode, was reported by Needham in England and in the U.S. the first plant nematologist was NA Cobb (often referred to as the father of nematology). Chitwood BG was one of the first to study the entire spectrum of nematodes and to publish a book on the subject in 1950s (Nguyen 2011 and references therein).

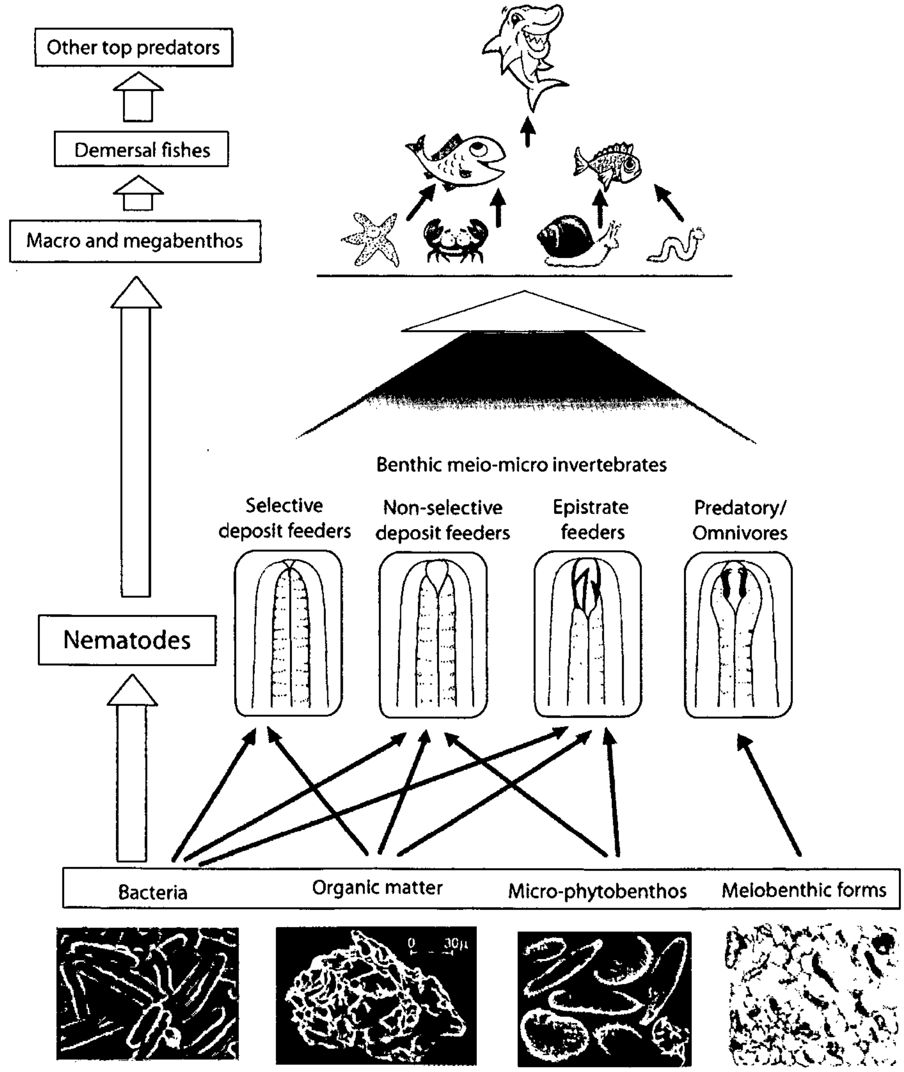

Fig 1.1: Flow diagram showing the role of nematodes in the benthic food chain

1.3 Nematodes in marine environment

Nematodes are considered to be the most abundant taxa on the planet since 1 out of 4 being nematodes. The nematodes cover the whole ocean floor carpetting each an every benthic habitat.

In the marine environment their abundance is generally 10^5-10^7 per square meter in shallow sediments, diversity is often more than 40 species in an area of 10 square centimeters. They have high metabolic rates, have very high turnover rates and an ability to metabolize toxicants (Millward and Grant 2000; Hermi et al. 2008). They play a major role in nutrient regeneration, detritus re-mineralization, and as food for larger organisms (Fig 1.1), all serve to render further knowledge of their importance. They play a major role in enhancing bacterial biomass by secreting mucus conducive for the growth of bacteria. However, their small size (usually 1-2mm in length) and general vermiform shape causes discrimination among species to be difficult: to the non-specialist, *they all look alike*. Complementing the above two difficulties is the fact that most of the taxonomic literature appears as single, isolated papers, often in journals that are not readily available to many libraries and laboratories.

1.4 Literature on marine nematodes

Much of the literature is not in English, and keys to most marine genera and species are few. The most widely used key to the species of marine nematodes is the Wolfgang Wieser's Free-living Marine Nematodes, Reports of the Lund University Chile Expedition, 1948-49, published in four parts between 1953 and 1959. Obviously, many new species have been described, and taxonomic revisions made, since then. Several unpublished guides to higher taxonomic levels (usually families) for the specialist and non-specialist have appeared, but have not been given wide circulation. Thus a need for a working guide to marine nematodes for both the specialist and serious amateur has existed for many years. The book by Platt and Warwick (1983) endeavors to fulfill this need.

Platt and Warwick (1983), provides a basis for the identification of the genera of free-living marine nematodes. Hope and Murphy (1972), Gerlach and Riemann (1973), Andrassy (1976), Lorenzen (1981), and Inglis (1983) have also published classifications of free-living marine nematodes. Platt and Warwick (1983) provided descriptions and figures for all the marine species from Britain in three volumes.

Ecological studies on marine nematodes were triggered by a hallmark finding by Wieser (1953; 1959) on the feeding types of marine nematodes based on the observations and buccal morphology.

Extensive studies on the ecology of marine nematode were contributed in the second half of the 21st century by Lambshead PJD, Riemann F, Warwick RM, Austen MC, Alongi D, Vincx M, Vanrusel A, Heip CHR, Middleberg JJ, Herman PMJ, Bonger T, Boucher G.

A review by Heip et al. (1985) gives a comprehensive summary on nematode literature. Many new conclusions were drawn about marine nematodes such as there diversity in the deep sea (Lambshead and Boucher 2003) being estimated to be more than a million species and Kotwicki et al. (2005) analysed the latitudinal gradient pattern of the beach nematodes.

Wide range of habitats has been investigated including estuaries (Soetaert et al. 1995), mangroves (Gwyther 2003), mudflats (Pascal et al. 2008), sea grasses (Fisher and Sheaves 2003) and continental shelf (Soetaert and Heip 1995). Jensen (1987) and Moens and Vincx (1997) worked extensively for illustrating the exact feeding behaviour and the role of nematodes trophic dynamics in benthic food web. Few isotopic studies have recorded for the carbon flow and the benthic food chain through nematode experimentations (Riera et al. 1996; Moens and Vincx 2000; Rzeznik-Orignac et al. 2008) and in deep sea (Debenham et al. 2004). In a recent review, Vanrusel et al. (2010) confirmed global distribution and high adaptability of nematodes that help them to flourish in extreme environments such as the polar region, saltpans; hydrothermal vents, cold seeps and many sulfidic types of sediment.

1.5 Marine nematodes in environmental studies

The use of marine nematodes in detecting environmental change, pollution and other anthropogenic impacts has taken a leap in the recent past. The impact of trawling (Liu et al. 2007), harbour pollution (Franco et al. 2008), impact of drilling, hydrocarbon pollution (Mahmaudi et al. 2005), metal toxicity (Vranken and Heip 1986), and combinations of pollutants (Millward et al. 2004), dredging, dredging disposal (Boyd et al. 2000; Schratzberger et al. 2002), different disturbance activities (Schratzberger et al. 2000), organic pollution (Essink and Romeyn 1994) and sandy beach disturbance (Gheskiere et al. 2005; 2006; Ingole et al. 2006) have been studies.

Maturity Index (MI) which gives the status of the environment in terms of disturbance was developed for soil nematodes (Bonger 1990) and later it was successfully applied to the marine nematodes (Bonger et al. 1991). This index gives a valid reasoning for its application as it has been designed keeping in mind the life history patterns and accordingly its response to the surrounding habitat.

Clarke and Warwick (1994) have proposed new diversity indices of average taxonomic distance (AvTD) and variation in taxonomic distinctness (VarTD) for computing marine nematode biodiversity based on classification trees.

1.6 Nematodes and the Indian Ocean

Most of the oceans and its habitat have been explored for nematode communities (Heip et al. 1985) but yet no clear picture of the trends in nematode communities have been derived. For conclusive trends, it requires extensive data from different corners of the planet and covering as much as ground possible. Indian Ocean remains one of the least explored oceans compared to the Atlantic and the Pacific (Vanrusel et al. 2010). The Southern Ocean and the polar region are under investigation. From the Indian Ocean the Western margin and the coastal African continent (Ndaro and Olafsson 1999) has been explored. The Indian coast largely remains a black hole in terms of nematode taxonomy on the global map looking at the extent of work published from rest of the world. Nevertheless, few studies from the intertidal (Ingole and Goltekar 2004; Ingole et al. 2006); estuarine, coastal regions (Nanajkar and Ingole 2007; Chinnadurai and Fernando 2007; Singh and Ingole 2010); OMZ (Cook et al. 2002; Ingole et al. 2010); margins (Ingole et al. 2009; Venrusel et al. 2010). Abyssal Indian Ocean (Muthambi et al. 2004; Ingole et al. 2005; 2009 ; Ingole and Koslow 2005; Pavitran et al. 2007; 2009). Apart from these studies the Indian Ocean particularly the west cost of India remains largely understudied in terms of nematode ecology. Considering these unexplored regions and the need to contribute to global nematode distribution the following study was planned. Pertaining to these shortcomings the following objectives were investigated during the present study:

1.7 Objectives of the present study

- Investigating *alpha* and *beta* diversity of nematodes from the Central west coast of India.
- Spatial and temporal distribution of nematode communities from the region.
- Implementing nematode diversity studies for habitat perturbation and distinction.

Chapter 2:

Methodology

2 Methodology

2.1 Study area

Indian Ocean is the only ocean that is surrounded by land from the north and is connected to the Southern Ocean by south. It is considered unique due to its biogeochemistry (Naqvi et al. 2000; Ingole et al. 2010). The northern Indian Ocean has two basins of contrasting oceanographic conditions: the Arabian Sea and the Bay of Bengal. The present work was arried out in the eastern part of the Arabian Sea (Fig 2.1). The monsoons, seasonally reversing from SW in June to September to NE in December to March, determine climate and surface circulation in both basins. The biological productivity is closely related to the seasonal changes in the mixed-layer depth. Low productivity during the inter-monsoons is due to nutrient-poor surface waters resulting from strong stratification caused by high solar radiation and low wind speeds. Wind speeds increase and solar radiation drops during both monsoons and increase nutrient concentrations in surface waters by mixed-layer erosion and convective overturn. Summer monsoon upwelling in the western Arabian Sea leads to productivity maxima during this season. The strong monsoon winds carry large amounts of dust from the Arabian Peninsula, Somali and Thar deserts to the Arabian Sea. Resulting denitrification makes the Arabian Sea one of the major oceanic nitrogen sinks (Gaye-Haake et al. 2005; Naqvi et al. 2000).

2.2 Sample collection sites

Samples for the present study were collected from three different habitats viz; Intertidal, Estuarine and Subtidal (Fig 2.1).

Subtidal

Subtidal sample collection was done using three types of bottom gears. Sediment from the estuarine and near shore region was sampled with the help of free-fall van Veen grab (0.04 m^2 and 0.16m^2 area) on board *CRV Sagar-Sukti* and fishing trawlers (Plate 1a). A spade box core (Plate 1b) was used on board *ORV Sagar-Kanya* (Plate 1c) for collecting the deep-sea samples. All the samples were further sub-sampled using an acrylic core (4.5 cm Θ; Plate 1d). Triplicate core samples were taken from each station. Separate sediments were taken for the analysis of other sedimentary parameters such as sediment chlorophyll-a, sediment organic carbon and grain size.

Intertidal

To study the distribution, abundance and diversity of nematodes in various marine habitats, sediment samples were collected by acrylic (4.5cm Θ) core. All the samples were immediately preserved in 5% buffered seawater formalin solution with Rose Bengal as stain.

The details of each sampling site and the particularities of sampling strategies for each section are described in respective section.

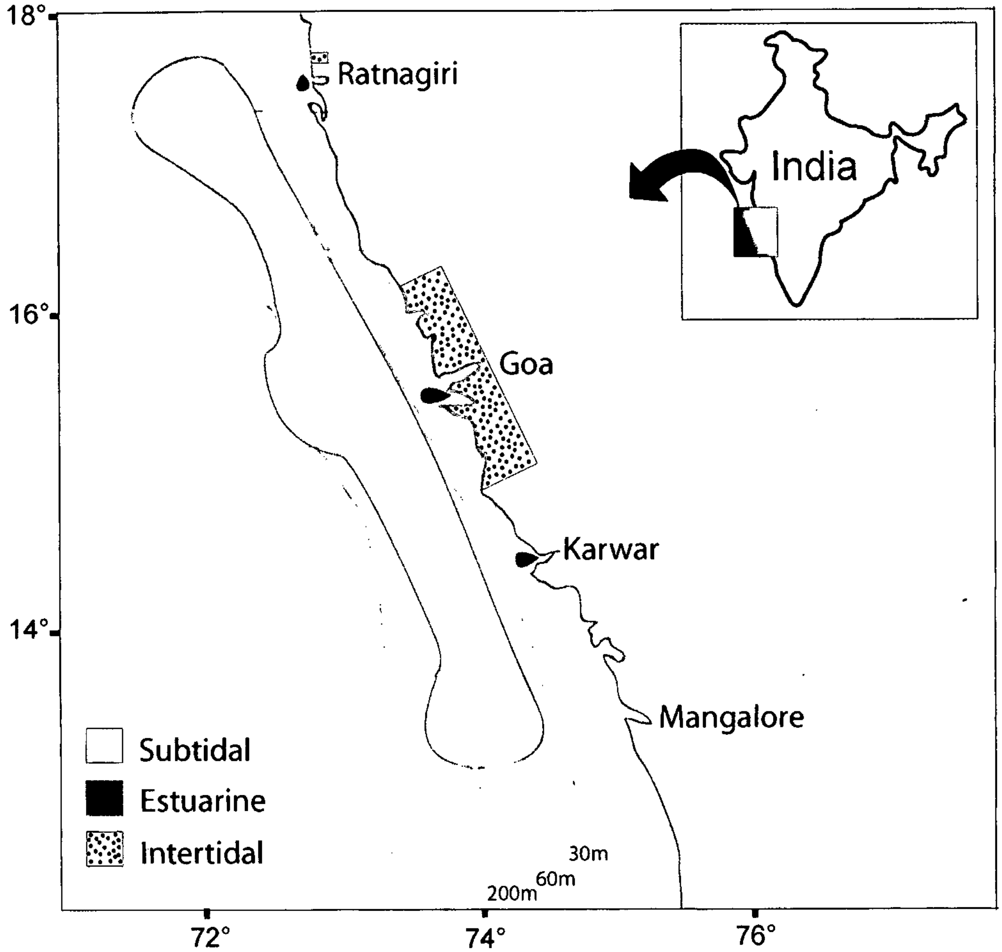

Fig 2.1: Map showing the study area covered from the central west coast of India.

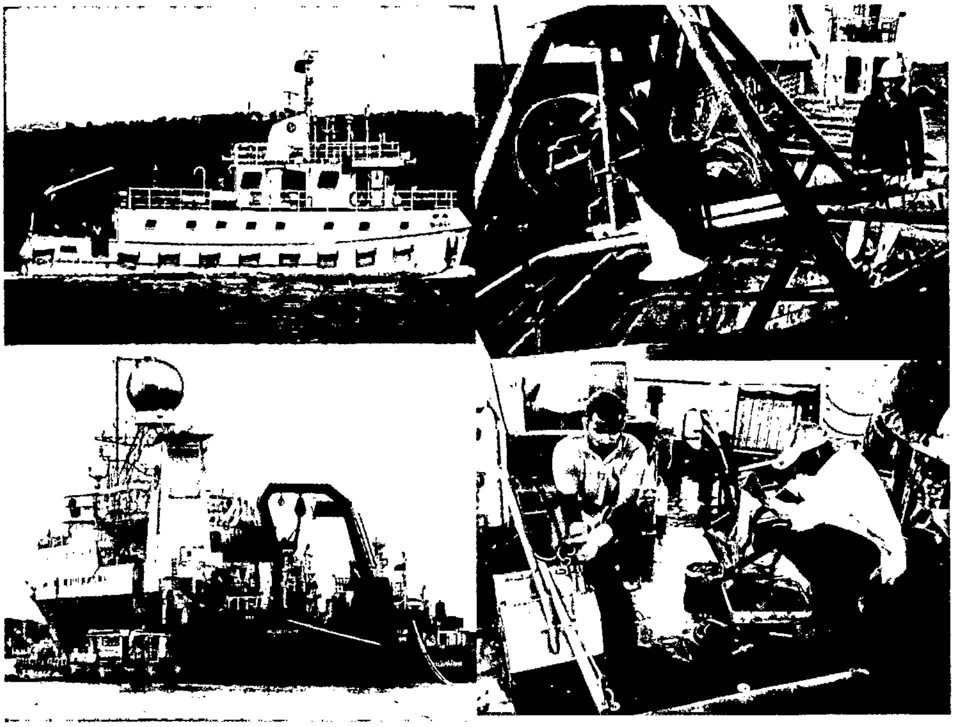

Plate 2.1: CRV Sagar Sukti (a); Spade box core (b); ORV Sağar Kanya (c) and onboard sampling with the help of van Veen grab and acrylic core (d).

2.3 Laboratory analysis

Environmental parameters

Sediment chlorophyll-*a* analysis was carried out by flurometric method (Holm-Hansen and Riemann 1978). The organic carbon of the sediment was estimated by wet oxidation method (El Wakeel and Riley 1957).

For the analysis of sediment grain size, samples were dried, weighed and sieved with 63 µm to separate the sand fraction and pipette method was employed to determine the silt and the clay fraction (Folk 1968). Grain size measurements were also carried out on the wet sediments, where approximate 1 g of sediment was put in distilled water for disintegration and later for complete disintegration of samples were kept in ultrasound sonic bath for 10 min. These samples were analysed with a Malvern laser particle size analyzer (Master-Sizer 2000).

The oxygen concentration of bottom water collected in box cores was measured by two methods, using the silicon optic probe and the conventional titration method (Strickland and Parsons 1972).

Nematodes

The samples for nematodes were sieved with 500 µm sieve and then by 45 µm mesh. Material retained on the 45µm sieve was considered for nematode analysis. Meiobenthic nematodes were then sorted under binocular stereoscopic microscope (Olympus SZX-7). The specimens were mounted on a temporary glycerol mount sealed with DPX for identification, which was done under bright field stereo-zoom microscope (Olympus BX-52). All the unidentified specimens were sketched for the details of cephalic region, buccal cavity and tail region. Separate microphotographs were taken for further identification under a bright field phase contrast compound microscope. The specimens were identified up to genus/ species level following the standard key developed by Platt and Warwick (1983) and Warwick et al. (1998). It was impossible to identify all nematode specimens to the species level, as many appeared undescribed, hence they were referred as unnamed congeneric species and were listed as sp1, 2 or 3.

2.4 Data Analysis

Diversity indices and statistics

The meiofaunal abundance was converted and expressed for a standard 10 cm^2 area. Nematode species data (ind. 10 cm^{-2}) were used to calculate the diversity as the number of species per sample (*S*), the Shannon-Wiener diversity index (*H'*) and Simpson's diversity index. Species richness (*d'*) was estimated from Margalef's formula as $d' = (S-1)/\ln N$, Evenness was calculated using Pielou's (*J'*).

Untransformed nematode abundance data was used to construct the non-metric Multi-Dimensional Scaling (MDS) ordination-using Bray-Curtis similarity measure to analyse the similarity between the sampling stations. Cluster analysis was also performed using the Bray-Curtis similarity measure. Diversity patterns were visualised by *k*-dominance curves. The species contributing to dissimilarities between zones were investigated using a similarity-percentages procedure (SIMPER). The analysis for the difference in sampling stations was performed by plotting geometric class. Formal significance tests for differences in nematode community structure between the samples were performed using the two-way ANOSIM tests with untransformed nematode species abundance data.

Correlation-based principal components analysis (PCA) was applied to ordinate results from the sediment and faunal analyses where the positions of samples are determined in relation to axes representing the full set of environmental variables measured (one axis for each of the ten variables included in the analysis). All the above analysis was done using the PRIMER 6.0 software.

Differences in biotic data between sampling seasons and between zones were analysed using two-way ANOVA performed using the STATISTICA software package.

Feeding types and Maturity Index

The maturity index (MI) was calculated as the weighted mean of the individual taxon scores (Bongers et al. 1991):

$$MI = \Sigma\, v\,(i) \times f\,(i)$$

Where, v is the colonisers-persisters (c-p) value of taxon i (as given in Appendix A by Bongers et al. 1991) and f is the frequency of that taxon in a sample.

The index is represented by a colonizer-persister (CP) value that ranges from a colonizer (CP = 1) to a persister (CP = 5) with the index values representing life-history characteristics associated with *r*- and *K*-selection, respectively. Those with a CP=1 are *r*-selected or colonizers, with short generation times, large population fluctuations, and high fecundity.

Analysis on nematode feeding types was performed by categorising nematodes into four functional groups according to Wieser (1953):

1A: Selective deposit feeders: nematodes with a very small unarmed buccal cavity.

1B: Non-selective deposit feeders: nematodes with unarmed buccal cavities of moderate size.

2A: Epistratum feeders: nematodes with medium size buccal cavities, provided with small teeth.

2B: Predators /omnivores: nematodes with wide buccal cavities, large teeth or other powerful buccal structures.

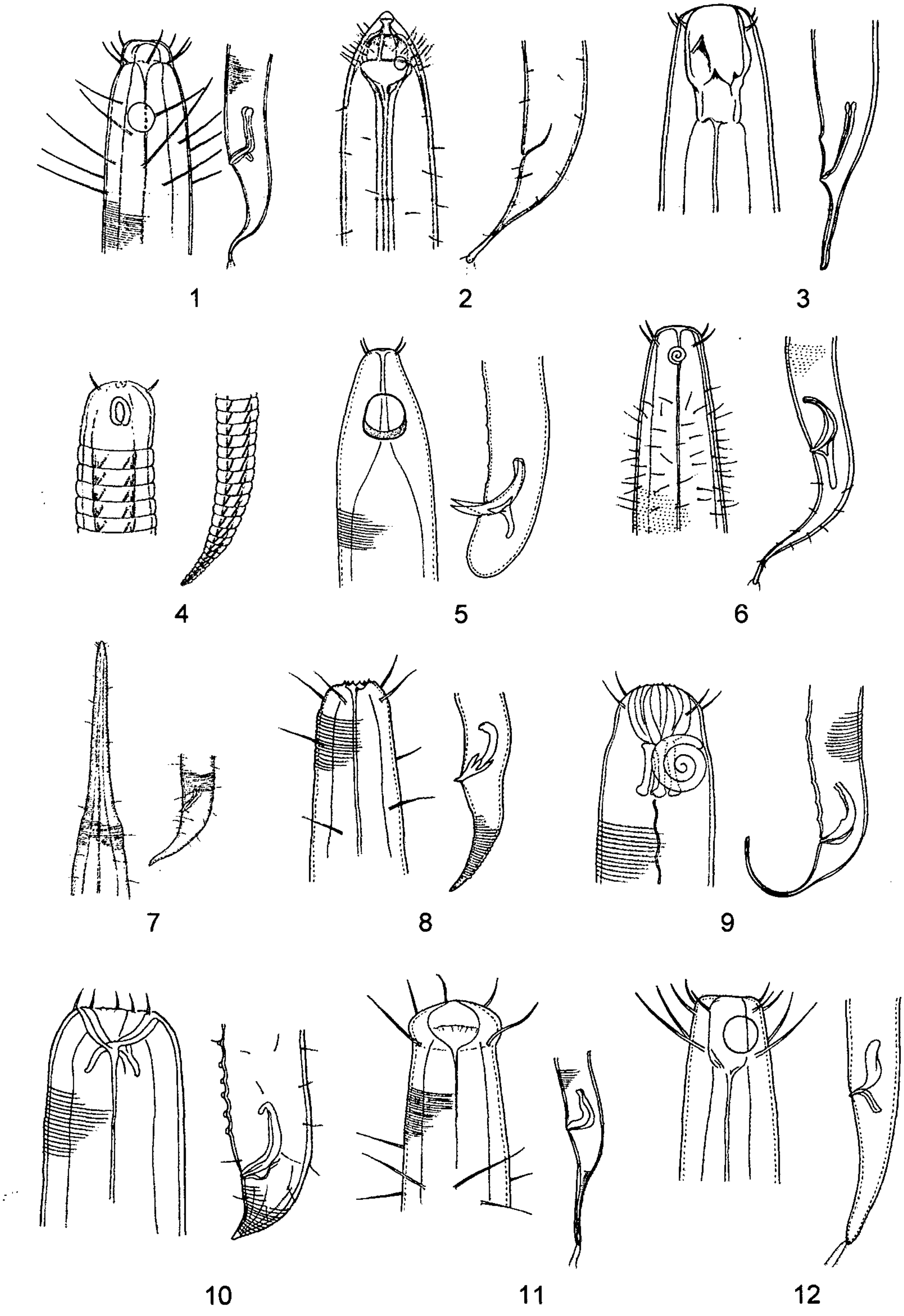

Plate 2.2: Sketches of nematodes; 1: *Trichotheristus* sp., 2: *Sphaerolaimus* sp., 3: *Oncholaimus* sp., 4: *Pselionema* sp., 5: *Siphonolaimus* sp., 6: *Actarjania* sp., 7: *Rynchonema* sp., 8: *Bolbolaimus* sp., 9: Selachinematidae, 10: *Latronema* sp., 11: *Daptonema* sp. and 12: *Eumorpholaimus* sp.

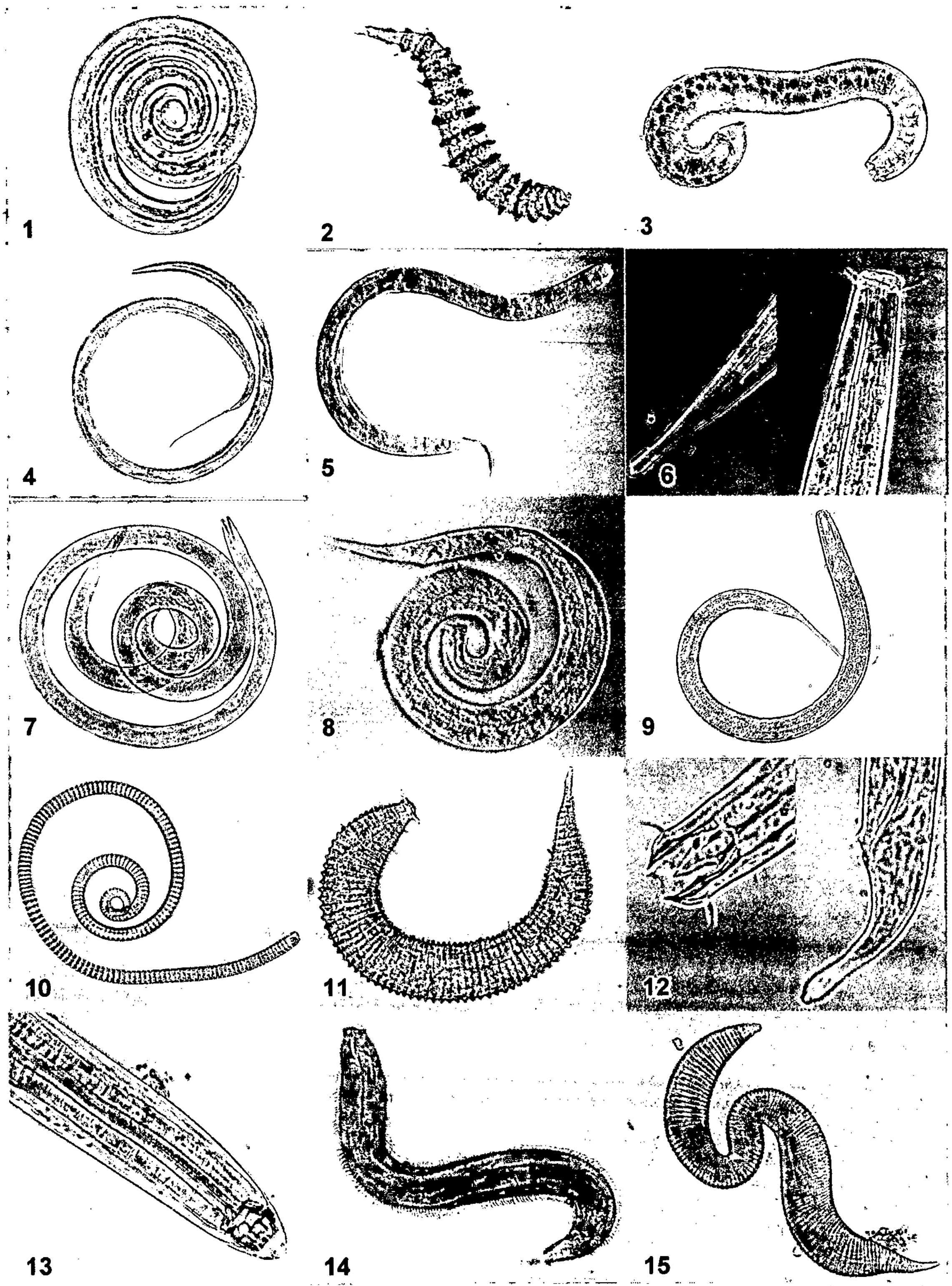

Plate 2.3: Microphotographs of nematode species from the study area. 1: *Campylaimus* sp., 2: *Desmoscolex* sp., 3: *Latronema* sp., 4: *Halalaimus* sp., 5: *Halicoanolaimus* sp., 6: *Trichotheristus* sp., 7: *Odententophora* sp., 8: Microlaimidae, 9: *Terschellingia longicaudata*, 10: *Pselionema* sp., 11: *Tricoma* sp., 12: *Metoncholaimus* sp., 13: *Sphaerolaimus* sp. 14: Unidentified and 15: *Epsilonema* sp.

Chapter 3:

Subtidal nematodes

3 Subtidal nematode community from the central west coast of India

Introduction

Meiobenthic nematodes are among the most diverse and numerically dominant metazoans in the marine habitat (Heip et al. 1982; De Ley and Blaxter 2001), with a global species estimate (Lambshead and Boucher 2003) between 10^5 and 10^8. Despite their remarkable diversity and their potential use as indicators, nematodes are among the less studied components of meiofauna. Nematodes play an important role in the benthic environment by i) mechanical breakdown of the detritus, ii) excretion of limiting nutrients to bacteria, iii) producing microfilm conducive to bacterial growth and iv) bioturbating sediment around detritus (Tietjen 1980). Nematode diversity has been well documented from the Atlantic and the Pacific Ocean (Heip et al. 1985) whereas studies from the Indian Ocean are rare. Meiofauna (Coull and Chandler 1992) and nematode communities (Bonger 1990) have been widely used in bio-monitoring programmes to assess the benthic environmental health and many species are good pollution indicators (Heip et al. 1985).

The central west coast of India has unique physical settings and dynamic biogeochemistry, with intense seasonality due to the influence of monsoon, coastal upwelling, seasonal anoxia and phytoplankton bloom (Naqvi et al. 2000).

The main objective of this study was to investigate the meiofaunal community and nematode species diversity from the central west coast of India, which has no past account in any literature dealing with nematode community distribution.

Materials and Methods

Study Area

Sampling sites were located along the central west coast of India (Fig 3.1). In total, 18 subtidal sites were selected randomly between Ratnagiri and Mangalore (Table 3.1). Six stations were selected near the Zuari river mouth i.e. the harbour area so as to cover the shallower estuarine region. In the north, the first two stations were taken in the deeper region (500 m). The river mouth sites (Stn. 5 to 10) were in shallower depth between 7 m and 15 m. The remaining sites were in 20 to 100 m water depths.

Sediment samples from the deeper depths were collected on board CRV *Sagar Sukti* (SASU-60) and *ORV Sagar Kanya* (SK-211). The sampling in the shallower locations, particularly the harbour area (Zuari river mouth) was done with a fishing trawler. Sediment samples were collected with a van Veen grab (0.11 m^2) and by deploying a spade box corer (147.894 cm^2). Separate samples were collected for sediment chlorophyll-a, organic carbon and granulometry, and immediately preserved in deep freeze. The details of sample analysis and data processing is described in Chapter 2.

Results

The highest (3.36 µg/g) sediment chl-a was observed at station 16 and the lowest (0.02 µg/g) was at station 6, 7 and 10 each. Sedimentary organic carbon was highest (3.56 %) at station 4 and the lowest (0.03 %) was at station 18 (Table 3.1).

Nematode families

The family Xyalidae was the most dominant and was represented by 13 out of 94 species (Table 3.2). A highest of 17 families were observed at station 2, 11, 12, 13, 14 and 17 each. Lowest of 6 families occurred at station 5. Highest (35) number of genus and species were recorded at station 12 and the lowest (7) genus and species were recorded at station 7 (Table 3.2).

Nematode community

A total of 94 nematode species were recorded from the study area (Table 3.3). The highest number of species (34) were observed at station 12 and lowest (07) were at station 6 (Table 3.3).

The highest (8.3) nematode species richness (d') was observed at station 13 while the lowest (1.7) was at station 7. The species evenness (J') was seen highest (0.936) at station 15 and the lowest (0.723) was observed at station 7. The Shannon-Weaver's diversity function was highest (3.2) at station 14 and lowest (1.4) at 7 (Table 3.4).

Correlation

The sediment chlorophyll negatively correlated with water depth (r= -0.16, Figure 3.2), whereas the relation between sediment organic carbon and water depth was positive (r= 0.32, Fig 3.2).

MDS

The multi-dimensional scaling ordinates for nematode species abundance shows a clear differentiation between the habitats where the estuarine stations show similarity (stations 5 to 10) and the shelf community can be seen separated (stations 11 to 18) and the deepest (500 m) (stations 3 and 4) are well separated from others (Fig 3.3). The Multidimensional scaling for nematodes species abundance for stations makes clear differentiation between the shelf region and the estuarine nematode community.

Species area curve

Nonintersecting k-dominance curves (Fig 3.4) indicate a difference in species diversity of two areas that is the estuarine and the shelf region, the curve for estuarine region represents low community diversity compared to the shelf region. Similar trend was observed by Eyulem-Abebe et al. (2004), which mean that the estimates of diversity observed in this study are not completely satisfactory.

Species dominance

The dominant species, which contributed more that 30% of the nematode abundance collectively, were *Desmoscolex* sp, *Terschellingia longicaudata, Actarjania* sp and *Polysigma* sp. The most widely distributed species was *Actarjania* sp., accounted from all the stations (Table 3.3). The species *Polysigma* sp. was most conspicuous in occurrence in terms of abundance (126 nos. 10 cm^{-2}). *Actarjania* sp and *Polysigma* sp. contributed 8% each to the total nematode abundance whereas *Desmoscolex* sp and *T. longicaudata* contributed 7% each (Fig 3.5).

Feeding types

The study area was dominated by non-selective deposit feeders (38%) and selective deposit feeders (26%). The epistrate feeders (15%) were the least dominant group represented by the community (Fig 3.6).

Discussion

In open ocean, light penetration limits the benthic primary production in deeper water, restricting the availability of chlorophyll in the sediment. On the other hand, organic matter in the sediment is accumulated over a time period both from the pelagic flux as well as contribution from riverine sources (Rao and Veerayya 2000). The increasing depth is positively correlated with species richness, which suggests that as depth increases the conditions become more stable for the species to distribute uniformly. But the diversity did not show any significant trend with increasing depth.

Habitat heterogeneity clearly separates the nematode community according to the habitats and the hydrodynamics of that particular location (Schratzberger et al. 2006). Food source is also an important aspect for the distribution of nematode species and organic matter plays an important role in structuring the nematode community (Pusceddu et al. 2009).

It may suggest the dependence of the nematode community on the thriving bacterial biomass and the organic matter reaching the sediments (Meyer-Reil and Faubel 1980; Danovaro 1996).

Nematodes were found at all the stations and were the most dominant with mean abundance of 84%. As per the families the nematode species belonging to Comesomatidae were the most dominant but the feeding groups according to Wieser (1953) depicted the dominant of deposit feeders. These results might suggest that many of the Comesomatidae consume detritus and are less dependence on the fresh microphytobenthos. The dominance of genus *Actarjania* and *Paracomesoma* (at the river mouth site) the family Comesomatidae shows its dominance, which was also seen in the Western Indian Ocean (WIO; Muthumbi et al. 2004). Second most dominant was Linhomoidae and Desmodoridae as genus *T. longicaudata* and *Polysigma* dominated at most of the sites.

The sub-tidal nematode community from the central west coast has groups of genus in common with the Western Indian Ocean (Muthumbi et al. 2004; Alongi, 1990; Soataert and Heip 1995). Although the density of those particular species varied with the local conditions.

The groups in this study included *T. longicaudata, Desmoscolex, Trichoma, Halalaimus, Molgolaimus* and *Greiffellia*. This group was also noted by Tietjen (1984) in different type of sediments as low fidelity group with two different genus. The northern sites showed highest percent dominance of *Polysigma* (13%) but the group composed of *Draconema, Desmoscolex, Polysigma, Halalaimus, T. longicaudata* and *Greeffiella*. The estuarine sites with very high dominance of *Actarjania* (36%) also had a combination of *Desmoscolex, Halalaimus* sp., *H. isaitshikovi, Axonolaimus* and *Dorylaimopsis*. The southern stations were dominated by *Paracomesoma* (9%) including *Desmoscolex, Polysigma, Halalaimus, T. longicaudata, Molgolaimus* and *Sabatieria*.

The genus *T. longicaudata* and *Desmoscolex* have mouthparts, with merely any dentition, and may clearly indicate that fresh detritus and bacterial biomass must be available for them to thrive. Although the presence of these species in the deeper, shallower as well as harbour stations indicates that the basic food supplement for them is available at this spatial level, depending upon the food available might be the changes in the densities.

Dorylaimopsis has been found dominating in silt and mud (Muthumbi et al. 2004) but was only noticed (3 %) in the estuarine sediment. *Halalaimus sp.* percent abundance was high at all different habitats but *H. isaitshikovi* (3 %) was found only in the estuarine site. Presence of *Molgolaimus* (5 %) was overall significant because it was only in the southern stations, which had high abundance in the WIO and the Antarctic sea (Muthumbi et al., 2004). *Terschellingia* sp has been often reported dominant in silty and muddy sediments where the sediment accumulation occurs (Muthumbi et al., 2004). *T. longicaudata* was high (8%) in the southern stations and lower (3 %) in northern stations which suggests that more of sediment accumulation takes place in southern as compared to northern area. *Sabatieria* is one of the common inhabitants of fine grained sediment with very low oxygen conditions (Soetaert and Heip 1995) and was only found in the southern sites that too with very less densities, which may give the indication of lowered oxygen concentration at that site.

Feeding types

The widely used traditional Wieser's classification for nematode feeding types was followed in this study. The dominant feeding type for all the stations was non-selective deposit feeder, which is commonly reported from other sites (Soetart and Heip 1995; Tita et al. 2002; Tietjen 1984). *Actarjania* in the estuarine sites was responsible for higher number of epistrate feeders. Second dominant was the selective deposit feeder, which suggests that high abundance of bacteria and microphytobenthos must be available for these selective feeders. But in the sea-grass studies epistrate feeders were the most dominant (Novak 1989) as compared to the present study, where they were just 18% probably due to settling of decomposed organic detritus and absence of large particle size in the sediment which are known to influence the epistrate feeders abundance.

Table 3.1: Geographical location of the sampling stations and the details of the parameters.

St.	Lat. (°N)	Long. (°E)	Depth (m)	Substrate type	Gear used	Sedi. Chl (µg/g)	Sedi. OC (%)
1	17 30 00	71 12 00	500	Clayey	Box corer	0.11	2.17
2	17 30 00	71 12 00	500	Clayey	Box corer	0.16	1.88
3	17 30 00	72 44 00	50	Silty sand	Box corer	0.5	1.84
4	17 30 00	72 44 00	50	Silty sand	Box corer	0.19	3.56
5	15 25 02	73 48 00	15	Silty	van Veen grab	0.04	0.58
6	15 25 40	73 48 17	9	Clayey	van Veen grab	0.02	1
7	15 25 60	73 48 40	9	Clayey	van Veen grab	0.02	1.55
8	15 25 00	73 48 40	8	Clayey	van Veen grab	0.04	0.5
9	15 24 99	73 48 63	7	Clayey	van Veen grab	0.03	1.96
10	15 25 04	73 48 85	7	Silty	van Veen grab	0.02	1.44
11	15 30 00	73 40 00	23	Silty	van Veen grab	0.09	0.11
12	15 30 00	73 35 00	35	Silty	van Veen grab	3.22	0.14
13	15 30 00	73 00 00	112	Silty sand	van Veen grab	2.21	0.14
14	15 00 00	73 45 00	43	Clayey	van Veen grab	3.22	0.06
15	14 06 00	74 18 00	32	Silty	van Veen grab	2.9	0.08
16	13 00 76	74 30 11	29	Silty	van Veen grab	3.36	0.07
17	13 00 00	74 15 00	60	Silty sand	van Veen grab	1.75	0.04
18	13 00 11	74 03 00	97	Silty	van Veen grab	2.35	0.03

Table 3.2: Nematodes represented in families, genera and species for each station.

	Nematode		
Stn. No	Families	Genera	Species
1	14	20	20
2	17	25	25
3	16	30	30
4	16	26	26
5	6	9	10
6	11	18	19
7	7	7	7
8	9	11	12
9	10	12	13
10	8	14	15
11	17	32	32
12	17	35	35
13	17	34	34
14	17	33	33
15	12	20	20
16	15	25	25
17	17	29	29
18	8	16	16
Mean	13	22	22

Table 3.3: Occurrence of nematode species at the sampling stations.

Genus\Stns.	1	2		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Actarjania sp.	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	-	+	+
Aerolaimus paucisetosus	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anoplostoma sp.	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apodontium sp.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Ascolaimus sp.	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	-	-	-
Axonolaimus sp.	-	-	+	+	-	-	+	+	-	+	+	-	-	-	-	+	+	-
Bathylaimus sp.	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Calligyrus sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Calomicrolaimus sp.	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Campylaimus sp.	-	-	+	+	-	-	-	-	-	-	+	+	+	-	-	+	-	-
Cantholaimus sp.	-	-	-	-	-	-	-	-	-	-	+	-	+	+	+	-	+	-
Ceramonema sp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetonema sp.	-	+	+	+	-	-	-	-	-	-	-	+	-	-	-	-	+	-
Chrmaspirina sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromadorita sp.	-	-	-	+	-	-	-	+	-	-	-	+	+	-	+	+	+	+
Cobbia trefusaeformis	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Comesa sp.	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Daptonema sp.1	+	+	-	-	-	-	-	-	-	-	+	+	+	+	+	+	-	+
Daptonema sp.2	+	-	-	+	-	-	-	-	-	+	+	-	-	-	-	-	-	-
Desmodora sp.	-	-	-	-	-	+	-	-	-	-	+	+	+	+	-	-	+	-
Desmoscolex sp.	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	-
Dichromadora sp.	-	+	-	-	-	-	-	-	-	-	-	+	+	+	-	-	+	-
Diplopeltoides sp.	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dorylaimopsis sp.	-	-	-	-	-	+	-	-	-	-	+	-	+	+	-	+	+	+
Draconema sp.	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Elzalia sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Enoplolaimus sp.	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-
Epacanthion sp.	-	-	-	-	-	-	-	-	-	-	+	-	+	+	-	-	+	-
Eumorpholaimus sp.	-	+	-	-	+	+	-	-	+	-	-	-	-	+	-	-	-	-
Eurystomina caesiterides	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gammanema sp.	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gnomoxyla sp.	-	-	+	-	+	-	+	-	+	-	-	-	-	-	-	+	-	-
Gomphionchus sp.	-	-	-	+	-	-	-	-	-	-	+	+	-	-	-	+	-	-
Gonionchus sp.	+	+	-	-	-	-	-	-	-	-	+	+	+	+	+	-	+	+
Greeffiella sp.	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Halalaimus isaitshikovi	-	+	+	+	-	+	-	-	+	+	+	+	+	+	+	+	+	-
Halanonchus sp.	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Halichoanolaimus sp.	-	-	+	+	-	+	-	+	-	-	+	+	+	-	-	+	-	-
Hopperia sp.	-	-	-	-	+	+	-	+	-	+	+	+	+	-	-	-	-	-
Latronema sp.1	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Latronema sp.2	-	-	-	-	-	-	-	-	-	+	+	+	-	-	+	-	-	-
Leptolaimus sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Marylynnia sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Megadesmolaimus sp.	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Metachromadora sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Metacyantholaimus sp.	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-
Metadasynemalla sp.	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Metalinhomoeus sp.1	+	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Meyersia sp.	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Microlaimus sp.	-	-	-	-	-	+	+	-	-	-	-	+	+	+	-	-	+	+
Molgolaimus sp.	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+
Monhystrid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Notochaetosoma sp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oncholaimid	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Oncholaimus sp.	+	-	-	-	-	-	-	-	-	-	+	+	+	+	+	-	-	-
Onyx sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxystomina sp.	-	-	+	-	-	-	-	-	-	-	+	+	+	+	-	+	+	+
Paracomesoma sp.	-	-	-	-	-	-	-	-	-	+	+	+	-	+	+	+	-	-
Paralinhomoeus sp.	-	+	-	+	-	-	-	-	-	-	+	+	+	+	+	+	+	+
Paralongiciantholaimus sp.	-	-	-	-	-	-	-	-	-	-	+	-	+	+	-	+	-	-
Paramesonchium sp.	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Paramicrolaimus sp.	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Paramonhystera sp.	+	+	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-
Pierrikia sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polysigma sp.	+	+	+	+	-	+	-	-	+	-	+	+	+	+	-	-	+	-
Promonhystera sp.	-	+	+	-	+	-	-	-	-	-	+	+	+	+	-	+	+	+
Pselionema sp.	+	+	+	-	-	-	-	-	-	-	+	+	+	+	-	+	+	-
Quadricoma sp.	+	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	+	-
Rhabditis sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhabdocoma sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sabateria sp.	-	-	-	-	-	-	-	-	-	+	-	+	+	+	+	-	-	+
Sclachinematidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Siphonolaimus sp.	-	-	-	-	+	+	-	+	+	+	-	-	-	+	-	+	+	-
Sphaerolaimus sp.	-	-	+	+	-	-	-	-	+	-	+	+	+	+	+	+	-	-
Spirinia sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spirobolbolaimus sp.	-	-	-	-	-	+	-	-	-	-	-	+	+	+	-	-	-	-
Steineria sp.	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+
Subsphaerolaimus sp.	-	+	-	-	-	-	-	-	-	-	-	+	-	+	-	-	+	-
Tarvaia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	-
Terschellingia sp.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-
Terschellangia longicaudata	-	-	+	+	+	+	-	-	+	+	+	+	-	-	+	+	+	+
Terschellangia sp.	-	+	+	+	-	-	-	-	-	-	+	-	+	+	+	+	+	-
Theristus sp.	-	-	-	-	-	-	-	-	-	+	-	+	+	+	+	-	-	+
Theristus sp.2	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichoma sp.	-	-	-	-	-	+	-	-	+	-	-	+	-	-	-	-	-	-
Trissonchulus sp.	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vasostoma sp.	-	-	+	-	-	-	-	-	-	-	+	+	+	-	+	-	+	+
Viscosia abyssorum	-	-	-	+	-	-	-	+	+	-	+	-	-	-	-	-	-	-
Unidentified	-	+	+	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Total No. of species	20	25	30	26	10	19	7	12	13	15	32	35	34	33	20	25	29	16

Table 3.4: Nematode species diversity indices for each station.

