Beyond the Tsunami

Macro and Mega Faunal Communities of Intertidal Ecosystems on the Tamil Nadu Coast, India

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Front cover photo: The intertidal zone between the high tide and low tide lines is a particularly dynamic environment with constant wave action. (Photo credit: K. Shanker, 2008)
Back cover photo: Starfish are found in benthic habitats including intertidal zones; they are predators of bivalves and other molluscs. (Photo credit: K. Shanker, 2007)
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Executive Summary

The December 2004 tsunami had major impacts on human populations, coastal ecosystems and islands of the region. While it may not be possible to device man-made protection measures to protect and control the impacts of major natural catastrophes like the December 2004 tsunami, the value of natural protecting coastal systems such as coastal vegetation, coral reefs, mangroves and most importantly sand-dunes and sandy shores are now being increasingly recognized. The coastal area, especially the sandy shores and beaches act as a buffer-zone between the marine and the terrestrial realms, soaking up a major portion of the impact and energy of waves and storms.

Although impact studies have been conducted in some areas along the coast, a complete understanding of the impacts and long-term recovery of ecosystems does not exist. Along the east coast of India (Tamil Nadu coast), where the December 2004 Tsunami wreaked major havoc, the nearshore ecosystems bore the brunt of the impacts and was the most heavily impacted of the coastal ecosystems. A comprehensive analysis of published and grey literature on coastal and marine ecosystems in the affected states was carried out during the first phase of the project, to get an understanding of (a) pre-tsunami conditions in ecosystems and (b) gaps in knowledge. The literature analysis revealed that the nearshore intertidal ecosystems (sandy beaches and mudflats) are generally a much overlooked and neglected ecosystem in India. Studies in the past have been confined to certain areas along the coast and do not provide a broad baseline of information on these ecosystems before the tsunami. There are, therefore, no reliable baseline studies to compare pre and post tsunami data, emphasising the need to initiate monitoring programmes.

Objectives

- To characterise the medium-term (3 year) impact of the tsunami on the intertidal marine environment.
- To compare the distribution, abundance and composition of intertidal communities accross different ecosystems, latitude and human disturbance.
- To identify the major parameters that control the distribution, diversity and abundance of intertidal beach fauna.

Major Findings

Macrofauna

The abundance of macrofauna showed was uniform across most stations. Areas that were highly impacted by the tsunami showed a higher abundance and species evenness, whereas species richness was the highest in less affected sites. In terms of composition, oligochaetes showed a very high abundance rates of about 2,000 individuals/m^2 in sites that were highly impacted by the tsunami, while they were less in areas that were moderately or less impacted. Oligochaetes, archiannelids, polychaetes and nematodes dominated the highly impacted areas.

Abundance and species richness were highest in highly disturbed areas followed by moderately and less disturbed areas, while undisturbed areas showed the highest values in species evenness. Oligochaetes, archiannelids, polychaetes and nematodes were considerably higher in more disturbed areas. The abundance of crustaceans steadily increased from highly disturbed to undisturbed beaches.

Macrofaunal abundance was highest on the Coromandel Coast, followed by Palk Bay and Gulf of Mannar. Species richness and evenness on the other hand was higher in the Gulf of Mannar, followed by Coromandel Coast and the Palk Bay. Coromandel Coast populations were dominated by oligochaetes and archiannelids, followed by polychaetes, while nematode and crustacean abundance was also comparatively high. Palk Bay had an impoverished population in terms of the number of groups present. The abundance of macrofauna showed an increasing pattern with increasing latitude. Species richness and evenness was higher between 9-10ºN and 12-13 ºN.

Megafauna

The abundance and species evenness showed the highest values in less impacted areas followed by highly and moderately impacted areas. Total species richness and diversity was the highest in areas that were less impacted by the tsunami while highly and moderately impacted areas showed similar values.

Moderately disturbed areas showed the highest values in abundance, species richness and species diversity, while species evenness was higher in the highly disturbed beaches. The abundance was more or less similar in the Coromandel and the Palk Bay followed by the Gulf of Mannar. Palk Bay had the highest species richness and evenness followed by the Gulf of Mannar and the Coramandel Coast. Coramandel coast however, showed higher diversity, followed by Palk Bay and Gulf of Mannar. Species richness decreased as latitude increased. The abundance however was the highest in 11-12 ºN latitude and lowest in 9-10 ºN latitude.

Conclusions

1. In the absence of published baseline pre-tsunami data on near shore ecosystems, it is not possible to infer the impact of the tsunami or recovery and recolonisation of these ecosystems along the Tamil Nadu coast.
2. However, macrofaunal and megafaunal communities (especially oligochaetes, nematodes, archiannelids, certain species of polychaetes and *Emerita asiatica*) are sensitive to human disturbance and can be used as indicators of human induced disturbance
3. There are patterns in species composition of megafauna in relation to ecoregions and latitude that require further investigation

Recommendations

1. A long-term monitoring strategy can to be developed for oligocheates and other intertidal fauna along the Indian coast; monitoring needs to be conducted yearly to identify temporal patterns in richness and abundance.
2. More thorough and intensive research needs to be carried out to understand the inherent resilience, adaptive capacities and responses of these ecosystems.

1. Introduction

India has a coastline of about 7,500 km (Chandramohan *et al.* 2001) and nearly 250 million people live within a distance of 50 km from the coast (Areti 2007). With increasing realisation of the economic value and the ecosystem services that are derived from coastal areas, and owing to increasing human population, urbanisation and accelerated developmental activities, coastal areas are receiving more attention and importance in recent years. Many of these anthropogenic activities have put tremendous pressure on the fragile coastal environment. Further, coastal areas are also prone to cyclones and natural disasters. The entire east and west coast of India, and the islands of Lakshadweep, and Andaman and Nicobar face frequent cyclonic events which sometimes cause large-scale destruction of life and property. Meteorological information shows that more than 1000 cyclonic disturbances occurred in the Bay of Bengal during the last century (Shrestha 1998), among which over 500 were either depressions or deep depressions, and over 400 were either cyclonic storms or severe storms.

The December 2004 tsunami had major impacts on human populations, coastal ecosystems and the islands of the region. While it may not be possible to device man-made protection measures for protecting and controlling the impacts of major natural catastrophes like the December 2004 tsunami, the value of natural protecting coastal systems such as coastal vegetation, coral reefs, mangroves and most importantly sand-dunes and sandy shores are now being increasingly recognised. The coastal area, especially the sandy shores and beaches act as a buffer-zone between the marine and the terrestrial realms, soaking up a major portion of the impact and energy of waves and storms (Mascarenhas 2004).