Stn	Species no. *S*	Number *N*	Richness *d*	Evenness *J'*	Shannon *H (loge)*	Simpson's *1-Lambda*
1	20	41	5.1	0.875	2.6	0.91
2	25	57	5.9	0.934	3.0	0.96
3	30	303	5.1	0.780	2.7	0.89
4	26	174	4.8	0.790	2.6	0.89
5	9	60	2.0	0.805	1.8	0.80
6	18	66	4.1	0.883	2.6	0.91
7	7	33	1.7	0.723	1.4	0.65
8	11	37	2.8	0.858	2.1	0.85
9	12	47	2.9	0.875	2.2	0.87
10	14	57	3.2	0.741	2.0	0.75
11	32	114	6.5	0.838	2.9	0.92
12	35	120	7.1	0.759	2.7	0.87
13	34	52	8.3	0.872	3.1	0.94
14	33	63	7.7	0.917	3.2	0.96
15	20	44	5.0	0.936	2.8	0.95
16	25	150	4.8	0.842	2.7	0.91
17	29	89	6.2	0.908	3.1	0.95
18	16	24	4.7	0.880	2.4	0.92

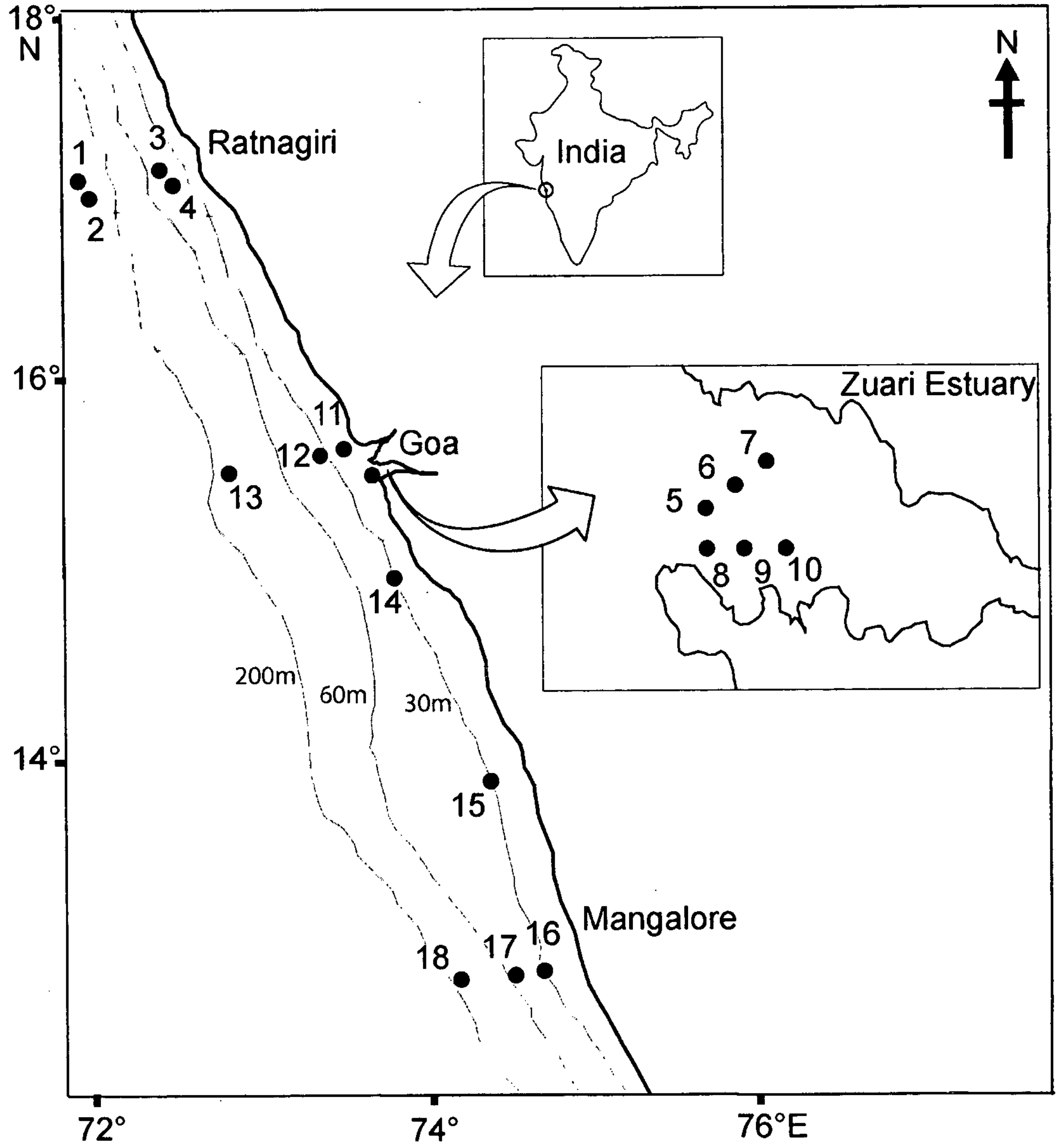

Fig 3.1: Sampling locations in the study area.

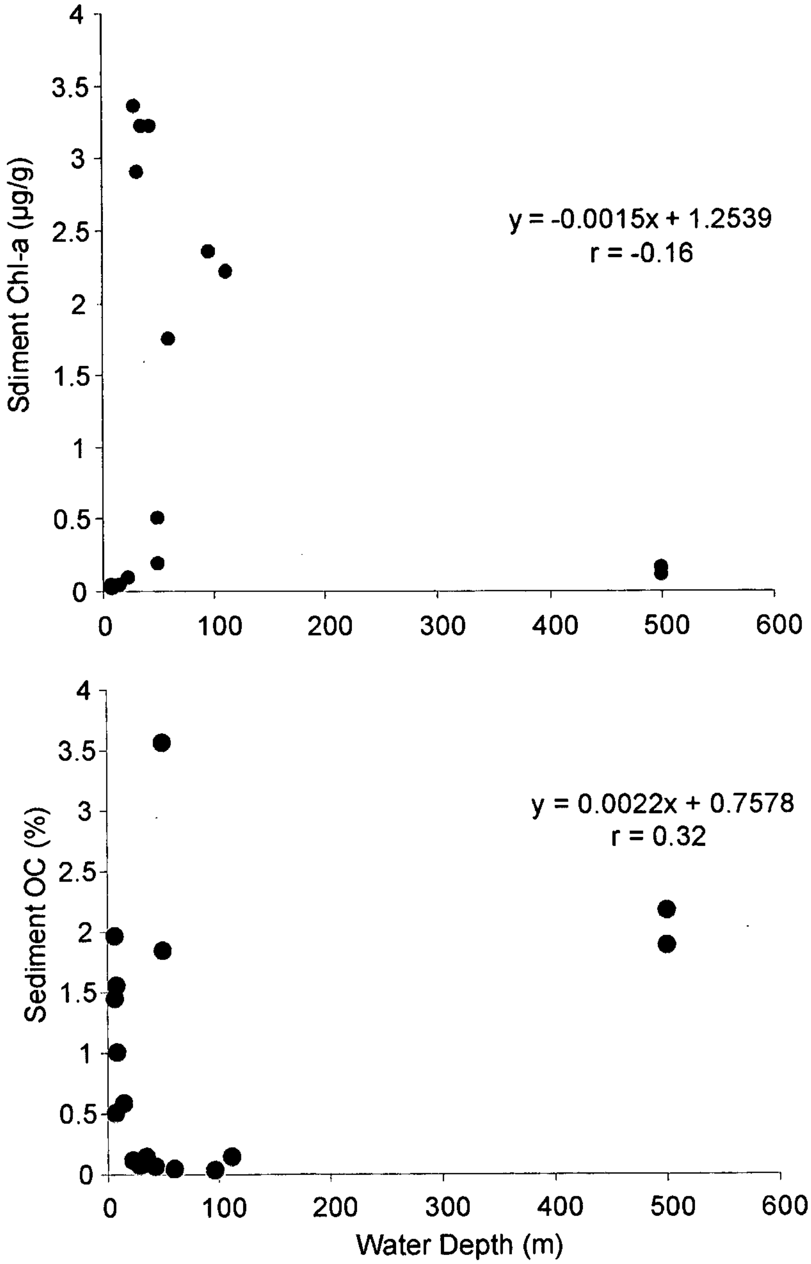

Fig 3.2: Correlation of sediment chlorophyll-a (µg/g) and sediment organic carbon (%) with the water depth.

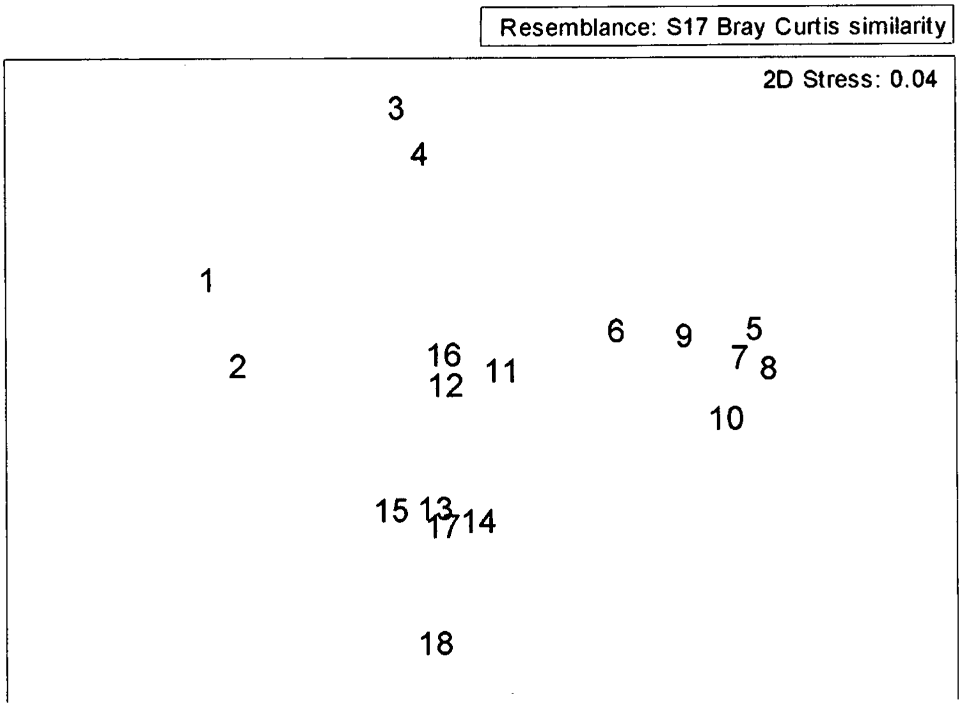

Fig 3.3: Multi-Dimensional Scaling (MDS) ordination for untransformed meiofaunal (a) and nematode (b) abundance.

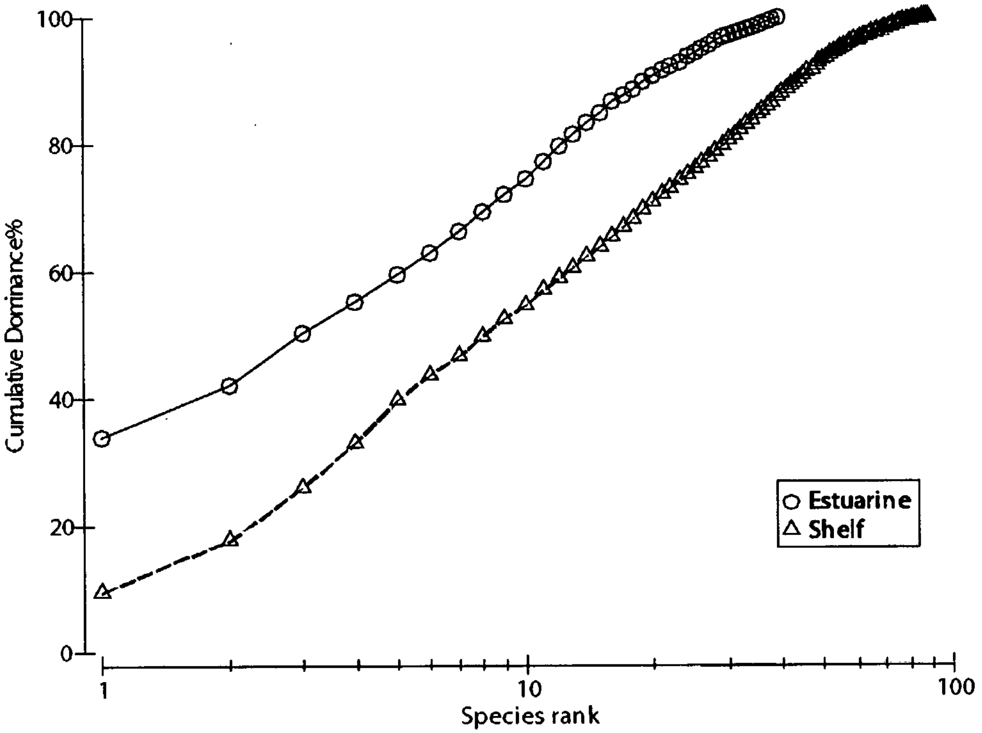

Fig 3.4: Percent cumulative dominance curve of nematode species abundance for estuarine and shelf community.

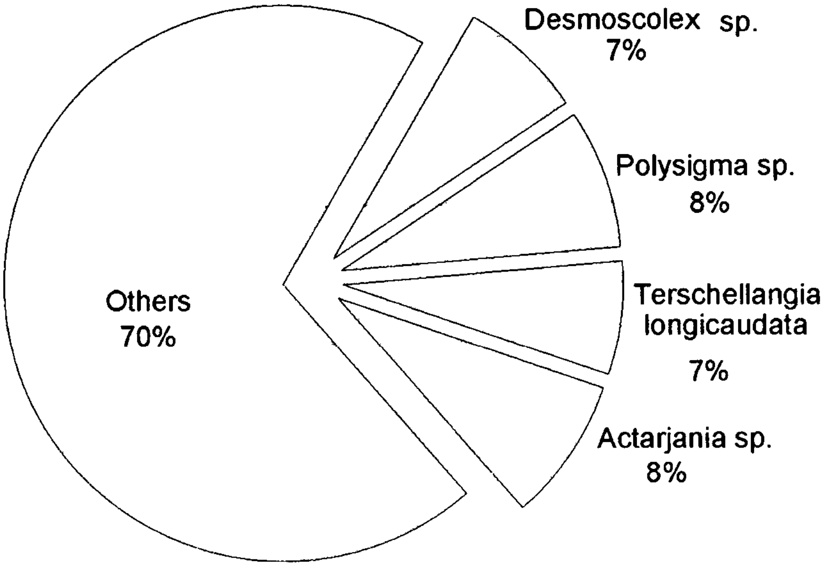

Fig 3.5: Percent contribution of dominance nematode species from the study area.

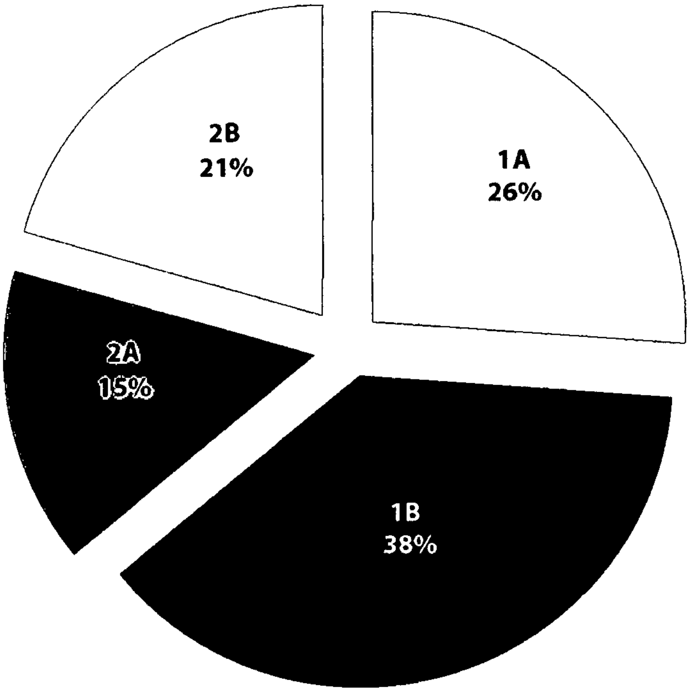

Fig 3.6: Total percent feeding type of nematodes from the study area.

Chapter 4:

Intertidal nematodes

4 Intertidal nematodes

4.1: Spatial distribution of nematode community along the central west coast of India.

Introduction

The intertidal region holds diverse habitats, which tends to accumulate high biological diversity. It is a harsh environment with a magnitude of changing parameters viz: amount of desiccation, salinity, temperature, food availability and changes in grain size. The meiobenthic nematodes occupy all possible habitats in the coastal region but are understudied from the tropical coastal areas and apparently very less from the Indian coasts. The central west coast of India holds many exposed sandy beaches, mangroves and mudflats. To know the differences and/or similarities in nematode community between these habitats, 25 different sites were investigated for the present study. For the purpose of comparison, they were classified into beaches, mudflats and mangroves.

Methodology

Study area

A total of 15 open ocean sandy beaches, 5 mudflats and 5 mangrove habitats were sampled in the mid tide region of Goa (Fig 4.1.1). Triplicate samples were taken at each site with an acrylic core of 4.5 cm diameter upto 5 cm depth. The details of sample analysis and data processing are described in Chapter 2.

Results

The sediment from mangroves regions, mudflats and beaches together accounted for 74 nematode species. The highest species (21) number was observed at Terechol mudflat located in the north Goa whereas only one species was recorded from the sandy beach at Cannaginium (Table 4.1.1).

The highest (2.99) species richness (*d'*) was observed at mudflat (Ribander) and the lowest (0.69) was at sandy beach (Palolem). The evenness (*J'*) was highest (0.80) at Galjibag mudflat while the lowest (0.12) was observed at Dias beach (Table 4.1.2). The Sannon-Weaver's information function for species diversity (*H'*) was highest (2.27) at Galjibagh mudflat and the lowest (0.21) at Dias beach. Simpson's diversity Index was highest (0.86) at Terechol mudflat and the lowest (0.12) at Sinquerem and Palolem beach (Table 4.1.2).

Pair-wise ANOSIM revealed a significant difference between mudflat and beach sites and mangroves and the beaches also had significant difference (Table 4.1.3) in the nematode community. The ANOSIM treatment did not show any significant difference between the mangroves and the mudflats (Table 4.1.3).

Based on the non-metric multi-dimensional scaling ordinations for the untransformed abundance of nematode species clearly shows a difference for beach nematode community separating it from mudflats and mangroves. But there was no distinction between mudflat and mangrove nematode community (Fig 4.1.2).

K-dominance curve suggest a better representation of the community in the mangroves and the mudflat while the sampling efforts was more for beach habitat still the nematode community has less number of rare species diversity (Fig 4.1.3).

On mudflats the species dominance by the first three species overall was 37%. The three most dominant species were *Chromadorita* sp. (14%), *Desmodora* sp. (13%) and *Daptonema* sp1 (10%). For the mangrove sites, the three most dominant species contributed 40% of the total nematode abundance. *Marylynnia* sp. (14%), *Sabatieria* sp2. (16%) and *Chromadora* sp1. (10%) contributed the highest dominance in the mangroves. On the sandy beaches, the three species together counted for 34% of the total nematode density were *Adoncholaimus* sp1 (12%), *Viscosia* sp2 (9%) and *Viscosia* sp3 (13%; Fig 4.1.4).

The mudflats were dominated by epistrate feeders (47%) followed by non-selective deposit feeders (36%) but in the mangroves non-selective deposit feeders dominated (46%) and epistrate feeders were subdominant (36%). The beach nematode community was dominated (73%) by the predatory/omnivores (Fig. 4.1.5).

Discussion

The results suggest a clear difference between the beaches and the other two habitats (mangroves and mudflats). The difference in these habitats can be attributed to the harsh conditions prevailing on the beaches, as the high-energy beaches have dynamic swash zone. On the other hand, the mangrove and the mudflats share a much similar nematode community and the ANOSIM shows no significant difference between these two habitats. The reason for such similarity can be the similar sediment type and grain size of mangroves and mudflat. Secondly, these habitats are mostly associated with the estuarine habitat where a constant exchange of sediments is possible due to seasonal physical changes. Because of this constant exchange the similarity in the physico-chemical parameters is evident and apparently exchange of fauna also takes place resulting in similar communities. The only differentiation between these two habitats was the dominance of species and feeding type. Food resources on the mudflat and the mangroves are different as mangroves are sheltered habitats with flora and the mudflats are more open with dense microalgal mats. This difference in resource availability tends to change the species composition as well as the dominance of species.

Comparison with other regions

Sandy beaches and mudflats have been extensively studied from the temperate regions but there are few investigations from the tropics. As the mangroves are confined to the tropical region only, thus there are relatively very few studies from these habitats. The Australian mangroves have been investigated for nematode species and some studies are available from African and the South American continent.

The mangroves from the east coast of India constituted only 18 genera (Krishnamurthy et al. 1984). Deposit feeders and bacterivores dominate the mangroves (Gee and Somerfield 1997; Tietjen and Alongi 1990). Mangrove leaf litter has a significant influence on the community, which shows an increase in epigrowth feeders (Gwyther 2003). The difference in the mangrove nematode community can be attributed to temperature changes in different geographical areas (Gwyther 2003).

European sandy beaches and mudflats tend to show very high species richness because of the dissipative nature and low tidal flushing in such habitats. A high number of species were recorded from diverse habitats in a microtidal lagoon from Zanzibar (Ndaro and Olafsson 1999). A total of 44 species were documented from Australian mangroves (Nicholas et al. 1991) and 37 species are reported from the east coast of India (Chinnadurai and Fernando 2007). Red mangroves from Puerto Rico accounted for 25 species while *Avicennia marina* from Australia had 21 species. Comparatively, the present study area consisted of 47 species, which is higher than the other sites.

In comparison to the mudflats worldwide the central west coast of India had only 45 species

Only 24 species were present from the beaches of present study area but much similar richness was documented from southeastern Australia (Nicholas and

Hodda 1999; 48 genera) and Alongi (1986) recorded only 25 species from nine different beaches. European temperate sandy beaches harboured high species number such as De Panne (88 species), San Rossore (66 species), Hel beach (56 species), Punta Estrella (67 species) and Santa Clara (55 species) (Gheskiere et al. 2005, 2006; Mundo-Ocampo et al. 2007).

The beaches, which are reflective in nature, have similar species number from other tropical regions but much lower species richness when compared to temperate regions of the world. The mangroves from the central west coast have much higher species number compared to the other tropical regions.

Species dominance was highest on the mudflat followed by mangroves and sandy beaches. The mudflats were dominated by *Chormadorita* sp., *Desmodora* and *Daptonema* sp. Mudflats have been generally seen dominated by *Daptonema* sp. (Warwick 1971; Eskin and Coull 1987; Soetaert et al. 1995). The mudflat nematode community accounts for maximum consumption of benthic productivity and plays an important part in the trophic dynamics (Rzeznik-Orignac et al. 2003).

All these species are epistrate feeders consuming microalgal growth and bacteria biomass on the sediment particle and the overall dominance was also by the epistrate feeders (Fig 4.1.5) suggesting the main food resource on the mudflats was the growth of microphytobenthos structuring the nematode community. Nematodes do take-up the major portion of their food from the microphytobenthic diatioms (Riera et al. 1996) and microalgae (Pascal et al. 2008). While on the mangrove sediments *Marylynnia* sp, *Sabatieria* sp. and *Chromadorita* sp. dominated the community which as mostly opportunistic species especially *Sabatieria* sp. suggesting more stressed conditions. The growth of miro-algae is retarded on the mangrove sediments due to very less light penetration and tannins released by the mangrove trees. This is evident from the dominance of non-selective deposit feeders (Wieser 1953) in the mangroves, which are indiscriminate feeders. The sandy beaches were dominated by predators viz: *Adoncholaimus* sp., *Viscosia* sp and *Viscosia* sp2. The overall community was also dominated by predatory/omnivores, which revealed a complete different benthic habitat compared to mangroves and the mudflats. As very less organic matter accumulated in the beach sediments and very low benthic production due to dynamic sediments and constant flushing of the surf zone (McLachan and Brown 2006) making the habitat oligotrophic compared to the mangroves and the mudflats. This allows the increase in density of other forms such as ciliates, oligochaetes, turbellarians and other prey species that are directly captured by the predatory nematodes.

The hydrodynamic factors and the physico-chemical parameters regulate the sediment type, benthic productivity and the accumulation of organic matter in the intertidal region. These factors indirectly structure the nematode community based on the life history pattern and the physiological requirements (Heip et al. 1985). Overall, it may be concluded that mudflats of this tropical region harbour high diversity and abundance of nematodes. The mangroves have high diversity and abundance compared to other parts of the planet but still remains less diverse compared to the mudflats from the same region. The mangrove nematode community shows a sign of stress revealed by the dominance of some species known to invade stressed sediments. And the sandy beaches of this region have low diversity and abundance compared to the other beaches of the world and the important factor for such low nematode diversity can be the reflective nature of these open ocean beaches.

Table 4.1.1: The occurrence of nematode species in different sampling location.

	Mudflats					Mangroves					Beaches														
	Terechol	Old-Goa	Galjibag	Talpona	Raibander	Terechol	Chapora	Chorao	Talpona	Galjibag	Morjem	Mandre	Candolim	Vagator	Keri	Miramar	Colva	Canaginium	Palolem	Dias	Caranzalem	Benaulem	Rajbaga	Varca	Sinquerem
Viscosia sp1	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Daptonema sp1	+	+	-	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paramonhystera sp.	+	+	+		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Metadesmolaimus sp1	+	-	+	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cobbia sp	+	+	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nannolaimoides sp.	+	+	-	-	-	-	+	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Paramesonchium sp.	+	+	+	-	+	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Odentophora sp1	+	-	-	+	-	+	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-
Desmodora sp.	+	+	+	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dorylaimposis sp.	+	+	-	+	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sphaerolaimus sp.	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trissonchulus sp.	-	-	-	+	+	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Terschellingia sp1	+	+	+	-	+	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. longicaudata	-	-	-	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Daptonema sp2	-	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spilophorella sp.	-	+	-	+	-	+	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Haliplectus sp.	+	-	+	-	+	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nemanema sp.	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified 1	-	+	-	-	+	+	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pierrickia sp.	-	-	+	-	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Innocuonema	-	-	-	+	-	-	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Daptonema sp3	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Halalaimus sp1	+	-	+	-	-	-	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Halalaimus sp2	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Theristus sp2	-	-	+	+	-	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Desmodora sp1	-	+	+	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Metachromadora sp.	-	+	-	-	+	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Siphonolaimus sp.	+	-	+	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paralinhoemous sp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eumorpholaimus sp.	+	+	+	-	-	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microlaimus sp.	-	-	+	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromadora sp1	+	+	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromadora sp2	-	+	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromadorita sp.	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromadorella sp.	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sabatieria sp1	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sabatieria sp2	+	-	+	-	+	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxystomina sp.	-	-	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhabdocoma sp.	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Stieneria sp.	+	-	+	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Megadesmolaimus sp.	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Axonolaimus sp.	-	-	+	-	+	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Marylynnia sp.	+	-	-	-	+	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Metacyatholaimus sp.	-	+	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Latronema sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichromadora sp.	-	+	+	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oncholaimus sp2	+	-	-	+	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Metachromadora sp2	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paracomesoma sp.	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Comesomoides sp.	+	+	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Adoncholaimus sp1	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	+	-	-	-
Syringolaimus sp.	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Xyala sp1	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Triplyoides sp.	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	+	+	-	-	-	-	+
Adoncholaimus sp2	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	+	+	+	-
Viscosia sp2	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	+	+	-	-	+	-
Xyala sp2	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	+	-	-	-	-	-	-	+	-	-
Odentophora sp2	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	+	-	-	-	-	+
Unidentified 2	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	+	-	+	-	-	+	-
Unidentified 3	-	-	-	-	-	-	+	-	-	-	+	-	+	+	-	+	-	-	-	-	-	+	+	-	+
Pontonema sp.	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-
Comesomatid	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-
Viscosia sp3	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	+	+	-	-	-	-	+	-
Metadesmolaimus sp.	-	-	-	-	-	-	-	-	-	-	+	+	-	+	-	-	-	-	-	-	+	+	+	-	-
Promonhystera sp1	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	+	-
Polysigma sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	-	-	-
Gammanema sp.	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	+	-	+	-	-	+	-	-	+
Daptonema sp3	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-	-	+	-	-	+	-
Trileptium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-
Mesacnthion sp.	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	-	+	-	+	-	+	-
Phanodermopsis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	-	-	-	-	-	-	-	-	+
Paraconesoma sp.	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Theristus sp.	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+
Oncholaimus sp.	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Total	21	20	19	16	25	14	24	12	15	17	8	9	6	8	7	5	5	1	4	6	5	5	6	7	6

Table 4.1.2: Nematode species diversity indices at each of the sampling site.

	d	*J*	*H*	Simpson's
Terechol-MF	2.63	0.77	2.26	0.86
Old-Goa-MF	2.43	0.74	2.15	0.85
Galjibag-MF	2.22	0.80	2.27	0.86
Talpona-MF	1.78	0.62	1.64	0.73
Raibander-MF	2.99	0.56	1.77	0.69
Terechol-M	1.76	0.75	1.92	0.83
Chapora-M	2.94	0.60	1.88	0.76
Chorao-M	1.79	0.67	1.67	0.73
Talpona-M	1.93	0.72	1.95	0.81
Galjibag-M	2.01	0.69	1.87	0.79
Keri-B	1.35	0.47	0.91	0.44
Mandre-B	1.61	0.61	1.33	0.66
Morjem-B	1.42	0.57	1.18	0.62
Vagator-B	1.53	0.50	1.04	0.50
Candolim-B	1.16	0.60	1.08	0.57
Sinquerem-B	1.06	0.18	0.32	0.12
Miramar-B	0.73	0.44	0.71	0.44
Caranzalem-B	0.82	0.52	0.84	0.50
Dias-B	0.98	0.12	0.21	0.07
Colva-B	0.88	0.51	0.82	0.49
Benaulem-B	1.15	0.34	0.54	0.23
Varca-B	1.49	0.31	0.59	0.23
Canaginium-B	0	0	0	0
Palolem-B	0.69	0.21	0.30	0.12
Rajbaga-B	1.21	0.48	0.86	0.44

Table 4.1.3: Pair-wise tests for one-way ANOSIM with a global R=0.573 for all the locations.

	Pair-wise R	Significance Level %
Groups		
Mudflats, Mangroves	0.096	29.4
Mudflats, Beaches	0.735	0.1
Mangroves, Beaches	0.737	0.1

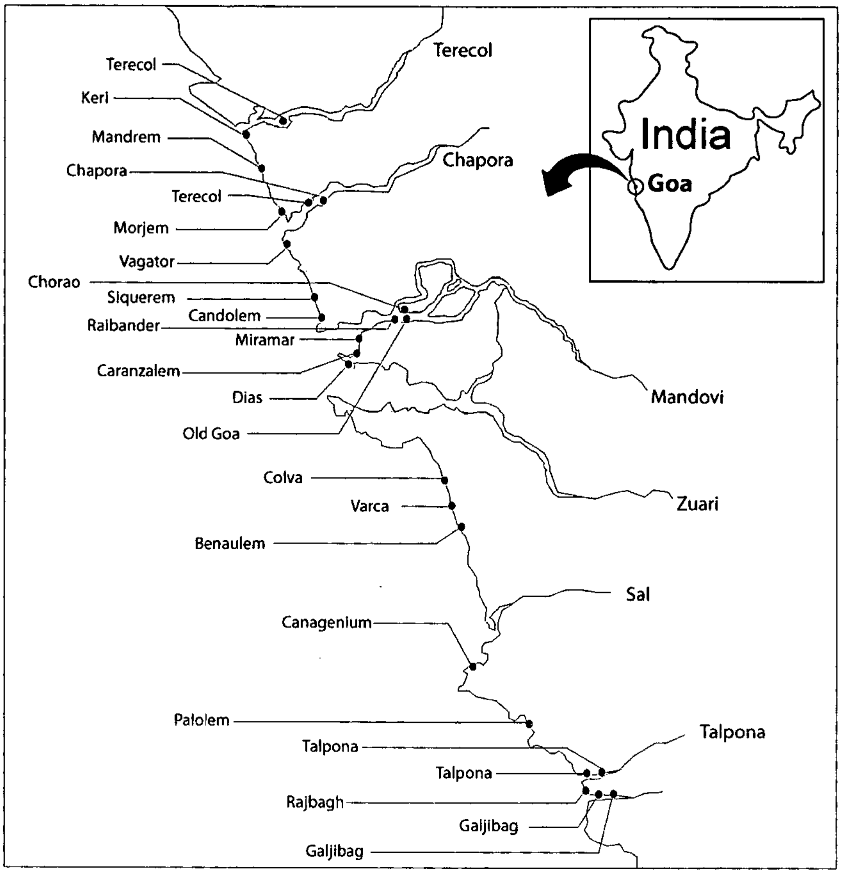

Fig 4.1.1: Sampling locations covering three different habitat types from the Goa coast.

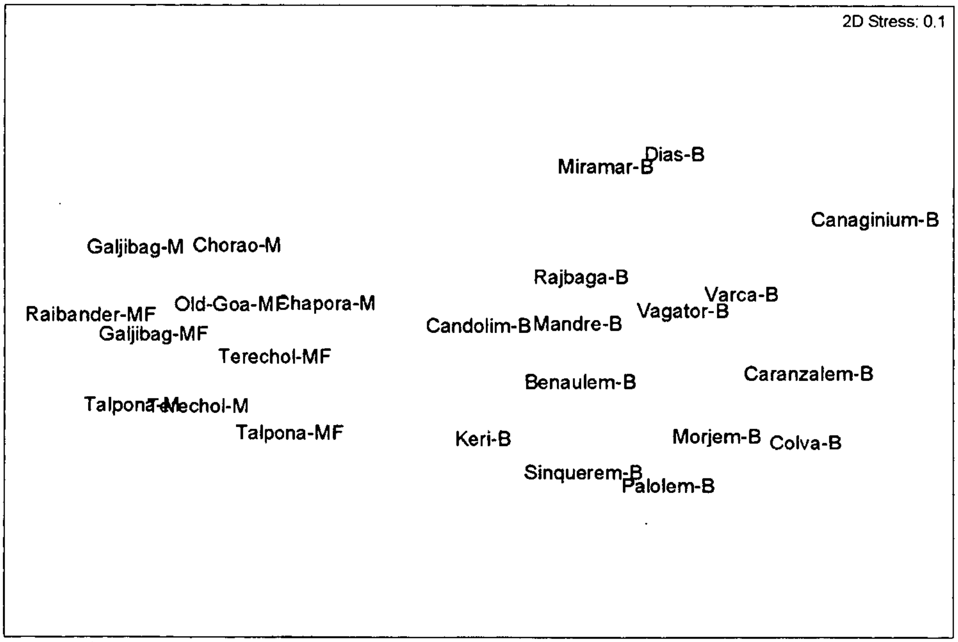

Fig 4.1.2: Multi Dimensional Scaling ordinate for each of the sampling site based on nematode species abundance.

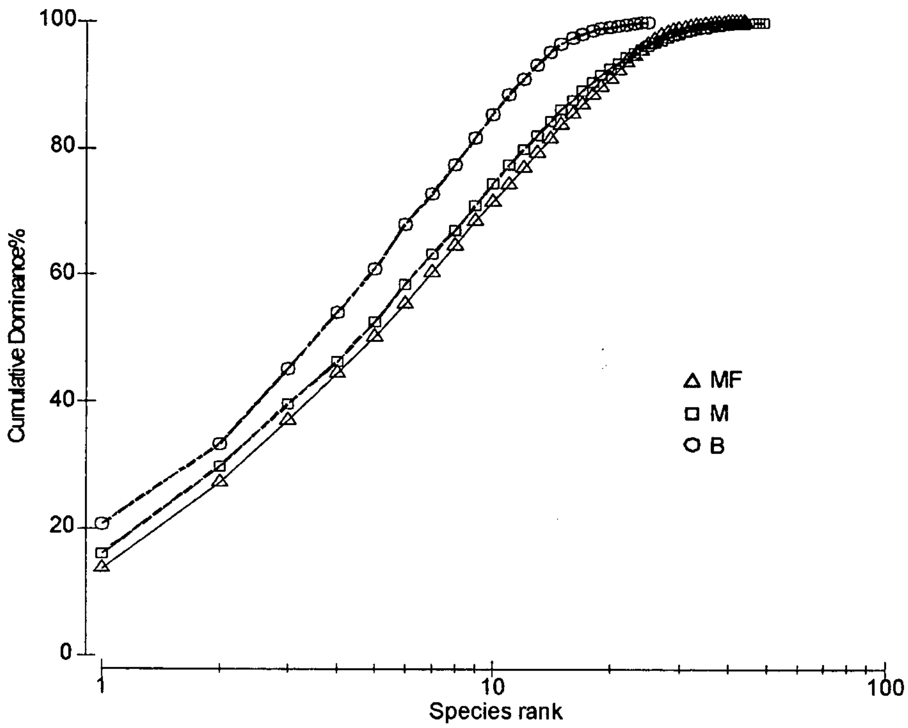

Fig 4.1.3: Percent dominance curve for nematode species from the three different habitats (MF-Mudflats, M-Mangroves and B-Beaches)

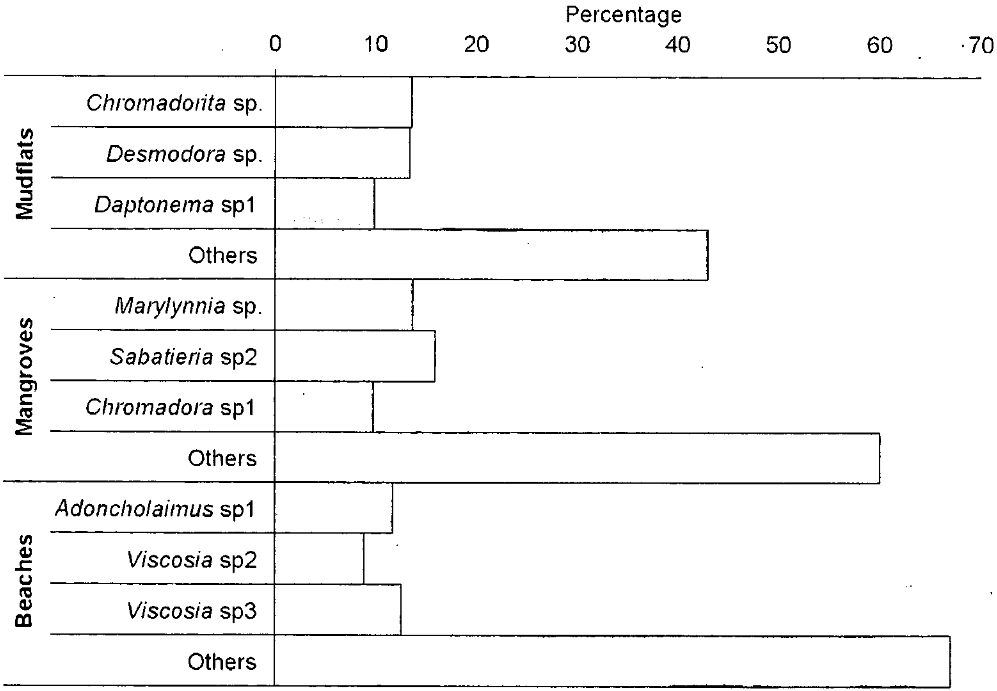

Fig 4.1.4: Percent distribution of the most dominant nematode species in the three different habitats from the study area.

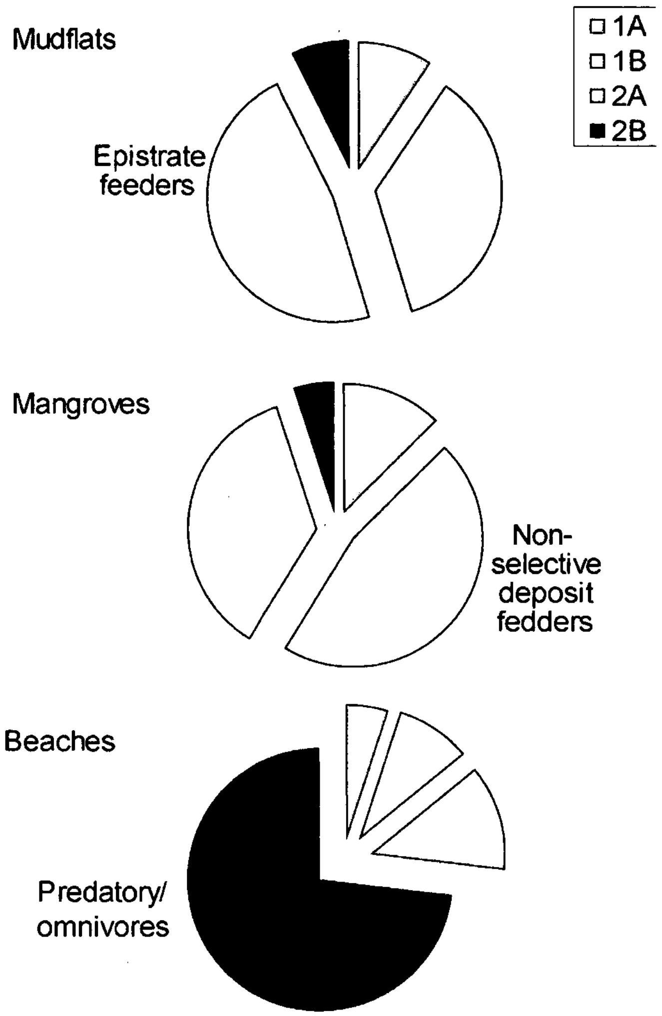

Fig 4.1.5: Feeding type distribution (Wieser 1953) for each of the habitats from the study area.

4.2: Seasonality in nematode community from Kalabadevi beach, Ratnagiri Central west coast of India.

Introduction:

Perusal of the available literature revealed that there is lack of knowledge on the general biodiversity of sandy beaches from Indian coast (Sivdas et al. 2005). In addition, there is a general lack of detailed information on nematode species/genera and the factors governing their distribution from Indian beaches. Nematode communities from tropical beaches have been investigated earlier (Alongi 1986; Hansen et al. 1987) but not from Indian subcontinent. However, the sampling was restricted in space and time. It has been suggested that seasonality and the monsoons are important factors structuring the nematode communities in the tropics (Alongi 1987; Long and Othman 2005). Considering the crucial role of seasonality, it is important to investigate how the community composition and resource utilization change over time. The west coast of India experiences a heavy impact of south west monsoon and it can have a great impact of on the beach community. In this study, I have investigated the nematode communities from a tropical beach by sampling the beach in space and time (at different tidal heights during different periods of the year). This will allow assessing the importance of seasonal versus local varying environmental circumstances in structuring nematode communities. Following hypotheses were investigated: 1) Seasonality influences the nematode community on the tropical sandy beach. 2) Nematode community is spatially influenced by the tropical monsoon.

Material and methods

Study area

The beach at Kalbadevi, Ratnagiri (Lat.17°02' 68" to 17° 04' 07"N; Long. 73° 16' 93" to 73°17' 32" E; Fig. 4.2.1) is ~5 km long and ~250 m wide, bordered by estuaries on either side of the beach and is anthropogenically undisturbed. However, it is one of the future commercial site due to its potential for placer mineral harvesting.

The beach is considered to be a reflective high-energy beach from the tropical region (Knox 2001). General oceanographic settings of this beach have been described in Sivadas et al. (2005).

Field sampling: In all, four sampling surveys were conducted during 2004, which included the post monsoon (February 2004), pre-monsoon (May 2004; but with unusually heavy rains), monsoon (August 2004) and followed by the post-monsoon (November 2004). An acrylic core of 4.5 cm ∅ was used to collect nematodes. Duplicate cores were taken down to a sediment depth of 20 cm, at each tidal zone (Fig 4.2.2). The cores were sectioned at 5 cm interval. The details of sample analysis and data processing are described in Chapter 2.

Results:

Nematode abundance and diversity

A marked seasonal variation was observed in the nematode community spatio-temporally. February showed high abundance and diversity, which reduced drastically during May because of heavy rains. During February, all the samples from different sediment depths at all the locations were represented by nematodes and the highest (145 ind.10cm^2) nematode abundance was observed in 0-5cm sediment depth of the low tide location (Fig 4.2.3). A drastic decline in the faunal abundance was seen due to unexpected heavy rain during May and the regular monsoon season during August. Very low densities were observed during May and maximum abundance (228 ind.10cm^2) observed was at low tide (0-5cm section) but most of the sampling depths were devoid of nematodes. During August too very low abundance was observed at most of the beach locations, as it was a regular monsoon season in this part of the tropics. During August, the maximum nematode abundance (71 ind.10cm^2) was in the 0-5cm sediment section of the berm region (Fig 4.2.3). November was the season with a peak in nematode abundance at all the beach locations and highest abundance was observed at 0-5 cm depth of the high tide region (822 ind.10cm^2) followed by low tide region (716 ind.10cm^2; Fig 4.2.3).

A total of 38 nematode species and an average of 16 species per location were encountered during the study period. The berm location during August showed the lowest number of nematode species (4); the highest species number (26) was observed at the mid-tide location during February. During May and August the highest species number were 13 (at low tide) and 12 (at mid tide) respectively and average number per beach location were 7 species. The dune region was devoid of any nematodes in both these seasons. In November, a maximum number of 25 species occurred at both low and high tide location with an average of 19 species at each beach location (Table 4.2.1).

The two-way ANOSIM treatment without replicates for nematode abundance revealed a significant difference between each season (R= 0.335; p=0.002). Diversity indices (Shannon-Weaver's and Simpson's Index) revealed a significant difference between the seasons as well as beach locations (Table 4.2.2).

The MDS (Fig 4.2.4) for each season also showed the variation, separating the less diverse dune and the berm in February and November. This segregation was completely swept away during August, which is a peak monsoon season and unexpected heavy rains showed its impact during May, which should have shown the highest diversity and zonation at the beach locations.

The MDS plot (Fig 4.2.5) for each beach location showed a marked zonation for different seasons. Considering each beach location for all seasons, the most affected regions during the monsoon (August) were dune and berm, with dune being more affected compared to berm. The mid tide region also showed a submissive influence of monsoon (August) as well as unseasonal heavy rain (May). At the low and the mid tide region the influence of rains during May was more pronounced than August (Fig 4.2.5).

Species dominance

The SIMPER analysis showed the average dissimilarity between the seasons ranging from 88.72 to 97.06 %. The species cumulative contribution of upto 50% was considered where the contribution by *M. scanicus* was found during all seasonal differences. The other species contributed for the differences between the seasons were *Theristus otoplanobius, Theristus* sp. 2, *Oncholaimus skawensis, Enoplolaimus propinquus,* Unidentified sp1. Absence of *Theristus otoplanobius* during August made the difference (17%) between two rain influenced months that is May and August (Table 4.2.3).

Feeding types

Epistrate feeder (50%) had the highest mean dominance at all the beach locations and seasons whereas deposit feeders together (1A+1B) contributed only 23%. Only during November, the predatory/omnivores dominated (54%) while all the other seasons were dominated by epistrate feeders and were highest during August (61%). The monsoon affected August had its highest negative impact on non-selective deposit feeders (4%) followed by selective deposit feeders (7%; Table 4.2.4).

Discussion:

Patchy distribution of marine nematodes and the factors governing them have been described by many workers (Findlay 1981; Heip et al. 1985; Sommerfield et al. 2007). The sandy beach nematode diversity is governed by a few factors mostly of physical nature (Sommerfield et al. 2007) as the tidal forces governing these coastal intertidal areas are more pronounced compared to the physico-chemical parameters (Gheskiere et al. 2005; Moreno et al. 2008).

The sandy beach nematode diversity is not just governed by its biogeography but also depend on regional settings, physico-chemical parameters and the most important suspected reason is the physical nature of the beach (McLachlan and Brown 2006). The present study area consisted of 38 species, which are comparatively less considering other temperate beaches such as De Panne (88 species), San Rossore (66 species), Hel beach (56 species), Punta Estrella (67 species) and Santa Clara (55 species) from Europe (Gheskiere et al. 2005; Mundo-Ocampo et al. 2007). Alongi (1986) recorded only 25 species from nine different beaches where as Nicholas and Hodda (1999) reported 48 genera from southeastern Australia. A total of 37 genera were documented from a Mexican tropical Bay (Jesus-Navarrete and Herrera-Gomez 2002) which were much similar to the numbers in the present study but the arctic region again represents very low (8 genera) nematode diversity (Urban-Malinga et al. 2005). The European beaches depict considerably high nematode diversity attributed to the dissipative nature of the beaches where as reflective beaches are rare on the open coasts in the temperate region but are common in the tropics (McLachlan and Brown 2006) including the present study area. A typical temperate (dissipative) beach will hold richer fauna than the tropics (McLachlan and Brown 2006), which might be the major reason for lowered species number on the present beach.

Seasonal variation in nematode community:

Pronounce seasonality has been observed on the temperate Australian beaches (Nicholas 2001) and the impact of monsoon has shown reduced abundance and diversity of the nematode community. The Kalbadevi beach nematodes do show a marked difference in the diversity and abundance because of seasonal changes, variation in the tidal regimes and impact of freshwater flux during monsoon. The nematode abundance reaches its peak in February and the diversity reaches its peak during November (Table 1) depicting high dominance of fewer species in premonsoon (Nicholas and Hodda 1999). The dominant species those made the difference in these two peak seasons were *M. scanicus, O. skawensis* and *E. propinquus* (Table 4.2.3). May is the peak summer but during 2004, heavy storm and rains devastated the intertidal region disrupting the usual beach profile and draining huge quantities of dune sand, which changed the nematode assemblages particularly in the high tide region (Fig 4.2.4). May and August seasons showed very low nematode densities and species richness but difference in diversity implying that the nematode community reacted differently to the sudden rush of fresh water due to stormy rains during May and a continuous steady monsoonal rain during August.

During February and November, spatially the dune and the berm fauna were well separated from the high-, mid- and the low tide location (Fig 4.2.4) and during November the low tide was the most stable region with peak abundance and diversity (Fig 4.2.4 and Table 4.2.1). Generally this region shows a peak in meiofaunal abundance in premonsoon season (Ingole and Parulekar 1998) but during May the abrupt heavy rains swept away the nematodes, reducing the diversity drastically and leaving dune without any nematofauna. This type of faunal reshuffling due to stormy events has been reported in other studies (Nicholas 2001). August was the regular monsoon season and its impact can be seen in the zonation difference on the beach where mid and high tide locations had much similar community to the dune and the berm (Fig 4.2.4). The monsoon affected dune and the berm nematode communities (Fig 4.2.5) might have shifted down to the high tide and the lower tidal region and the littoral sediments still further in the subtidal region due to the freshwater flux and draining of the sediments from the dune and the berm slope. Reportedly due to attrition during monsoon, high losses in the beach communities occur in the tropical region. (Alongi 1987; Long and Othman 2005).

Low nematode species richness in the dune and the berm region is usually expected due to conditions controlled by physical factors such as extremes of temperatures and desiccation (Gheskiere et al. 2005). Contrasting conditions like heavy freshwater flux during monsoon again results in lowered species number as well as abundance (Alongi 1987; Long and Othman 2005) suggesting overall stressed condition for the nematode community during all the seasons.

While both May and August showed low abundance and the nematode assemblages were not similar due to the distinction in the abundance of *Theristus otoplanobis, T. sp2* and *M. scanicus* (Table 4.2.3). *M. scanicus* dominates such habitats (Procel 2001) and at the present study site its dominance was the most important contribution for all the seasonal differences in the community. *M. scanicus* is a non-selective deposit feeder according to Wieser's (1953) classification but the nematode community was overall dominated collectively by epistrate feeders. This shows that in spite of ample resource availability for epistrate feeders to flourish, life history constraints favoured *M. scanicus* to dominate the community. It was only in November that the predatory/omnivores increased in number probably due to changing resource availability and patchiness (Findlay 1981; Heip 1985) although the exact food sources could not be known. The dynamism and complexities on the beach gives rise to high species richness and co-existence (Armoneis and Reise 2000) signifying the importance of freshwater influx into the beach sediments as governing factor for structuring the nematode community seasonally.

Table 4.2.1: Occurrence of nematode species at each zone and season at Kalbadevi beach.

	Sampling seasons																			
	February					May					August					November				
Tidal zones	LT	MT	HT	B	D	LT	MT	HT	B	D	LT	MT	HT	B	D	LT	MT	HT	B	D
Oncholaimus skawensis	+	+	+			+		+								+	+	+		+
Theristus sp.1	+	+				+		+								+	+	+		
Metadesmolaimus scanicus	+	+	+		+	+		+			+					+	+	+		+
Metalinhomoeus sp.		+				+	+	+	+									+		
Pselionema sp.		+				+										+		+		
Trefusia sp.1	+	+	+	+		+		+								+	+	+		
Rhabdodemania sp.	+	+				+										+	+	+		
Sigmophoranema sp.	+	+	+	+		+										+	+	+		+
Microlaimus sp.		+	+	+		+										+		+		+
Theristus otoplanobius	+	+	+	+			+	+								+		+		
Polysigma sp.	+	+		+	+		+	+								+		+		
Desmoscolex sp.		+					+													
Mesacanthion sp.		+	+	+			+		+							+		+		
Anomonema sp.							+	+			+							+	+	+
Unidentified sp.1								+				+								
Gammanema sp.		+						+									+			
Theristus sp.2	+		+	+	+		+	+				+	+	+				+	+	+
Synonchium sp.			+	+				+								+				
Innocuonema sp.	+	+							+								+			
Unidentified sp.2	+	+	+	+	+		+	+	+		+	+	+	+		+	+	+	+	
Trefusia sp.3	+	+	+						+		+	+	+			+	+	+	+	
Rhabdocoma sp.	+	+		+	+				+							+	+	+		
Camacolaimus sp.	+	+							+							+	+	+		
Choanolaimus sp.	+	+		+							+	+				+	+	+		
Spiliphera sp.											+	+	+	+			+			
Promonhystera sp.		+		+							+	+					+			
Synodontium sp.			+								+	+				+				
Enoplolaimus propinquus		+	+								+	+				+	+	+	+	+
Daptonema sp.	+	+									+	+	+	+		+	+			+
Oncholaimus sp.2		+	+									+	+			+	+	+	+	+
Chromadora sp.													+			+			+	
Rhynchonema sp.											+									
Enoplolaimus litoralis		+										+	+			+	+	+	+	
Cobbia sp.	+	+	+														+		+	+
Gerlachius sp.			+													+	+	+	+	
Latronema sp.			+													+	+			
Paracyatholaimus sp.				+													+	+		
Enoplid	+			+	+												+			
Total genera/ spp.	18	26	17	14	7	9	8	13	7	-	9	12	8	4	-	25	24	25	10	10

Table 4.2.2: Results of ANOVA for effects of zones and months on the diversity indices of nematodes at Ratnagiri.

	df	*MS*	*F*	*P-value*
S				
Seasons	3	286.3	16.50144	6.22E-08
Zones	4	82	4.726225	0.002211
Seasons*zones	12	11.09167	0.639289	0.800257
Within subgroup error	60	0.251548		
N				
Seasons	3	57084.95	3.870725	0.013453
Zones	4	16891.36	1.145342	0.344043
Seasons*zones	12	8587.248	0.58227	0.847865
Within subgroup error	60	14747.87		
d				
Seasons	3	10.47178	17.37523	3.1E-08
Zones	4	4.32187	6.449829	0.000219
Seasons*zones	12	0.518736	1.417736	0.183245
Within subgroup error	60	0.721411		
J'				
Seasons	3	0.427797	7.240945	0.00033
Zones	4	0.321625	5.443857	0.000862
Seasons*zones	12	0.141044	2.387326	0.013972
Within subgroup error	60	0.05908		
H'				
Seasons	3	4.370701	17.37523	3.1E-08
Zones	4	1.622441	6.449829	0.000219
Seasons*zones	12	0.356629	1.417736	0.183245
Within subgroup error	60	0.251548		
Simpson Index				
Seasons	3	0.616469	11.22547	6.05E-06
Zones	4	0.300969	5.480447	0.000791
Seasons*zones	12	0.093196	1.697042	0.090158
Within subgroup error	60	0.054917		

Table 4.2.3: SIMPER analysis based on relative abundance of each species

Species	Group f Av. Abund	Group m Av. Abund	Av.Diss	Diss/ SD	Contrib %	Cum. %
Groups Feb & May Average dissimilarity = 91.48						
Metadesmolaimus scanicus	18.74	0.23	20.73	1.16	22.66	22.66
Theristus otoplanobius	2	5.77	11.06	0.72	12.09	34.75
Unidentified	3.74	1.69	6.52	0.72	7.13	41.87
Groups Feb & Aug Average dissimilarity = 91.41						
Metadesmolaimus scanicus	18.74	15.91	24.73	1.25	27.05	27.05
Theristus sp. 2	1.47	2.36	5.83	0.72	6.38	33.43
Unidentified	3.74	0.55	5.81	0.62	6.36	39.79
Groups May & Aug Average dissimilarity = 97.06						
Theristus otoplanobius	5.77	0	17.04	0.72	17.55	17.55
Theristus sp. 2	0.23	2.36	10.2	0.78	10.51	28.06
Metadesmolaimus scanicus	0.23	15.91	10.19	0.48	10.50	38.56
Groups Feb & Nov Average dissimilarity = 88.72						
Metadesmolaimus scanicus	18.74	29.25	19.87	1.12	22.4	22.4
Oncholaimus skawensis	1.89	49.2	14.97	0.71	16.87	39.26
Enoplolaimus propinquus	0.26	7.5	5.37	0.43	6.05	45.31
Groups May & Nov Average dissimilarity = 93.81						
Oncholaimus skawensis	1.23	49.2	19.55	0.79	20.83	20.83
Theristus otoplanobius	5.77	0.65	11.89	0.65	12.67	33.5
Metadesmolaimus scanicus	0.23	29.25	10.04	0.58	10.7	44.2
Groups Aug & Nov Average dissimilarity = 91.65						
Oncholaimus skawensis	0	49.2	17.47	0.71	19.06	19.06
Metadesmolaimus scanicus	15.91	29.25	15.96	0.72	17.42	36.48
Enoplolaimus propinquus	4.27	7.5	9.45	0.6	10.31	46.79

Table 4.2.4: Percent feeding distribution of the nematodes (Wieser, 1953) for each season.

Feeding types	**February**	**May**	**August**	**November**	**Mean**
Selective deposit feeders (1A)	13	11	7	12	11
Non-selective deposit feeders (1B)	12	27	4	5	12
Epistrate feeders (2A)	58	50	61	29	50
Predatory/omnivores (2B)	17	12	27	54	27

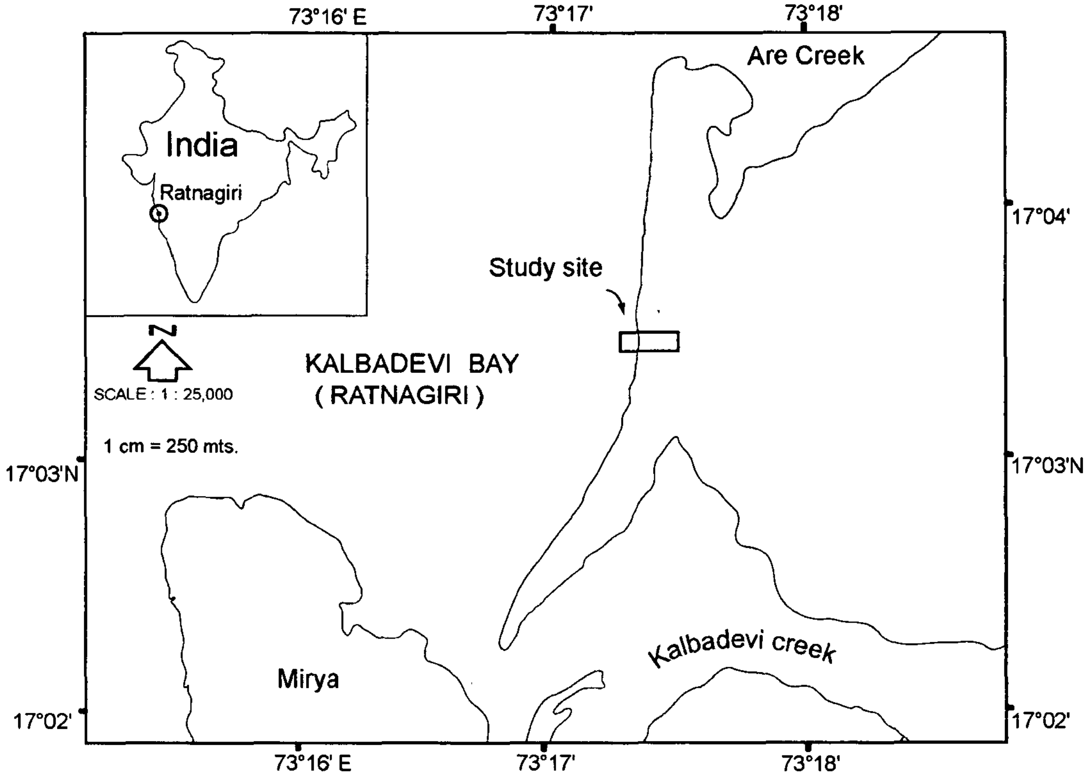

Fig 4.2.1: Map of study area with the location of sampling site.

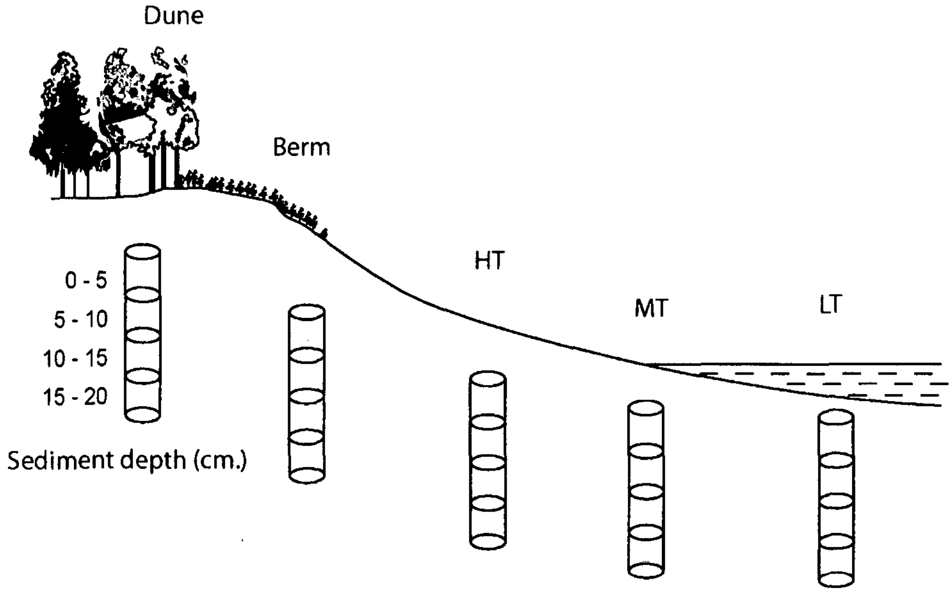

Fig 4.2.2: Cross section of the beach showing the sampling transect and the vertical sectioning intervel of the sediments.

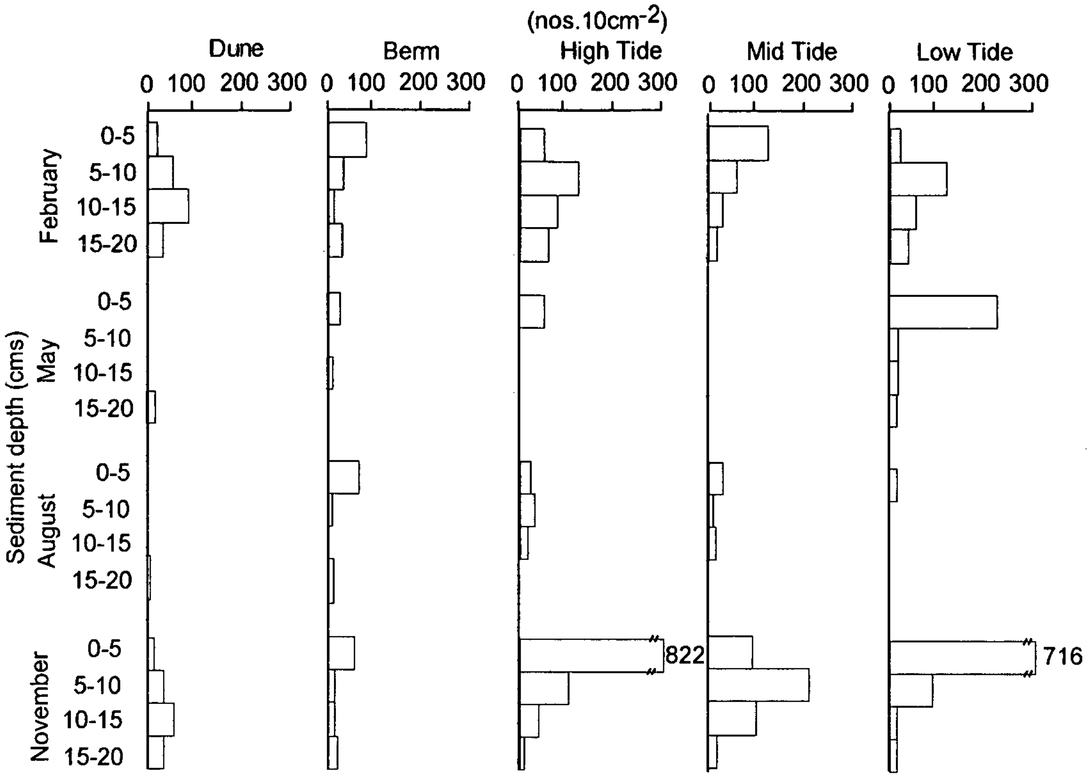

Fig 4.2.3: Multidimensional scaling ordinate for nematode abundance for each season.

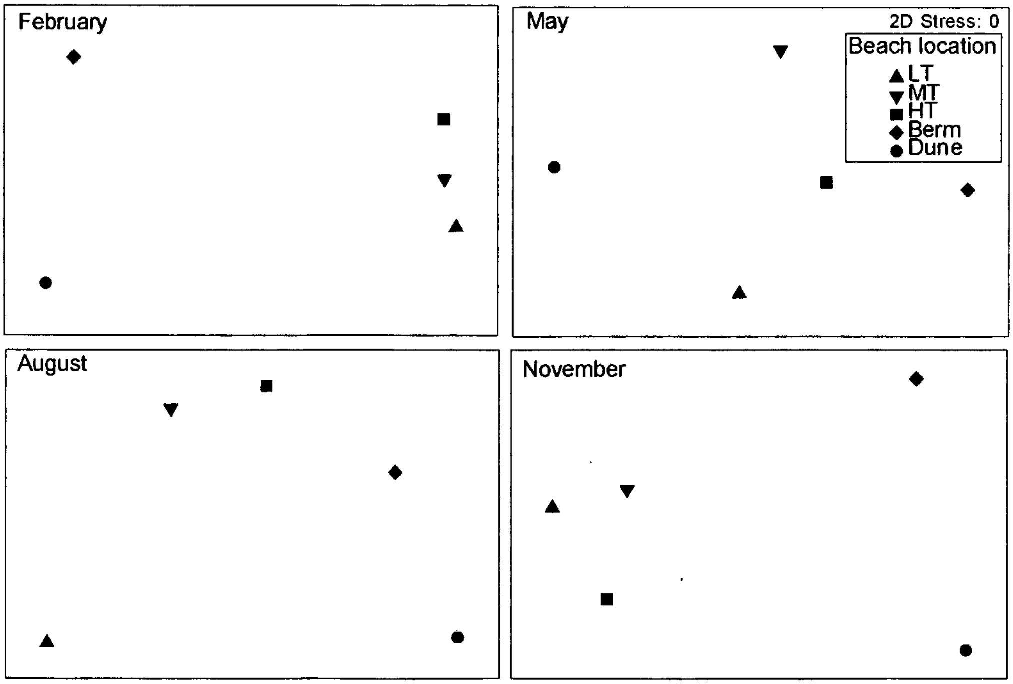

Fig 4.2.4: Multidimensional scaling ordinate for nematode abundance for each beach location within each season.

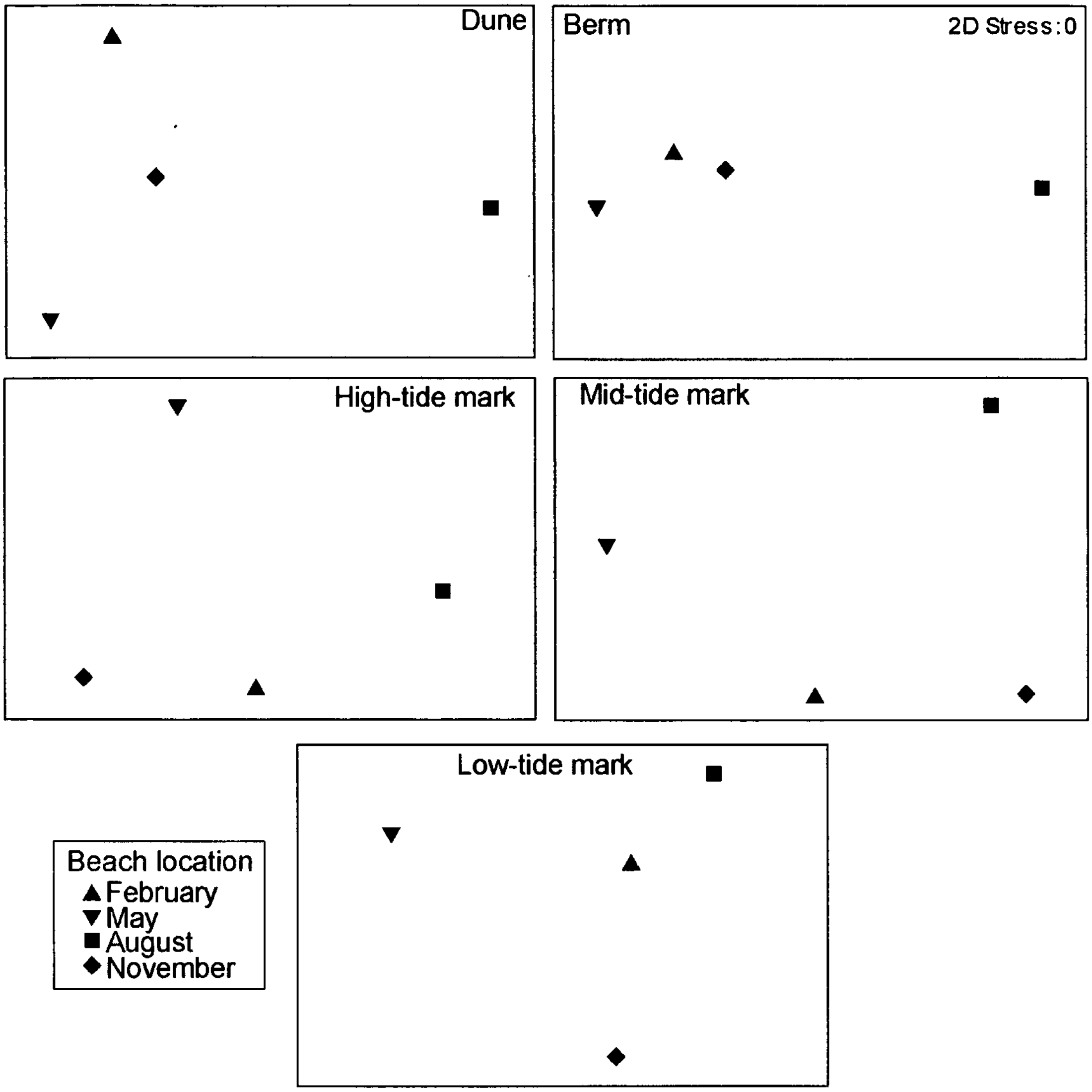

Fig 4.2.5: Multidimensional scaling ordinate for nematode abundance in showing zonation pattern during each season.

Chapter 5:

Nematodes and perturbed habitats

5 Nematodes and perturbed habitat

5.1. Influence of domestic sewage on the nematode community

Introduction

Panjim is a valuable aesthetic city with ecological and recreational asset, and due to its geographical position in a rapidly expanding urban area is subjected to influences and effects of various developments. This has led to increase in population with subsequent enhanced domestic sewage discharge and development of strategies to mitigate the environmental effects caused by these changes. As it is a known fact that nematodes are good indicators of pollution (see section 1.5) they were used as tool to investigate the impact of sewage discharge. The relationship between nematode density, diversity, community structure and environmental parameters at the domestic sewage disposal site, was established in an organically polluted estuarine sandy beach of Panjim city.

Methodology

Mandovi estuary, which opens into the Arabian Sea near Panjim city on the west coast of India with an average annual river discharge of 6004 Mm^3 (Suprit and Shankar 2008), use to receives about 1.3 Mm^3 litres of urban runoff annually (Ansari et al. 1984). During the present study, a section of estuarine beach receiving domestic sewage through *nullah* (Fig 5.1.1), was sampled during pre monsoon 2007. Nematode samples were collected from 5 stations along a decreasing gradient of sewage pollution, station 1 being at the discharge point and station 5 furthest away toward the seaward side (Fig 5.1.1).

Surface sediment was sampled with an acrylic core (4.5cm diameter) down to 5 cm depth in triplicates. Separate cores were taken for sediment organic carbon and grain size analysis. Overlying water was sampled for dissolved oxygen, pore water temperature and salinity was measure in-situ using Atago® make refractometer.

Results

Physicochemical parameters

The station PM1 had the lowest temperature (33.2°C) and salinity (25.32) whereas the highest temperature (35.8°C) and salinity (35.7) was recorded at PM5 (Table 5.1.1; Fig 5.1.2). The dissolved oxygen showed the gradient with lowest (0.25 ml/l) at station PM1 and highest (2.80 ml/l) at PM5 (Table 5.1. 1; Fig 5.1.2).

Nematode community

The occurrence of nematode species with their respective feeding types at all the sampling stations is shown in table 5.1.2. Highest (1769 nos.10cm^2) abundance was recorded at PM1 and lowest (43 nos.10cm^2) at PM5 (Table 5.1.3). The diversity indices revealed highest of 11 species at PM1 while lowest of only 3 species at PM5. Shannon-Weaver's information function showed highest (1.45) values at PM5 and the lowest (0.88) at PM1&2. But the Richness was highest (1.80) at PM4 and lowest (0.53) at PM5. The species Evenness was highest (0.70) at PM4 and lowest (0.37) at PM1. The Simpson's Index and the Maturity Index (MI) also showed a gradient (Table 5.1.3).

The SIMPER analysis showed an average dissimilarity of more than 90% for most of the comparisons (PM1&PM3, PM1&PM4, PM2&PM4 and PM3&PM4). The species that contributed highest for all the difference between all the stations was *Daptonema* sp1. The highest dissimilarity contributed by *Daptonema* sp1 was between PM2&PM3 (Table 5.1.4). The other species that contributed after *Daptonema* sp1 at all the station were *Daptonema* sp2, *Dorylaimopsis* sp., *Oxyonchus* sp. and *Trefusia* sp. (Table 5.1.4).

The cluster analysis based on the abundance of nematode species revealed a clear gradient of similarity, which was closest between station, PM1 and PM2 and progressively increased up to PM5 (Figure 5.1.3).

The cumulative dominance curve for nematode species revealed a difference in all the stations except PM1 and PM2 showing similar trends. PM5 showed a much smaller curve ending abruptly because of very low species number (Fig 5.1.4).

Nematode feeding types

The non-selective deposit feeders (1B) completely dominated the station PM1 with 94% of abundance and PM2 showed a similar trend with 89% dominance by 1B. The remarkable aspect was the absence of predatory/omnivores (2B) at PM1. PM3 was also dominated (84%) by 1B, while the dominance (41%) of selective deposit feeders (1A) increased at PM4 and 1B became sub-dominant (34%). A complete change in feeding dominance was observed at PM5 with the dominance (93%) of predatory/omnivores (Fig 5.1.5).

The gradient comparison for the physico-chemical parameters of the present study with the previous study (Ansari et al, 1984) showed very similar trends depicting no much change except for temperature. The values for salinity, dissolved oxygen and sediment organic carbon showed very similar trends (Fig 5.1.6) but for temperature exactly opposite trend was seen (Fig 5.1.6).

However the values for nematode abundance showed a contrasting gradient compared to the previous 1984 abundance, which increased away from the sewage discharge point whereas in 2007, the highest abundance was at the discharge point with a decreasing trend away from it (Fig 5.1.7).

Discussion:

The organic or the domestic sewage pollution has shown considerable impact on the benthic fauna. It has been revealed earlier that nematode community demonstrates a marked response to different pollutants (Heip et al. 1985; Essink and Romeyn 1994; Sommerfield et al. 2003). There is always a state of enrichment at the sewage outlet point due to the input of nutrients from the domestic sewage, which resulted in high number of species as well as very high abundance at the nearest sampling point of sewage discharge. But meiofaunal studies at the present study site (Ansari et al. 1984) demonstrated a clear gradient from very low meiofaunal diversity to increase towards the stations away from the sewage outlet. This reversing of trend in the gradient may indicate the reduction in the discharge of toxicants or the acclimation/succession of the nematode community to continuous organic waste.

The major effect of sewage is that it reduces the oxygen content and stimulates the formation of hydrogen sulphide. Such conditions can be disastrous to biota (Bozzini 1975). This is clear at the station nearest to the discharge point, where the oxygen level was low (Table 5.1.1) and the occurrence of a black sulphide layer below 5 to 6 cm sediment was observed (Ansari et al. 1984). This layer was not found in the top 5cm layer at station 3 onwards which are away from the sewage outlet having better flushing due to the riverine flow and the tidal action. But the decreasing gradient of diversity and abundance away from the discharge point reveals the increase of enrichment opportunistic species near the discharge point, which are also resistant to pollution as well as poorer oxygen conditions. *Daptonema* sp1, *Daptonema* sp2, *Terschellingia* sp., *T. longicaudata* and *Axonolaimus* sp. are known to be enrichment opportunistic species, as these can thrive in degraded and stressful conditions (Bonger 1990; Palacin et al. 1992; Essink and Romeyn 1994; Gyedu-Ababio et al. 1999; Sommerfield et al. 2003; Liu et al. 2008). A combination of Maturity Index (MI) and Shannon-Wiener diversity

Index (*H'*) are known to be good tools in pollution monitoring, especially, organic pollution involving nematodes (Gyedu-Ababio et al. 1999) and in the present study MI showed low values at all the stations and *H'* showed a decrease with decreasing pollution except at the farthest station from the discharge point. The species Evenness (J') at the sewage discharge point was low and gradually increase with increasing distance. This trend in evenness suggests high dominance of fewer species at the discharge point where the enrichment opportunists thrive well. The stations which were away and least affected by sewage showed high evenness suggesting low dominances and stable conditions.

The sewage discharge was responsible for the alterations in physic-chemical parameters forming an increasing gradient in temperature, salinity, sediment grain size and organic carbon from the discharge point and only reverse was true for dissolved oxygen (Fig 5.1.1). Generally, organic enrichment has been seen to influence the abundance of nematodes (Orren et al. 1979; Eleftheriou et al. 1982; Gee and Warwick 1985; Smol et al. 1994) but their numbers appear to increase up to a certain level of organic carbon concentration in the sediment i.e > 3% (Gyedu-Ababio et al. 1999). However, in the present study, the nematode community flourished at maximum under 4.5% organic carbon. Apart from the sediment composition and organic carbon, salinity also influences nematode species composition (Heip et al. 1985; Coull 1988; Vanreusel 1990; Soetart et al. 1995).

Overall gradient of all the parameters structure the gradient of nematode community, which seems to have gained advantage due to the sewage discharge but comprises of species, which are specialized to adapt in perturbed habitat. As the species diversity and abundance decreases away from the sewage discharge, the species are more of a typical sandy beach. *Daptonema* sp1 was the most dominant species, which is non-selective deposit feeder and also assumed to consume heavy bacterial biomass (Heininger et al. 2007). High pathogenic bacteria have been reported from the same study area (Ramaiah et al. 2007). Thus, consumption of bacteria by nematodes can help in bio-remediation of the site at the domestic sewage outlet and the dominance of *Daptonema* sp1 can be considered a positive aspect from the perspective of environmental health.

Nematode community is known to respond positively to decreasing level of organic pollution (Ansari et al. 1984; Essink and Romeyn 1994). Increase in nematode densities in the present study compared to earlier data (Fig 5.1.7), while no much change in other parameters (Fig 5.1.6) indicates succession in the nematode community. The high dominance of enrichment opportunistic and bacterivorous nematodes can help in mitigating pathogenic bacteria harmful for human health. Further knowledge is necessary about the exact feeding selectivity of such nematode species that can help in effluent treatment and bio-remediation processes. The present findings will be helpful in monitoring the status of benthic environment and the response to changing environmental regulations. It will be interesting to observe the future changes in the nematode community after the implementation of technically improved better sewage treatment plants that is being proposed by the authorities as an improved environmental management strategy.

Table 5.1.1: Physico-chemical parameters at sampling stations.

	PM1	PM2	PM3	PM4	PM5
Temperature (°C)	33.2	34.8	35.1	34.6	35.8
Salinity (‰)	25.32	32.56	34.4	35.64	35.71
Dissolved Oxygen (ml/l)	0.25	0.51	1.85	2.33	2.8
Organic Carbon (%)	4.51	3.69	2.11	0.3	0.51
Sediment grain size (%)					
Sand	81.05	92.82	96.34	96.62	96.79
Silt	19.49	2.63	2.65	2.72	2.58
Clay	0.46	0.37	0.32	0.29	0.63

Table 5.1.2: Occurrence of nematode species at the sampling stations and their feeding types (Wieser 1953)

	Feeding types	PM1	PM2	PM3	PM4	PM5
Actinonema sp	2A	-	+	+	+	-
Axonolaimus sp	1B	+	+	-	-	-
Bolbolaimus sp	2A	-	+	+	-	-
Comesoma sp	2A	+	+	+	+	-
Daptonema sp1	1B	+	+	-	+	-
Daptonema sp2	1B	+	+	+	-	-
Desmodora sp	1B	+	-	+	+	-
Dorylaimopsis sp	2B	-	+	-	+	-
Gammanema sp	2B	-	-	+	-	-
Oncholaimus sp	2B	-	-	-	-	+
Oxyonchus sp	2B	-	-	-	-	+
Paracyatholaimus sp	1B	+	-	+	-	-
Polysigma sp	2A	-	+	-	-	-
Praeacanthonchus sp	1B	+	-	-	-	-
T. longicaudata	1A	+	+	-	-	-
Terschellingia sp1	1A	+	+	-	-	-
Theristus sp1	1B	+	-	+	+	+
Trefusia sp	1A	-	-	-	+	-
Tripyloides sp	1A	-	-	-	+	-
Unidentified	1B	+	-	+	-	-
Viscosia sp	2B	-	-	+	-	-
Total Abundance (nos.10cm^{-2})		1769	874	150	59	43

Table 5.1.3: Diversity indices based of nematode species number.

	PM1	PM2	PM3	PM4	PM5
Species number (S)	11	10	10	8	3
Total abundance (N)	1769	874	150	59	43
Species Richness (*d'*)	1.34	1.33	1.80	1.72	0.53
Species Evenness (*J'*)	0.37	0.38	0.50	0.70	0.65
Shannon-Weaver's Index (*H'*)	0.88	0.88	1.14	1.45	0.72
Simpson's Index (1-Lambda)	0.38	0.39	0.48	0.73	0.42
Maturity Index (MI)	2.03	2.03	2.18	2.81	2.37

Table 5.1.4: SIMPER analysis for the difference between the stations based on species dominance.

Between stations	Average dissimilarity	First species	% Dissimilarity	Second species	% Dissimilarity
PM1& PM 2	69.13	*Daptonema* sp1	72.75	*Daptonema* sp2	9.47
PM 1& PM 3	92.04	*Daptonema* sp1	39.18	*Daptonema* sp2	31.93
PM 2& PM 3	79.30	*Daptonema* sp1	83.37	*Dorylaimopsis* sp	5.67
PM 1& PM 4	97.87	*Daptonema* sp1	47.19	*Oxyonchus* sp	16.03
PM 2& PM 4	95.50	*Daptonema* sp1	73.96	*Daptonema* sp2	10.44
PM 3& PM 4	92.34	*Daptonema* sp1	55.44	*Trefusia* sp	11.40

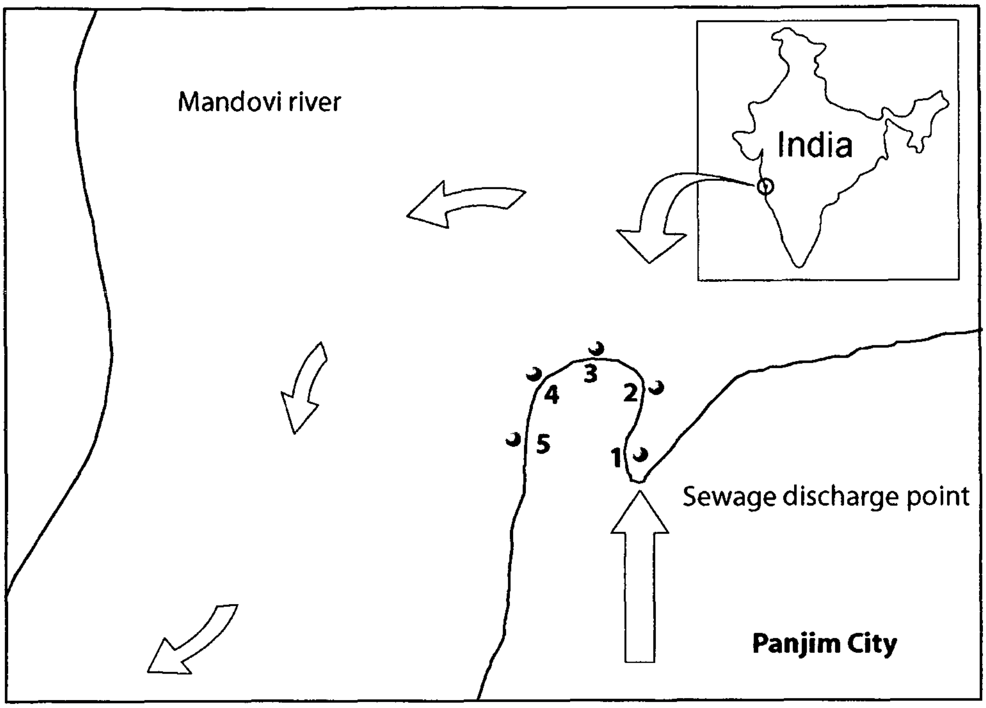

Fig 5.1.1: Map of the study area with sampling location.

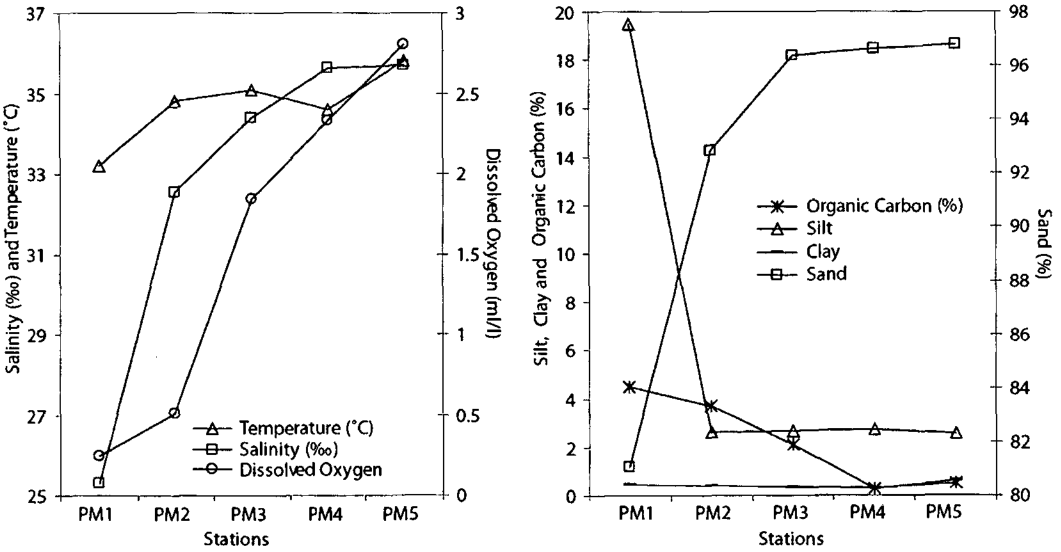

Fig 5.1.2: Physico-chemical and sedimentary parameters at the sampling stations.