Like most marine ecosystems, sandy beaches and dunes have also been under increasing pressure due to population increase, urbanisation and various developmental activities (Venkataraman 2003). Intertidal benthic fauna are excellent indicators of environmental stress (Somerfield *et al.* 2002). Due to differential tolerance and very restricted movements, they are among the most common organisms used to assess anthropogenic impacts. With comparatively longer life spans and as key elements in the food web of aquatic systems, they can integrate the effects of the environment (Ansari *et al.* 1986; Ansari and Ingole 2002).

Although impact studies have been conducted in some areas on particular ecosystems along the coast, a complete understanding of the impacts and long-term recovery of ecosystems post-tsunami does not exist. Studies in the past have been confined to certain areas along the coast and do not provide a broad baseline of information on these ecosystems prior to the tsunami. During first phase of the project, information on biological and environmental studies on coastal and marine ecosystems was collated to determine the current state of knowledge on various biological and environmental parameters of coastal and marine ecosystems. A comprehensive analysis of available published and grey literature available on coastal and marine ecosystems in the affected states was used to get an understanding of the (a) pre-tsunami conditions in ecosystems (2) gaps in knowledge about the ecology of these ecosystems.

The literature analysis revealed that the nearshore intertidal ecosystems (sandy beaches and mudflats) are a generally neglected ecosystem in India. Along the east coast of India, the intertidal nearshore ecosystem was the most heavily impacted of the coastal ecosystems after the tsunami. However, no reliable baseline studies exist to elicit comparison of pre- and post-tsunami data. We therefore initiated a study on macro and megafauna of intertidal ecosystems in Tamil Nadu.

2. Literature review

A literature review was undertaken during Phase I of the "Post Tsunami Environment Initiative" (PTEI), funded by the UNDP, to review existing baseline information and gaps research on sandy beaches along with many other major coastal and marine ecosystems (Gokul and Shanker 2007; Mukherjee *et al.* 2007; Muthuraman *et al.* 2007). The gap analysis from India (mainly from peer reviewed journals) revealed a dearth of information on coastal ecosystems, especially coastal intertidal ecosystems. While it is interesting to note that many pioneering and preliminary studies on the intertidal sandy shore fauna in the world were done in India, there has been a considerable neglect of these ecosystems in recent years, especially on the east coast. In the late 1960s and 1970s, considerable work was done on the sandy shore ecosystems of the west coast. Some notable works from this period are Nayar 1954; Alagarswami 1966; Ansell and Trevallion 1967; Sankarankutty 1967; Ansell and Trevallion 1969; Silas and Trevallion *et al.* 1970; Vohra 1971; Ansell *et al.* 1972a,b,c; Dwiveh *et al.* 1973; Parulekar 1973; Philip 1974; McLusky *et al.* 1975; Achuthankutty *et al.* 1978; Ansell *et al.* 1978; Nair 1978; Parulekar *et al.* 1980; Rodrigues 1984. Some scattered studies occurred later in the 1980s (Harkantra 1984; Harkantra & Parulekar 1984).

Unfortunately, in spite of these initial interest, there was little effort towards a more thorough and comprehensive understanding of the processes and factors that govern the sandy shore ecosystem. There is a great dearth of information in peer reviewed literature from the mid 1980s to early 2000s. Even after that, only one or two scattered studies have been conducted on coastal sandy shore ecosystems. Further, a majority of the earlier studies were restricted to the western Indian waters, except a few (Alagarswami 1966; McLusky *et al.* 1975), where the southeastern sandy shores of India were studied. Elsewhere, research on sandy beaches has evolved and advanced considerably, but unfortunately, in India, sandy beach research has not moved beyond diversity and status surveys.

Prior to the 1960s, very little was known and understood about the intertidal sandy shore ecosystem, its diversity, special adaptations of these animals and the factors that limit their distribution. The sandy shore fauna were the most common but equally neglected forms. The pioneering works of the 1960s, 1970s and 1980s lead to rapid advancement and understanding of sandy shore and benthic fauna, raising their profile as a highly and specially adapted group of fauna.

The present study aims at creating baseline data and examines the abundance and diversity of macrobenthos and megabenthos along the sandy shores that were most affected by the tsunami. It also aims to identify a potential set of indicators to initiate a long-term indicator based monitoring programmes. Due to their differential tolerance and very restricted movements, these organisms are excellent indicators of environmental stress (Somerfield *et al.* 2002). Benthic invertebrates are among the most common organisms used to assess anthropogenic impacts, as a majority of the species are sedentary and their responses correspond to the water and sediment quality changes. They can integrate the effects of the environment over a longer period of time as they live longer than most planktonic forms. Some species have relatively long life spans and are key elements in the food web of aquatic systems (Ansari *et al.* 1986; Ansari and Ingole 2002) and affect chemical fluxes between sediment and water column through bioturbation and suspension feeding activities (Gray 1974). Studies also helped recognise the value of benthic invertebrates; they act as food for higher aquatic and terrestrial invertebrates and vertebrate consumers. Macrobenthos and their abundance are closely related to the type of sediment and therefore serve as good biological indicators of the fertility of the region.

Some preliminary work on the nutrient content of water on intertidal sandy shore fauna was done by Ansell *et al.* (1972a, b, c; 1978). Beach soil texture, dead organic carbon content and latitudinal gradient were found to be important limiting factors of the fauna in the ecosystem (Vohra 1971). Compared to temperate regions, the zonation and the diversity of faunal communities have received less attention in tropical and subtropical sandy beaches (Vohra 1971; McLusky *et al.* 1975). Species in tropical countries like India exhibit greater activity, mobility, faster growth, shorter life span, higher mortality rates, and greater production than temperate species (Ansell *et al.* 1978). The macrofauna on the beach is a vital part of the system (Ansell *et al.* 1972b, c; 1978). The shifting sands and rapidly changing conditions make it a difficult habitat and therefore only a few species have been successful in adapting to this habitat. These species enjoy lower levels of competition and can grow to larger populations. According to Dexter (1992), macrofaunal communities increase in protected beaches.