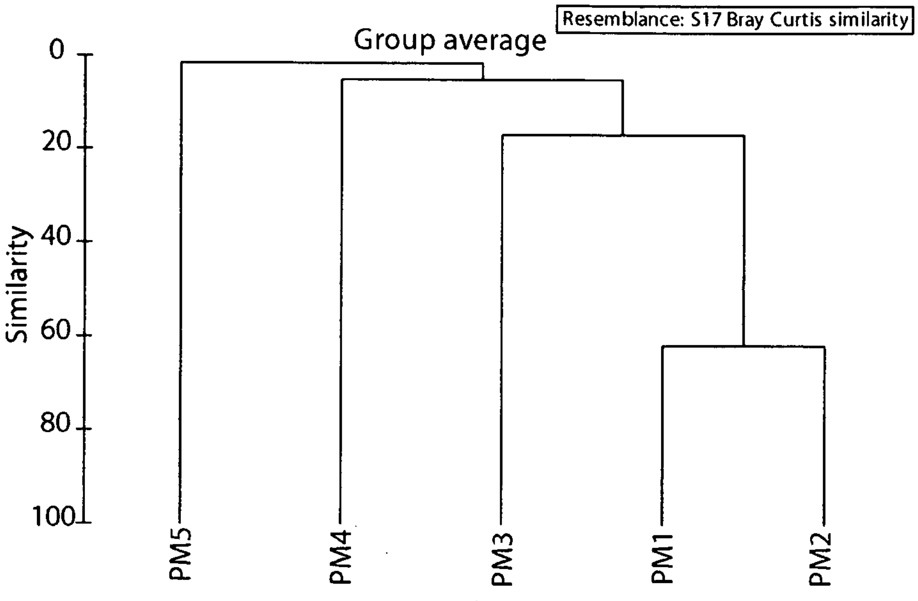

Fig 5.1.3: Cluster analysis of the sampling locations based on nematode species abundance.

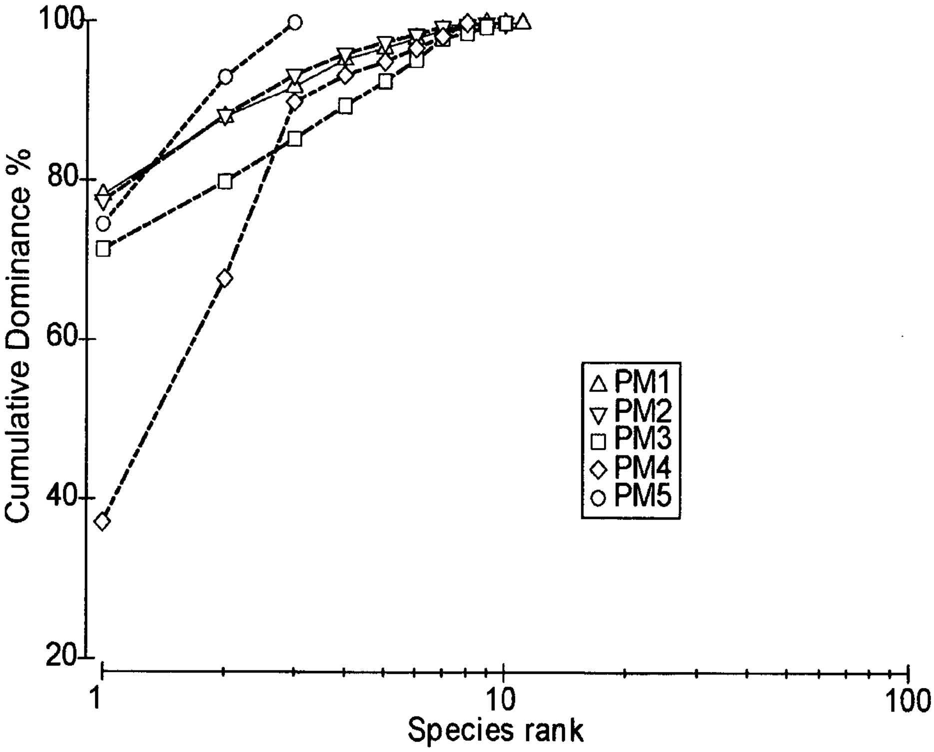

Fig 5.1.4: Cumulative dominance curve for nematode species for five stations.

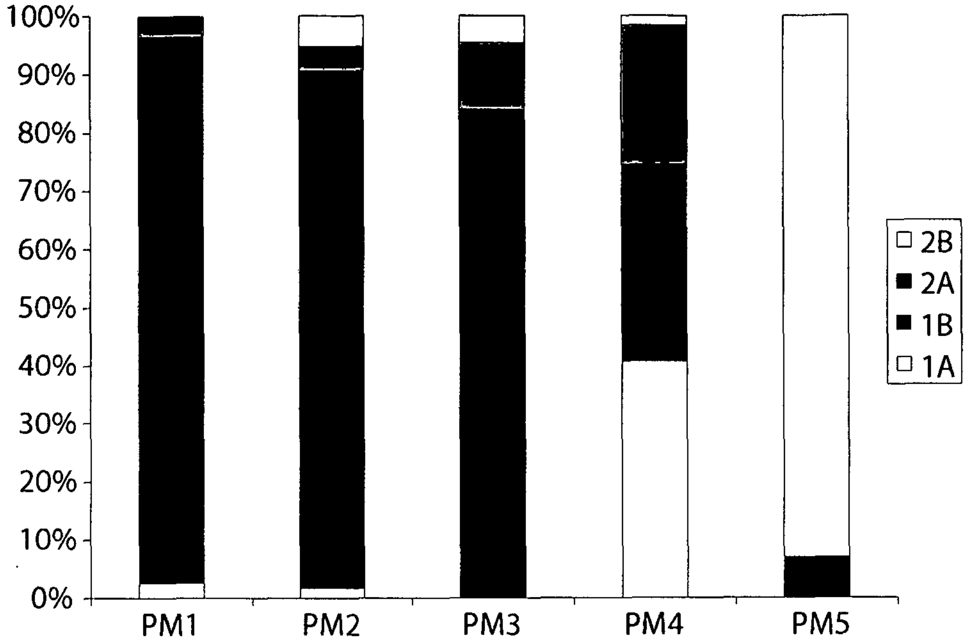

Fig 5.1.5: Nematode feeding type (%) based on Wieser's (1953) classification.

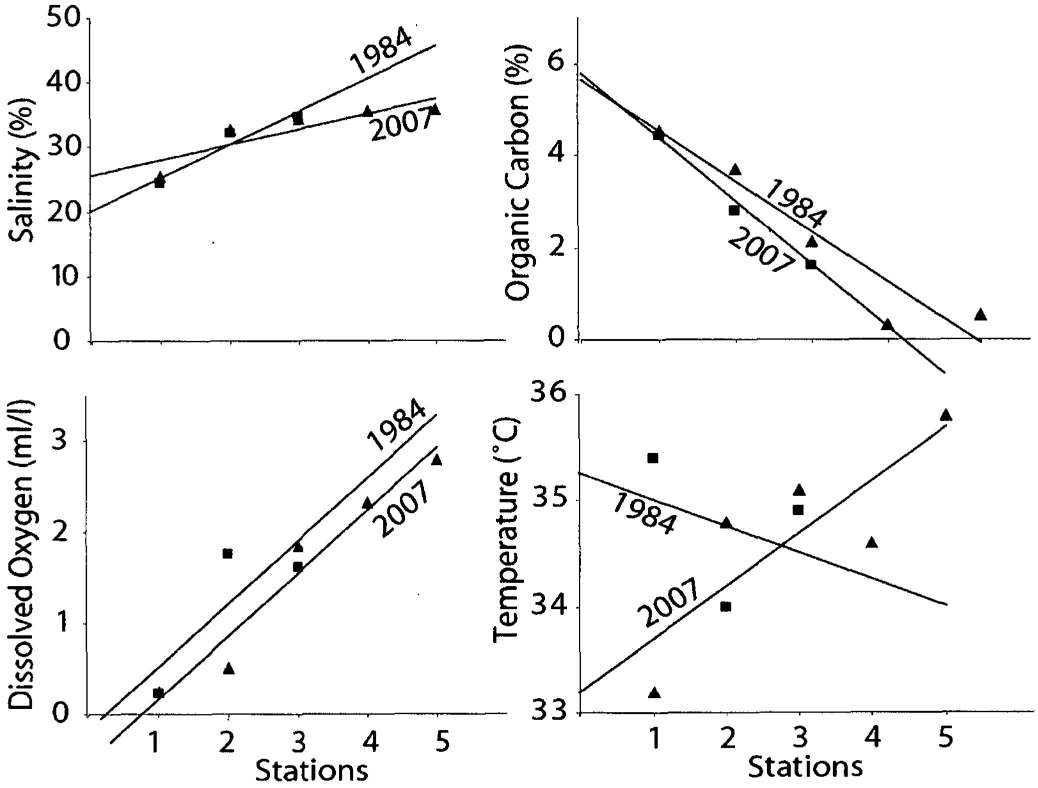

Fig 5.1.6: Comparison of physico-chemical parameters between 1982 (Ansari et al. 1984) and 2007 (present study).

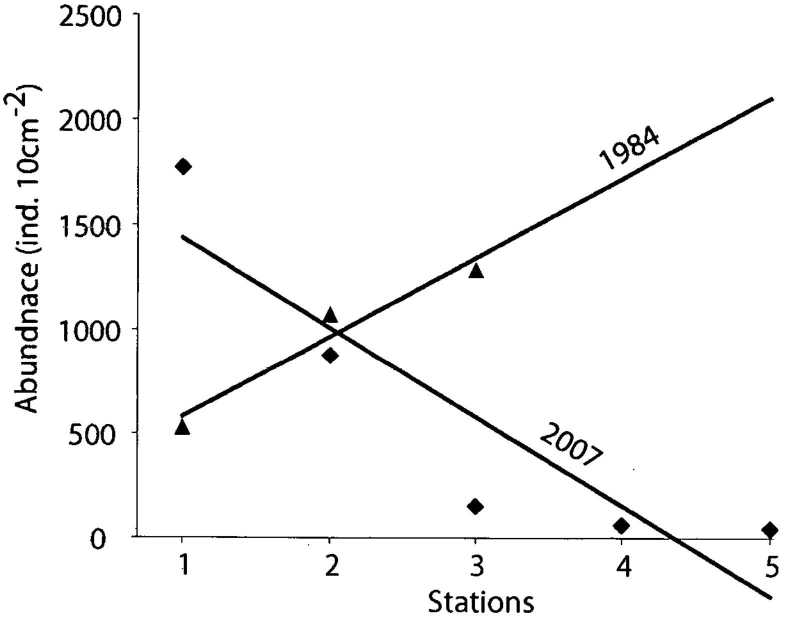

Fig 5.1.7: Comparison for the nematode abundance between earlier (Ansari et al.1984) and present (2007) study.

5.2. Marine nematodes as proxy for assessing the benthic environment of harbours.

Introduction

Harbours, as a major interface between coastal cities and the sea, are often under heavy pressure from human activities and increasingly suffer from environmental risks linked to poor water and sediment quality (Estacio et al. 1997). The central west coast of India has dense human habitation and is an industrial belt along with extensive agriculture. The commercial harbours in this region have heavy traffic, which increases the stress on the environment. Three harbours in the present study are situated on the river mouth, which possess a unique estuarine fauna. Macrobenthic communities of the harbour environments have been extensively used in pollution studies (Ingole et al. 2009; Sivdas et al. 2010).

The benthic environment of three harbours along the central west coast of India was investigated for their present health status using marine nematodes as surrogates. Ratnagiri, Mormugao and Karwar harbours from the central west coast of India are peculiar in the nature of activities. Ratnagiri is mainly a fishing harbour whereas Mormugao is mainly used for ore transport as 80% of India's inland waterway traffic is in this estuarine system for ore transportation and it operated about 39 billion tonnes in the last 3 years. Karwar is an intermediate port with more than 6 lakh tonnes of traffic each year. All three harbours are located on the mouth of rivers and the sediment is composed of estuarine fauna. The main objectives of the study were 1) To evaluate the use of nematode community as an indicator of stress, 2) comparative health of benthic environment within the three harbours and 3) impact of contaminants on the benthic meiofauna.

Methodology

Study area: Field sampling was conducted at Mormugao, Karwar and Ratnagiri (Fig 5.2.1). The Mormagao harbour is situated on the mouth of Zuari estuary along the Goa coast (15°27'48"N; 73°38'64"E) one of the oldest major ports on the west coast of India and ranks within the first 10 leading iron ore exporting ports of the world.

Ratnagiri harbour is situated (17°00'38"N and 73°15'34"E) along the Maharashtra coast. It is mainly a fishing harbour but also deals with the transport of cement, chemicals and petroleum products and could be developed as major all season harbour due to the increasing industrial development in the region. Karwar port is a natural all weather harbour situated in north Karnataka (14°50'36"N and 73°54'55"E) on the mouth of the river Kali.

Sample collection: Samples were collected onboard *CRV Sagar-Sukti* (SaSu-105) during January 2006 with a van-Veen grab (0.11 m^{-2}). Five grab samples were collected (in duplicates) at each harbour. Sub-samples for meiobenthic nematodes were collected upto 5cm depth with an acrylic core (4.5 cm diameter). The details of the sample analysis and data processing are described in Chapter 2.

Results

Environmental variables:

The water depth in the Ratnagiri and Karwar harbour was 20m whereas it was 25m in Mormugao. The bottom water temperature did not vary much with a mean 26.6^{0}C. Salinity was highest (35.43) at Karwar and lowest (34.76) at Marmugao. Bottom water dissolved oxygen was lowest (2.6ml/l) at Karwar and highest (4.4ml/l) at Ratnagiri (Table 5.2.1).

Nematode community:

Overall in the present study the nematode community comprised of 50 nematode species, where the fauna of Mormugao harbour was composed of highest (33 species) number and lowest number (20 species) was at Ratnagiri (Table 5.2.2).

The results of one-way ANOSIM confirmed the significance difference within the three sites, where high difference was observed between Ratnagiri and Karwar ($p<0.01$; Table. 3) followed by Karwar and Mormugao ($p<0.01$; Table 5.2.3). The cluster analysis based on the nematode species abundance for Karwar showed a separate branch off within Ratnagiri and Mormugao (at 30% similarity). The stations within Ratnagiri and Mormugao did not show similarity depicting varied species abundance for both the harbours (Fig 5.2.2).

The diversity indices showed highest mean values at Mormugao (Table. 5.2.4). The species richness (*d'*) was highest at Mormugao (1.74) followed by Karwar (1.34). The Shannon-Weaver's diversity (*H'*) was also highest at Mormugao (2.06) and Karwar (1.85) while all the indices including Maturity Index (MI) showed low values at Ratnagiri (Table 5.2.4).

There was a significant difference between the harbours for Shannon-Weaver diversity Index (H') (F= 5.59) at the level of 0.019. The Simpson's Index ($1-\lambda$) also showed a significant difference (F=7.26) at 0.008 level of significance. Maturity

Index (MI) was not highly significant (*F*=3.86) at 0.05 level of significance. Rest all the diversity measures (*S, N, d', J'*) did not show significant difference between the harbours (Table 5.2.5).

At Ratnagiri harbour, *Vasostoma* sp. was the most dominant contributing 37% of the total nematode community followed by *Sabatieria* sp1 constituting 11% and others constituted 29% of the total. At Mormugao harbour, *Vasostoma* species constituted the highest (41%) whereas *Sabatieria* sp1 contributed 23% followed by Unidentified species with 20%. At Karwar harbour, unidentified species was dominant with 43% of the total density followed by *Sabatieria* sp2 (20%). *Vasostoma* sp. formed only 17% of the total community abundance (Fig 5.2.3). The cumulative dominance curve for the three harbours showed a clear difference between the three harbours with Ratnagiri harbour being the least diverse with higher dominance of fewer species whereas higher diversity was at Mormugao with lower dominance (Fig 5.2.4).

Epistrate feeders (2A) was the most dominant feeding group contributing 44% at Ratnagiri, 55% at Mormugao and 52% at Karwar. The second dominant feeding type was Non-selective deposit feeders (1B) at Ranagiri and Mormugao with 26% each, whereas Predatory/omnivores (2B) with 22% contribution was dominant at Karwar. The ratio for 1B/2A varied from 0.24 to 0.42 for the three harbours (Table 5.2.4).

The geometric class plot depicts the least number of species with low abundance in the initial classes for all the three sites. Ratnagiri and Karwar are represented by 11 classes and Mormugao is represented by 10 classes (Fig 5.2.5).

SIMPER analysis revealed the contribution of the important species for the dissimilarity between three harbours where the species cumulative contribution of >50% were considered. The average dissimilarity between all the harbours ranged between 68.30 to 78.5%. Between Karwar and Ratnagiri, the major species contributing dissimilarity was *Vasostoma* sp (23.25%) followed by *Sabatieria* sp1 (13.93%) and the duo contributed for difference between Karwar and Mormugao (17.93 and 12.41% respectively) as well as Ratnagiri and Mormugao (22.67% and 13.8% respectively; Table 5.2.6).

Discussion

The meiobenthic nematodes are bound to the sediment throughout their life history (Suderman and Thistle 2003) and are often sensitive to many toxicants (Coull and

Chandler 1992; Guo et al. 2002), which makes them good candidate organisms for environmental quality assessment of harbours (Amjad and Gray 1983; Shiells and Anderson 1985; Lambshead 1986; Lampadariou et al. 1997; Fichet et al. 1999; Suderman and Thistle 2003; Liu et al. 2007; Moreno et al. 2008).

Present study accounted for a total of 50 nematode species from the tropical estuarine mouth region where the influence of river discharges, harbour activities and other anthropogenic input is high. The results are comparable to the other estuarine areas such as Swartkops estuary (Gyedu-Ababio et al. 1999) where same numbers of genera were recorded relatively less number (43 and 44) of genus/species was observed in the heavily polluted Genoa-Voltri Legurian Sea (Moreno et al. 2008) and Ems estuary (Essink and Romeyn 1994). Around 200 nematode species were recorded for 5 estuaries from England (Soeteart et al. 1995) and 74 species from laguna estuarine system, Brazil (Fonseca and Netto 2006) that were fairly clean habitats. Very low (27) number of species were reported from an estuarine region, which was organically polluted (Essink and Romeyn 1994). Accordingly, with the presence of 50 nematode species the benthic environment in study area can be considered as a grossly polluted.

There was low nematode species diversity at Ratnagiri harbour (Table 5.2.4). When the *k*-dominance plot was used along with diversity indices for Ratnagiri it conformed that this region has the least diverse assemblage (Fig 5.2.4; Table 5.2.4). In the Karwar harbour too, a similar nematode community is observed (Fig 5.2.2) suggesting a homogeneous environment compared to Ratnagiri and Mormugao. *Vasostoma* sp. and *Sabatieria* sp1, *S.* sp2, *Merylinnia* sp., *Daptonema* sp. (Fig 5.2.3) are all the members of epistrate or non-selective deposit feeder (Wieser 1953) and are known to dominate mostly in anoxic, degraded and polluted habitats. Thus, the varying dominance of these species reveals the intensity of pollution in the harbour sediments (Table 5.2.6).

The indicator species encountered in the present study such as *Sabatieria* sp., (Mirto et al. 2002; Nicholas 1975; Vincx et al.1990; Vanreusel 1990; Boyd et al. 2000), *Merylinnia* sp. (Mahmoudi et al. 2007) and *Sphaerolaimus* sp. (Gyedu-Ababio et al. 1999) are known to inhabit stressed, anoxic sediments. In addition the presence of many subdominant species (Table 5.2.2) viz; *Teschellingia* sp. (Nicholas 1975; Vincx et al. 1990; Vanreusel 1990), *Dorilaimopsis* sp. (Mirto et al.

2002; Vincx et al. 1990), *Daptonema* sp. (Vanreusel and Vincx 1989; Boyd et al. 2000), *Axonolaimus* sp. (Gyedu-Ababio et al. 1999 ; Bongers 1990), *Oxystomina* sp. (Mirto et al. 2002), *Theristus* sp. (Gyedu-Ababio et al. 1999) in the present study are good indicator of pollution.

Although the areas are known for high organic inputs (Ingole et al. 2009), the nematode community showed lower 1B/2A ratios (less than 0.5, Table 5.2.4), which suggest that more of fresh productivity is consumed by nematodes rather than organic matter. This depicts that unlike macrofauna (Ingole et al. 2009), high input of organic matter does not necessarily influence the nematode community of the area. The impact of a single factor (eg: organic matter flux) cannot be considered valid for the benthic community structure as these habitats have combinations of pollution inputs in the harbour region (Millward et al. 2004) and it has been shown that pollutants have considerable influence on nematode species.

High abundance of few species with low representation of rare species (Fig 5.2.5) can be due to the integrated impact of several anthropogenic activities in the harbour region. The altered diversity and average lower MI (Table 5.2.4; Heip et al. 1985) and the presence of many indicator species in the three harbours can mainly be attributed to the toxic inputs in the region and not the organic input due to lowered feeding ratios (Lambshead 1986; Fig 5.2.4). Reportedly, high contribution of pollutants in the harbour sediments such as petroleum hydrocarbons, pesticides (Kadam and Chouksey 2002; Sarkar et al. 1997 Sarkar et al. 2008), organotins (Bhosle et al. 2004; Jadhav et al. 2009), metals (Ramaiah and De 2003; Mesquita and Kaisary 2007; Nair et al 2003) and dredging activity (Quigley and Hall 1999) are mainly responsible for deteriorated benthic environment. Many nematode species such as *Rynchonema* sp. and *Araeolaimus sp.* are known to be sensitive to pollutants (Hermi et al. 2008) and stressed conditions which were not reported from the study site but are reported from the adjacent habitats (Ingole et al. 2006; Nanajkar and Ingole 2007).

Zuari estuary in Goa is constantly subjected to contaminants such as TBT, DBT and organotins from the shipping industry (Bhosle et al. 2004; Jadhav et al. 2008), which has shown negative impact on the nematode community (Schratzberger et al. 2002). Further, the deposition of metals such as Fe and Mn from the mining activity in the region (Mesquita and Kaisari 2007) may harm the nematode species

(Gyedu-Ababio et al. 1999; Davydkova et al. 2005). Recent reports showed increased levels of heavy metals such as mercury (Ramaiah and De 2003) and arsenic in the three harbours (Nair et al. 2003). Furthermore, sediments from Ratnagiri and Marmugao is known to have significantly high contents of PHC's (Chouksey et al. 2004; Kadam and Chouksey 2002), which will have deleterious impact on the benthic communities (Ingole et al. 2006; Sivadas et al. 2008). Communities are grossly influenced in the harbours where the co-contamination of several toxic inputs such as petroleum products, heavy metals and pesticides have cumulative effects (Millward et al. 2004). Moreover, the influence of toxicological synergisms will increase with mechanical disturbance in the harbours such as dredging (Quigley and Hall 1999). These factors together show their imprints in the nematode community of the three harbours, where altered diversity and presence of dominant indicator species signify the effect of pollutant discharge and harbour activities. Regulated discharge of effluents, well treated effluents, which are low in toxicity, can improve the benthic health. Improved management practices to restore benthic diversity may be helpful in fisheries as these estuarine mouths are nursery grounds for many commercially important fishes.

Table 5.2.1: Environmental parameters of bottom waters at the three harbours.

	Depth (m.)	Temp (^{0}C)	Salinity (PSU)	DO (ml/l)
Ratnagiri	20	26.6	35.30	4.40
Mormugao	25	27.5	34.76	3.00
Karwar	20	26.7	35.43	2.60

Table 5.2.2: Presence of nematode species at the three harbours

Species	Feeding type	Ratnagiri	Mormugao	Karwar
Sabatieria sp1	1A	+	+	-
Terschellingia longicaudata	1A	+	+	+
Terschellingia sp.	1A	-	-	-
Siphonolaimus sp.	2B	+	+	+
Paramonhystera sp.	1B	+	+	+
Daptonema sp.	1B	+	+	+
Dorylaimposis sp.	2A	-	-	+
Hopperia sp.	2A	-	-	-
Paramesonchium sp.	2B	-	+	+
Sphaerolaimus sp.	2B	+	+	+
Cheironchus sp.	2B	-	+	+
Bathyeurystomina sp.	1B	-	+	-
Polygastrophora sp.	2B	+	+	-
Oxystomina sp.	1A	-	+	+
Linhomoeus sp.	1B	-	+	-
Sabatieria sp2	1B	-	+	+
Marylynnia sp.	2A	-	+	+
Vasostoma sp.	2A	+	+	+
Adoncholaimus sp.	2B	-	+	+
Actarjania sp.	2A	-	-	+
Microlaimus sp.	2A	-	-	+
Comesomoides sp.	2A	-	-	+
Enoplolaimus sp.	2B	-	-	+
Chromadorita sp.	2A	-	-	-
Paralinhomoeus sp.	1B	-	-	-
Halalaimus sp.	1A	+	+	-
Axonolaimus sp.	1B	+	+	+
Theristus sp.	1B	+	+	+
Paracomesoma sp.	2A	+	+	+
Metacomesoma sp.	1B	-	-	+
Pierrickia sp.	1A	-	-	+
Unidentified 2	2A	+	-	+
Microlaimidae	2A	+	+	-
Quadricoma sp.	1A	-	-	-
Metacyantholaimus sp.	2A	+	+	-
Viscosia sp.	2B	+	-	-
Chromadora sp.	2A	-	-	-
Araeolaimus sp.	1A	+	-	-

Unidentified	2A	+	+	-
Odentophora sp.	1B	+	+	-
Pomponema sp.	2A	+	+	-
Unidentified 3	1A	-	-	-
Paralinhomoeus sp.	1B	-	+	-
Anticyathus sp.	1B	-	+	-
Trichotheristus sp.	1B	-	+	-
Choanolaimus sp.	2B	-	+	-
Polysigma sp.	2A	-	+	-
Trissonchulus sp.	2B	-	+	-
Platycoma sp.	2A	-	+	-
Enoplolaimus sp.	2B	-	+	-
Total	50	20	33	23
% Diversity	100	26	44	30

Table 5.2.3: ANOSIM for the difference between each harbour based on nematode abundance (Global R=0.329).

	R	% Significance
Karwar, Ratnagiri	0.62	0.8
Karwar, Mormugao	0.41	0.8
Mormugao, Ratnagiri	0.01	42.9

Table 5.2.4: Diversity indices and percent feeding types at each harbour (mean of 5 replicates)

Diversity indices	Ratnagiri	Mormugao	Karwar
Species (*S*)	9	12	9
Abundance (*N*)	510	518	588
Richness (*d'*)	1.26	1.74	1.34
Evenness (*J'*)	0.80	0.85	0.84
Shannon-Weaver (*H'*)	1.62	2.06	1.85
Simpsons Index (1-λ)	0.73	0.84	0.79
Maturity Index (MI)	2.25	2.57	2.29
Feeding types (%)			
1A	13	5	19
1B	26	26	7
2A	44	55	52
2B	17	14	22
Ratio 1B / 2A	0.39	0.24	0.42

Table 5.2.5: One-way ANOVA for all the nematode diversity indices.

Source of Variation	*F*	*P-value*
Species (*S*)	1.90	0.190
Abundance (*N*)	0.85	0.448
Richness (d')	1.87	0.195
Evenness (J')	0.72	0.505
Shannon-Weaver (H')	5.59	0.019
Simpsons Index ($1-\lambda$)	7.26	0.008
Maturity Index (MI)	3.86	0.050

Note: *df*: 2 and residual error for *df*: 12

Table 5.2.6: Percent contribution of dominant nematode species by SIMPER analysis for each harbour representing cumulative dominance of more than 50%.

	Group 1 Avg. Abund	Group 2 Avg. Abund	Av diss	Diss SD	Contrib %	Cum %
Groups Karwar & Ratnagiri						
Average dissimilarity = 71.07						
Vasostoma sp.	219.32	211.66	16.52	1.79	23.25	23.25
Sabatieria sp1	0.0	116.78	9.90	1.64	13.93	37.18
Sabatieria sp2	62.25	0.00	6.78	1.28	9.54	46.72
Marylynnia	52.09	0.00	3.98	0.72	5.6	52.32
Groups Karwar & Marmgao						
Average dissimilarity = 78.59						
Vasostoma sp.	219.32	86.60	14.09	1.56	17.93	17.93
Sabatieria sp1	0.0	105.97	9.75	1.84	12.41	30.34
Sabatieria sp2	62.25	6.38	5.33	1.57	6.78	37.12
Metacyantholaimus sp.	0.0	50.93	4.43	0.50	5.64	42.76
Marylynnia sp.	52.09	3.16	3.88	0.82	4.94	47.70
Sphaerolaimus sp.	48.67	16.93	3.68	1.28	4.68	52.37
Groups Ratnagiri & Marmagao						
Average dissimilarity = 68.30						
Vasostoma sp.	211.66	86.60	15.48	1.56	22.67	22.67
Sabatieria sp1	116.78	105.97	9.42	1.67	13.8	36.47
Metacyantholaimus sp.	2.04	50.93	5.06	0.50	7.41	43.88
Microlaimidae	39.98	16.96	3.42	1.25	5.00	48.88
Polysigma sp.	0.00	24.40	2.55	0.59	3.73	52.61

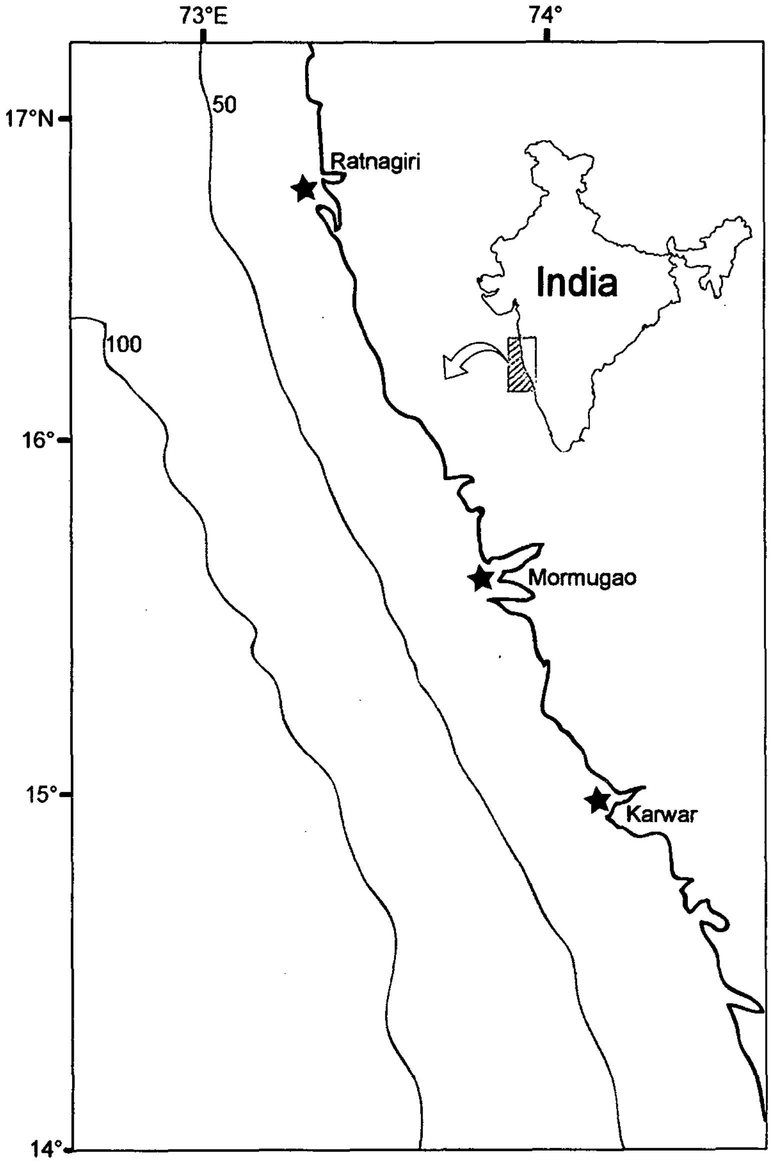

Fig 5.2.1: Location of the three harbours along the west coast of India.

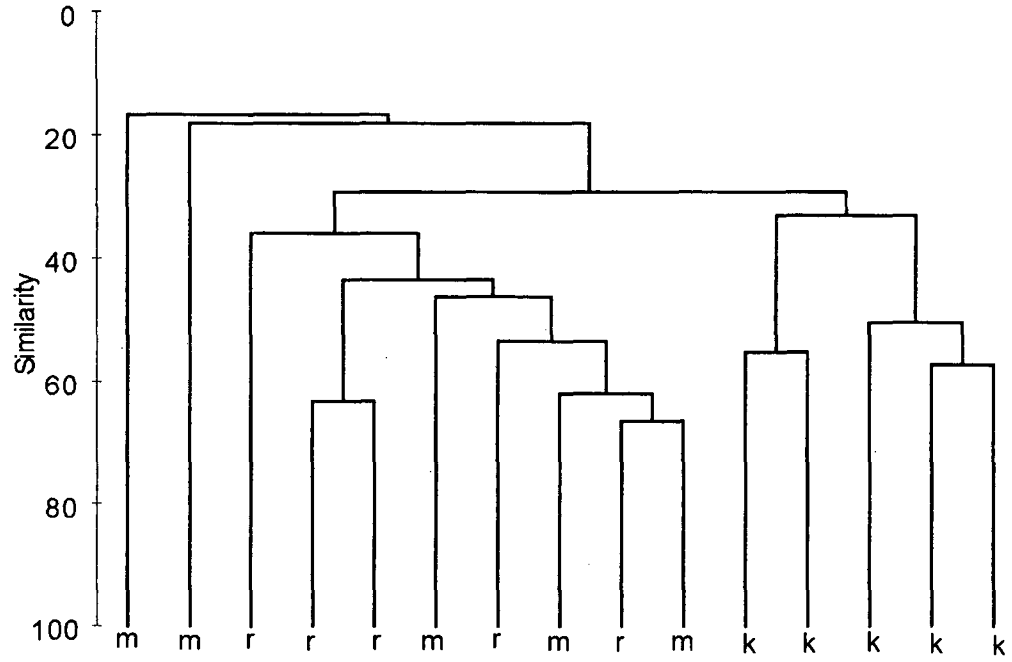

Fig 5.2.2: Cluster analysis based on the nematode abundance for three harbour locations (r- Ratnagiri, m-Mormugao and k-Karwar).

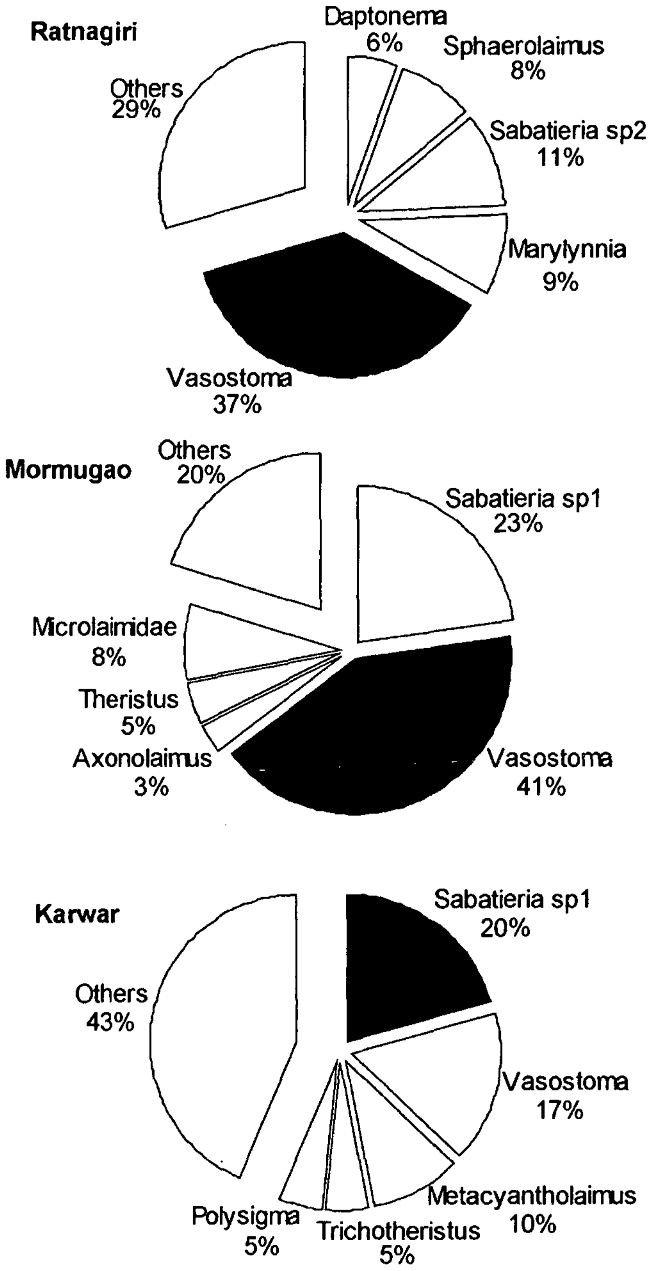

Fig 5.2.3: Percent contribution of dominant nematode species in the three harbours.

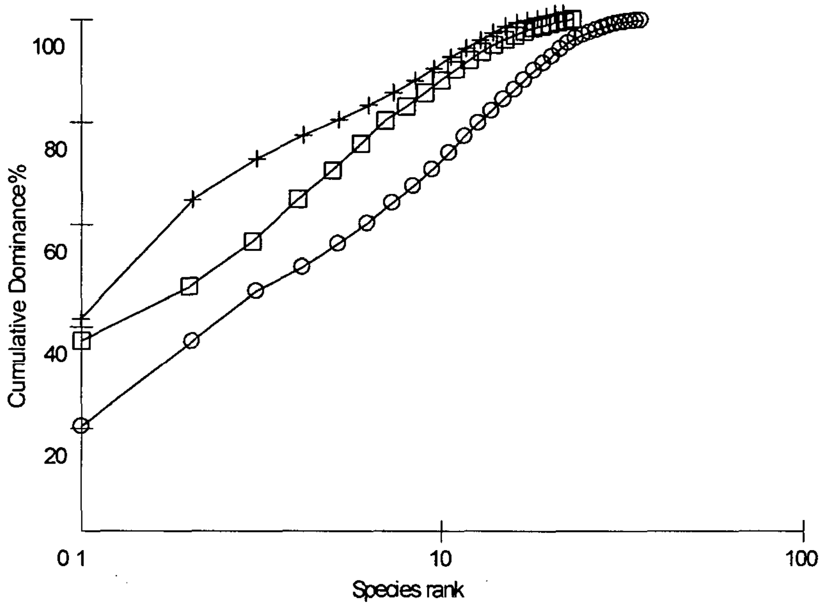

Fig 5.2.4: Cumulative species dominance for the three harbours (□- Karwar, +- Ratnagiri, O-Mormugao)

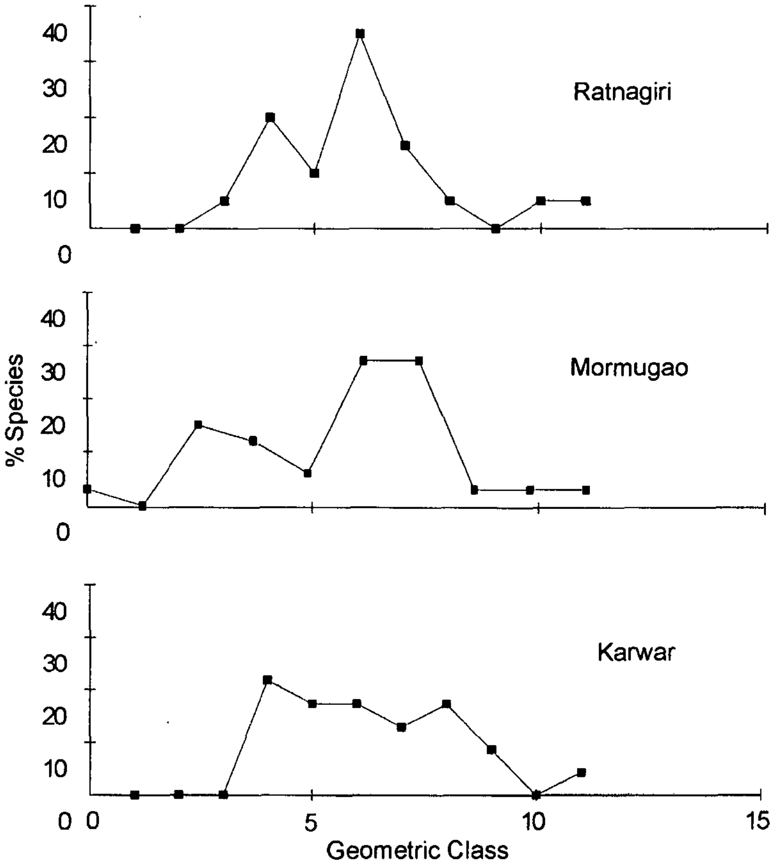

Fig 5.2.5: Geometric class for nematode species from the study area

5.3 Nematode community of the OMZ sediments from the Arabian Sea

Introduction

Oxygen Minimum Zones (OMZs) are mid-water regions of the ocean with hypoxic waters, where oxygen concentrations typically are <0.5 ml L^{-1} (or about < 20 µM). They usually occur in the middle of the water column at upper bathyal depths (200-1200 m; Wyrtki 1973). OMZs generally form where strong upwelling leads to high surface productivity that sinks and degrades, depleting oxygen within the water column. OMZs occur in much of the eastern Pacific Ocean, in the Arabian Sea and off West Africa (Kamykowski and Zentara 1990; Levin 2003). Deep-water hypoxia is also found in deep basins in the southern California borderland and in some fjords (Diaz and Rosenberg 1995). Off Mexico and in the Arabian Sea, the OMZ is about 1000 m thick (Wyrtki 1973). The current role of OMZ sediments as potential sinks for N and P, and past fluctuations that have occurred in upwelling, productivity and OMZ intensity, benthic processes in the Arabian Sea may have far-reaching effects on ocean productivity and global climate. The thickness of the OMZ varies regionally, and is strongly influenced by circulation (Levin 2003; Naqvi et al. 2000). The OMZ in the Arabian Sea is spread over 51, 5000 km^2, where ≈26% of it has the oxygen concentrations $\leq$ 0.5 ml/l and ≈30% of the area is having oxygen level <0.2 ml/l (Smith and Levin 2005).

Thus >55% of the Arabian Sea is under low (<0.5 ml/l) oxygen that has a great impact on the biogeochemical processes and the benthic ecological functioning (Levin 2003). The metazoan meiofauna in general have been found to be more tolerant to hypoxic conditions than the macrofauna (Levin et al. 1991) and the nematodes have proved to be the most resistant to the oxygen-depleted condition (Levin et al. 1991; Gooday et al. 2000; Venreusel et al. 2010). Dissolved oxygen is known to influence the distribution of nematode community markedly (Steyaert et al. 2002) but tolerance of nematodes still remains very high compared to the other benthic forms (Neira et al. 2001). Nevertheless, harpacticoid copepods and agglutinated foraminifera are also considered to be intolerant to low oxygen (Gooday et al. 2000).

The earlier study from the Arabian Sea revealed no change in the nematode community from the OMZ when compared with the surface sediment from the deep waters (Cook et al. 2000). Sommer and Pfannkuche (2000) investigated the deep-water sediments of the same study area and concluded that the meiobenthic nematode community was influence by the enhanced organic matter flux and hypoxia. Based on the earlier findings, we hypothesized that the nematode community in the OMZ will have unaffected vertical distribution in the sediments and the same is tested in the present study.

Methodology

As a part of Indo-Dutch collaborative program, a cruise was conducted onboard the Indian research vessel ORV *Sagar-Kanya* (SK-211) in October 2004, where 20 sediment samples were taken in the OMZ ($17^0$30'00"N and $71^0$12'00"E; 756 m water depth) and non-OMZ area ($17^0$30'00"N and $72^0$44'00"E; 50 m water depth). Samples were taken with two spade box core drops per stations in the shelf region off Ratnagiri (Fig 5.3.1). Duplicate sub-samples were taken for meiofauna by inserting a 3.6 cm diameter acrylic core down to 10 cm sediment depth from each spade core. Immediately after collecting, the cores were sectioned in 0-1, 1-3, 3-5, 5-7 and 7-10cm. The details of the sample analysis and data processing are described in Chapter 2.

Results

Physico-chemical parameters

The bottom water dissolved oxygen at the Non-OMZ station was 9.91 ml/l and at the OMZ station was 1.02 ml/l. In the non-OMZ region, the sedimentary chlorophyll-*a* (Chl-*a* µg/g) values were highest (0.41) at 0-1 cm section and the lowest (0.13) in 7-10 cm. In the OMZ, the highest values (0.21) were at 3-5 cm section and the lowest (0.09) was in 1-3 as well as 5-7 cm section (Fig 5.3.2).

The sedimentary organic carbon values were highest (2.19 %) in 7-10cm sections of non-OMZ sediment and lowest (2.01 %) in 0-1cm sections. In the OMZ region, the highest value of 7.73 % was present at 5-7cm and lowest (1.53 %) at top 0-1 cm section.