The fauna of beaches in southwest India have been shown to be quite diverse, and include crabs of the genus *Ocypode* and the isopod *Eurydice sp.*, which occur up to the high water mark, polychaetes of the genera *Glycera, Onuphis, Scoloplos* and *Lumbrinereis* in the mid-intertidal region and below, with occurrence of the tidal migrants like *Bullia melanoides* (Gastropoda), *Donax incarnatus* and *D. spiculum* (Bivalvia) and *Emerita holthuisi* (Crustacea) (Trevallion *et al.* 1970). The occurrence of *Donax incarnatus* and *D. spiculum* was also reported (Ansell *et al.* 1972a). Some of the common shore crabs observed along the sandy beaches of the coast are *Ocypode ceratophthalma, O. cordimana, O. macrocera, O. platytarsis, Scopimera proxima, S. pilula, Uca annulipes, Dotilla myctroides, Macrophthalmus depressus, Metapograpsus thukuar* (Silas & Sankarankutty 1967).

3. Objectives

It is clear from an analysis of the ecological literature that any attempt to examine trends and impacts of chronic or pulse disturbance events on the intertidal communities is severely hampered by the lack of quality information on species and ecosystem ranges, status of critical marine populations and communities, and ecosystem function. Not only do these gaps in our knowledge make it difficult to establish how these ecosystems and species respond to events like the tsunami and other localised man-made disturbances, it also makes rational scientific coastal planning for these systems fraught with uncertainty.

The present study is not aimed at addressing all of the above mentioned gaps. The study is a rapid survey to create baseline information and look at interesting macro-scale patterns in the composition, distribution, diversity and abundance of nearshore intertidal communities. This information would assist in undertaking more focused research in future.

The broad objectives of the study are to:

1. Create a baseline dataset and initiate long term monitoring of intertidal sandy shore ecosystems of the Tamil Nadu coast
2. Identify major threats to key coastal intertidal ecosystems such as sandy beaches and mudflats
3. Examine large scale patterns in community composition, species richness and abundance of intertidal sandy shore fauna along the Tamil Nadu and Puducherry coasts.

The specific objectives of the study are to:

1. Roughly characterise the medium-term (3 year) impacts of the tsunami on intertidal marine environment
2. Compare differences in the distribution, abundance and composition of intertidal faunal communities over a gradient of ecosystems, latitude and human disturbance
3. Identify the major abiotic parameters that limit/influence the density, diversity and distribution of intertidal fauna
4. Compare variations in abiotic parameters over the above mentioned gradients
5. Identify species or communities that can act as indicators of disturbance in order to develop an indicator-based approach in the future to monitor coastal ecosystem health
6. Design functionally relevant and ecologically sensitive monitoring programmes for key ecosystems along the coast

4. Methods

4.1. Study area

The coasts of Tamil Nadu and Puducherry were the most affected areas on the Indian mainland by the December 2004 tsunami (Figure 16). Tamil Nadu has the third largest coastline of the Indian mainland spanning 6 latitudes. It also has the longest stretch of sandy beach (Sanil Kumar *et al.* 2006) (refer Appendix 1). Sample collection was carried out over a period of eight months (September 2007 to May 2008).

In order to ensure that the entire stretch of Tamil Nadu was covered, the coast was divided into five sectors, namely:

a) Chennai to Puducherry,

b) Puducherry to Nagapattinam,

c) Nagapattinam to Rameswaram,

d) Rameswaram to Tuticorin, and

e) Tuticorin to Kanniyakumari.

Five sites were sampled from each sector, giving a total of 25 sites (Figure 15). The sites were more or less equidistant from each other. The details of the beaches are provided in Table 1. In addition, the response of communities to variations in abiotic factors like grain size and organic carbon availability were also analysed. Variations in nearshore intertidal community indices were examined along the following axes:

1. Ecoregions
2. Impacts of tsunami
3. Human disturbance
4. Latitudinal gradients

Intertidal fauna in relation to tsunami impacts

Characterising the impact of a large scale disturbance like the tsunami on coastal ecosystems is particularly difficult in the absence of baseline information, and more so given the passage of time after the tsunami. The recovery of impacted ecosystems varies within and between sites, depending on their inherent resilience. Distinguishing human disturbance and other natural processes from the effects of the tsunami is close to impossible considering the dynamic nature of coasts. Nevertheless, we divided the sites along the study area into three categories, namely, highly impacted (12 sites), moderately impacted (4 sites) and less impacted (9 sites), based on how the sites were affected by the tsunami (Refer Table 1 and Figure 15 for details) and compared the categories to look at differences in species composition, diversity and abundance.

Intertidal fauna in relation to human disturbance

For disturbance, the beaches were divided into three groups: highly disturbed, moderately disturbed and undisturbed, with 9 beaches in the first two groups and 7 in the other (Table 1). The extent of human disturbance on the nearshore intertidal ecosystems were calculated based on the presence of fishing villages and fishing related activities on the beach, foot traffic, use of beach for domestic purposes, tourist activities and construction in the immediate vicinity of beach. The levels of each type of disturbance were approximated and graded on a scale of 1-3 (Appendix 3, Figures 7-14).

Intertidal fauna in relation to the ecoregions

The Tamil Nadu has distinct coastlines associated with different ecosystems, namely, the Coromandel Coast, the Palk Bay and the Gulf of Mannar (Figures 1-6). The Coromandel coast (Chennai to Nagapattinam) is predominantly a sandy shore coastline with offshore muddy and sandy bottoms and interspersed rocky beds. The stretch of the Palk Bay is predominantly a lush sea-grass ecosystem, with the coastline being muddy sand to mudflats. The Gulf of Mannar is a coral reef dominated ecosystem with coral sand dominating the stretch from Rameswaram up to Tuticorin. In order to compare the composition and abundance of intertidal fauna in relation to the ecosystems, the coast was divided into three eco-regions, namely, the Coromandel Coast (10 stations), the Palk Bay (5 stations) and the Gulf of Mannar (10 stations) (Refer Table1 for details).

Intertidal fauna in relation to latitude

The coast of Tamil Nadu extends for more than 500 kilometers, spanning six latitudes. In order to understand the variations in community indices along the latitudinal gradients, the region was divided into five major groups, namely, 8-9°, 9-10°, 10-11°, 11-12° and > 12°N. Since Marina beach was the only site that was above the 13° latitude, the last group was included in the > 12°N category.