The sediment texture of the non-OMZ stations showed highest clay percentage (57.26 %) in the 0-1 cm sediment section, and the silt (46.95 %) was highest in the 7-10 cm section where highest (0.53 %) sand percent also occurred (Table 5.3.1). In the OMZ region silt was the dominant form where highest (69.36 %) occurred at 5-7 cm section and the highest sand percentage (30.28) was in the 0-1 cm section and the clay was highest (50.66 %) in the 3-5 cm section (Table 5.3.1).

The median grain size in non-OMZ region ranged from 3.46 to 3.87 in the 5-7 cm and 1-3 cm section respectively. In the OMZ region, the range was 5.67 to 8.13 cm in the 7-10 cm and 5-7 cm, respectively (Fig 5.3.2). In the non-OMZ region, the C/N ratio ranged from 8.90 to 9.69 in 0-1 cm section and 7-10 cm section respectively. While the range in the OMZ was 4.75 to 10.83 in the 0-1 cm and 5.7 cm section respectively (Fig 5.3.2).

Nematode diversity indices

Vertically in non-OMZ the highest (4) species richness (*d'*) was in the 1-3 cm section and values decreased gradually depth-wise. While in the OMZ region highest richness (3.9) was in the 0-1 cm and decreased in the 1-3cm and no richness values recorded below due to the absence of nematodes (Fig 5.3.3). The species evenness showed uniform values for all the sediment sections for the non-OMZ with the lowest value at the surface sediment (0-1cm). For the OMZ station, highest evenness (0.95) was recorded at the sediment depth of 1-3cm (Fig 5.3.3). The most dominant nematode genera in the non-OMZ region was *Halalaimus* sp. (16%), followed by *Sabatieria* sp. (10 %), *Polysigma* sp. (12%), *Desmoscolex* sp. (9%) and Enoplid (8%). The OMZ region was dominated by *Sabatieria* sp. (13 %), followed by *Polysigma* sp. (9%), *Gammanema* sp. and *Diplopeltoides* sp. (8%), *Paramonhystera* sp. (7%), *Halanonchus* sp. and *Desmoscolex* sp. (5%; Table 5.3.2).

Feeding types

Although, the selective deposit feeders were dominant in both the areas, their abundance was higher in non-OMZ sediment (59%), particularly in the 1-3 cm section. Non-selective deposit feeders were higher (14%) in the subsurface 3-5 cm section. As shown in fig 5.3.4, the epistrate feeders were highest (43%) in the bottom 7-10 cm section, whereas the predatory/omnivores were dominant (28%) in the top 0-1cm sediment sections. As in non-OMZ, the selective deposit feeder dominated (45%) the top 0-1cm sections of OMZ sediment. Only the non-selective deposit feeders were higher (21%) in the lower 1-3 cm section. The epistrate feeders (18%) and the predatory/omnivores (25%) were higher in the top 0-1 cm layer (Fig 5.3.4).

The minimum MI value of 2.50 was in the 1-3 cm and MI of 2.63 was in the 0-1 cm sections of the OMZ area (Table 5.3.3). Highest MI of 3.27 was in the non-OMZ (7-10 cm) region. The values in the non-OMZ region ranged from 2.83 to 3.27 (Table 5.3.3).

Nematode species

In total, 70 nematode genera were identified from the two locations. A total 29 genera were present in the OMZ region and 42 in the non-OMZ sediments. Among the 70 genera, only 4 viz; *Desmoscolex* sp., *Polysigma* sp., *Halichoanolaimus* sp., *Axonolaimus* sp. were common to both the sites. Nematodes in the non-OMZ were distributed down to the sediment depth of 10cm, but with the decreasing number downward (Fig 5.3.5a). In case of OMZ, distribution of nematodes was restricted only to top 3 cm (Fig 5.3.5b). In the OMZ region, 22 genera were confined to the surface 0-1 cm section and 19 were only present in the 1-3 cm layer. On the contrary, 17 genera were common to the 0-1 and 1-3 cm sections of non-OMZ sediment. Ten genera, which were in the 3-5 cm section of non-OMZ sediment, were not represented, in the overlying sections. *Viscosia* sp. and *Quadricoma* sp. were present only in 5-7 cm section (Fig 5.3.5).

Principal Component Analysis

The Principle component 1 and 2 accounted for 86% and 13.9% variation of non-OMZ sediment, while the principle component 1 and 2 of the OMZ region accounted 92.5% and 5.7% variation. In the non-OMZ region, component 1 showed highly positive values associated with sediment sections closely related C/N, OC, sand percent, Chl-a, nematode species diversity (H') and nematode maturity index (MI). In the OMZ region, component 1 showed positive values associated with sediment sections similar with C/N ratio, OC Chl-a, nematode species diversity (H') and Maturity Index (MI, Fig 5.3.6).

Discussion

Earlier reports from the Arabian Sea suggest that free-living nematode community of the surface sediments from the OMZ and the non-OMZ area do not display noteworthy effect of anoxia (Cook et al. 2000). However, the present investigation revealed the presence of meiofauna only in top 3cm sediment section in the OMZ compared to 10 cm section of the non-OMZ region. Sommer and Pfannkuche (2000) investigated the abyssal region of the Arabian Sea and found nematodes upto the sediment depth of 5cms outside the OMZ. They concluded that the monsoonal forcing is the major influential factor for structuring of the meiobenthic fauna and surface productivity also significantly affects the distribution of nematodes at abyssal depths. The absence of other meiofaunal taxa in the OMZ sediments (Table 5.3.2) other than nematodes suggests a clear faunal gradation due to reduced conditions (Neira et al. 2001).

The vertical distribution of sedimentary parameters such as the chl-*a* and the percent organic carbon, carbon/nitrogen ratios and the median grain size showed higher fluctuations (Fig 5.3.2) in the OMZ region suggesting changes in the patterns of surface productivity. These upwelling regions, especially those with associated mid-water oxygen depletion, have particularly organic-rich sediments (Cowie 2005). The enhanced accumulation of organic matter in upper slope sediments under current conditions of monsoon-driven upwelling and extreme oxygen depletion, combined with unusual vertical carbon fluxes across the entire basin, is due both to regionally high productivity and to reduced remineralization within the water column (Haake et al. 1993, 1996), may therefore mean that Arabian Sea sediments represent a disproportionately significant long-term carbon sink.

Nematodes show enhanced abundance in low oxygen (Neira et al. 2001) influenced by high food availability and quality and, potentially, by an indirect positive effect of very low oxygen availability through the removal of predators and competitors (Neira et al. 2001). But this was not the case in the present study where no nematodes occurred below the 3 cm OMZ sediment section. Predicted reason for such pattern of vertical distribution can be due to the type of organic matter degradation and subsurface intensification of anoxic condition in the sediments. Food being postulated to be the major influential factor rather than anoxia (Cook et al. 2000) but neither the OC nor the Chl-*a* had any significant role in the vertical distribution of the nematodes in OMZ sediments.

Vertical migration is common in nematodes (Schratzberger et al. 2000) depending on the type of organic matter and anoxia, (Steyaert et al. 2005), which might be responsible for favouring selective deposit feeders (44%) mostly in the surface sediments of the OMZ sediments.

The (Maturity Index) MI values in the OMZ region were lower than the non-OMZ region pointing toward a stressed OMZ habitat for the nematode community, whereas even in the deeper sediments of the non-OMZ showed more stable conditions than the surface layers of OMZ. Since the food is postulated to be the major limiting factor for vertical distribution of meiofauna (Cook et al. 2000;

Widbom and Elmgren 1988), non-existence of nematodes in the food rich deeper OMZ sediment was rather unanticipated and could have been largely due to the anoxia.

The total microbial biomass (TMB) values at the abyssal Arabian Sea sites were high (Cowie 2005) compared to sites at similar depths in the Atlantic and Pacific oceans, reflecting a generally enhanced export flux of particulate organic carbon (POC) in the Arabian Sea. Notably, TMB values at the abyssal stations were as high as some measured in estuarine sediments, clearly demonstrating the effects of unusual productivity in this area (Sommer and Pfannküche 2000). The down-core profiles of TMB generally showed a 2- to 4-fold decrease within the top 10cm at more oligotrophic sites (Cowie 2005). Many OMZ regions are known to grow microbial mats (Helly and Levin 2004; Neira et al. 2001) on the surface sediments responsible for the distribution of many taxa (Erbacher and Nelscamp 2006) and this ample microbial food resource drives nematodes towards the surface from the deeper sediment layers where selective deposit feeder were dominant in the present study.

Principle Component Analysis for both the sites revealed affinity of nematode species (H') and higher Maturity Index (MI) with C/N ratio, OC and chl-*a* on the first component (Fig 5.3.6) and one more additional parameter that is sand in the non-OMZ region (Fig 5.3.6). Thus the OC (Cowie 2005; Cowie et al. 1999), sediment chl-*a* (Andersson et al. 2007) and the C/N ratio have the most crucial role in structuring the meiobenthic nematode community. Microbial activity on the surface sediments in the OMZ sediments is known to play significant role (Erbacher and Nelscamp 2006) where local settings within the OMZ are crucial in determining community composition (Huges et al. 2009).

The nematode community in the OMZ has low total species number and within that more species categorized as opportunists (Table 5.3.3). This eliminates the number of species, which are termed as persisters, since they require more stable unstressed sediments (Bonger et al. 1991). Consequently, the OMZ region will restrict this category of the community to flourish. This partial diversity representation in the OMZ will affects the diversity and the benthic process spatio-temporally.

It is hard to identify a single factor responsible for the absence of nematodes below 3cm sediments section in the OMZ because previous studies report high nematode resistance in anoxic conditions (Cook et al. 2000; Giere 1993; Gooday et al. 2000; Levin et al. 1991). The Indian west coast mid-slope anoxia can be peculiar due to unusually high seasonal organic matter flux (Cowie 2005; Sommer and Pfannküche 2000), increased microbial activity and biomass (Sommer and Pfannküche 2000) and subsurface sedimentary anoxic conditions. These parameters together might well be responsible for increasing the inhabitable sediments for nematodes as well.

Table 5.3.1: Vertical distribution of sediment grain size (%) of the non-OMZ and OMZ sediment.

Sediment Depth (cm)	Non-OMZ Sand	Non-OMZ Silt	Non-OMZ Clay	OMZ Sand	OMZ Silt	OMZ Clay
0-1	0.25	42.49	57.26	30.28	65.86	31.92
1-3	0.28	46.61	53.14	23.23	65.34	34.65
3-5	0.32	44.67	55.01	14.99	49.28	50.66
5-7	0.34	42.39	57.27	15.41	69.36	30.63
7-10	0.53	46.53	52.99	10.42	56.92	43.07

Note: The total sand, silt and clay is not 100% because the sand was measured as weight/weight and silt and clay were measured volume/volume.

Table 5.3.2: Nematode species dominance (%).

Non-OMZ	% Dominance	OMZ	% Dominance
Halalaimus sp.	16	*Sabatieria* sp.	13
Polysigma sp.	12	*Polysigma* sp.	9
Sabatieria sp.	10	*Gammanema* sp.	8
Desmoscolex sp.	9	*Diplopeltoides* sp.	8
Enoplid	8	*Paramonhystera* sp.	7
		Halanonchus sp.	5
		Desmoscolex sp.	5

Table 5.3.3: Maturity Index (Bonger 1990) for each depth zone of the Non-OMZ and the OMZ area.

Sediment depth (cm.)	Non-OMZ	OMZ
0-1	2.99	2.63
1-3	3.08	2.5
3-5	2.83	
5-7	2.91	
7-10	3.27	

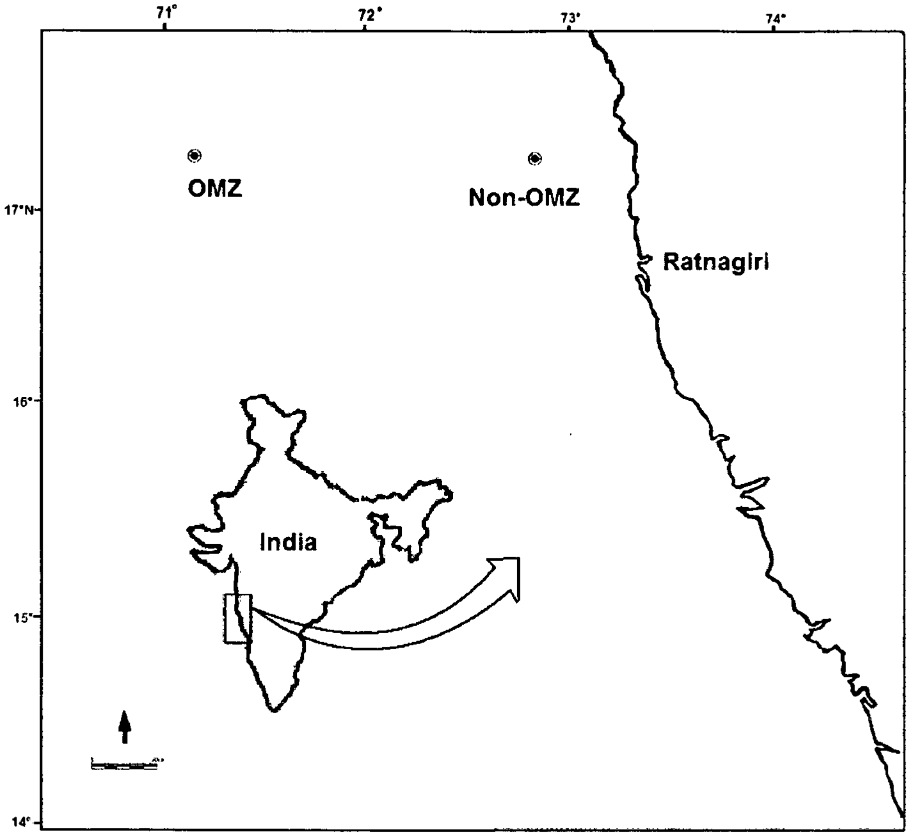

Fig 5.3.1: Map of the study area showing the location of OMZ and the non-OMZ sampling stations.

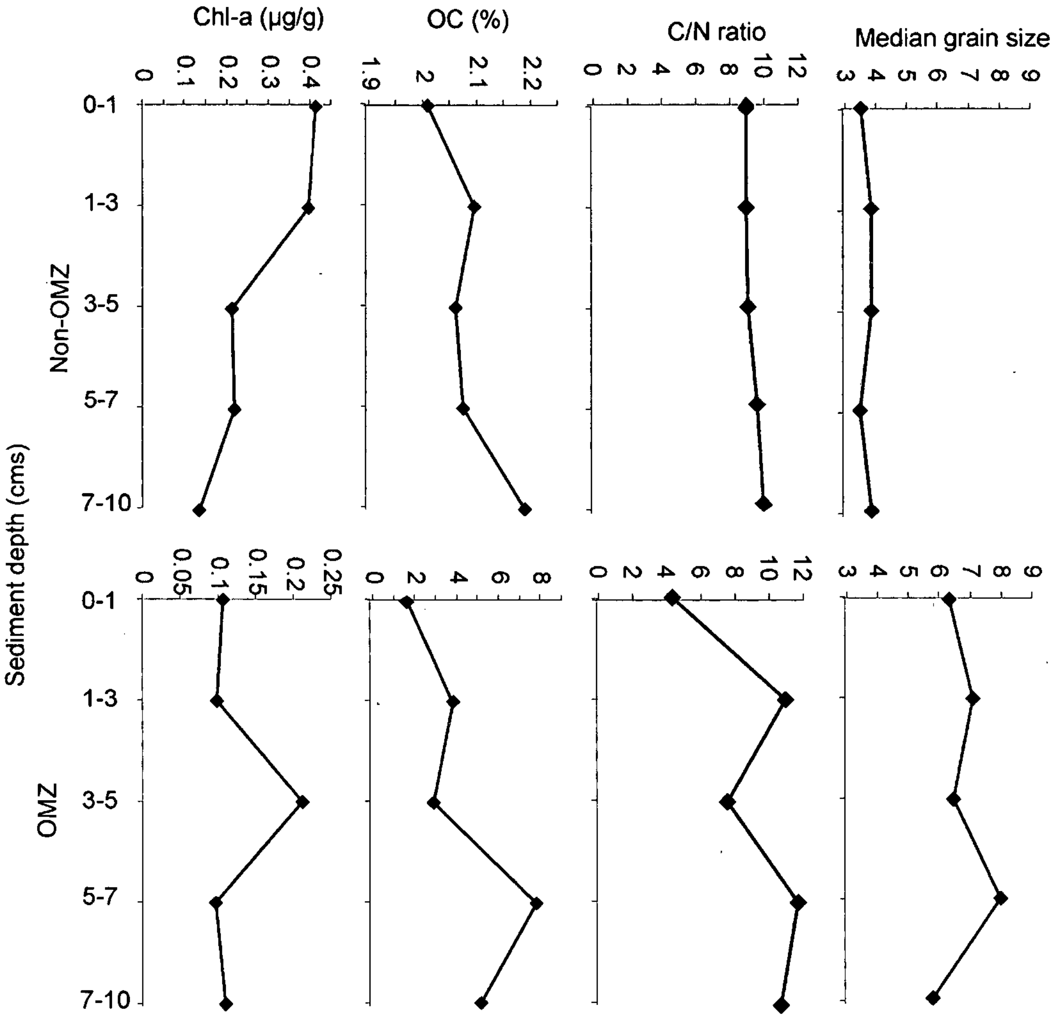

Fig 5.3.2: Vertical distribution of Chl-*a*, Organic carbon, C/N ratio and median sediment grain size at the OMZ and non-OMZ stations.

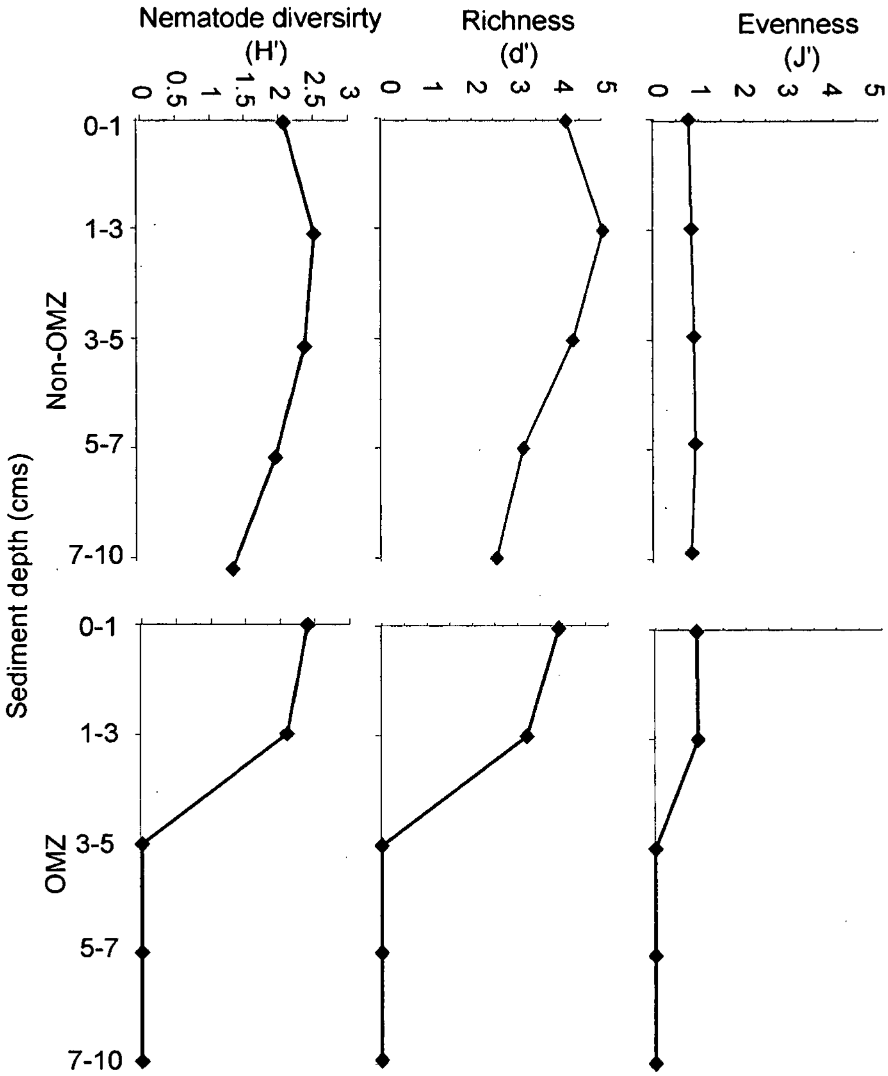

Fig 5.3.3: Vertical distribution of nematode species diversity indices at the OMZ and non-OMZ stations.

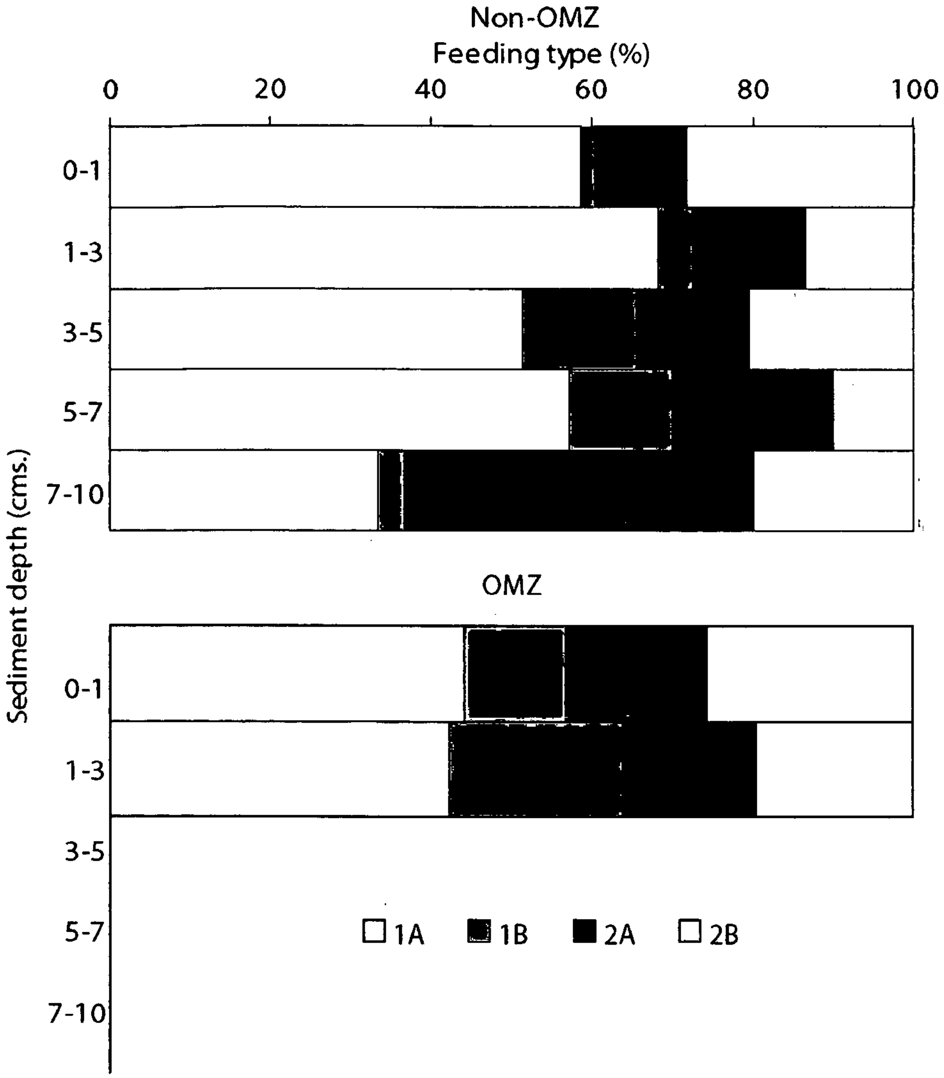

Fig 5.3.4: Depth-wise distribution of nematode feeding types at the two stations [1A- Selective deposit feeder, 1B- Non-selective deposit feeder, 2A- Epistrate feeder and 2B- Predatory omnivores.]

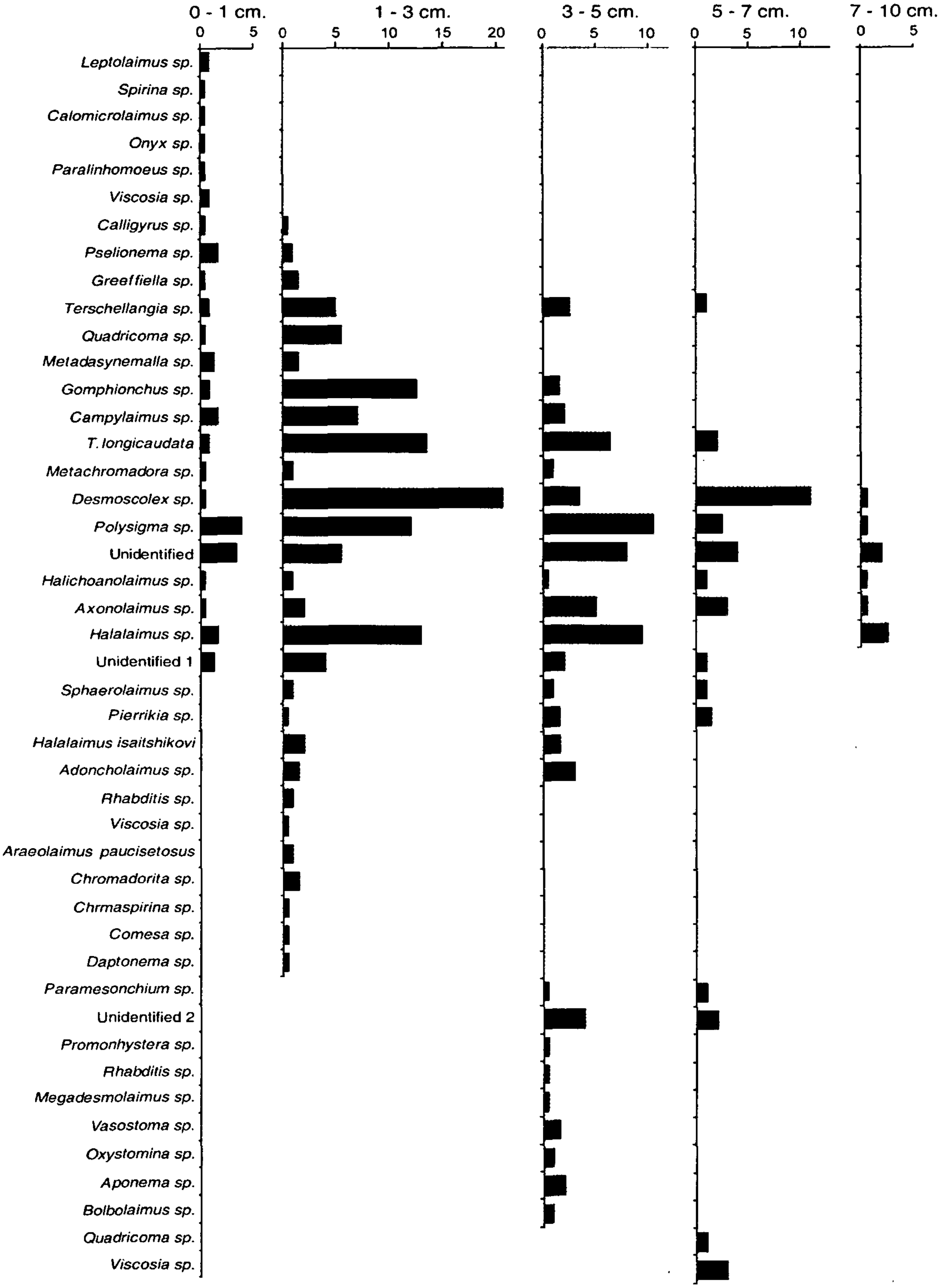

Fig 5.3.5a: Vertical distribution of nematode species in the non-OMZ regions.

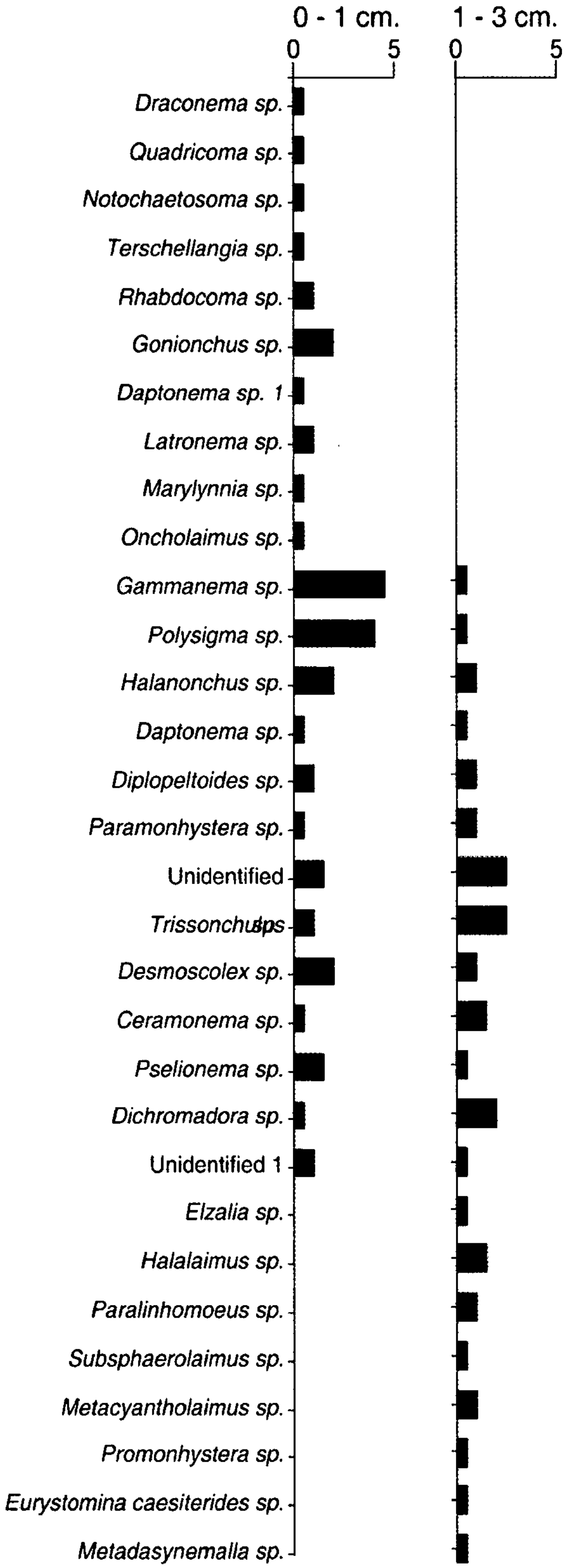

Fig 5.3.5b: Vertical distribution of nematode species in the OMZ regions.

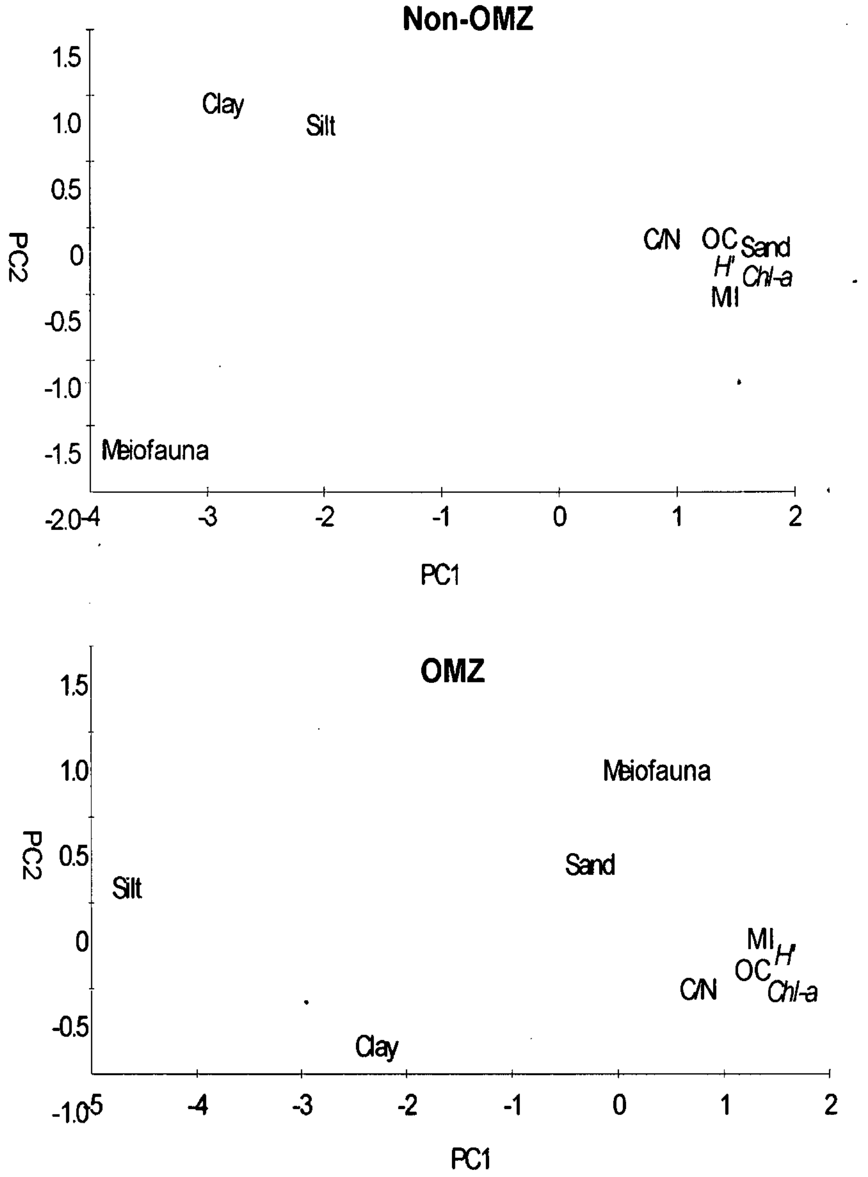

Fig 5.3.6: Principle component analysis of the sedimentary environmental parameters, nematode species diversity and maturity index for each sediment section.

5.4. Climate change and the intertidal nematode community: Predictions for the future.

Introduction

It seems prudent today to take 100 years as the horizon for most planning exercises in the coastal zone and as a reasonable goal for the development of integrated coastal zone management. One task, therefore, is to provide reasonable scenarios for the effects of global change of a magnitude on coastal processes, particularly processes controlling the coastal sediment budget and the position of the shoreline on a timescale of a century. The first quarter of the centaury is predicted to have heavy impact in the developing countries (Brown and McLachlan 2002) wherein the present study area is located. According to IPCC (2007) predication the intertidal habitat will be the most vulnerable to all the changing atmospheric and oceanography parameters.

Warming

Temperature rise was 0.4 to 0.8^{0}C in the past century and is expected to accelerate (IPCC 2007). The impact of temperature rise will result in expansion of world oceans. More impact can be seen in the tropical intertidal region, resulting in increased desiccation on the beach and narrowing of the moisture-laden habitat for the intertidal organisms.

Circulations: Atmospheric circulation changes will affect the precipitation affecting the salinity of coastal waters, turbidity and terrestrial flux of nutrients and pollutants. The present study area (Kalabadevi Ratnagiri), a tropical region generally has many riverine sources and estuaries intermittently spaced with beaches and will show significant influence of the improved flux.

Sea level rise

In addition to inundation, long-term sea level rise can cause erosion and shoreline retreat by creating a sediment budget deficit (Bird 1993). Simplifying considerably, for a sandy beach the nearby seafloor profile takes on a shape primarily dependent on sand grain size, and secondarily on the energy of the incoming waves. In particular, the higher the energy of the waves, the greater the depth at which the wave action will disturb the depth profile and the further offshore this limiting effect will occur.

Rise in sea level is expected by 2mm per year (IPCC 2007) and some other predictions go to 3 to 6mm per year (Davidson-Arnott 2005), which again narrows down the intertidal region. And overall the intertidal region is predicted to reduce in a range of 20-70% for the millennia depending on the type of coast and processes operating therein (Galbraith et al. 2002).

Beach morphology

More dynamic coastal processes will profoundly influence the intertidal habitat from the low tide region upto the dune. The elevation of the beach will increase due to higher wave action and finer sediment will be washed in the near-shore subtidal region (Brown and McLachlan 2002). Morphologically the beach will be composed of coarser sediment with steep elevation. This will lower the water table and water retention capacity of the beach, removing the moisture and reducing the habitat for the interstitial organisms.

Chemical changes

About 30% of modern CO_2 emissions are absorbed by the ocean today (Feely et al. 2004). Expected decrease in pH in the next 100 years range from 0.3 to 0.5 units and these are higher than any other pH changes in the past 200-300 million years (Calderia and Wickett 2003; Feely et al. 2004).

Seasonality

Recent changes show extreme rainfall events in southern Asia with decrease in the number of rainy days (Singh and Sontakke 2001 in IPCC, 2001) and the intensity of rains will be predictably to be more.

Marine nematodes

Here we forecast the impact of global change on the marine nematode community from an intertidal habitat. Nematodes tend to show community as well as species level changes in the perturbed habitat and have long been used for pollution monitoring and disturbance studies (Heip et al. 1985). Marine nematodes can be used as a yardstick for the future global change studies considering their supremacy in terms of abundance, diversity and distribution in the marine sediments (Lambshead and Boucher 2003) and their community features reflect small change in the ambient environment. Many species-specific traits reflect influence of the changing environment where the sensitive ones will reduce or vanish and the resistant species will thrive or flourish.

The species-specific attributes, life history traits and high abundance and diversity can be a useful tool for assessing the impact of global change in today's scenario. Forecasting the long-term impact on the nematode community for the changing parameters predicted (IPCC report, 2007) in the intertidal region. Different species traits and life history characters were considered from the past literature. The long-term nematode community response was predicted based on present empirical data.

Methodology

Study area: Sampling was performed at the beach of Kalbadevi, Ratnagiri (Lat.17°02' 68" to 17° 04' 07"N; Long. 73° 16' 93" to 73°17' 32" E; Fig 5.4.1). This beach is ~5 km long and ~250 m wide, bordered by estuaries on either side of the beach and is considered to be anthropogenically undisturbed. The beach is considered to be a reflective high-energy beach from the tropical region (Knox 2001). General oceanographic settings of the Kalbadevi area are described by Sivadas et al. (2005).

Field sampling: Spatial patterns at the beach were investigated by sampling the dune, berm, high tide level, mid tide level and the low tide level (Fig 5.4.2). In all, four sampling surveys were conducted during 2004, including the post monsoon (February 2004), pre-monsoon (May 2004; but with unusually heavy rains), monsoon (August 2004) and followed by the post-monsoon (November 2004). The average height for all the seasons at dune was 3.16m above MSL, berm was 1.99m, high tide location was 1.31m, mid tide location was 1.11m and the low tide location was 0.59m above MSL. An acrylic core of 4.5 cm ∅ was used to collect nematodes. Duplicate cores were taken down to a sediment depth of 20 cm, at each tidal zone (Fig 5.4.2). The cores were sectioned at 5 cm interval and preserved in 5% buffered formalin-Rose Bengal solution.

Laboratory analysis: Sediment samples were passed through 500 μm and 63 μm mesh size. All the nematodes retained on the finer mesh were handpicked and mounted on a temporary glycerol mount sealed with DPX. Identification was carried out under stereoscopic binocular microscope using standard taxonomic keys by Platt and Warwick (1983) and Warwick et al. (1998). The nematode abundance for the core area was converted to ind.10cm^{-2}. It was impossible to identify all nematode specimens to the species level, as many appeared undescribed, hence they were referred as unnamed congeneric species and were listed as 1, 2 or 3. A total of 9078 nematode specimens were picked from 160 sub-sections of 60 sediment cores.

Rainfall data (Fig 5.4.3) of last five years (2004-08) was considered. The predictive impacts of global change were evaluated considering the IPCC guidelines/reports (IPCC 2007). Different species traits and life history characters were considered from the past literature and the long-term nematode community response was predicted based on the present empirical data.

Results

Beach morphology and intertidal nematode community:

At Kalbadevi beach, a total of 38 nematode species occurred for all the three seasons. The list of species including their feeding types and maturity index values are given in table 5.4.1.

The Kalbadevi beach is a reflective open ocean beach considered to be a high-energy environment. Seasonality plays a critical role in morpho-dynamics of the beach where monsoon play a critical role. Rainwater flushing is considered to be devastating event with heavy beach sand runoff from littoral into the subtidal region. During the cyclonal rains in May 2004 (Fig 5.4.3) heavy erosion in dune, berm and high tide region was observed (Fig 5.4.4). The erosion in upper tidal regions of the beach was brought about during continuous monsoon (August) as the flux of fresh water eroding beach sediment into the subtidal region. The washing away of the surface sand resulted in massive defaunation. The benthic communities in dune as well as berm experienced highest reduction in diversity and abundance (Fig 5.4.5). Post monsoon season was a stable period and slow accretion took place in the upper tidal zones (Fig 5.4.4) with some recovery of nematofauna. The pre monsoon showed high deposition of sand on the beach, bringing stability that increased the abundance and diversity of nematodes (Fig 5.4.5).

The area that will be lost, if submerged due to sea level rise, designated under intertidal region will be appr.$1x10^5m^2$. Based on the available meiobenthic, especially the nematode biomass, the amount of estimated average carbon lost for nematodes will be 433 kg/km^{-2} (Table 5.4.2). The maximum amount of carbon that would be lost is for the low tide region (806 kg/km^{-2}; Table 5.4.2).

Schematic diagram shows a cross section of the beach with the habitat occupied by the nematode community in the intertidal region, whereas the predicted changes will transform the area into a reflective beach with narrow intertidal region that has a reduced habitable region for nematodes (Fig 5.4.6).

As the Kalbadevi beach will be gradually transformed (Fig 5.4.6) in the coming millennia, apparently the nematode community will also show a gradual change. The changes will be in terms of species richness, evenness and overall diversity (Fig 5.4.7). The predicated change will be mainly in the intertidal zone and may not be applicable to dune and berm as these habitats might be completely eliminated, depending upon region. Nematode feeding groups (Wieser 1953) will be affected considerably (Fig 5.4.8) due change in resource availability. Thus the approximate area lost at Kalbadevi, if the sea level increases by 1m will be significant and is shown in figure 5.4.9.

Discussion

The combined effects of two or more variables cannot be predicted from the individual effect of each. Independent effects of climate change and local anthropogenic impacts cannot be separated as the influence will be synergistic as far as each species is concerned. As stated by Harley et al. (2006) it is better to discuss each climate variable and its impact rather than complex levels of biological organizations.

The physical changes in the intertidal region will act as mechanical disturbers for the nematode community since they are generally of size 1-2mm long. This stress will only sort the species according to adaptations they possess for dealing harsh conditions like, the heavily cuticularised body wall, number of setae, other ornamentations on the body like serrations, papillae and strength of the individual to hold on substrate, tail length and secretion for attachment and lastly the shape and size of the body.

The chemical changes will sort the species according to their physiological tolarence to increasing temperature, pH, CO_2 and other inputs from the terrigenous sources. Few of these parameters might benefit the nematodes at community level but heavy changes in the community composition appear obvious.

The changes being predicted for the next millennia will be gradual and will not be drastic which might give many species a chance to adjust and adapt as far as the sandy beaches are concerned (Brown and McLachlan 2002) but still gradual species level changes will ultimately result in certain degree of alterations in the community structure and its functionality.

Species richness tends to be more on dissipative beaches and as the beaches become reflective the richness decreases (Brown and McLachlan 2002) and the predicted global trends will metamorphose the beaches into reflective beach depending on the regional settings ultimately reducing the species richness therein.

Effect of physico-chemical parameters (increased temperature, pH, CO_2 and salinity)

Nematode species tend to inhabit many areas, which are low in oxygen, and they penetrate the sediments with almost no oxygen. Species such as *Terschellingia longicaudata,* known to use very low oxygen concentrations and consumes bacteria (Wieser 1953; 1959) will replace the ones with higher demands. Facultative anaerobes such as *Sabatieria* sp. (Jensen 1981) and thiobiotic species will successfully have positive impact of increasing CO_2 concentrations for example species like *Adoncholaimus thalassiophagus* as they get attracted to CO_2 (Riemann and Schrage 1988). Increase or decrease in salinity has shown high juvenile mortality in nematodes (Moens and Vincx 2000). Thus all the parameters will have certain impact on the community directly or indirectly.

The empty zone

Total niche in upper tidal region will be reduced (Fig 5.4.6) considering the increase in beach elevation and coarser sediment grain size (Cooper and Pilkey 2004) and reduced water retention capacity of the sediment. High desiccation due to rising temperature as well as less water retention by coarser sediments in upper tidal zones of the beach will be critical in demarcating a clear boundary between marine and dune nematofauna. Nematodes tend to thrive in high numbers near the surface sediments (0 to 5 cms) but dune, berm and high tide regions will be most vacant from faunal aspect and a clear '*empty zone*' might form between marine and terrestrial/off shore dune communities. Few species such as *Trefusia* sp., *Latronema* sp., *Campylaimus* sp. *Oxyonchus* sp., *Choanolaimus* sp. and *Tricoma* sp. have been found dominant in coarse sediment and few of them have short, stout, annulated body adapted for large interstitial spaces (Heip et al. 1985). High tide region might have such species and increased evaporation will desiccate dune and berm region making an empty zone destroying an ecotone and demarcating a clear marine boundary.

The '*squeeze effect*' (Harley et al. 2006) will arise due to narrowing of species range due to abiotic changes, ultimately overlapping the niche. The effect will be horizontal as well as vertical as the abiotic factors acting will be more. The reduction in the beach area is predicted to decrease due to increasing sea level, increase in beach elevation and increase in coarse grained sediments.

Of course it is known that many parameters (other than sediment grain size) determine shore-face shape including wave energy, storm frequency, and sand supply (Cooper and Pilkey 2004) that will again have their own impact.

Alterations in resource availability and feeding

Detritivorous might dominate the other feeding groups as the change will shift towards more detritus based food web (Williams and Heck 2001) but very less organic matter will be trapped in upper tidal level due to increased grain size and beach elevation. Upwelling enhanced productivity will bring more phytoplankton into the intertidal area where species like *Theristus* sp., *Chromadorita sp.* and *Chormadora sp.* feeding mainly on diatoms (Boucher 1974; Jensen 1987; Tietjen and Lee 1973) might become opportunist. Increase or decrease in predatory nematodes will solely depend on life strategies (Table 5.4.1) to increased harsh environments and the prey species available.

The species diversity will generally decrease as the number of species will be reduced due to heavy inter and intra species competition and habitable niche with large grain size and less water retention capacity. The species evenness will reduce, as distribution of species will be dependent on influencing parameter and response of each species on the beach. The species dominance will increase as the least affected will increase in number where species like *Sabatieria* sp., *Daptonema* sp., *Monhystera disjuncta* (Vrenken et al. 1991). will have more abundance due to shorter generation time. Sensitive species like *Rynchonema* sp. (Heip et al. 1985) will not be able to cope with the harsh fluctuations and might disappear.

Multiple changing parameters do not allow an estimate of exact feeding dominance for nematodes and moreover it is a known fact that many nematodes tend to change the feeding strategy according to environmental conditions and resources available (Moens and Vincx 1997). Overall it appears that the dynamics of intertidal region and flexibility of consumer species mostly can support the omnivorous species to dominate.

Life history patterns and the Maturity Index (MI)

Experimental studies show that many species tend to change their life cycles depending on the temperature changes. Shortening of generation time with increase in temperature by *Monhystera denticulate* (Tietjen and Lee 1972). *Oncholaimus cobbi* reaches high densities during warmest months on a tropical tidal flat (Esteves et al. 2003). Many reports suggest very long generation time in suboptimal temperatures (3-7°C) for species such as *Desmodora scaldensis, Oncholaimus brachycercus* and *Halichoanolaimus robustus* (Gerlach and Schrage 1972). The thermal tolerance of many species is limited but nematode species tend to show a positive response to elevated temperatures as far as the generation time is considered.

The *r*-strategist will have better prospects in such predicted scenarios compared to *k*-strategist as the former has shorter life span and can cope with changing environment. But an increase in global temperature will accommodate more generations in lesser time thus changing the species from *k*- to *r*- strategist. This will change the fundamental principle on which the Maturity Index (Bonger et al. 1991) is based. The change in community due to disturbance/pollution is reflected in MI where it states that the disturbed habitat will have colonizers or opportunistic species which have shorter life cycle and can dominate in constantly stressed habitats, compared to the persisters that have very long life cycle and need stable environmental conditions to complete its life cycle. They are given a scale from 1-5 based on its life history pattern from *c-p* (where *c-* is colonizers and *p-* persisters). But the effect of temperature rise will shorten the generation time of a few species, which will change the values given by Bonger et al. (1991) on *c-p* scale. Thus the calculations based on present scale given by Bonger will remain the same in elevated temperature situation but in reality the species that are considered, as persisters might have changed to colonizers. In the predicted changing conditions MI might conclude wrongly about the status of the environment depending on the life history status given by Bonger. The MI needs critical attention as it might lead to misinterpretation of pollution status of an environment altered due to cumulative global changes.

Alterations in trophic dynamics

The figures were derived considering the area that can be lost as per IPCC (2007) report for a 1m rise in sea level (Fig 5.4.7). Apart from this loss the buffer zone between the marine and terrestrial biomes will be lost. The loss will harm in long term because nematodes are known to have high turnover rates. The re-mineralization process in the intertidal region will be slowed down.

The other components of the benthic community such as polychaetes, bivalves, gastropods will be lost as well. The biological impact on the beach will be synergistic as most of the components are interdependent. The most abundant and dominant, a gastropod *Umbonium vestiarium* population might collapse due to changing biophysical nature of the beach.

Storms, cyclones, hurricanes and their impact

Generally May is considered a peak pre-monsoon month for higher diversity and abundance of intertidal meiobenthic taxa (Ingole 1994; Parulekar 1998). However, heavy stormy rains struck the central west coast of India in May 2004 (Fig 5.4.3). These unseasonal stormy rains devastated the coastal flora and fauna, destroying the Mango (*Mangifera indica*) yield -a major cash crop in this coastal belt. This single event devastated the intertidal region bringing drastic reduction in the meio- and macrofauna (Annon 2005), and also in nematode community (Fig 5.4.5). The top sandy layer of intertidal beach was completely swept away due to the rapid erosion, changing the zonation pattern. These events alter the community structure and disrupt the stable zonation of a community. With the prediction in the increased frequencies of such events in the coastal region (IPCC 2007), the intertidal benthic fauna will be exceedingly vulnerable to reduction in diversity and abundance. The India coast is expected to experience the increase in frequency of cyclones, which makes the coastal habitat the most susceptible to such events.

Other complications

Seasonal intensity is believed to increase but the scale is difficult to calculate and its impact will be still unknown. Temperature rise is predicted to increase events such as El Nino and Southern Oscillation (*ENSO*) and more frequent *El Nino* like conditions (Timmermann et al. 1999). Indian Ocean has a unique biogeochemistry that holds some phenomenon like coastal upwelling, algal blooms and seasonal anoxia that will also change and will have a gross effect on the coastal communities. Storm intensities are expected to increase; a major physical stress for the coastal organisms of small size and withstanding it will be species dependent. Other direct anthropogenic activities such as flux of pollutant and human activities such as beach sand mining and construction activities will have cumulative effects on the intertidal community.

Implications of nematode community as a long-term monitoring tool in future studies

Several indices which are used today for evaluating the status of the habitat, if can be standardized for evaluating the integrated impact of global change that can help in future conservation goals. The in-depth evaluation of the nematode community and changing indices can yield conclusions that differentiate between the impact of global climate change and the local anthropogenic impact will prove useful for the policy makers to mitigate issues like pollution, mining and construction etc. Further, setting the thresholds for many nematode species can be helpful as indicator species of climate change, such as the species sensitive to small changes in temperature reflected in its generation time.

Model development and integrated experimentation

A general traditional experimentation method includes one or two physical, chemical or biological factors correlated with faunal components to evaluate the effects and the patterns therein. In today's scenario, *global change* is a real time large-scale experiment that considers dozens of physical, chemical and biological factors synchronously making impact at individual, species and community level. The whole impact is borne by the ecosystem, which ultimately reduce its services.

It would require quantitative information not just on how changing parameters will affect the producers, consumers and detritivores, but also on how it would affect all other aspects of trophic interactions and functionality. This information is lacking, and without it one cannot build realistic models forecasting the effects of global change.

Table 5.4.1: List of nematode species from Kalbadevi beach Ratnagiri, with their feeding types (Wieser 1953) and Maturity Index (MI) values (Bonger 1990) depicting life strategies.

	Feeding type	MI	Persisters	Colonizers
Anomonema sp.	1A	3		
Camacolaimus sp.	2A	3		
Choanolaimus sp.	2B	3		
Chromadora sp.	2A	3		
Cobbia sp.	1B	3		
Daptonema sp.	1B	2		√
Desmoscolex sp.	1A	4	√	
Enoplidae	1B	5	√	
Enoplolaimus litoralis	2B	2		√
Enoplolaimus propinquus	2B	2		√
Gammanema sp.	2B	3		
Gerlachius sp.	1A	4	√	
Innocuonema sp.	2A	3		
Latronema sp.	2B	3		
Mesacanthion sp.	2B	3		
Metadesmolaimus scanicus	1B	2		√
Metalinhomoeus sp.	1B	2		√
Microlaimus sp.	2A	2		√
Oncholaimus skawensis	2B	4	√	
Oncholaimus sp.2	2B	4	√	
Paracyatholaimus sp.	2A	2		√
Polysigma sp.	2A	3		
Promonhystera sp.	1B	2		√
Pselionema sp.	1A	3		
Rhabdocoma sp.	1A	4	√	
Rhabdodemania sp.	2A	4	√	
Rhynchonema sp.	1A	3		
Sigmophoranema sp.	2A	3		
Spiliphera sp.	2A	3		
Synodontium sp.	2A	2		√
Synonchium sp.	2B	3		
Theristus otoplanobius	1B	2		√
Theristus sp.1	1B	2		√
Theristus sp.2	1B	2		√
Trefusia sp.1	1A	4	√	
Trefusia sp.3	1A	4	√	
Unidentified sp.1	1B	-		
Unidentified sp.2	1B	-		

Table 5.4.2: Loss of nematode biomass in each zone of the beach based on the predicted area loss due to the sea level rise.

	Abundance (ind.10cm^{-2})	Dry wt. (µg/10cm^{-2})	kg / km^{-2}
Dune	19.5	41.34	41
Berm	71	150.52	151
HT	335.5	711.26	711
MT	214.75	455.27	455
LT	380.25	806.13	806
Avg.	204.2	432.904	433

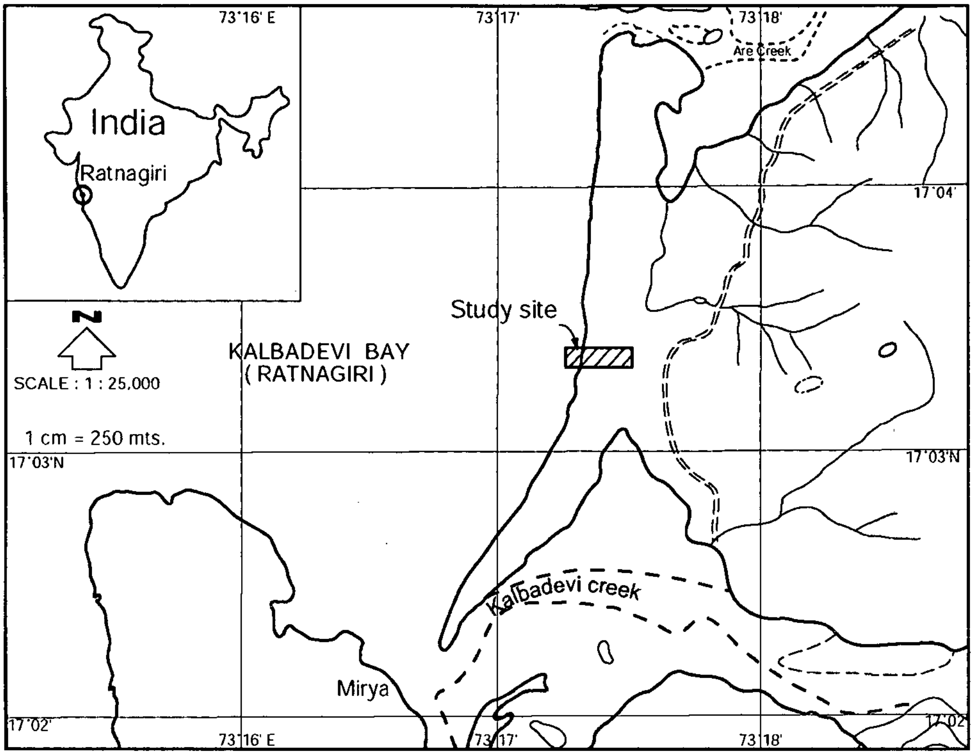

Fig 5.4.1: Study area with study location on Kalbadevi beach, Ratnagiri.

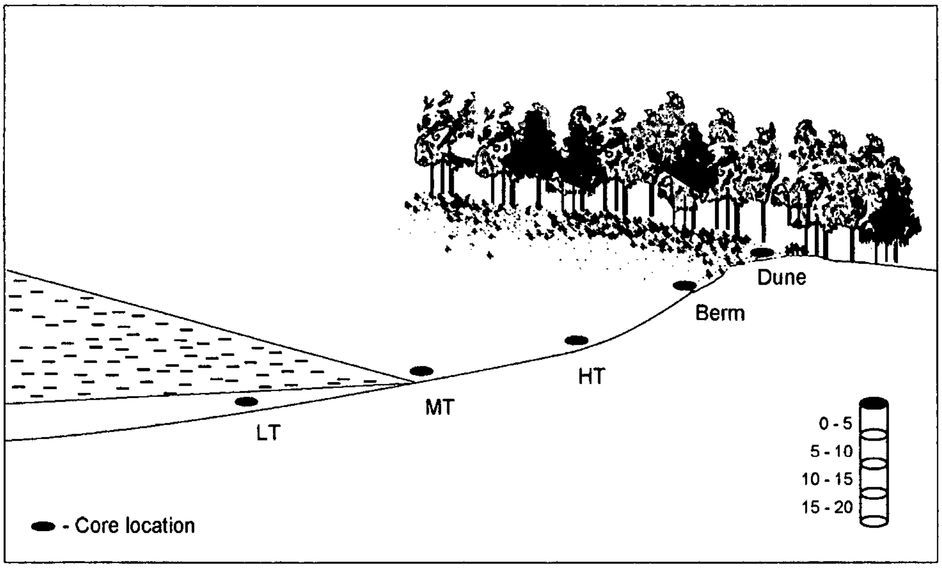

Fig 5.4.2: Cross section of the Kalabdevi beach with sampling sites and zonation.

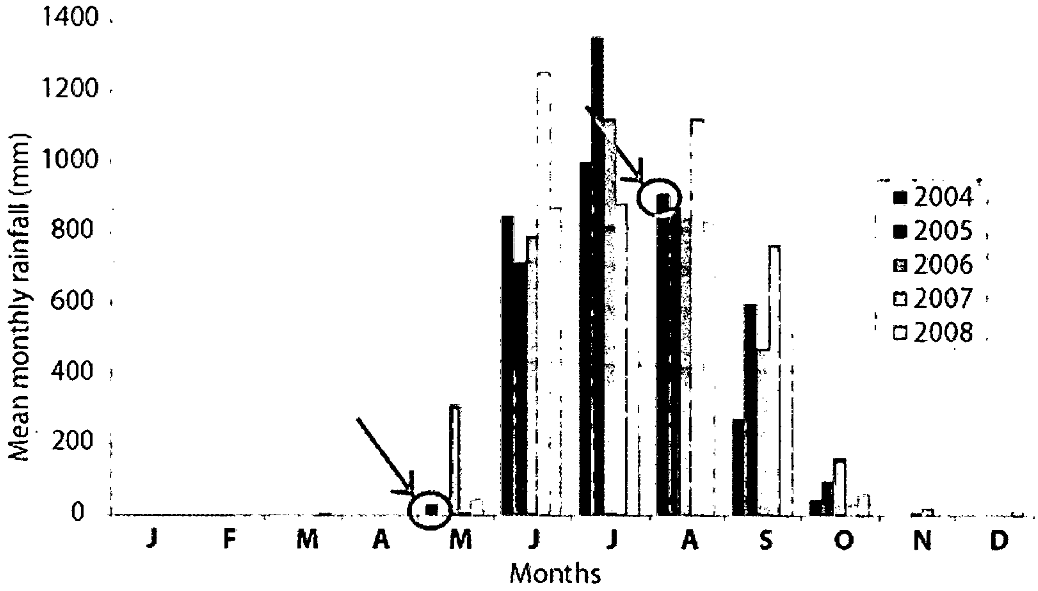

Fig 5.4.3: Annual mean monthly rainfall (mm) during 2004-08 (Arrows indicate the sampling months for the present study0.

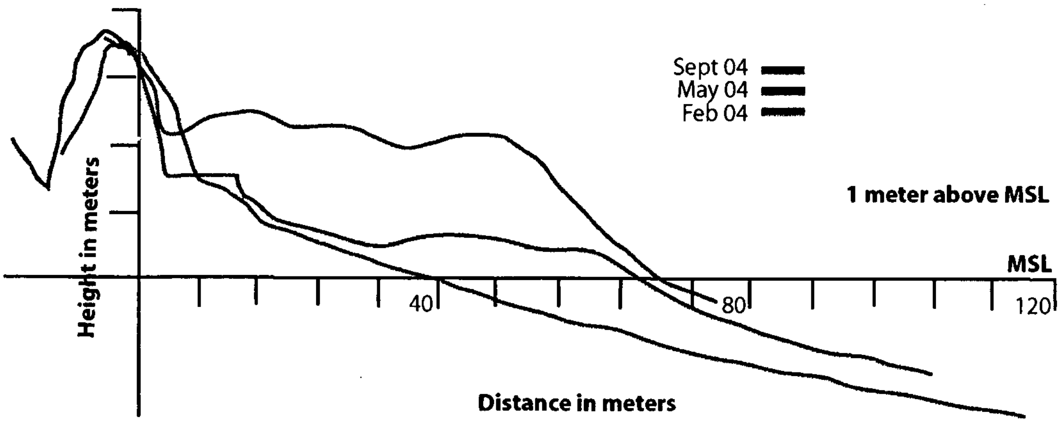

Fig 5.4.4: Beach profile of the area considered for sampling transect and the predicted 1m sea level rise (IPCC 2001).

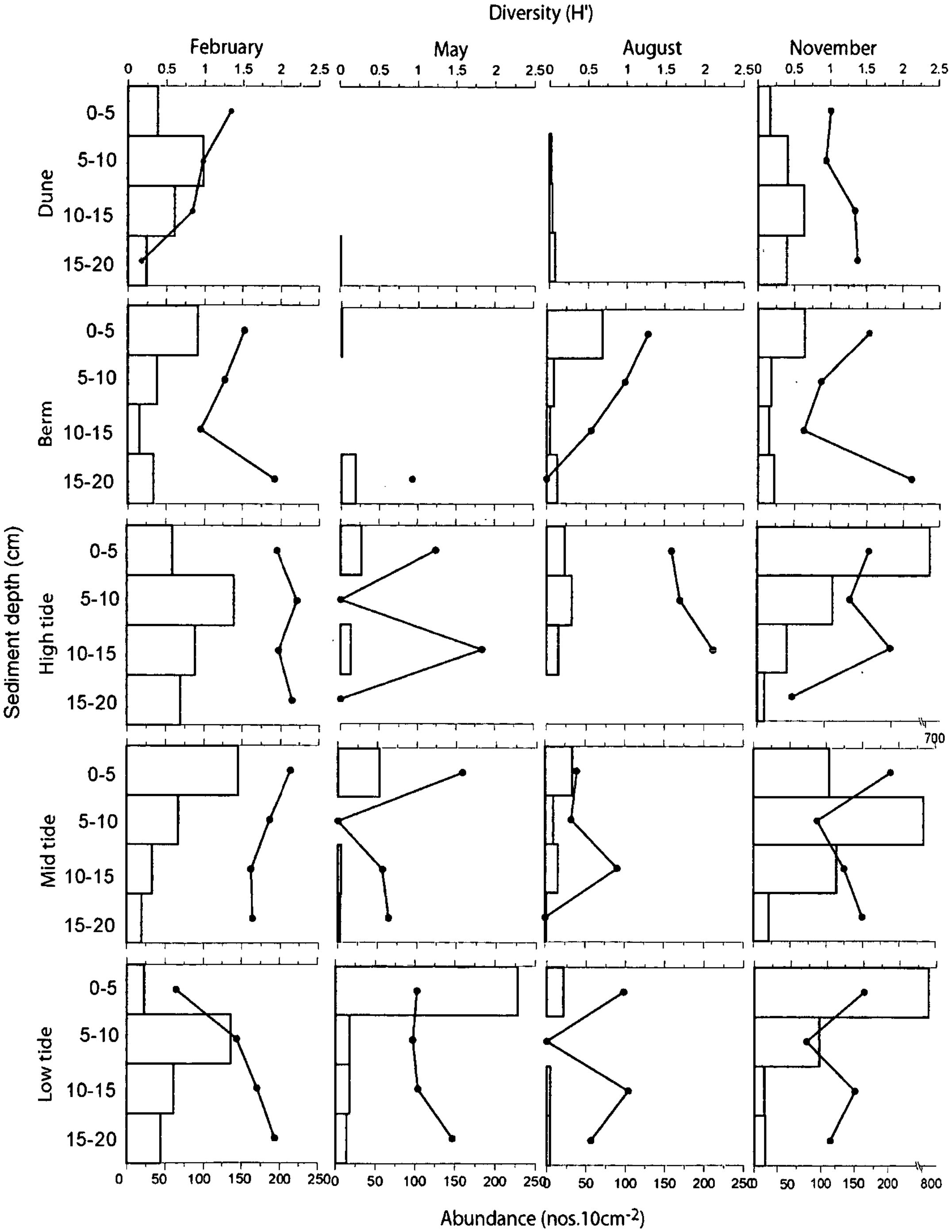

Fig 5.4.5: Nematode abundance (histogram) and diversity-*H'* (•) at each sediment depth for all beach location on a single transects during each season.

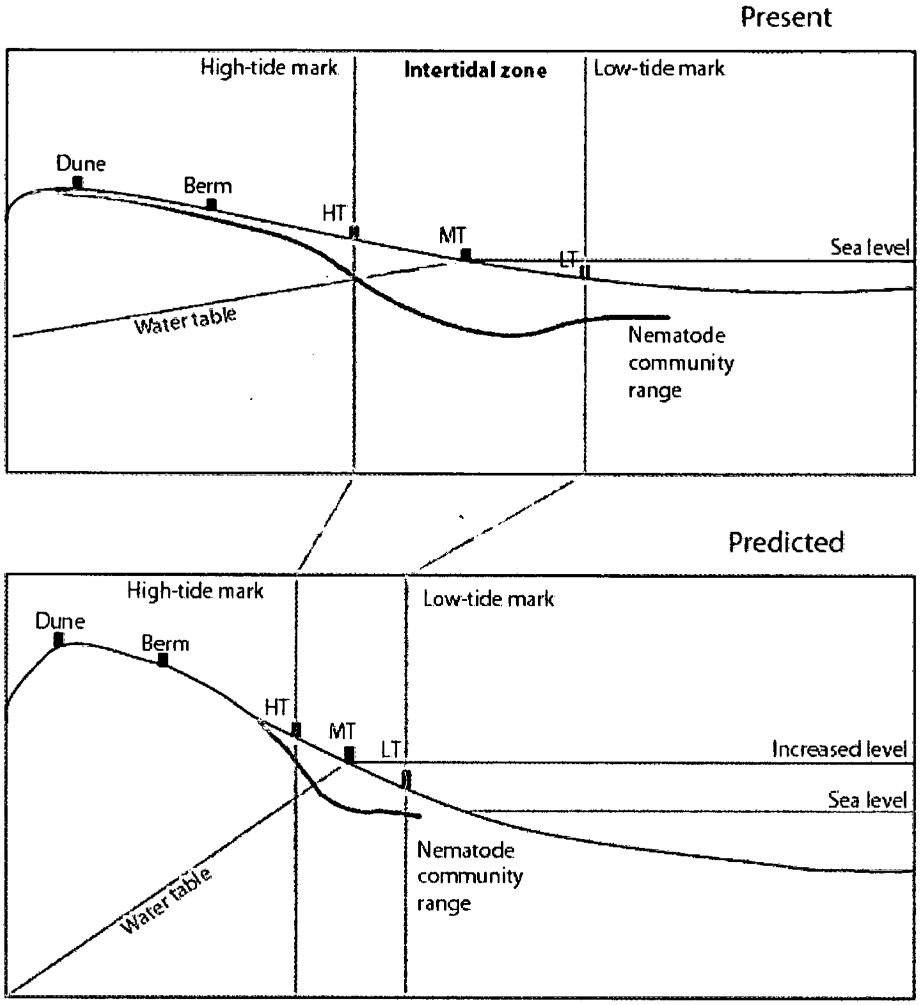

Fig 5.4.6: Schematic diagram for comparison of habitat available for nematode community at present and in predicted scenarios (IPCC 2001; figure modified from Davidson-Arnott, 2005).

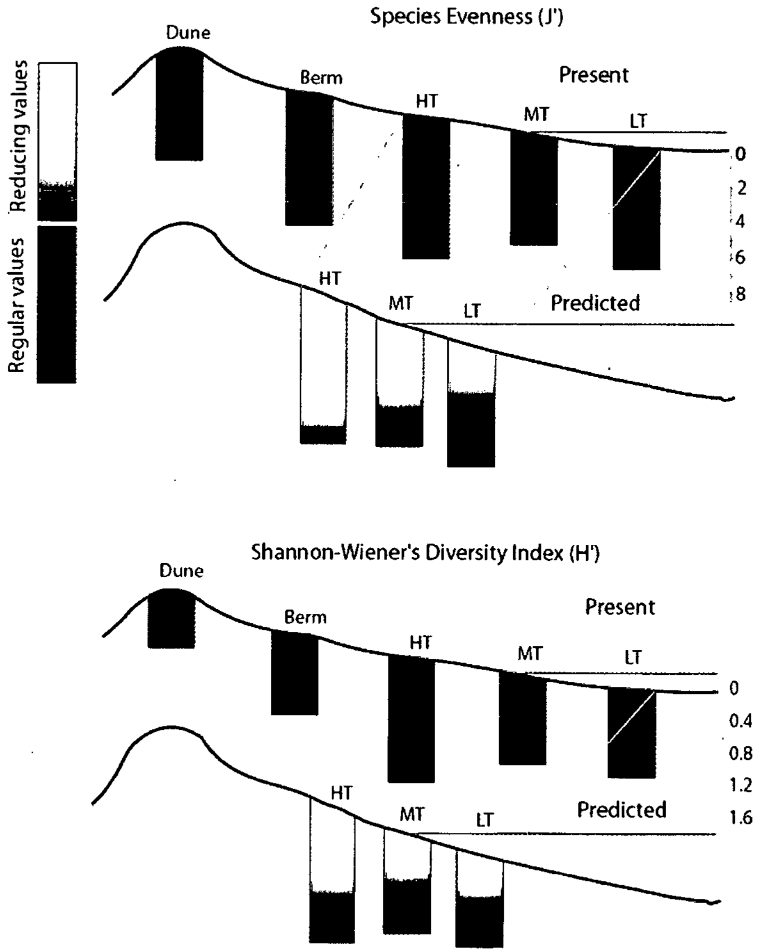

Fig 5.4.7: Fate of the nematode community (Species richness, Evenness and Diversity) based on the IPCC predictions.

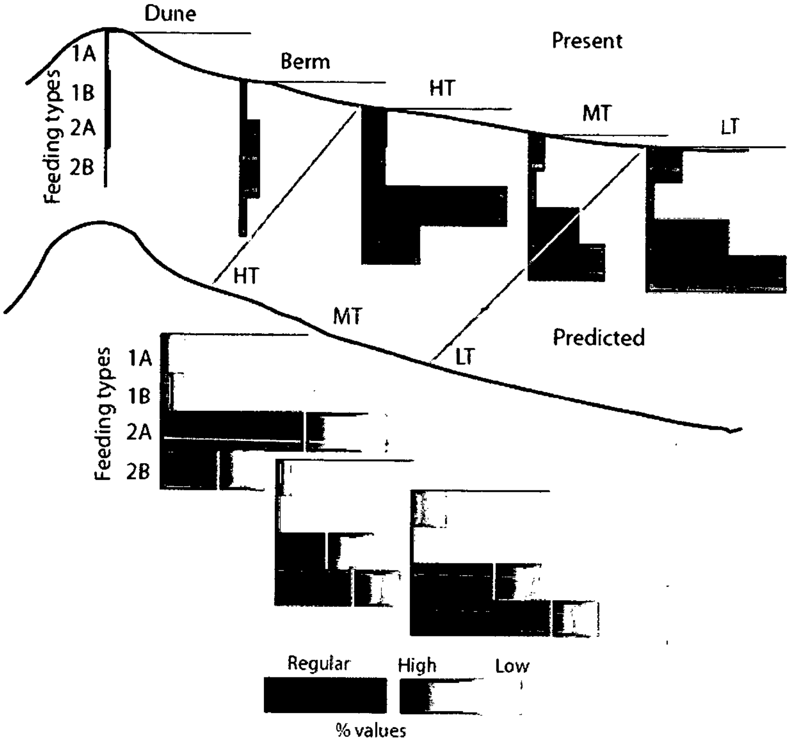

Fig 5.4.8: Fate of the nematode feeding types (%) based on the IPCC predictions.

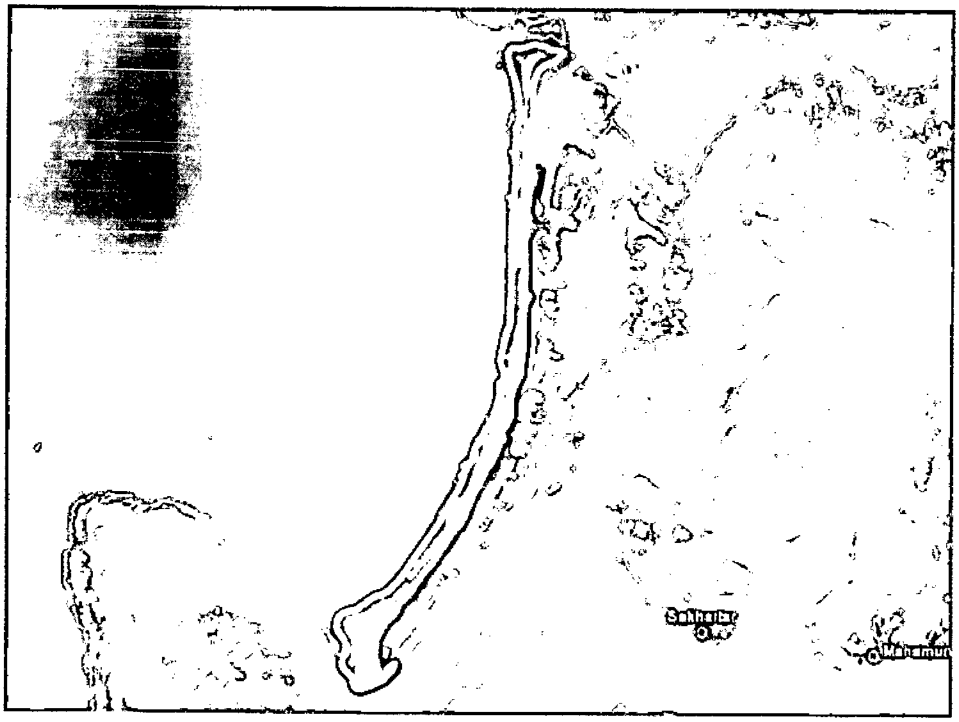

Fig 5.4.9: Map of Kalbadevi beach showing beach area that will be lost after 1m rise in sea level.

Conclusions

Conclusions:

Present study provides a comprehensive account of marine nematode communities from different benthic habitats of the central west coast of India. It also contributes the use of marine nematodes as environmental indicator in anthropogenically disturbed areas. A total of 88 nematode species were recorded from the subtidal regions along the central west coast where in *Terschellingia longicaudata* was the dominant with wider distribution. The various intertidal habitats explored once accounted for 74 nematode species and number is likely to increase as the data presented is based on preliminary screening of the samples. The sandy beach nematode community dynamically changes temporally and shows a marked seasonality significantly influenced by monsoon. An organically polluted sewage discharge site consisted of 21 species while the subtidal areas around three major harbours were represented by 50 nematode species. These sites were mostly dominated by opportunistic and pollution indicator species such as *Daptonema* sp., *Sabatieria* sp1, *Sabatieria* sp2., *Vasostoma* sp. and *Marylynnia* sp. Sediments of the oxygen minimum zone accounted for 31 species and were restricted to the top 3cm layer, largely due to the depleted oxygen conditions and other oceanographic processes involved therein. Lastly, the predictions of contemporary global change influencing the benthic community revealed a great negative impact on nematode diversity. A brief summary of findings for each section is provided bellow:

- The subtidal region of the central west of India is highly diverse in terms of number of nematode species. A cosmopolitan *Terscellingia longicaudata* was the most widely distributed species in this region.

- Among the intertidal habitats, sandy beaches harbour low nematode diversity as well as abundance compared to mangroves and mudflats. Lower representation of nematode community is attributed to the reflective nature of the beaches, larger grain size and lower organic matter retention. Mudflats and the mangroves harbour high diversity and nematode abundance, primarily due to the availability of fine particle size, high flux of organic matter reaching the sediments and sheltered habitat type.

- Notable seasonal variation in the nematode community was observed on different zones of a sandy beach. Monsoon was most critical factor that reduced the diversity and nematode abundance. Spatially, the berm and the dune regions exhibit highly stressed habitat for many species to exist due very low moisture content in these zones. A clear spatio-temporal variation occurs largely influenced by monsoon. During monsoon, most of the dominant species collapse in population and only few resistant species survived with low abundance significantly due to physical forcing of tides, wave action and increased fresh water flux. The post monsoon is the stable season for population recovery while pre monsoon is the most conducive for population growth.

- Opportunistic nematode *Daptonema* sp dominates the sewage discharge point indicating a stressed and organically polluted habitat. As the distance increases from sewage discharge point, a clear gradient of decreasing pollution coincides with the decreasing dominance of the detritivorous and opportunistic species. Nematode abundance shows a reversing trend along the gradient when compared with earlier data.

- The dominance of opportunistic and pollution indicator species reveal stressed benthic environment in three major harbours. Comparatively, Ratnagiri was the most stressed and Karwar being the least polluted benthic environment.

- OMZ restrict the vertical distribution of nematode. The Arabian Sea anoxia and the seasonal organic matter flux influence the benthic community distribution directly or indirectly in the OMZ region.

- Human induced global change will have the greatest negative impact at the land-sea-interface and sandy beaches will be the most affected habitats. Multiple changing parameters such as sea level, temperature, salinity, pH, carbon, tidal regime, wave action and seasonal shifts will have devastating impact on the beach fauna. Small size benthic communities such as nematodes will be greatly impacted altering their diversity abundance, resource availability and life history pattern.

- Finally, the increase in sea level (IPCC) will have a potentially negative impact on beach flora and fauna thereby reducing the habitable zones for much of the benthic biodiversity.

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Publications

Cah. Biol. Mar. (2010) 51 : 9-18

Comparison of tropical nematode communities from three harbours, west coast of India

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Abstract: The three major harbours from the central west coast of India were investigated for their benthic environmental status using nematodes as surrogate community. As these three harbours have shown deteriorated conditions revealed from macrobenthic community, our main objective was to investigate and inter-compare the nematode communities within these harbours and with other similar habitats worldwide. A total of 50 nematode species was encountered in the study area, wherein highest (34 species) were recorded at Mormugao harbour and lowest (23 species) at Ratnagiri harbour. The presence of dominant species like *Vasostoma* sp. (41%), *Sabatieria* sp.1 (23%) and *Sabatieria* sp.2. (20%) designate these harbours as altered benthic habitats under stress. The diversity indices demonstrate Ratnagiri harbour as the most stressed and Karwar being the least stressed comparatively. Intense anthropogenic activities, input of many pollutants such as heavy metals, pesticides, petroleum derivatives, TBT's and dredging activity in the harbours can be held responsible for the altered nematode community.

Résumé : *Comparaison des communautés de nématodes tropicaux de trois ports de la côte occidentale de l'Inde.* Les trois principaux ports de la côte occidentale centrale de l'Inde ont été prospectés afin de déterminer le statut du système benthique via l'étude de leur communauté de nématodes. Ces trois ports montrant des signes de détérioration des conditions environnementales révélées par l'état de leurs communautés macrobenthiques, notre objectif principal était de prospecter et de comparer les communautés de nématodes de ces ports entre eux et avec d'autres habitats au niveau mondial. Un total de 50 espèces de nématodes a été récolté, le plus grand nombre dans le port de Mormugao (34 espèces) et le plus petit dans le port de Ratnagiri (23 espèces). La présence d'espèces dominantes telles que *Vasostoma* sp. (41%), *Sabatieria* sp.1 (23%) et *Sabatieria* sp.2 (20%) indiquent que les habitats benthiques de ces ports sont altérés et sous stress. Les indices de diversité montrent que le port de Ratnagiri représente le milieu le plus stressé et celui de Karwar le moins stressé. Les intenses activités humaines, les apports de nombreux polluants tels que métaux lourds, pesticides, dérivés du pétrole, TBT, ainsi que les activités de dragage peuvent être tenus pour responsables de la dégradation de la communauté.

Keywords: Marine nematodes • Harbour pollution • Benthic health • Indicator species • West coast • India

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Reçu le 17 août 2009 ; accepté après révision le 2 février 2010.
Received 17 August 2009; accepted in revised form 2 February 2010.

Introduction

Harbours, as a major interface between coastal cities and the sea, are often under heavy pressure from human activities and increasingly suffer from environmental risks linked to poor water and sediment quality (Estacio et al., 1997). The central west coast of India has dense human habitation and is an industrial belt along with extensive agriculture. The harbours in this region have heavy traffic, which all together increases the stress on this environment. All the three harbours in the study area are situated on the river mouth.

Benthic communities have been extensively used in assessing the health of marine environment and biodiversity (Millward & Grant, 2000; Dovgal et al., 2008; Ingole et al., 2009) and in the present study area macrobenthos indicated a stressed benthic environment (Alongi, 1990; Ingole et al., 2009). Further investigations for a better picture of pollution status by using meiobenthic taxa for assessment have been suggested, which hold certain advantages (Gyedu-Ababio et al., 1999). No pelagic dispersal stages, higher species richness than macrofauna (Moore & Bett, 1989) and exhibit differential response to stress makes meiofauna a sensitive indicator of stress (Gyedu-Ababio et al., 1999). Within meiobenthos, nematodes are an excellent taxon as ecological indicators of benthic environment (Schratzberger et al., 2000). They have a ubiquitous distribution, with high density and diversity (with a range from very tolerant to very sensitive species) and short generation time (Heip et al., 1985).

We investigated the three harbour sediments from the central west coast of India for the status of benthic environment using marine nematodes as surrogates. Ratnagiri, Mormugao and Karwar harbours from the west coast of India are peculiar in the nature of activities where Ratnagiri is mainly a fishing harbour. Mormugao is mainly used for ore transport as 80% of India's inland waterway traffic is in this estuarine system for ore transportation and it operated about 39 billion tons in the last 3 years. Karwar is an intermediate port with more than 6 lakh tonnes of traffic each year.

The objective of the present study was firstly, to investigate and inter-compare the benthic environment of the harbours using nematode communities and predefined pollution indictor species. Secondly, to document an inventory of nematode community from this tropical estuarine region and compare it with other similar habitats worldwide.

Materials and Methods

Study area

Field sampling was conducted at Mormugao, Karwar and Ratnagiri (Fig. 1). The Mormagao harbour is situated on the mouth of Zuari estuary along the Goa coast (15°27'48"N-73°38'64"E) one of the oldest major ports on the west coast of India ranks within the first 10 leading iron ore exporting ports of the world. Ratnagiri harbour is situated (17°00'38"N-73°15'34"E) along Maharashtra coast and deals with transport of cement, chemicals and petroleum products because of recent industrial development in the region. Karwar port is a natural all weather harbour situated in north Karnataka (14°50'36"N-73°54'55"E) on the mouth of the river Kali.

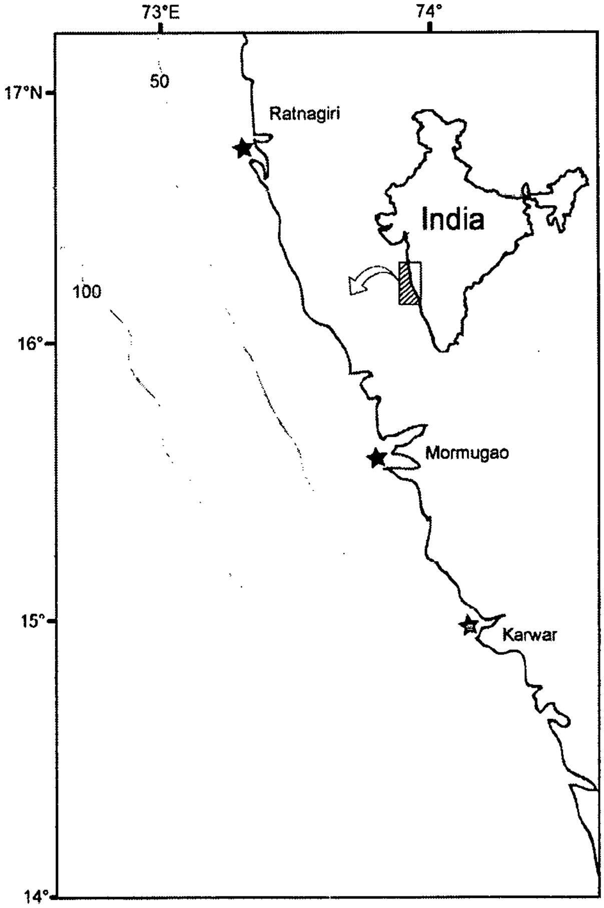

Figure 1. Location of the study sites (* showing the harbour locations).

Figure 1. Localisation des sites étudiés (* indique la localisation des ports).

Sample collection

Samples were collected onboard *CRV Sagar-Sukti* (SaSu-105) during January 2006 with a van-Veen grab (0.11 m^2). Five grabs were operated in each harbour at approximately 100 m distance. Two sub-samples from each grab were collected up to 5 cm depth with an acrylic core (4.5 cm diameter) for the analysis of meiobenthic nematodes. Samples were immediately preserved in 5% buffered Rose Bengal formalin solution. In laboratory, the samples were sieved with a 45 µm mesh sieve and all the nematode specimens were handpicked and temporary glycerol mount were prepared for taxonomic identification. Abundance (mean ± standard deviation SD) is given in ind.10 cm^{-2}. Identification was done up to lowest possible level using pictorial key by Warwick et al. (1998). Depth, temperature and salinity were measured at each sampling station using a CTD (Seabird®). Bottom water dissolved oxygen was measured by Wrinkler's method. At each station, sediment sample was taken separately with an acrylic core (Ø 4.5 cm) for the analysis of sediment chlorophyll, phaeo-pigment and organic carbon. Chlorophyll-*a* (Chl-*a)* and phaeo-pigment were analysed by acetone extraction method and organic carbon was estimated with CO_2 Coulometer after acidification of sediment to remove the inorganic carbon. All the environmental parameters for water and sediment were taken in duplicate for each harbour.

Data analysis

Margalef's species richness (*d'*), Shannon-Weaver diversity function (*H'*), Pielou's evenness (*J'*) and Simpson's dominance ($1\text{-}\lambda$) were performed on the namatode community. Bray-Curtis similarity cluster was constructed based on log transformed $\log_{10}$ (x+1) nematode species abundance. *k*-dominance curve were plotted for comparison between each harbours. Formal significance tests for differences in nematode community structure between habitats were performed using one-way ANOVA and one-way ANOSIM test. SIMPER analysis was conducted for the differences between the harbours based on species dissimilarity. Percent species contribution was plotted using geometric class. All the diversity functions for nematode species were calculated using PRIMER 6 statistical package. The maturity index (MI) was calculated as the weighted mean of the individual taxon scores (Bongers et al., 1991):

$$MI = \Sigma\, v\,(i) \times f\,(i) \qquad (1)$$

Where, v is the colonisers-persisters (*c-p*) value of taxon *i* (as given in Appendix A by Bongers et al., 1991) and *f* is the frequency of that taxon in a sample. They were sorted into functional groups according to Wieser (1953):

- 1A: selective deposit feeders: nematodes with a very small unarmed buccal cavity
- 1B: non-selective deposit feeders: nematodes with unarmed buccal cavities of moderate size
- 2A: epistratum feeders: nematodes with medium size buccal cavities, provided with small teeth
- 2B: predators or omnivores: nematodes with wide buccal cavities, large teeth or other powerful buccal structures.

1B/2A ratio was calculated for knowing the status of harbours where 2A group are a constant factor but that contamination is associated with a relative increase in the 1B group. This can be conveniently expressed as a 1B/2A ratio.

Results

Environmental variables

The average water depth at Ratnagiri and Karwar harbour was 20 m whereas at Mormugao it was 25 m. No much variation was observed for bottom water temperature (mean = 26.6°C). Salinity was highest (35.43) at Mormugao and lowest (34.76) at Karwar. Bottom water dissolved oxygen was lowest (2.6 $ml.l^{-1}$) at Karwar and highest (4.4 $ml.l^{-1}$) at Ratnagiri (Table 1). The sediment chl-*a* values ranged from 0.18 to 0.35 $\mu g.g^{-1}$ with highest values recorded at Mormugao and lowest at Ratnagiri harbour. Sediment organic carbon ranged from 1.4% to 3.5% with highest values at Mormugao.

Table 1. Environmental parameters at the three harbours.
Tableau 1. Paramètres environnementaux de trois ports.

	Depth (m)	Temp (°C)	Salinity	DO ($ml.l^{-1}$)
Ratnagiri	20	26.6	35.30	4.40
Mormugao	25	27.5	34.76	3.00
Karwar	20	26.7	35.43	2.60

Nematode community

Overall the study area consisted of 50 nematode species, where Mormugao harbour was composed of the highest (34 species) number and Ratnagiri of the lowest (20 species) number recorded (Table 2).

The results of one-way ANOSIM confirmed the difference within the three harbours where significant difference was observed between Ratnagiri and Karwar ($p < 0.01$, Table 3) followed by Karwar and Mormugao ($p < 0.01$). The cluster analysis based on the nematode species abundance for Karwar showed a separate cluster within Ratnagiri and Mormugao (at 30% similarity). The stations

Table 2. Abundance (ind.10 cm^{-2}) of nematode species at the three harbours (Feeding types are according to Wieser, 1953)
Tableau 2. Abondance (ind.10 cm^{-2}) des nématodes de trois ports (Les types d'alimentation sont d'après Wieser, 1953).