The beaches sampled varied in shape, slope, tidal amplitude and grain size. Beach index is also a vital parameter in determining the nearshore intertidal fauna. While data has been recorded with reference to beach indices, it has not been analysed in detail. In general, the beaches varied from reflective, various stages of intermediate to dissipative beaches.

Ecoregions

Coromandel Coast

Figure 1. Cuddalore OT – Dissipative beach

Figure 2. Mahaballipuram – Reflective beach

Palk Bay

Figure 3. Eripurakkarai – Reflective beach

Figure 4. Devipattnam - Dissipative mudflat

Gulf of Mannar

Figure 5. Vembar – Intermediate beach

Figure 6. Vallinokam – Intermediate beach

Human disturbances on beaches

Figure 7. Fishing related activities on Marina beach

Figure 8. Foot traffic on Ovari beach

Figure 9. Marina beach used for domestic use

Figure 10. Seawalls on Puducherry beach

Figure 11. Construction of a groyne on Karraikal beach

Figure 12. Beach shell collection on Kovalam

Figure 13. Plastic waste dumped on Marina Beach

Figure 14. People on Puducherry beach

Table 1. Classification of sites based on latitude, anthropogenic disturbance, impacts of tsunami and ecoregions. (HD-Highly Disturbed, MD-Moderately Disturbed, UD-Undisturbed)

No.	Station name	Latitude	Disturbance index	Tsunami Impact	Region
1	Marina	N 13° 02. 315'	HD	High impact	Coromandel
2	Kovallam	N 12° 47. 357'	MD	High impact	Coromandel
3	Mahaballipuram	N 12° 37. 105'	HD	High impact	Coromandel
4	Kadapakam	N 12° 16. 061'	UD	High impact	Coromandel
5	Puducherry	N 11° 55. 386'	HD	High impact	Coromandel
6	Cuddalore OT	N 11° 43. 315	MD	High impact	Coromandel
7	Parangipettai	N 11° 31. 602'	UD	High impact	Coromandel
8	Poombuhar	N 11° 08. 685'	HD	High impact	Coromandel
9	Karaikkal	N 10° 54. 938'	UD	High impact	Coromandel
10	Nagapattinam	N 10° 44. 694'	MD	High impact	Coromandel
11	Kodiakarai	N 10° 16. 481'	MD	High impact	Palk Bay
12	Eripurakarai	N 10° 18. 911'	UD	Less impact	Palk Bay
13	Thondi	N 09° 44. 559'	HD	Less impact	Palk Bay
14	Devipattinam	N 09° 28. 529'	MD	Less impact	Palk Bay
15	Rameswaram	N 09° 16. 573'	HD	Less impact	Palk Bay
16	Dhanushkodi	N 09° 11.930'	MD	Less impact	Gulf of Mannar
17	Mandapam	N 09° 16.611'	HD	Less impact	Gulf of Mannar
18	Vallinokkam	N 09° 09.772'	UD	Less impact	Gulf of Mannar
19	Vembar	N 09° 04.549'	MD	Less impact	Gulf of Mannar
20	Vellapatti	N 08° 51.170'	MD	Less impact	Gulf of Mannar
21	Punna Kayal	N 8° 32.283'	UD	Moderate	Gulf of Mannar
22	Alanthali	N 08° 29.284'	HD	Moderate	Gulf of Mannar
23	Oovari	N 08° 16.528'	HD	Moderate	Gulf of Mannar
24	Vattakottai	N 08° 07.394'	MD	Moderate	Gulf of Mannar
25	Kovalam	N 08° 04.947'	UD	Moderate	Gulf of Mannar