Species	**Feeding type**	**Ratnagiri**		**Mormugao**		**Karwar**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Sabatieria sp1	1A	0.0	0.0	116.8	106.8	106.0	62.5
Terschellingia longicaudata	1A	10.9	15.1	1.8	4.1	13.5	20.3
Terschellingia sp.	1A	0.0	0.0	0.0	0.0	0.0	0.0
Siphonolaimus sp.	2B	16.2	19.9	8.4	13.9	9.7	21.8
Paramonhystera sp.	1B	15.8	31.1	7.5	16.8	1.4	3.2
Daptonema sp.	1B	32.8	42.6	11.5	17.9	20.7	28.5
Dorylaimopsis sp.	2A	2.0	4.4	0.0	0.0	0.0	0.0
Hopperia sp.	2A	0.2	0.4	0.0	0.0	0.0	0.0
Paramesonchium sp.	2B	1.6	3.6	0.0	0.0	7.1	15.8
Sphaerolaimus sp.	2B	48.7	56.9	13.7	15.6	16.9	22.2
Cheironchus sp.	2B	5.9	13.3	0.0	0.0	0.7	1.6
Bathyeurystomina sp.	1B	0.0	0.0	0.0	0.0	1.4	3.2
Polygastrophora sp.	2B	0.0	0.0	2.0	4.6	16.9	18.4
Oxystomina sp.	1A	2.0	4.4	0.0	0.0	0.7	1.6
Linhomoeus sp.	1B	0.0	0.0	0.0	0.0	0.7	1.6
Sabatieria sp2	1B	62.3	55.9	0.0	0.0	6.4	14.3
Marylynnia sp.	2A	52.1	73.3	0.0	0.0	3.2	5.3
Vasostoma sp.	2A	219.3	118.7	211.7	217.3	86.6	80.6
Adoncholaimus sp.	2B	26.5	36.5	0.0	0.0	7.2	10.7
Actarjania sp.	2A	7.9	17.7	0.0	0.0	0.0	0.0
Microlaimus sp.	2A	3.6	5.0	0.0	0.0	0.0	0.0
Comesomoides sp.	2A	2.0	4.4	0.0	0.0	0.0	0.0
Enoplolaimus sp.	2B	14.2	17.1	0.0	0.0	0.0	0.0
Chromadorita sp.	2A	0.0	0.0	0.2	0.4	0.0	0.0
Paralinhomoeus sp.	1B	0.0	0.0	0.2	0.4	0.0	0.0
Halalaimus sp.	1A	0.0	0.0	12.4	16.4	12.1	17.2
Axonolaimus sp.	1B	4.7	10.5	15.2	16.8	20.8	23.0
Theristus sp.	1B	9.5	15.4	23.2	34.0	7.1	16.0
Paracomesoma sp.	2A	4.7	10.5	11.9	15.4	11.6	16.6
Metacomesoma sp.	1B	2.4	5.3	0.0	0.0	0.0	0.0
Pierrickia sp.	1A	30.8	68.8	0.0	0.0	0.0	0.0
Unidentified 2	2A	12.3	27.5	3.7	8.2	0.0	0.0
Microlaimidae	2A	0.0	0.0	40.0	45.7	17.0	23.7
Quadricoma sp.	1A	0.0	0.0	0.0	0.0	0.0	0.0
Metacyantholaimus sp.	2A	0.0	0.0	2.0	4.6	50.9	107.7
Viscosia sp.	2B	0.0	0.0	0.8	1.9	0.0	0.0
Chromadora sp.	2A	0.0	0.0	0.2	0.4	0.0	0.0
Araeolaimus sp.	1A	0.0	0.0	2.0	4.6	0.0	0.0
Unidentified	2A	0.0	0.0	6.1	13.7	16.7	20.4
Odontophora sp.	1B	0.0	0.0	11.6	17.0	2.5	5.5
Pomponema sp.	2A	0.0	0.0	7.5	16.8	9.7	21.8
Unidentified 3	1A	0.2	0.4	0.0	0.0	0.0	0.0
Paralinhomoeus sp.	1B	0.0	0.0	0.0	0.0	2.5	5.5
Anticyathus sp.	1B	0.0	0.0	0.0	0.0	2.5	5.5
Trichotheristus sp.	1B	0.0	0.0	0.0	0.0	23.9	37.6
Choanolaimus sp.	2B	0.0	0.0	0.0	0.0	4.9	11.0
Polysigma sp.	2A	0.0	0.0	0.0	0.0	24.4	42.5
Trissonchulus sp.	2B	0.0	0.0	0.0	0.0	2.2	5.0
Platycoma sp.	2A	0.0	0.0	0.0	0.0	9.7	21.8
Enoplolaimus sp.	2B	0.0	0.0	0.0	0.0	0.2	0.4
Total species	**50**	**20**		**34**		**23**	
Percent diversity	**100**	**26**		**44**		**30**	

Table 3. ANOSIM for the difference between each harbour based on nematode species abundance (Global R = 0.329).

Tableau 3. ANOSIM pour la différence entre chaque port basé sur l'abondance des nématodes (R global = 0,329).

	R	p
Karwar, Ratnagiri	0.62	0.008
Karwar, Mormugao	0.41	0.008
Mormugao, Ratnagiri	0.01	0.429

within Ratnagiri and Mormugao did not show similarity depicting varied abundance for both the harbours (Fig. 2).

The average diversity indices showed highest mean values at Mormugao (Table 4). The species richness (*d'*) was highest at Mormugao (1.74) followed by Karwar (1.34). The Shannon-Weaver's diversity (*H'*) was also highest at Mormugao (2.06) and Karwar (1.85) while all the indices including Maturity Index (MI) showed low values at Ratnagiri (Table 4).

There was a significant difference between the harbours for Shannon-Weaver diversity Index (*H'*) ($F = 5.59$, $p < 0.01$). The Simpson's Index ($1-\lambda$) also showed a significant difference ($F = 7.26$, $p < 0.01$). Maturity Index (MI) was not highly significant ($F = 3.86$, $p = 0.05$) (Table 5).

At Ratnagiri harbour *Vasostoma* sp. (219 ± 118 ind.10 cm^{-2}; Table 2) was the most dominant contributing 37% of the total community followed by *Sabatieria* sp2 (62 ± 55 ind.10 cm^{-2}, Table 2) constituting 11%. At Mormugao harbour *Vasostoma* sp. (211 ± 217 ind.10 cm^{-2}) was the dominant species with 41% contribution followed by *Sabatieria* sp.1 (116 ± 106 ind.10 cm^{-2}) contributing 23%. At Karwar harbour *Vasostoma* sp. (86 ± 80 ind.10 cm^{-2}) was dominant with 17% of the total followed by *Sabatieria* sp.1 (106 ± 62 ind.10 cm^{-2}) with 20% contribution. 'Others' constituted 43% of the total community (Fig. 3). The cumulative dominance curve for the three harbours showed the difference with Ratnagiri harbour being the least diverse with more dominance whereas Mormugao harbour was with higher diversity and lower dominance (Fig. 4).

The geometric class plot constructed depicts the least number of species with least abundance in the initial classes for all the three sites. Wherein the Ratnagiri and Karwar harbours are represented by 11 classes (Fig. 5) and Mormugao harbours is represented by 10 classes (Fig. 5).

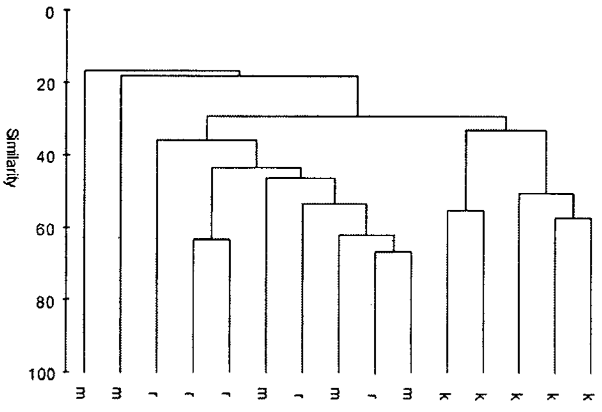

Figure 2. Cluster analysis based on the nematode species abundance for all sampling stations from the three harbours (r-Ratnagiri, m-Mormugao and k-Karwar).

Figure 2. Analyse par groupement fondé sur l'abondance spécifique des nématodes dans chaque échantillon des trios ports (r- Ratnagiri, m-Mormugao and k-Karwar).

Table 4. Diversity indices and percent feeding types (Wieser, 1953) at each harbour (mean of 5 replicates).

Tableau 4. Indices de diversité et pourcentage des types d'alimentation (Wieser, 1953) à à chaque port (moyenne de 5 replicats).

Diversity indices	**Ratnagiri**		**Mormugao**		**Karwar**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Species (*S*)	21	3.36	32	2.30	23	1.79
Abundance (*N*)	510	476.88	518	2335.17	588	336.87
Richness (*d'*)	1.26	0.46	1.74	0.43	1.34	0.36
Evenness (*J'*)	0.80	0.11	0.85	0.04	0.84	0.06
Shannon-Weaver (*H'*)	1.62	0.23	2.06	0.25	1.85	0.12
Simpsons Index ($1-\lambda$)	0.73	0.06	0.84	0.05	0.79	0.03
Maturity Index (MI)	2.25	0.09	2.57	0.29	2.29	0.16
Feeding types (%)						
1A	13		5		19	
1B	26		26		7	
2A	44		55		52	
2B	17		14		22	
Ratio 1B / 2A	0.39		0.24		0.42	

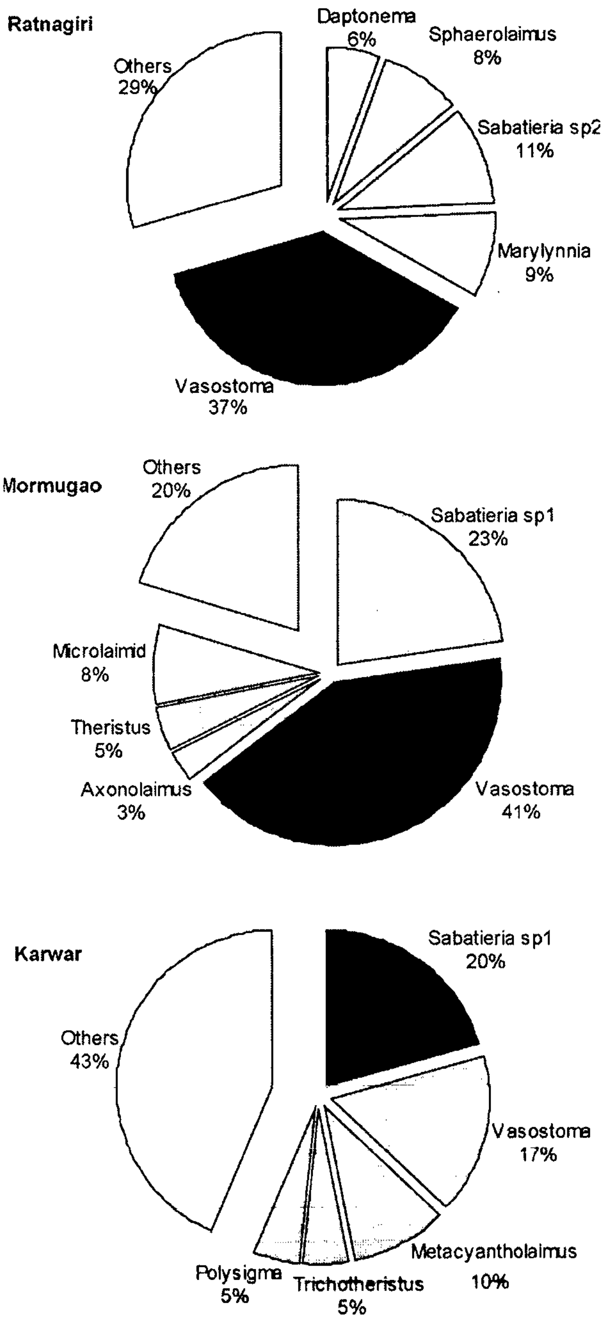

Figure 3. Percent contribution of dominant species in the three harbours.

Figure 3. Pourcentage de contribution des espèces dominantes dans les trois ports.

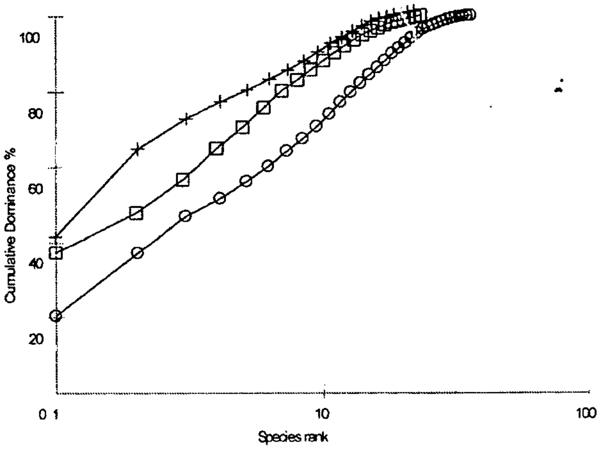

Figure 4. Cumulative species dominance for the three harbours (□: Karwar, +: Ratnagiri, O:Mormugao).

Figure 4. Courbes de dominance cumulée des espèces dans les trois ports (□ : Karwar, + : Ratnagiri, O : Mormugao).

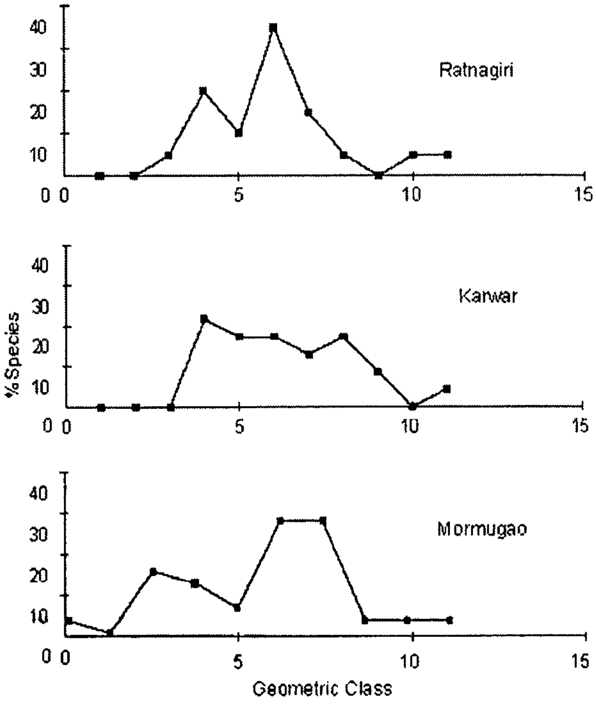

Figure 5. Geometric class of nematode species abundance from the three harbours.

Figure 5. Classe géométrique des abondances spécifiques des nématodes des trois ports.

Simper analysis revealed the contribution of the important species for the dissimilarity between the harbours where the species cumulative contribution of more than 50% were considered. The average dissimilarity between all the harbours ranged between 68.30 to 78.5%. Between Karwar and Ratnagiri harbour the major species contributing dissimilarity was *Vasostoma* sp. (23.25%) followed by *Sabatieria* sp.1 (13.93%) and the same two species contributed for difference between Karwar and Mormugao (17.93 and 12.41% respectively). *Vasostoma* sp. (22.67%) and *Sabatieria* sp.1 (13.8%) for difference between Ratnagiri and Mormugao (Table 6).

Epistrate feeders (2A) were the most dominant feeding group contributing 44% at Ratnagiri, 55% at Mormugao and 52% at Karwar. The second dominant feeding type was Non-selective deposit feeders (1B) at Ranagiri and Mormugao with 26% each, whereas at Karwar it was Predatory/omnivores (2B) with 22% contribution. The ratio for 1B/2A varied from 0.24 to 0.42 at all the three harbours (Table 4).

Discussion

The meiobenthic nematodes are bound to the sediment throughout their life history and therefore are sensitive to many toxicants (Coull & Chandler, 1992). They are considered to be good candidate organisms for environmental quality assessment of harbours (Liu et al., 2008; Moreno et al., 2008) because the overall community response is species specific.

Present study accounted for a total 50 nematode species from the three estuarine benthic environments where there was influence of river discharge, harbour activities and other anthropogenic inputs. We compare the species richness with other estuarine areas where same numbers of genera were recorded from Swartkops estuary (Gyedu-Ababio et al., 1999) but a subtropical harbour had 127 species (Liu et al., 2008). Fewer species (43 and 44 genus/species) were observed at Genoa-Voltri Legurian Sea and Ems estuary, respectively (Moreno et al., 2008) in the heavily polluted estuaries. Around 200 species were recorded for 5 unpolluted estuaries of Western Europe. A very low (27) number of species was reported from an estuarine region, which was organically polluted (Essink & Romeyn, 1994) and accordingly it may be conclude from the low number of species that the present study area seems to be a grossly polluted benthic environment.

Low nematode species diversity was observed at Ratnagiri harbour, which was conformed by the *k*-dominance plot recommended to be used after using diversity indices in a polluted habitat (Platt et al. 1984). Within Karwar harbour, a very similar nematode community (Fig. 2) suggests a homogeneous environment compared to Ratnagiri and Mormugao. Karwar harbour showed a significant difference with the other two harbours (Table 3) as Ratnagiri and Mormugao both had a high abundance of dominant species. The dominant species in the present study were *Vasostoma* sp., *Sabatieria* sp.1, *S.* sp.2, *Merylinnia* sp. and *Daptonema* sp. Which are all members of epistrate and non-selective deposit feeder (Wieser, 1953) and have been reported dominant mostly from anoxic, degraded and polluted habitats. The indicator species encountered in the present study such as *Sabatieria* sp. (Vanreusel, 1990; Vincx et al., 1990; Boyd et al., 2000; Mirto et al., 2002), *Merylinnia* sp. (Mahmoudi et al., 2007) and *Sphaerolaimus* sp. (Gyedu-Ababio et al., 1999) are again known to inhabit stressed and anoxic sediments. The presence of many subdominant species (Table 2) was also an indication of pollution and dredging activity, e.g. *Terschellingia* sp. (Vanreusel, 1990; Vincx et al., 1990), *Dorilaimopsis* sp. (Vincx et al., 1990; Mirto et al., 2002), *Daptonema* sp. (Vanreusel & Vincx, 1989; Boyd et al., 2000), *Axonolaimus* sp. (Gyedu-Ababio et al., 1999), *Oxystomina* sp. (Mirto et al., 2002), *Theristus* sp. (Gyedu-Ababio et al., 1999).

Table 5. One way ANOVA for all the nematode diversity indices (*df*: 2 and residual error for *df*: 12).

Tableau 5. ANOVA pour tous les indices de diversité des nématodes (df : 2 et erreur résiduelle pour df : 12).

Source of Variation	*F*	*P-value*
Species (*S*)	1.90	0.190
Abundance (*N*)	0.85	0.448
Richness (*d'*)	1.87	0.195
Evenness (*J'*)	0.72	0.505
Shannon-Weaver (*H'*)	5.59	0.019
Simpsons Index (1-λ)	7.26	0.008
Maturity Index (MI)	3.86	0.050

The analysis of variance showed a significant differentiation between the harbours for the diversity indices such as the Shannon-Weaver (H') and Simpson's indices (Table 5) overall suggesting that the three harbours are influenced at varying degrees resulting in different communities.

Although these harbours are known to have high organic inputs which influenced the macrobenthic community (Ingole et al., 2009), the nematode community showed lower 1B/2A ratios (less than 0.5, Table 4) which suggests that more of fresh productivity was consumed by nematode community rather than the organic matter. This depicts that unlike macrofauna (Alongi, 1990; Ingole et al., 2009) high input of organic matter does not necessarily influence the nematode community structure.

Pollutants have shown considerable influence on nematodes (Millward & Grant, 2000) and the impact of a

Table 6. Percent contribution of dominant nematode species by SIMPER analysis for each harbour representing cumulative dominance of more than 50%.

Tableau 6. Pourcentage de la contribution des nématodes dominants par l'analyse SIMPER pour chaque port représentant la dominance cumulative de plus de 50%.

	Group 1 Average Abundance	**Group 2 Average Abundance**	**Average dissimilarity**	**Dissimilarity SD**	**Contribution %**	**Cumulative %**
Groups Karwar & Ratnagiri						
Average dissimilarity = 71.07						
Vasostoma *sp.*	219.32	211.66	16.52	1.79	23.25	23.25
Sabatieria sp1	0.0	116.78	9.90	1.64	13.93	37.18
Sabatieria sp2	62.25	0.00	6.78	1.28	9.54	46.72
Marylynnia *sp.*	52.09	0.00	3.98	0.72	5.6	52.32
Groups Karwar & Mormugao						
Average dissimilarity = 78.59						
Vasostoma *sp.*	219.32	86.60	14.09	1.56	17.93	17.93
Sabatieria sp1	0.0	105.97	9.75	1.84	12.41	30.34
Sabatieria sp2	62.25	6.38	5.33	1.57	6.78	37.12
Metacyantholaimus *sp.*	0.0	50.93	4.43	0.50	5.64	42.76
Marylynnia *sp.*	52.09	3.16	3.88	0.82	4.94	47.70
Sphaerolaimus *sp.*	48.67	16.93	3.68	1.28	4.68	52.37
Groups Ratnagiri & Mormugao						
Average dissimilarity = 68.30						
Vasostoma *sp.*	211.66	86.60	15.48	1.56	22.67	22.67
Sabatieria sp1	116.78	105.97	9.42	1.67	13.8	36.47
Metacyantholaimus *sp.*	2.04	50.93	5.06	0.50	7.41	43.88
Microlaimidae	39.98	16.96	3.42	1.25	5.00	48.88
Polysigma *sp.*	0.00	24.40	2.55	0.59	3.73	52.61

single factor (organic matter in the present case) cannot be considered valid for the community as these harbours have combinations of pollution inputs. High abundance of many species and few representatives of rare species (Fig. 5) can be due to the integrated impact of several anthropogenic activities in the harbour region (Alongi, 1990). The altered diversity, average lower MI (Table 4, Heip et al., 1985) and the presence of many pollution indicator species in the three harbours can mainly be attributed to the toxic inputs in the region and not the organic input shown by the lowered feeding ratios (Fig. 4). Reportedly high input of pollutants in these harbour sediments such as petroleum hydrocarbons, pesticides (Sarkar et al., 2008), organotins (Jadhav et al., 2009), metals (Nair et al., 2003; Ramaiah & De, 2003; Mesquita & Kaisary, 2007) and dredging activity is mainly responsible for deterioration of the harbour environment. Many nematode species such as *Rhynchonema* sp. and *Araeolaimus* sp. are known to be sensitive to pollutants and such species were absent from the study area but were reported from the adjacent habitats from the same region (Ingole et al., 2006).

Mormugao harbour is constantly subjected to contaminants from the shipping industry such as TBT, DBT and organotins (Jadhav et al., 2009) which have shown negative impact on the nematode community (Schratzberger et al., 2002) and deposition of metals such as Fe and Mn from the mining activity in the region (Mesquita & Kaisari, 2007) are also known to harm the nematode species (Gyedu-Ababio et al., 1999). Recent reports reveal an increase in the concentration of heavy metals such as mercury (Ramaiah & De, 2003) and high concentration of arsenic in all the three harbours (Nair et al., 2003). At Ratnagiri, sediments had significantly high PHC's (Chouksey et al., 2004), which had shown deleterious impact on the benthic community due to shipwrecks in this region (Ingole et al., 2006; Sivadas et al., 2008). Nematode species composition shows the dominance of opportunistic community due to stress at all the three harbours. Anthropogenic activities had gross influence in the harbours where the co-contamination of several toxicants such as petroleum products, heavy metals and pesticides show cumulative effects (Millward & Grant, 2000). Moreover, the influence of toxicological synergisms will increase with mechanical disturbance in the harbours caused by dredging. These factors together show their imprints in the nematode community of the three harbours where altered diversity and presence of dominant indicator species suggest the impact of pollution and harbour activities. Investigating such benthic indicators for the precise determination of different anthropogenic impacts on the benthic community can increase monitoring efficiency and reduce cost of scientific analysis in the future.

Acknowledgment

The authors would like to thank the Director NIO for the facilities. We also would like to thank M. Austen of PML UK for providing training for nematode identification under the Darwin World-wide pollution-monitoring program. Financial assistance was provided by the Department of Biotechnology, Govt. of India. We acknowledge the help rendered by crewmembers and all the participants of *Sagar-Sukti* cruise. This is NIO (CSIR) contribution no. 4684.

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Italian Journal of Zoology, Xxxxx 2010; 00(00): 1–9

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Spatial distribution of the nematodes in the subtidal community of the Central West Coast of India with emphasis on *Tershellingia longicaudata* (Nematoda: Linhomoeidae)

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(Received 28 November 2008; accepted 14 January 2010)

Abstract

Meiofaunal nematodes are among the most important components of the benthic environment. They have unusually high abundance and diversity. They are largely understudied in many parts of the world and explored very little from the Indian subcontinent, possibly due to lack of expertise. Meiofauna was investigated with emphasis on nematodes, which were the most dominant group and one species – *Terschellingia longicaudata* (De Man, 1907) – along the central west coast of India, stretching between Ratnagiri and Mangalore, during 2004. Maximum nematode diversity was found at the offshore location at the water depth of 35 m, while the minimum was found in the estuarine region. Nematode density was positively correlated with sediment organic matter ($r = 0.73$, $p < 0.05$). Among the 94 identified nematode species, *T. longicaudata* was one of the dominant species comprising >21% of nematodes and 15% of the total meiofaunal population. The species had high abundance at the stations mostly characterized by silty sediment. *T. longicaudata* has been hypothesized to have a global distribution and the present study, for the first time, adds to the inventory of its distribution along the central west coast of India.

Keywords: *Nematodes,* Terschellingia longicaudata, *meiofauna, west coast, India*

Introduction

Meiobenthic nematodes are among the most diverse and numerically dominant metazoans in the marine habitat (Heip et al. 1982; De Ley & Blaxter 2001), with a global species estimate (Lambshead & Boucher 2003) between 10^5 and 10^8. Despite their remarkable diversity and their potential use as indicators, nematodes are among the least studied components of meiofauna (Heip et al. 1985). Nematodes play an important role in the benthic environment by (i) mechanical breakdown of the detritus, (ii) excretion of limiting nutrients to bacteria, (iii) producing microfilm conducive to bacterial growth and (iv) bioturbating sediment around detritus (Tietjen 1980). Nematode diversity has been well documented from the Atlantic and the Pacific Ocean (Heip et al. 1985). Ingole et al. (1998, 2005, 2006) and Ingole and Koslow (2005) have studied the meiofaunal communities from the deep and continental Indian Ocean, but very few studies are available on the nematode community dynamics (Ndaro & Olafsson 1999; Muthumbi et al. 2004; Raes et al. 2007). Meiofauna (Coull & Chandler 1992; Kennedy & Jacoby 1999) and nematode communities (Bongers et al. 1991) have been widely used in bio-monitoring programmes to assess the benthic environmental health and many species are good pollution indicators (Heip et al. 1985).

The central west coast of India has unique physical settings and dynamic biogeochemistry, with intense seasonality due to the influence of monsoon, coastal upwelling, seasonal anoxia and phytoplankton bloom (Naqvi et al. 2000). The main objective of this study was to investigate the meiofaunal community and nematode species diversity from the central west coast of India, which has no past account in any literature dealing with nematode community distribution. The aim was also to investigate the

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ISSN 1125-0003 print/ISSN 1748-5851 online © 2010 Unione Zoologica Italiana
DOI: 10.1080/11250001003652601

distribution and abundance of a nematode species *Terschellingia longicaudata* from this subtidal region, as it is hypothesized that *T. longicaudata* has a cosmopolitan distribution (Bhadury et al. 2005). This nematode species has gained importance due to its ability to thrive in low oxygen sediments (Sergeeva 1991) and its presence in polluted habitats (Liu et al. 2008).

Materials and methods

Study area

Sampling sites were located along the central west coast of India (Figure 1). In total, 18 subtidal sites were selected randomly between Ratnagiri and Mangalore (Table I). Sampling locations 1 and 2 were from the marginal region, locations 3, 4 and 5–10 were from Zuari river mouth, a shallow estuarine region and 11–18 were from the shelf region. In the north, the first two stations were taken in the deeper region (500 m). The river mouth sites (Stations 5–10) were in shallower depths between 7 and 15 m. The remaining sites were in 20–100 m water depths. All the stations had silty/muddy type of sediments.

The sediment samples from the deeper depths were collected on board CRV *Sagar Sukti* (SASU-60) and *ORV Sagar Kanya* (SK-211). The sampling in the shallower locations, particularly the harbour area (Zuari river mouth), was done with a country craft. Sediment samples were collected with a van Veen grab (0.11 m^2) and by deploying a spade box corer (147.894 cm^2). Separate samples were collected for sediment chlorophyll-*a*, organic carbon and

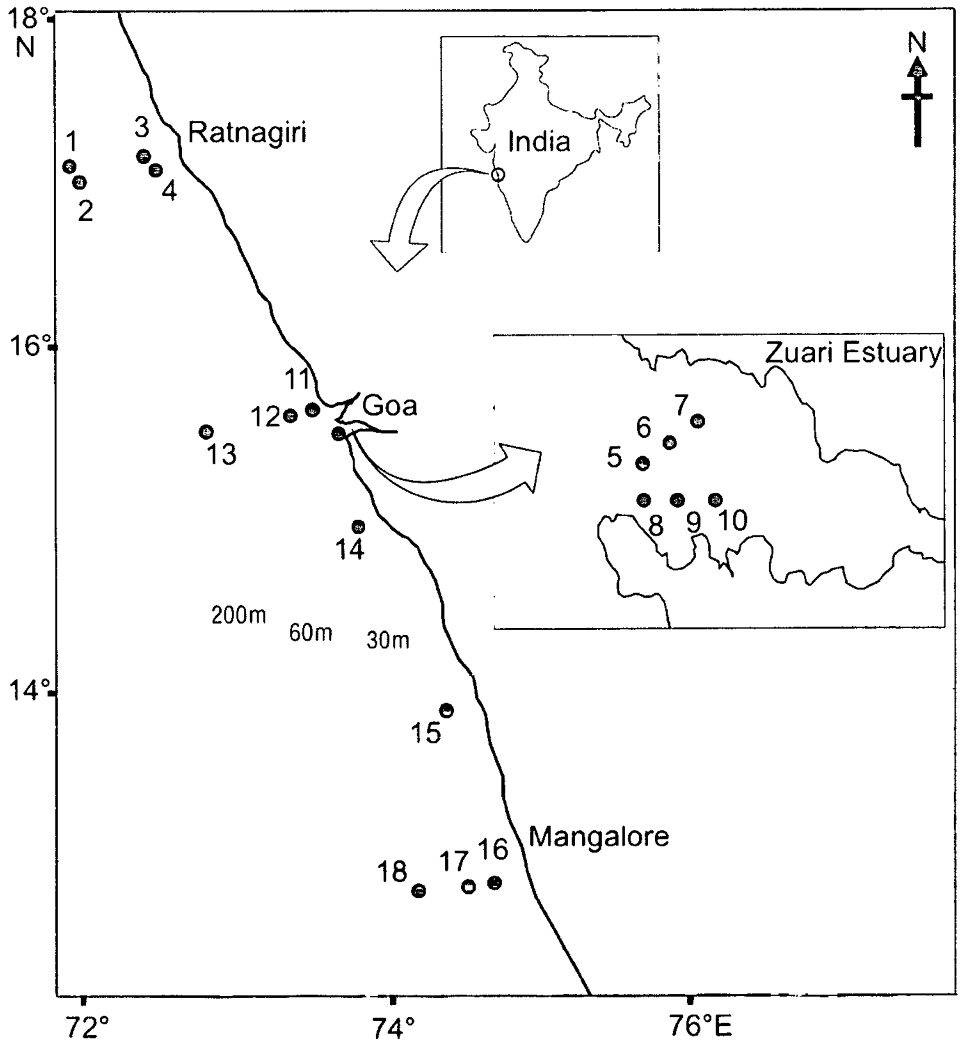

Figure 1. Station locations marked by numbers in the study area.

Table I. Stations and parameters.

Station	Lat. (°N)	Long. (°E)	Depth (m)	Substrate	Gear used	Chl (μg g^{-1})	OC (%)
1	17 30 00	71 12 00	500	Clayey	Box corer	0.11	2.17
2	17 30 00	71 12 00	500	Clayey	Box corer	0.16	1.88
3	17 30 00	72 44 00	50	Silty sand	Box corer	0.5	1.84
4	17 30 00	72 44 00	50	Silty sand	Box corer	0.19	3.56
5	15 25 02	73 48 00	15	Silty	van Veen Grab	0.04	0.58
6	15 25 40	73 48 17	9	Clayey	van Veen Grab	0.02	1
7	15 25 60	73 48 40	9	Clayey	van Veen Grab	0.02	1.55
8	15 25 00	73 48 40	8	Clayey	van Veen Grab	0.04	0.5
9	15 24 99	73 48 63	7	Clayey	van Veen Grab	0.03	1.96
10	15 25 04	73 48 85	7	Silty	van Veen Grab	0.02	1.44
11	15 30 00	73 40 00	23	Silty	van Veen Grab	0.09	0.11
12	15 30 00	73 35 00	35	Silty	van Veen Grab	3.22	0.14
13	15 30 00	73 00 00	112	Silty sand	van Veen Grab	2.21	0.14
14	15 00 00	73 45 00	43	Clayey	van Veen Grab	3.22	0.06
15	14 06 00	74 18 00	32	Silty	van Veen Grab	2.9	0.08
16	13 00 76	74 30 11	29	Silty	van Veen Grab	3.36	0.07
17	13 00 00	74 15 00	60	Silty sand	van Veen Grab	1.75	0.04
18	13 00 11	74 03 00	97	Silty	van Veen Grab	2.35	0.03

granulometry, and immediately preserved in deep freeze. The sediment chlorophyll-*a* analysis was carried out by flurometric method (Holm-Hansen et al. 1965). The organic carbon of the sediment was estimated by wet oxidation method (El Wakeel & Riley 1957). For the analysis of sediment grain size, samples were dried, weighed and sieved with a 63-μm sieve to separate the sand fraction and pipette method was employed to determine the silt and the clay fraction (Folk 1968). For meiofaunal samples, an acrylic core (4.5 cm diameter) was used to sample the top 0–5 cm sediment layer. Duplicate cores were taken from each station. All samples were immediately preserved in 5% buffered seawater formalin solution with Rose Bengal as stain. The samples were sieved with 500 μm mesh and then by 45-μm sieve. Material retained on the 45-μm sieve was investigated for meiofauna. Meiofauna was sorted under binocular stereoscopic microscope and mounted in glycerol for taxonomic identification. Meiofaunal identification up to group level was done using the key by Higgins and Thiel (1988) and the nematodes were identified up to the lowest possible taxa (genus/species) using a pictorial key by Platt and Warwick (1983, 1988) and Warwick et al. (1998). The meiofaunal abundance was converted to ind. 10 cm^{-2}. The Bray–Curtis similarity using untransformed meiofaunal and nematode abundance was made by the multi-dimensional scaling (MDS) ordination using PRIMER 6.0 software.

Results and discussion

In the open ocean, light penetration limits the benthic primary production in deeper water, restricting the availability of chlorophyll in the sediment. On the other hand, organic matter in the sediment is accumulated over a time period both from the pelagic flux as well as contribution from riverine sources (Rao & Veerayya 2000; Ingole et al. 2001). In this study there was a positive correlation between sediment organic carbon and water depth ($r = 0.32$, Figure 2).

Meiofauna is an important link between the bacteria–detritus and the carnivore level (Chardy & Dauvin 1992).

Among meiofauna; nematodes, ostracods, turbellarians, polychaetes, harpacticoid copepods, bivalves and oligochaetes were recorded from the sampling area besides hydroids, nauplii and gastropodes. The group with unidentified specimens was kept under others. The nematode density was highest at Station 3 (303 ind. 10 cm^{-2}) and lowest at Station 18 (19 ind. 10 cm^{-2}). Very high numbers of harpacticoid

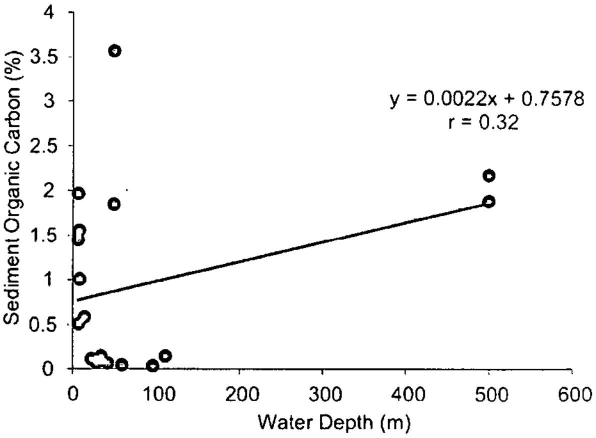

Figure 2. Correlation of water depth (m) with sediment chlorophyll-*a* (μg/g) and organic carbon (%).

copepods were seen at Station 6 (35 ind. 10 cm^{-2}) (Figure 3). Maximum numbers of meiofaunal groups were recorded at Stations 12, 16 and 17 in the study area and the minimum were at Stations 6 and 8. There was positive correlation between the sediment organic carbon and meiofaunal density ($r = 0.72$, $p < 0.05$; Figure 4). Moreover, the MDS ordinates for meiofauna abundance revealed no clear distinction of the habitats (Figure 5). The low densities of meiofauna differences were attributed to high hydrodynamic stress around the continental slope (Rao & Veeryya 2000) preventing phytoplankton from reaching the deeper sediments (Vanaverbeke et al. 2000). Moreover, higher current speed above the sediment increases the risk of the meiobenthos being eroded or suspended (Vanaverbeke et al. 2000). Low occurrence of meiofaunal groups and high percent dominance of nematodes suggests sensitivity of other meiofaunal groups to dynamic habitat compared to nematodes (Heip et al. 1985; Coull & Chandler 1992). Therefore, in-depth taxonomic resolution of the nematode community might give a better picture of the heterogeneous habitats.

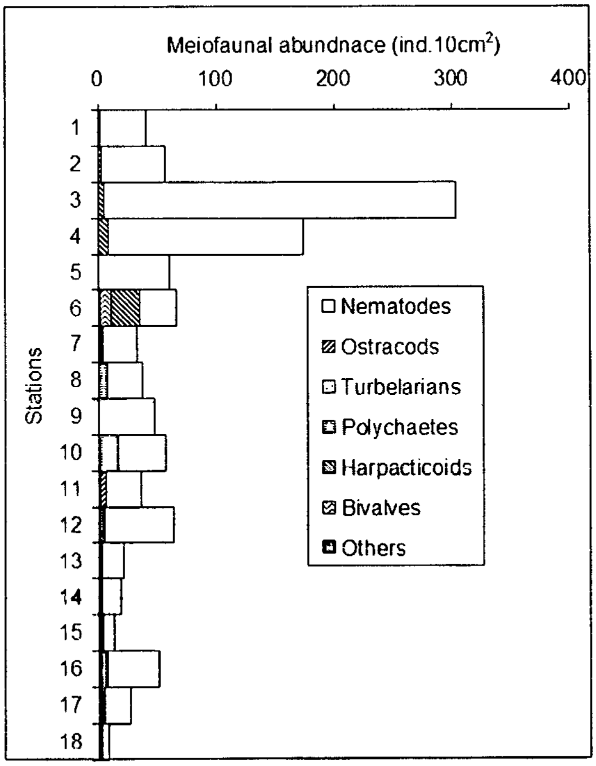

Figure 3. Abundance (ind. 10 cm^{-2}) of mieiofaunal taxa at each station.

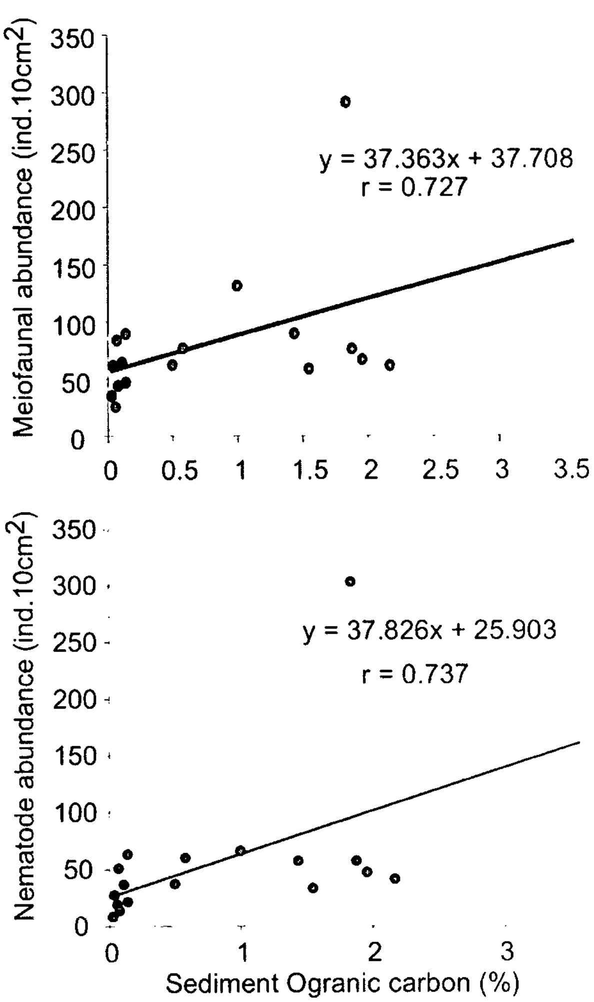

Figure 4. Correlation of meiofaunal and nematode abundance with sediment organic carbon (%).

Nematodes were found at all stations and were the most dominant with mean abundance of 84%, followed by harpacticoids and polychaetes with 5% each (Figure 3). The highest number of species (35) was found at Station 12 and lowest (07) was at Station 7 (Table II). The total number of nematode species recorded from the study area was 94 (Table II). The family Xyalidae was the most dominant and was represented by 13 out of 94 species (Table III). The MDS ordinates for nematode species abundance shows a clear differentiation between the habitats where the estuarine stations show grouping (Stations 5–10) and the shelf community can be seen separated (Stations 11–18) and the deepest (500 m; Stations 1 and 2) are again well separated from the others (Figure 5). Cluster analysis depicts that Stations 3 and 4 are part of the shelf community (Stations 11–18) while a very different estuarine community (Stations 5–10) is separated from the continental marginal (Stations 1 and 2) and shelf community (Figure 6). As Stations 3 and 4 fall in the depth range of the shelf region and share similar

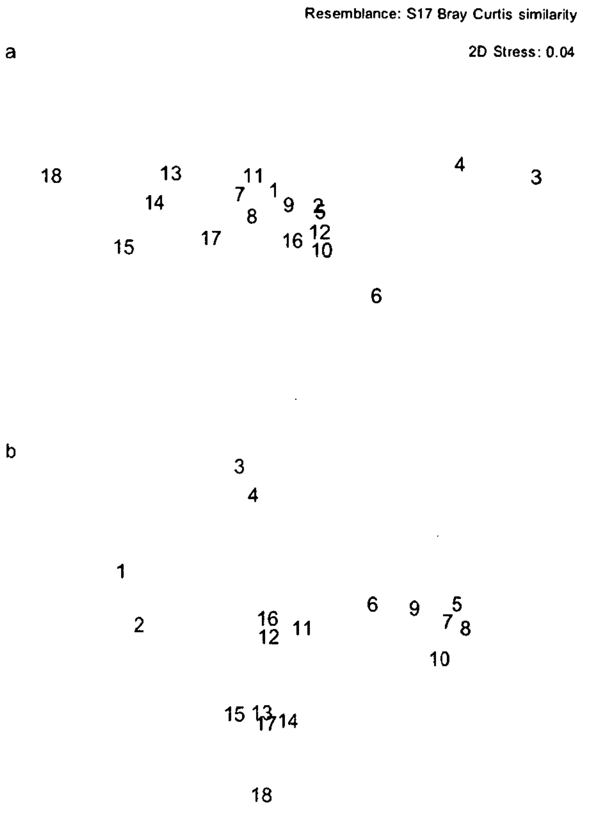

Figure 5. Multi-dimensional scaling (MDS) ordination for untransformed meiofaunal (a) and nematode (b) abundance on a two-dimensional scale at each station location.

hydrodynamic settings, the nematodes also reveal marked similarity with the shelf community. Habitat heterogeneity clearly separates the nematode community according to the habitats and the hydrodynamics of that particular location (Vanaverbeke et al. 2000; Schratzberger et al. 2006). The most widely distributed nematode was *Desmoscolex* sp., accounted from all the stations (Table II). The species *Polysigma* sp. was most conspicuous in occurrence in terms of abundance (126 ind. 10 cm^{-2}). Food source is also an important aspect for the distribution of nematode species (Moens et al. 1999). Organic matter plays an important role in structuring the nematode community (Pusceddu et al. 2009) and apparently nematode abundance shows positive correlation with sediment organic carbon (r = 0.73, $p < 0.05$; Figure 4). It may suggest the dependence of the nematode community on the bacterial biomass and the organic matter reaching the sediments (Meyer-Reil & Faubel 1980; Danovaro 1996).

The percent dominance was calculated for mean abundance of *T. longicaudata* at all the stations. *T. longicaudata* was present at 12 out of the 18 sampled locations (Table III). The highest percent dominance was observed at station 18 (86%) and it constituted about 21% of the nematode community and 15% of the meiofauna (Figure 7).