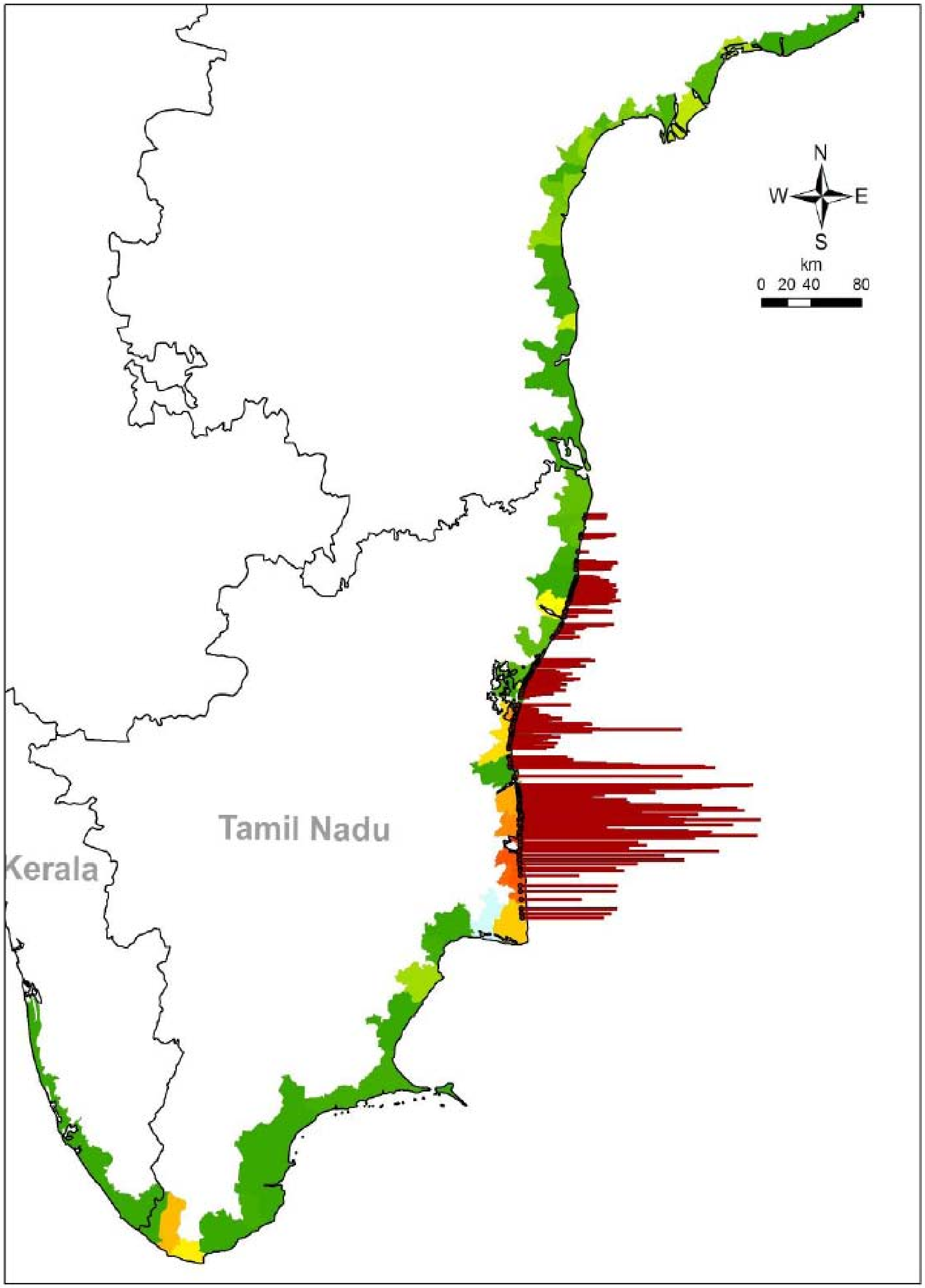

Figure 15. Map indicating the run-up distance of the December 2004 Tsunami along the Coromandel coast. Longer red bars indicating greater distances of water ingress. Green (low) to orange (high) indicate human casualty in the tsunami. Source: Madhusudhan *et al.* 2007.

Figure 16. Map showing the beaches that were sampled from marina in the north to Kovallam in the south

4.2. Macro and mega fauna field sampling methods

The sampling protocol was designed during a pre-sampling trip to a few beaches along the coast. This enabled us to bring out an effective sampling method that would represent the diversity and abundance of both groups.

The collection of sediment for macrofauna was done using a 15 × 15 cm cylindrical core (Figure 18). For the megafauna, a metal core of 25cm diameter was used. These cores for megafauna were taken up to a depth of 25cm (Figure 19).

Samples were collected along transects oriented in an east-west direction along the intertidal zone (Figure 17). The intertidal zone was divided into high, mid and low tidal levels to aid in sampling. Four transects were laid per beach with a distance of ~ 200m between transects (in Puducherry and Mahabalipuram, the distance was less due to the total length of the beach). Two cores for macrofauna were collected at each tidal level. Five samples for megafauna were also collected randomly in a 2 m^2 area between low and mid tide.

Macro and megafauna were extracted from the sand using sieves of 500 µm and 2cm respectively (Figures 20, 21). Samples were then transferred into labeled packets, stained (macrofaunal samples only) and preserved in 5% buffered formalin. Sample collection for each beach took approximately 4-5 hours.

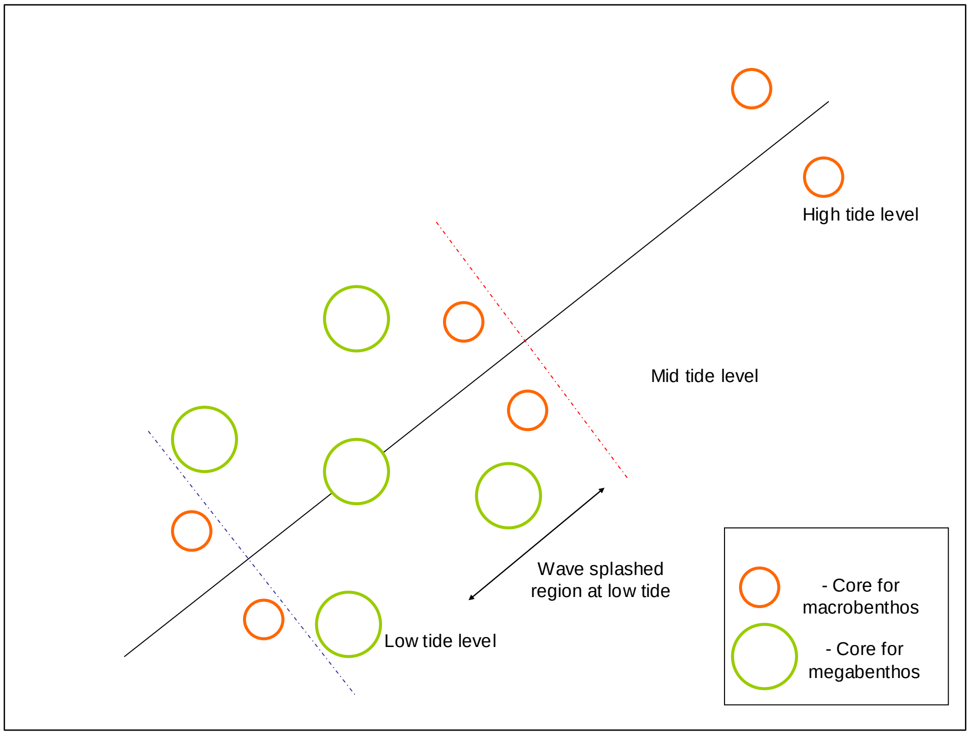

Figure 17. Diagram illustrating the sample design for a single transect

Common macrofauna groups encountered

Figure 18. Amphipod

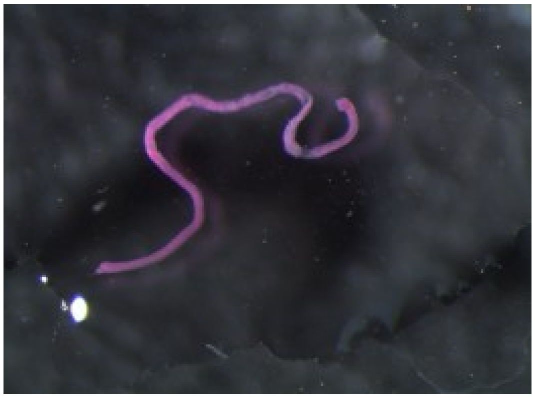

Figure 19. Archiannelid

Figure 20. Capitellid

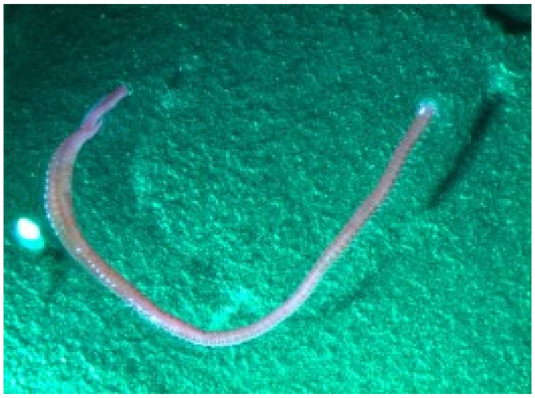

Figure 21. Glycerid

Figure 22. Isopod

Figure 23. Oligochaete

Figure 24. Pisionid

Figure 25. Polydorid

Figure 26. *Donax faba*

Figure 27. *Donax cuneatu*

Figure 28. *Certhidea cingulata*

Figure 29. *Umbonium vestiariu*
m

Figure 30. *Cardita bicolor*

Figure 31. *Lucina edentula*

Figure 32. *Nassarius stollatu*
s

Figure 33. Unidentified bivalve sp.