T. longicaudata is a selective deposit feeder (Wieser 1953), mainly feeding on heterotrophic bacteria and detritus with EPS (Rezeznik-Orignac et al. 2008). It has been reported from most of the world's oceans

Table II. Occurrence of nematode species at the sampling stations.

Genus\Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Actarjania sp.	–	–	–	–	+	+	+	+	+	+	+	+	+	+	+	–	+	+
Aerolaimus paucisetosus	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Anoplostoma sp.	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Apodontium sp.	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
Ascolaimus sp.	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	–	–	–
Axonolaimus sp.	–	–	+	+	–	–	+	+	–	+	+	–	–	–	–	+	+	–
Bathylaimus sp.	+	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
Calligyrus sp.	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
Calomicrolaimus sp.	–	–	–	+	–	–	–	–	–	–	+	–	–	–	–	–	–	–
Campylaimus sp.	–	–	+	+	–	–	–	–	–	–	+	+	+	–	–	+	–	–
Cantholaimus sp.	–	–	–	–	–	–	–	–	–	–	+	–	+	+	+	–	+	–
Ceramonema sp.	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Chaetonema sp.	–	+	+	+	–	–	–	–	–	–	–	+	–	–	–	–	+	–
Chromaspirina sp.	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Chromadorita sp.	–	–	–	+	–	–	–	+	–	–	–	+	+	–	+	+	+	+
Cobbia trefusaeformis	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
Comesa sp.	–	–	–	+	–	–	–	–	–	–	–	+	–	–	–	–	–	–
Daptonema sp.1	+	+	–	–	–	–	–	–	–	–	+	+	+	+	+	+	–	+
Daptonema sp.2	+	–	–	+	–	–	–	–	–	+	+	–	–	–	–	–	–	–
Desmodora sp.	–	–	–	–	–	+	–	–	–	–	+	+	+	+	–	–	+	–
Desmoscolex sp.	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	–

(*Continued*)

Table II. (Continued).

Genus\Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Dichromadora sp.	–	+	–	–	–	–	–	–	–	–	–	+	+	+	–	–	+	–
Diplopeltoides sp.	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Dorylaimopsis sp.	–	–	–	–	–	+	–	–	–	–	+	–	+	+	–	+	+	+
Draconema sp.	+	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elzalia sp.	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Enoplolaimus sp.	–	–	–	–	–	+	–	–	–	–	–	–	–	+	–	–	–	–
Epacanthion sp.	–	–	–	–	–	–	–	–	–	–	+	–	+	+	–	–	+	–
Eumorpholaimus sp.	–	+	–	–	+	+	–	–	+	–	–	–	–	+	–	–	–	–
Eurystomina caesiterides	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gammanema sp.	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gnomoxyla sp.	–	–	+	–	+	–	+	–	+	–	–	–	–	–	–	+	–	–
Gomphionchus sp.	–	–	–	+	–	–	–	–	–	–	+	+	–	–	–	+	–	–
Gonionchus sp.	+	+	–	–	–	–	–	–	–	–	+	+	+	+	+	–	+	+
Greeffiella sp.	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Halalaimus isaitshikovi	–	+	+	+	–	+	–	–	+	+	+	+	+	+	+	+	+	–
Halanonchus sp.	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Halichoanolaimus sp.	–	–	+	+	–	+	–	+	–	–	+	+	+	–	–	+	–	–
Hopperia sp.	–	–	–	–	+	+	–	+	–	+	+	+	+	–	–	–	–	–
Latronema sp.1	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Latronema sp.2	–	–	–	–	–	–	–	–	–	+	+	+	–	–	+	–	–	–
Leptolaimus sp.	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Marylynnia sp.	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Megadesmolaimus sp.	–	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–
Metachromadora sp.	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Metacyantholaimus sp.	–	–	–	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–
Metadasynemalla sp.	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Metalinhomoeus sp.1	+	–	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–
Meyersia sp.	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–
Microlaimus sp.	–	–	–	–	–	+	+	–	–	–	–	+	+	+	–	–	+	+
Molgolaimus sp.	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+
Monhystrid	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
Notochaetosoma sp.	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oncholaimid	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+
Oncholaimus sp.	+	–	–	–	–	–	–	–	–	–	+	+	+	+	+	–	–	–
Onyx sp.	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oxystomina sp.	–	–	+	–	–	–	–	–	–	–	+	+	+	+	–	+	+	+
Paracomesoma sp.	–	–	–	–	–	–	–	–	–	+	+	+	–	+	+	+	–	–
Paralinhomoeus sp.	–	+	–	+	–	–	–	–	–	–	+	+	+	+	+	+	+	+
Paralongicianthlolaimus sp.	–	–	–	–	–	–	–	–	–	–	+	–	+	+	–	+	–	–
Paramesonchium sp.	–	–	+	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
Paramicrolaimus sp.	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–
Paramonhystera sp.	+	+	–	–	–	–	–	–	–	–	–	+	+	+	–	–	–	–
Pierrikia sp.	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Polysigma sp.	+	+	+	+	–	+	–	–	+	–	+	+	+	+	–	–	+	–
Promonhystera sp.	–	+	+	–	+	–	–	–	–	–	+	+	+	+	–	+	+	+
Pselionema sp.	+	+	+	–	–		–	–	–	–	+	+	+	+	–	+	+	–
Quadricoma sp.	+	–	–	–	+	–	–	–	–	–	–	–	+	–	–	–	+	–
Rhabditis sp.	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rhabdocoma sp.	+	–	–	–	–	–	–	–	–	–	–		–	–			–	–
Sabatieria sp.	–	–	–	–	–	–	–	–	–	+	–	+	+	+	+	–	–	+
Sclachinematidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
Siphonolaimus sp.	–	–	–	–	+	+	–	+	+	+	–	–		+	–	+	+	–
Sphaerolaimus sp.	–	–	+	+	–	–	–	–	+	–	+	+	+	+	+	+	–	–
Spirinia sp.	–	–	–	+	–	–	–	–	–	–	–			–			–	–
Spirobolbolaimus sp.	–	–	–	–	–	+	–	–	–	–	–	+	+	+	–	–	–	–
Steineria sp.	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+
Subsphaerolaimus sp.	–	+	–	–	–	–	–	–	–	–	–	+	–	+	–	–	+	–
Tarvaia sp.	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	+	+	–
Terschellingia sp.1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	
Terschellingia longicaudata	–	–	+	+	+	+	–	–	+	+	+	+	–	–	+	+	+	+

(*Continued*)

Table II. (Continued).

Genus\Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Terschellingia sp.	–	+	+	+	–	–	–	–	–	–	+	–	+	+	+	+	+	–
Theristus sp.	–	–	–	–	–	–	–	–	–	+	–	+	+	+	+	–	–	+
Theristus sp.2	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Trichoma sp.	–	–	–	–	–	+	–	–	+	–	–	+	–	–	–	–	–	–
Trissonchulus sp.	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Vasostoma sp.	–	–	+	–	–	–	–	–	–	–	+	+	+	–	+	–	+	+
Viscosia abyssorum	–	–	–	+	–	–	–	+	+	–	+	–	–	–	–	–	–	–
Unidentified	–	+	+	+	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Total no. of species	20	25	30	26	10	19	7	12	13	15	32	35	34	33	20	25	29	16

Table III. Details of nematode family and genera and percent occurrence and prevalence of *T. longicaudata* at various stations.

	Nematode			*T. longicaudata*	
Station	Families	Genera	Species	Occurrence	% abundance
1	14	20	20	–	0
2	17	25	25	–	0
3	16	30	30	+	9
4	16	26	26	+	5
5	6	9	10	+	37
6	11	18	19	+	8
7	7	7	7	–	0
8	9	11	12	–	0
9	10	12	13	+	5
10	8	14	15	+	54
11	17	32	32	+	60
12	17	35	35	+	13
13	17	34	34	–	0
14	17	33	33	–	0
15	12	20	20	+	29
16	15	25	25	+	57
17	17	29	29	+	7
18	8	16	16	+	86
Mean	13	22	22	–/+	21

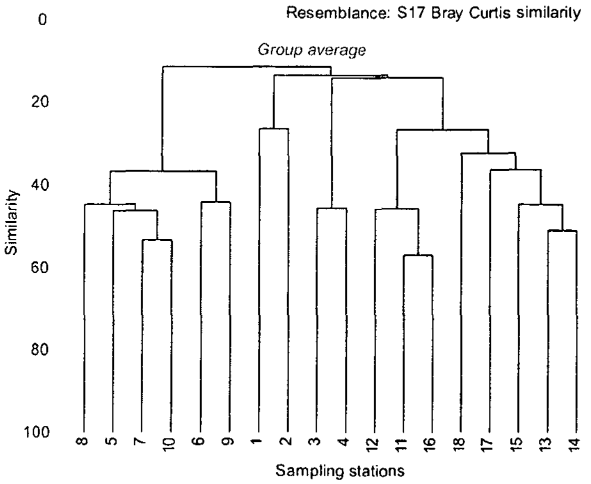

Figure 6. Bray-Curtis similarity cluster analysis based on nematode species abundance at each station location.

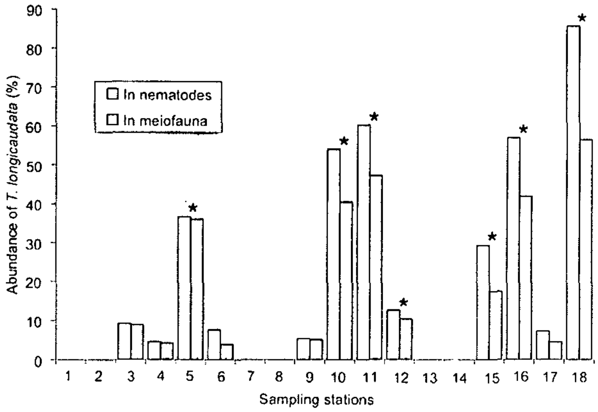

Figure 7. Percent composition of *Terschellingia longicaudata* in nematodes and meiofauna (*stations with a silty type of sediment).

and estuaries and was typically the dominant species in soft sediments from inshore water, and is also considered as having a cosmopolitan distribution (Bhadury et al. 2005).

The presence of *T. longicaudata* in heterogeneous habitats proves its ubiquitous distribution in the marine sediments such as mangroves, mudflats (Hodda & Nicholas 1985), various subtidal habitats (Heip et al. 1985; Travizi & Vidakovic 1997; Tita et al. 2002; Schratzberger et al. 2004, 2006; Bhadury et al. 2005), seagrass bed (Novak 1989) and lagoons (Villano & Warwick 1995). The species is also known to excel in anthropogenically disturbed and polluted habitats (Lambshead 1986; Schratzberger & Warwick 1998; Liu et al. 2008). *T. longicaudata* seems to show affinity towards silty sediment type (Tietjen 1980) and this stands true in this part of the tropical Indian Ocean (Figure 7).

Dominance of *T. longicaudata* from the intertidal regions of Eastern Australia and seagrass bed has been reported by Alongi (1990) and Fisher and Sheaves (2003), respectively. The dominance of *T. longicaudata* at most locations might be due to few factors, but the most evident is the silty sediment type.

The presence of *T. longicaudata* in most of the marine habitats indicates its adaptability to different type of sediments (Sergeeva 1991). Detailed phenotypic variation in *T. longicaudata* along with molecular evolutionary studies has already been initiated (Bhadury et al. 2005). Comparison of molecular data from various locations will probably provide direct evidence of genetic variability, if any, and be the pathway for determining worldwide distribution of this species. The present study confirms its presence from the coastal Indian Ocean and supports the notion of its ubiquity with species preference for silty sediments.

Acknowledgements

The authors thank the Director, NIO, Goa for the facilities. They would like to express their gratitude to all the cruise participants for their assistance in onboard sampling. They acknowledge the help of Dr Melanie Austen, of Plymouth Marine Laboratory, Plymouth, UK, for confirming the nematode taxonomy through the Darwin nematode workshop and the three anonymous reviewers for providing helpful comments on the manuscript. This is the contribution no. 4678.NIO (CSIR) Goa.

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ISSN : 0254-8704
http : //www.jeb.co.in

J/249

J. Environ. Biol.
31, (2010)
info@jeb.co.in

Impact of sewage disposal on a nematode community of a tropical sandy beach

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(Received: July 23, 2009; Revised received: October 15, 2009; Accepted:)

Abstract: *Free-living marine nematodes from a intertidal sandy beach from Goa near the Panjim city, central west coast of India was investigated along a gradient of sewage pollution. High nematode diversity (11 species) and abundance was observed near the sewage discharge point, which decreased gradually away from the discharge site. The salinity and dissolved oxygen of the estuarine water increased from the discharge point whereas reverse trend was observed for the sedimentary organic carbon. The total nematode densities indicated three-fold increase (from 523 to 1769 ind.10 cm^2) in 25 yr with a contrasting gradient of nematode abundance spatially from the source point of sewage discharge. Daptonema sp is known to be a good indicator of stressed and polluted habitats and was observed to be the most dominant species at the study site. Being exposed to the domestic sewage, the area also has high counts of pathogenic bacteria (e.g. E coli and other colifrom types). Daptonema sp are known to consume bacteria and presence of high bacterial biomass due to nutrient enrichment from the discharged sewage enhanced their abundance. Thus, the increasing nematode densities specifically like Daptonema sp at organically polluted sites can be of immense aid to reduce pathogenicity and can potentially be applied in pollution management and act as agents of natural bio-remediation.*

Key words: *Free-living nematodes, Daptonema sp., Sandy beach, Bacterial feeding, Pathogen, Sewage pollution, Bio-remediation, West coast*

Introduction

Free-living nematodes are ubiquitous and persistent as a taxon in all environmental conditions that can support metazoan life. Their small size facilitates very precise spot samples giving better picture of the environment. Nematodes have conservative life cycles (*i.e.* no highly mobile pelagic life stages) so local contamination effects should not be hidden by immigration. Ironically, the conceptual arguments against the use of these organisms for biomonitoring rest on this very property of diversity (Lambshead, 1986). This, coupled with chaotic taxonomy, has made the taxon difficult for the non-specialist. However, better pictoral keys and descriptions (Lorenzen, 1981; Platt and Warwick, 1983; Platt *et al.*, 1984; Kamat, 2009) have started to rectify this situation bringing accurate nematode identification and application within the scope of extension workers. Now the nematode community attributes are turning out to be suitable for monitoring sediment quality, with generic composition being the most accurate indicator for assessing differences (Heininger *et al.*, 2007). Studies have shown that sewage can change structural and functional attributes of biodiversity, but effects can vary depending on the response variables considered and the type of analysis (Pearson and Rosenberg, 1978; Chapman *et al.*, 1995; Otway *et al.*, 1996; Smith *et al.*, 1999; Shiddamallayya and Pratima, 2008; Khanna and Bansal, 2008).

Panjim is a valuable aesthetic city, ecological and recreational asset, and due to its geographical position in a rapidly expanding urban area; subjected to the influence of various developmental activities related to tourism industry. This has led to increase in domestic sewage discharge from the city into the pristine estuarine region. Even though, the development of strategies to mitigate the environmental effects caused by sewage disposal has initiated since long but were not very effective till recent. The sewage treatment was initialized in 1976, which had great difficulties in smooth running hence mostly sulfidic conditions remained throughout the sewage channel due to periodic stagnancy (Kamat, 2009). A new technologically improvised system was installed in 2005 with a sewage treatment capacity of 12.5 million l d^{-1} (Annon, 2007). However, it normally handles 7-8 million liters, in a region where intense monsoon activity can cause floods (Annon, 2007). The present study was aimed to observe the free-living meiobenthic nematode community along a decreasing gradient from the sewage discharge outlet and comparing it with a previous study for the changing trends. Hence, the relationship between nematode community structure, environmental parameters and domestic sewage disposal gradient was established in an organically polluted estuarine sandy beach of Panjim city on the west coast of India.

Materials and Methods

Mandovi estuary, which opens into the Arabian Sea near Panjim city on the west coast of India with an average annual river discharge of 6004 Mm^3 (Suprit and Shankar, 2008), used to receive about 1.3 Mm^3 liters of urban runoff annually in early 1980's (Ansari *et al.*, 1984). During the present study, a section of estuarine beach receiving domestic sewage through *"St. Inez Nullah"* was sampled during April 2007. Nematode samples were collected from 5 stations

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along a decreasing gradient of sewage pollution. Station PM1 was at the discharge point, other four stations *i.e.*, PM2-PM5 each at 100 m interval towards the seaward side (Fig. 1). Surface sediment was sampled with an acrylic core (4.5 cm. diameter) down to 5 cm depth in triplicates. Separate cores were taken for sediment organic carbon and grain size analysis. Organic carbon was analysed using wet Oxidation method (Wakeel and Riley, 1957) employing chromic acid as oxidizing agent. For grain size analysis approximately one gram of sediment after passing through 63µm was put in distilled water for disintegration. Later, complete disintegration of these samples was achieved by keeping them in ultrasound sonic bath for 10 min. These samples were analysed with a Malvern laser particle size analyzer (Master-Sizer, 2000).

Overlying water was sampled for dissolved oxygen and was analysed using Wrinkler's method (Strickland and Parsons, 1972) The pore water temperature and salinity was measure in-situ using hand held mercury thermometer (±0.5°C accuracy) and Atago® make refractometer, respectively.

Sample processing: Nematode samples were immediately preserved in 5% buffered formalin rose Bengal solution. In laboratory the samples were sieved with 500 and 45 µm sieve.

The fauna retained on 45 µm was considered for meiofaunal and nematode analysis. Nematodes were sorted and temporary glycerol mounted slides were prepared for identification. Identification was done using pictorial key of Platt and Warwick (1983), Warwick *et al.* (1998).

Statistical analysis: Nematode species data for individual [illegible] 10 cm²) were used to calculate the diversity as the number of species per sample (*S*), the Shannon-Wiener diversity index [illegible] and Simpson's diversity index. Species richness (*d'*) was estimated from Margalef's formula as *d'*=(S"1)/ln [illegible] evenness was calculated using Pielou's (*J'*). Diversity patterns were visualized by [illegible] curves. The nematode community structure was analyzed by cluster analysis using the untransformed species abundance Bray-Curtis similarity measure. The species contributing to dissimilarity between zones were investigated using a similarity percentages procedure (SIMPER).

All the diversity functions for nematode species were calculated using PR'MER 6 (Clarke and Warwick, 1994) statistical package. The maturity index (MI) was calculated as the weighted mean [illegible] individual [illegible] scores (Bongers, 1990; Bongers *et al.*, 1991). MI = Ó v (i) [illegible]

Where, [illegible] is the colonisers-persisters (*c-p*) value of taxon *i* (as given in Appendix [illegible] 1991) and *f* is the frequency of that taxon in a sample. Nematode species were enumerated into functional groups according to Wieser (1953).

Table - 1: Occurrence of nematode species at the sampling location with respective feeding types*

	Feeding types*	PM1	PM2	PM3	PM4	PM5
Actinonema sp	2A	-	[illegible]	[illegible]	+	-
Axonolaimus sp	1B	+	+	[illegible]	-	-
Bolbolaimus sp	2A	-	+	[illegible]	-	-
Comesoma sp	2A	+	+	+	[illegible]	-
Daptonema sp1	1B	+	+	-	[illegible]	[illegible]
Daptonema sp2	1B	+	+	[illegible]	-	-
Desmodora sp	1B	+	-	[illegible]	+	-
Dorylaimopsis sp	2B	-	+	-	+	-
Gammanema sp	2B	-	[illegible]	+	-	-
Oncholaimus sp	2B	-	[illegible]	[illegible]	-	+
Oxyonchus sp	2B	[illegible]	-	-	-	+
Paracyatholaimus sp	[illegible]	+	[illegible]	+	-	-
Polysigma sp	[illegible]	-	[illegible]	-	-	-
Praeacanthonchus sp	[illegible]	+	[illegible]	-	-	-
Terschellingia sp	1A	[illegible]	[illegible]	-	-	-
T. longicaudata	1A	[illegible]	+	-	-	-
Theristus sp1	1B	+	-	+	+	+
[illegible]	[illegible]	-	-	-	+	-
[illegible]	1A	-	-	-	+	-
Viscosia sp	2B	-	-	+	-	-
Unidentified	1B	+	-	+	-	-
Abund. (ind/10 cm²)		1769	874	150	59	43

* = Wieser (1953), 1A = Selective deposit feeders, 1B = Non-selective deposit feeders, 2A = Epigrowth feeders and 2B = Predatory/omnivores, + = Present, - = Absent

Table - 2: Diversity indices based of nematode species number

Diversity Indices	Stations				
	PM1	PM2	PM3	PM4	PM5
Species number (S)	11	10	10	8	3
Total abundance (N)	1769	874	150	59	43
Species Richness (*d'*)	1.34	1.33	1.80	1.72	0.53
Species Evenness (*J'*)	0.37	0.38	0.50	0.70	0.65
Shannon-Weaver's (*H'*)	0.88	0.88	1.14	1.45	0.72
Simpson's (1-Lambda)	0.38	0.39	0.48	0.73	0.42
Maturity Index (MI)	2.03	2.03	2.18	2.81	2.37

Table - 3: SIMPER analysis for the difference (%) between the stations based on species dominance

Between stations	Average dissimilarity	1st two species contribution	% Dissimilarity
PM1 and PM2	69.13	*Daptonema* sp1	72.75
		Daptonema sp2	9.47
PM1 and PM3	92.04	*Daptonema* sp1	39.18
		Daptonema sp2	31.93
PM2 and PM3	79.30	*Daptonema* sp1	83.37
		Dorylaimopsis sp	5.67
PM1 and PM4	97.87	*Daptonema* sp1	47.19
		Oxyonchus sp	16.03
PM2 and PM4	95.50	*Daptonema* sp1	73.96
		Daptonema sp2	10.44
PM3 and PM4	92.34	*Daptonema* sp1	55.44
		Trefusia sp	11.40

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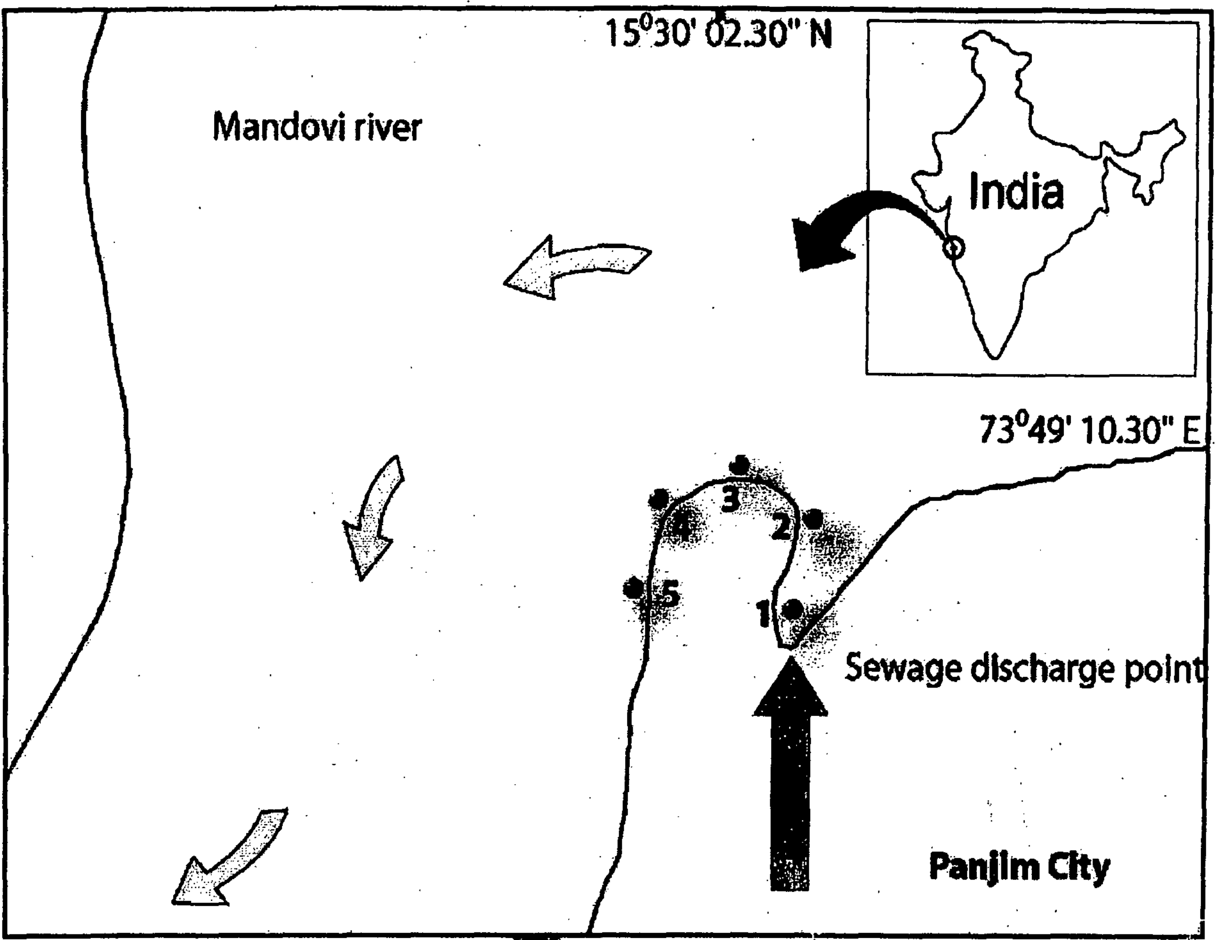

Fig. 1: Map of the study area with sampling location, [redacted]

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Results and Discussion

The domestic sewage pollution is known to have considerable impact on the sediment dwelling fauna (Pearson and Rosenberg, 1978; Ansari *et al.*, 1984,1986; Chapman *et al.*, 1995; Smith *et al.*, 1999; Otway *et al.*, 1996). Nematode community demonstrates a marked response to different pollutants (Heip *et al.*, 1985; Essink and Romeyn, 1994; Somerfield, 2000) and in the present study, nematode community at the sewage discharge point seems to have benefited from the resultant enrichment of nutrients.

Physico-chemical parameters: The station PM1 had the lowest temperature (32.2°C) and salinity (25.32 PSU) whereas the highest temperature (35.8°C) and salinity (35.71 PSU) was recorded at PM5 (Fig. 2). The dissolved oxygen showed the gradient with lowest values (0.25 ml l^{-1}) recorded at PM1 and highest (2.80 ml l^{-1}) at PM5 (Fig. 2). The sewage discharge at the study site was almost certainly responsible for the observed gradient in temperature, organic carbon and dissolved oxygen from the discharge point (Fig. 2). Organic enrichment has been reported to influence nematode community structure (Orren *et al.*, 1979; Eleftheriou *et al.*, 1982; Gee and Warwick, 1985; Smol *et al.*, 1994). Moreover, the nematode numbers appear to increase up to a certain level of organic carbon concentration (<3%) in the sediment, (Gyedu-Ababio *et al.*, [illegible]) but in the present study, the nematode community seems to be flourishing even at higher (4.5%) content of organic carbon. Although this point needs further evaluation, it certainly suggests ability of certain nematode species to tolerate high organic load.

Apart from the sediment composition and organic carbon, salinity also influenced the species composition of nematode communities (Heip *et al.*, 1985; Coull, 1988; Vanreusel, 1990; Soetart *et al.*, 1995). Salinity was low at discharge point and showed a gradual increase, possibly due to mixing of fresh water with the sewage. The major effect of sewage is that it reduces the oxygen content and stimulates the formation of hydrogen sulfide. Such conditions can be disastrous to biota (Bozzini, 1975). This is clear at station nearest to the discharge point, where the oxygen level was low and the occurrence of a black sulfide layer below 5 to 6 cm sediment was visible (Ansari *et al.*, 1984). However, this layer was not found in the top 5 cm at station 3 onwards which are away from the sewage outlet, perhaps due to better flushing by the riverine flow and the wave action. The gradient comparison for the physico-chemical parameters of the present study with the previous study

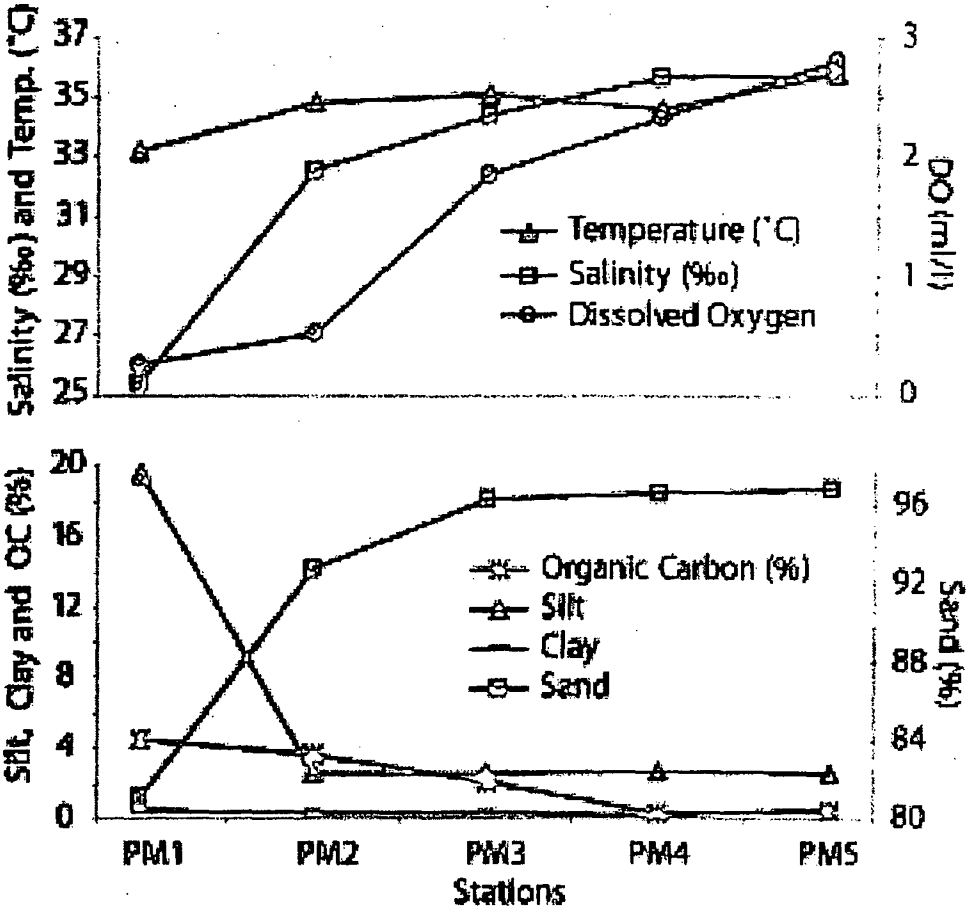

Fig. 2: Physico-chemical and sedimentary parameters at the sampling locations

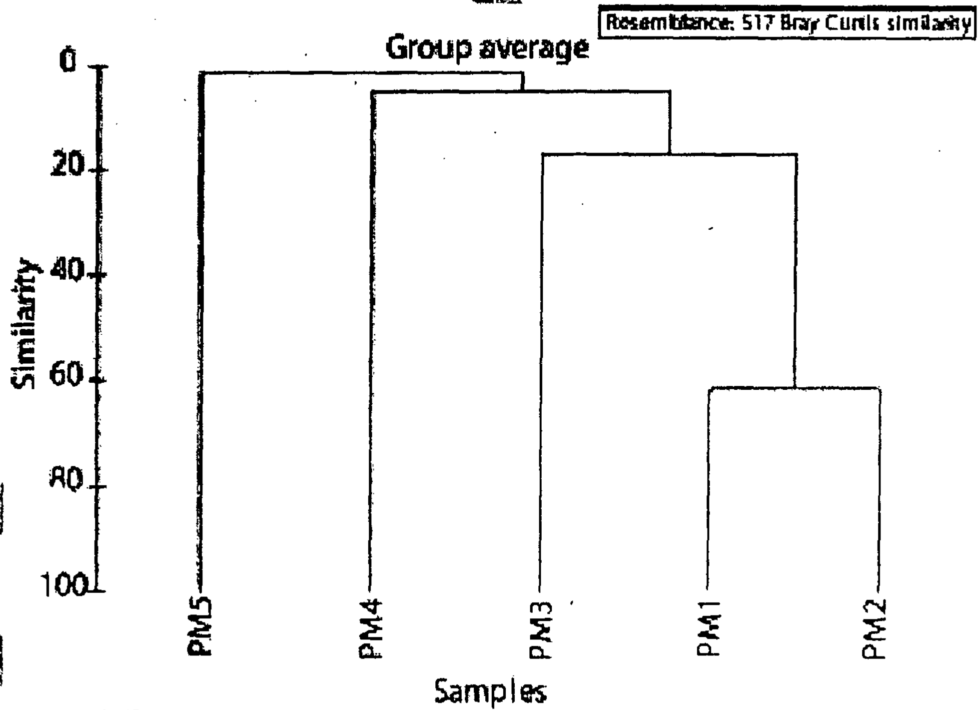

Fig. 3: Cluster analysis of the sampling locations based on nematode species abundance

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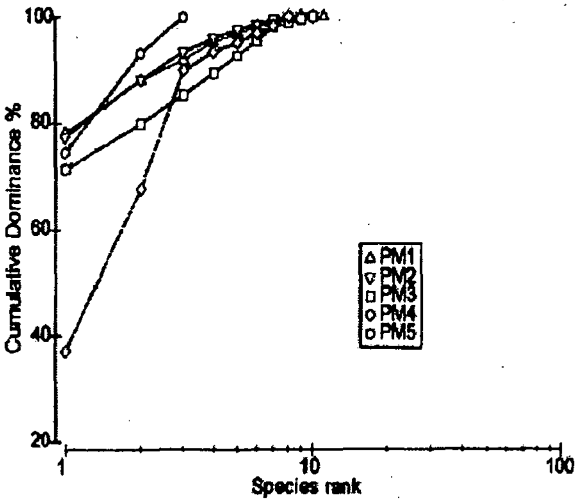

Fig. 4: Cumulative dominance curve for nematode species at the sampling locations

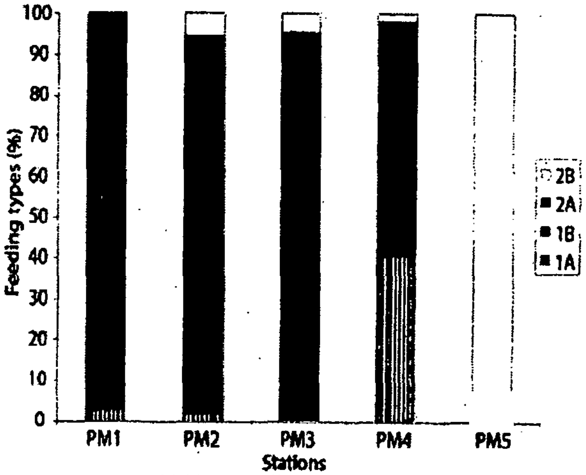

Fig. 5: Percent feeding type of nematode species based on Wieser's (1953) classification (1A- Selective deposit feeders, 1B-Non-selective deposit feeders, 2A- Epistrate feeders and 2B-Predatory/omnivores)

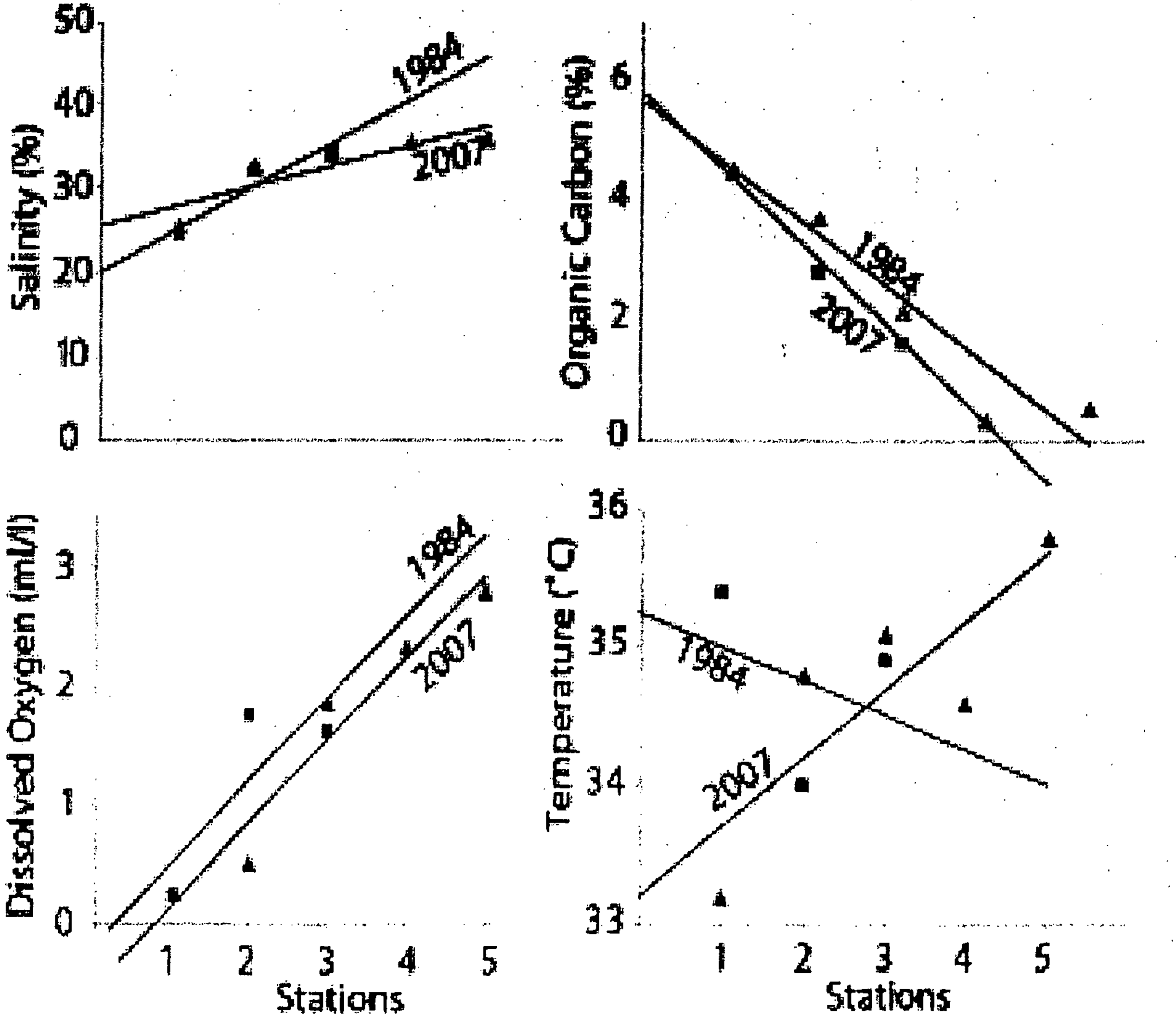

Fig. 6: Comparative trends in environmental parameters between 1984* and 2007 (*data source: Ansari *et al.*, 1984)

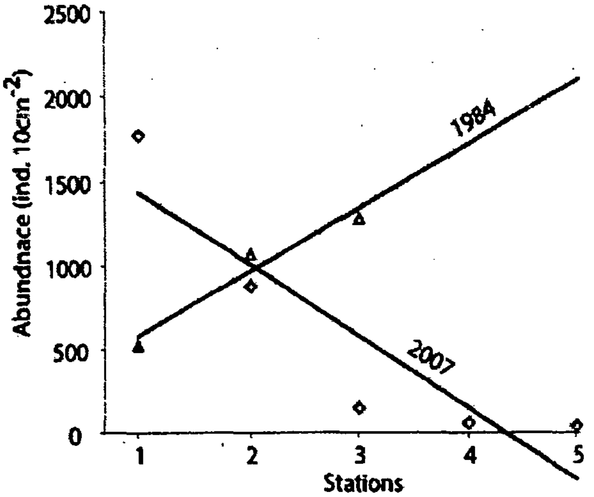

Fig. 7: Comparative trends in nematode abundance between 1984* and 2007 (*data source: Ansari *et al.*, 1984)

(Ansari *et al.*, 1984) showed very similar trends depicting no significant change in parameters, except temperature.

Community: The occurrence of nematode species with their respective feeding types at all the sampling stations has been stated in Table 1. Highest (1769 nos.10 cm^{-2}) abundance was recorded at PM1 and lowest (43 nos.10 cm^{-2}) at PM5 (Table 1). The diversity indices revealed highest of 11 species at PM1 while, only 3 species were recorded at PM5. Shannon-Wiener's (*H'*) information function showed highest (1.72) values at PM5 and the lowest (0.88) at PM1 and PM2. But the Richness (d') was highest (1.72) at PM3 and lowest (0.37) at PM1. The species evenness (J') was highest (0.70) at PM4 and lowest (0.37) at PM1. The Simpson's Index and the Maturity Index (MI) also showed a gradient (Table 2).

The SIMPER analysis showed an average dissimilarity of more than 90% for most of the spatial comparisons of stations (PM1 and PM3, PM1 and PM4, PM2 and PM4, PM3 and PM4). The species that contributed highest for the maximum difference between the stations was *Daptonema* sp1. The highest dissimilarity contributed by *Daptonema* sp1 was between PM2 and PM3 (Table 3). The other species that contributed after *Daptonema* sp1 at all the stations were *Daptonema* sp2 *Dorylaimopsis* sp, *Oxyonchus* sp, *Trefusia* sp (Table 3). The nematode community composition was very similar for stations near the discharge point and gradually differed away from the swage disposal point (Fig. 3). This was due to the successful colonization of enrichment opportunist species. *Daptonema* sp1, *Daptonema* sp2, *Terschellingia* sp, *T. longicaudata* and *Axonolaimus* sp are actually known to thrive in degraded and stressful conditions (Bonger, 1990; Gyedu-Ababio *et al.*, 1999; Palacin *et al.*, 1992; Sommerfield *et al.*, 2003; Liu *et al.*, 2008; Essink and Romeyn, 1994).

Overall, gradient of all the parameters structure the incline of nematode community spatially and the species specialized in adapting in perturbed habitats, seems to have gained advantage due to the sewage discharge. The high abundance at the discharge point and very low density away from the discharge point revealed the increase of enrichment opportunistic species near the discharge point, which are also resistant to pollution as well as lowered oxygen conditions.

A combination of Maturity Index (MI) and Shannon-Wiener diversity Index (*H'*) are known to be good tools in pollution monitoring, especially, organic pollution involving nematodes (Gyedu-Ababio *et al.*, 1999) and in the present study MI showed low values at all the stations and *H'* decreased with decreasing pollution, except for the last station, which recorded only three species with very low abundance.

The cumulative dominance curve for nematode species revealed a difference in all the stations where PM1 and PM2 showed much similarity but PM5 showed a smaller curve ending abruptly because of very low species number (Fig. 4).

Feeding types: The non-selective deposit feeders (1B) completely dominated the station PM1 with 94% abundance. PM2 showed a similar trend with 89% followed by PM3 with 84% dominance by 1B. The remarkable aspect of the study area was the absence of predatory/omnivores (2B) at the sewage disposal site station PM1 (mouth of *Nulla*). While, the dominance (41%) of selective deposit feeding nematodes (1A) increased at PM4 and non-selective deposit feeders (1B), became sub-dominant (34%), a complete change in feeding dominance was observed at PM5 with the dominance (93%) of predatory/omnivores (Fig. 5).

Daptonema sp1 was the most dominant species, which is non-selective deposit feeder and known to consume heavy bacterial biomass (Heininger *et al.*, 2007; Singh and Ingole, 2009). Reportedly high pathogenic bacteria such as *E. coli* and other coliform types are present in the study area (Ramaiah *et al.*, 2007). Bacterial consumption by nematodes can help in bio-remediation of the site at the domestic sewage outlet and the dominance of *Daptonema* sp1 can be considered a positive aspect from the perspective of environmental health.

Comparing the present results with a previous study (Ansari *et al.*, 1986) showed very similar trends for values of salinity, dissolved oxygen and sediment organic carbon but exactly opposite trend was seen for temperature (Fig. 6). The values for nematode abundance from the present study showed contrasting values with the nematode abundance of 1984. The values in 1984, shows increasing trend away from the sewage discharge point whereas in 2007, the highest abundance was at the discharge point with a decreasing trend away from it (Fig. 7). This reversing of trend in the gradient may indicate the reduction in the toxicants of sewage or the succession of the benthic community due to continuous organic waste

(Ansari *et al.*, 1986). Nematode community is known to respond positively to decreasing level of organic pollution (Essink and Romeyn, 1994). The increase in nematode densities compared to earlier data (Fig. 7), while no much change in other parameters indicates the succession of nematode species such as *Daptonema* sp1. Thus, the high dominance of enrichment opportunistic and bacterivorous nematodes can help in mitigating pathogenic bacteria harmful to human health.

Further, detailed study is required on feeding selectivity of nematode species that can help in effluent treatment and bioremediation processes. The present findings will be helpful in monitoring the status of benthic environment and the response to changing environmental regulations. It will be interesting to observe future changes in the nematode community after the implementation of technically improved better sewage treatment plants as an environmental management strategy. Nevertheless, laboratory culture of opportunistic nematode species such as *Daptonema* sp could be a handy tool for pollution studies, especially for exploring the mitigating measures. Efforts are therefore being made to develop appropriate methods to rear *Daptonema* spp. in laboratory.

Acknowledgments

We are grateful to the, Director, NIO, Goa, for his encouragement. We also wish to thank our colleague Mr. Ravail Singh for helping in the fieldwork. The first author was supported by Council of Scientific and Industrial Research, (CSIR) Govt. of India Fellowship.

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