Figure 34. *Emerita asiatica* - dorsal view

Figure 35. *Emerita asiatica*- ventral view

4.3. Laboratory analysis

Assistants were hired to pick out macrofauna from the sand samples that were preserved and stained. The macrofauna were then sorted into groups under a stereo zoom dissection microscope. Sorted specimens were then counted, labeled and preserved in 75% alcohol in vials for species level identification. As species level identification of all the macrofaunal groups was beyond the scope of the study, a group level taxonomic magnification was employed (Figures 26-33). Megafauna were identified to species level (Figures 34-43).

The sediment samples for analysing sand texture and organic carbon were sun dried prior to treatment and analysis. Sand texture was considered an important parameter as grain size determines the amount of pore water present (Boaden 1968), the stability of the sediment, penetrability of the sand which determines the composition of macro and megafauna. Grain size analysis was done following Ingram (1970) method. A brief description of the protocol is given below.

The sediment samples were mixed thoroughly, coned and then quartered. The sand from one quarter was taken and weighed to 20g. The sediment was then treated with hydrogen chloride (HCl), hydrogen peroxide (H_2O_2) and oxalic acid to dissolve the calcium carbonate, organic matter and iron content present. The sediment was later dried in an oven at 60ºC, weighed again and put through a set of sieves. Fractions of sediment that were retained on each sieve were then weighed separately. Grain size is expressed as *phi* following the Krumbein *phi* (φ) scale (Krumbein and Sloss 1963), a modification of the Wentworth scale (Wentworth 1922) (See Appendix 2 for details).

Granulometric analysis was done using GRADISTAT software (Grain Size Analysis Program) (Copyright Simon Blott 2000)[1].

Organic carbon in the sand (Total Organic Carbon) acts as a source of food for infaunal species and limits their distribution. Total Organic Carbon in the sand samples was determined using the titration method by Wakeel and Riley (1957). The protocol was modified to make it economical to carry out the experiment for 300 samples. A brief description of the protocol is given below:

2g of the sample was taken in a 500ml conical flask. 1ml of potassium dichromate and 2ml of sulphuric acid was added, shaken well and left to stand for 30mins. Then 20ml of water, 1ml phosphoric acid and 0.1 diphenylamine indicator is added. This solution was titrated against ferrous ammonium sulphate solution till the end point was reached (till the solution turned green).

Calculations:

Weight of soil taken = W g
Volume of 0.5N ferrous ammonium sulphate required for reducing 10ml potassium dichromate solution = X ml
Volume of 0.5N ferrous ammonium sulphate required for reducing the excess of dichromate (experimental reading) = Y ml
Difference = (X – Y) ml
1 ml of 1N Potassium dichromate = 0.003g carbon
% of C in soil = ((X – Y) x N x 0.003 x 100)/ W
Where N = normality of ferrous ammonium sulphate.

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[1] Copyright Simon Blott 2000, Department of Geology, Royal Holloway University of London, UK (http://scape.brandonu.ca/download/gradistat.zip)

5. Results

Since both macrofauna and megafauna were sampled, sorted and analysed separately, we provide the results of the analysis separately. Since species level identification was carried out for megafauna, we compared patterns of diversity abundance along four axes, namely tsunami impact, anthropogenic disturbance, ecoregions and latitude. For macro fauna, variation in species composition was determined along the four axes.

Table 2. Shows various axes of analysis of macrofauna viz., latitude, ecoregion, human disturbance and tsunami impacts and the various parameters analysed viz., S- species richness, N - abundance and J - evenness

(S. No. – Site number, HD – Highly disturbed, MD – Moderately Disturbed and UD – Undisturbed)

S. No	Site	Latitude	Region	Human disturbance	Tsunami impact	S	N	J'
1.	Marina	N 13° 02. 315'	Coromandel	HD	High	7	29467	0.44
2.	Kovalam-C	N 12° 47. 357'	Coromandel	MD	High	5	6065	0.38
3.	Mahabalipuram	N 12° 37. 105'	Coromandel	HD	High	5	5021	0.69
4.	Kadapakam	N 12° 16. 061'	Coromandel	UD	High	7	1103	0.76
5.	Puducherry	N 11° 55. 386'	Coromandel	HD	High	5	8927	0.61
6.	Cuddalore	N 11° 43. 315	Coromandel	MD	High	7	337	0.57
7.	Parangipettai	N 11° 31. 602'	Coromandel	UD	High	4	1138	0.53
8.	Poompuhar	N 11° 08. 685'	Coromandel	HD	High	3	434	0.46
9.	Karaikkal	N 10° 54. 938'	Coromandel	UD	High	5	290	0.49
10.	Nagapatinam	N 10° 44. 694'	Coromandel	MD	High	4	636	0.57
11.	Kodiakarai	N 10° 16. 481'	Palk Bay	MD	High	4	441	0.17
12.	Eripurakarai	N 10° 18. 911'	Palk Bay	UD	Less impact	4	554	0.72
13.	Thondi	N 09° 44. 559'	Palk Bay	HD	Less impact	5	273	0.65
14.	Devipatinam	N 09° 28. 529'	Palk Bay	MD	Less impact	3	1042	0.20
15.	Rameswaram	N 09° 16. 573'	Palk Bay	HD	Less impact	5	1726	0.30
16.	Dhanushkodi	N 09° 11.930'	Gulf of Mannar	MD	Less impact	7	423	0.70
17.	Mandapam	N 09° 16.611'	Gulf of Mannar	HD	Less impact	7	843	0.42
18.	Valinokam	N 09° 09.772'	Gulf of Mannar	UD	Less impact	5	590	0.57
19.	Vembar	N 09° 04.549'	Gulf of Mannar	MD	Less impact	7	540	0.54
20.	Vellapati	N 08° 51.170'	Gulf of Mannar	MD	Less impact	5	755	0.71
21.	Punnakayal	N 08° 32.283'	Gulf of Mannar	UD	Moderate	3	189	0.78
22.	Ovari	N 08° 16.528'	Gulf of Mannar	HD	Moderate	6	606	0.54
23.	Vattakotai	N 08° 07.394'	Gulf of Mannar	MD	High	4	94	0.47
24.	Kovalam-K	N 08° 04.947'	Gulf of Mannar	UD	High	5	361	0.59

5.1. Abiotic parameters

5.1.1. Granulometry

The composition of sand showed considerable variation with respect to sites sampled (Figure 36). Puducherry beach was the only beach with coarse sand. The beaches of the northern Coromandel (Chennai to Puducherry) were more or less coarse to medium fine sand, while the southern Coromandel had much finer sand.

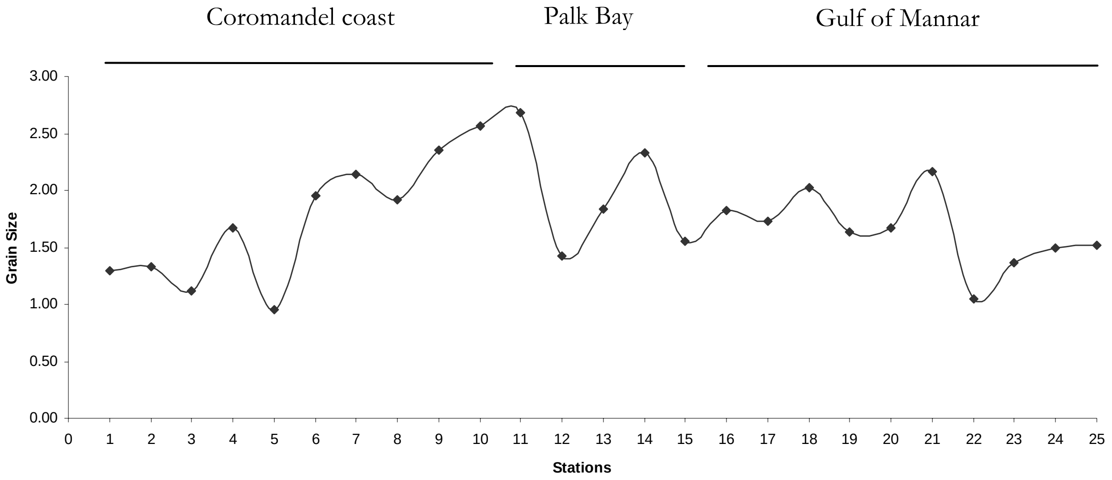

Figure 36. Variation in average grain size (Ø) along the twenty five stations. Station numbers on the x-axis coincide with the Sl. No. provided in Table 6

5.1.2. Total Organic Carbon (TOC)

The total organic carbon percentage in the sediment varied from 0.06% to 1.48% (Figure 37 and Table 2). The highest values were recorded from beaches in the Palk Bay area (11-15), with the mudflat at Devipattinam showing the highest value of organic carbon with 1.48%.

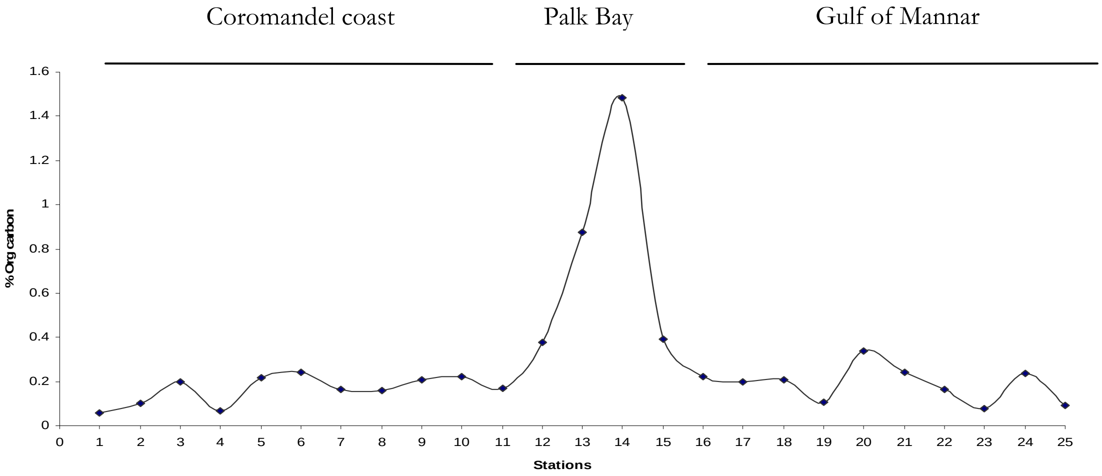

Figure 37. Percentage composition of organic carbon along all twenty five stations. Station numbers on the X-axis coincide with the Sl. No. provided in Table 6

5.1.3. Total Dissolved Solids (TDS)

TDS of seawater ranged from 28-39 ppt, with considerable variations between eco-regions (Figure 38 and Table 2). For example the sites of the Coromandel Coast (except site 7) fluctuated within a narrow range of variation (33-37 ppt) while the Palk Bay stretch in general had a higher TDS value (except Rameswaram, site 15). The northern stretch of the Gulf of Mannar showed considerably lower TDS values, while the southern region of the gulf had higher values. Salinity also showed variations similar to that of TDS.

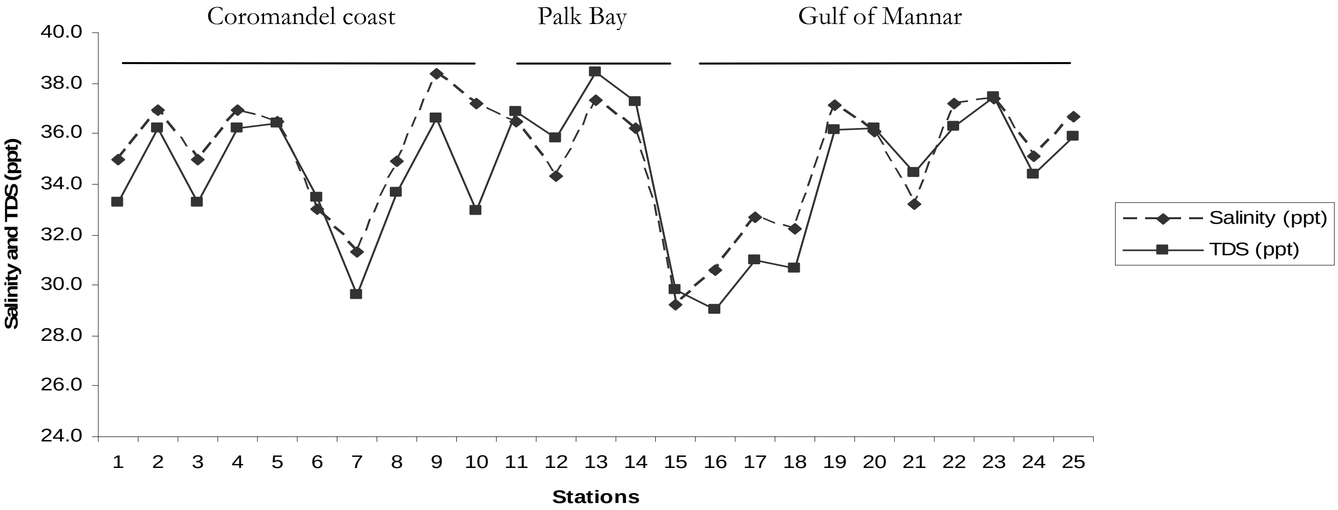

Figure 38. TDS of seawater for all the twenty five stations. Station numbers on the x-axis coincide with the Sl. No. provided in Table 6

5.1.4. pH

The pH for most of the sites fell within the normal range for seawater (7.4-8.3). Stations in the Palk Bay (12-15) showed considerably higher pH (acidic nature), while the stations of the southern Coromandel coast (6-11) showed considerably lower values of pH (alkaline in nature) (Figure 39).

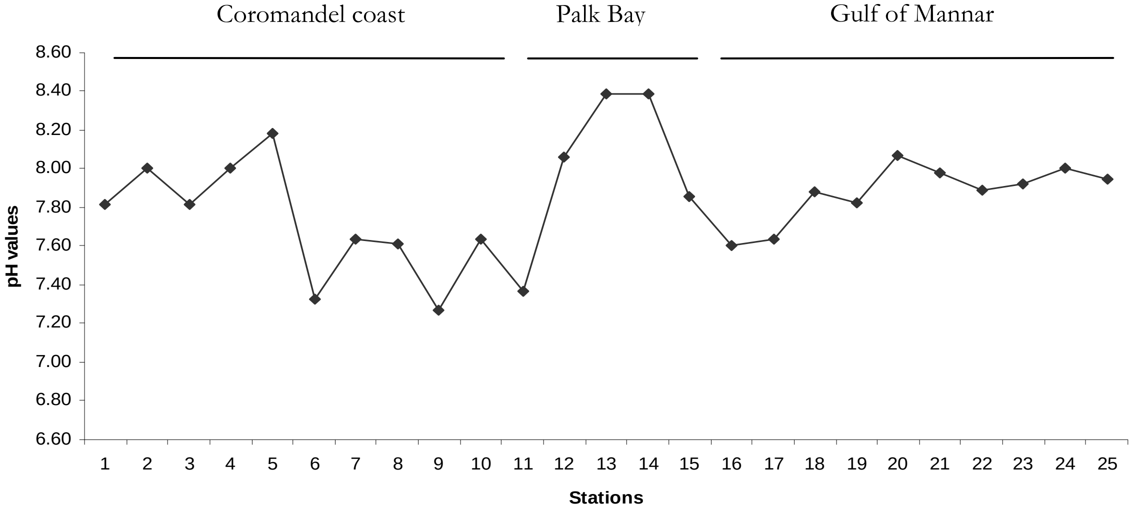

Figure 39. pH of seawater for all the twenty five stations. Station numbers on the x-axis coincide with the Sl. No. provided in Table 6

5.1.5. Electrical Conductivity (EC)

Electrical conductivity was lowest in Rameswaram and highest in Karaikkal. The variations in electrical conductivity showed no particular pattern (Figure 40).

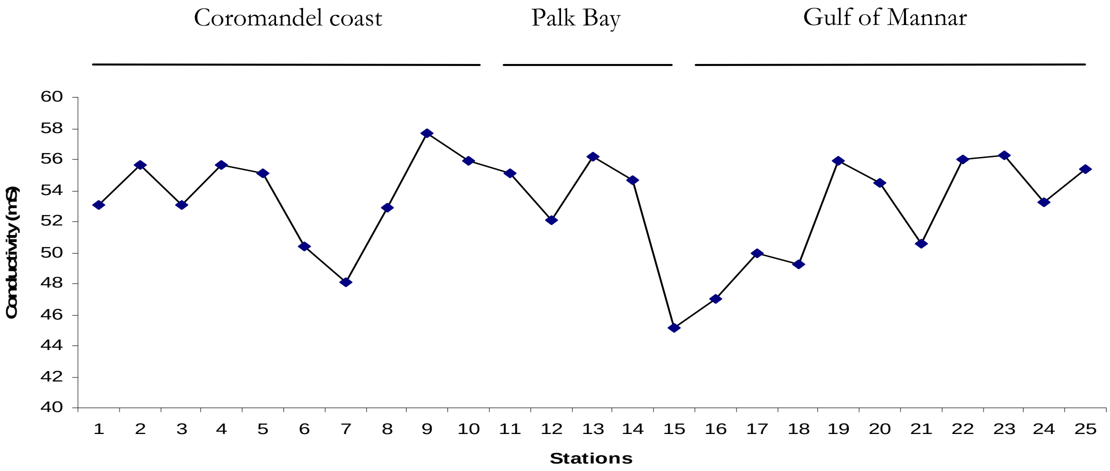

Figure 40. Variations in conductivity (mS) along the stations

5.2. Analysis of nearshore intertidal macrofauna

5.2.1. Macrofaunal abundance along the Tamil Nadu coast

Except sites 1-5, all the other stations showed a more or less uniform abundance of macrofauna. Abundance of macrofauna showed considerable correlation with the levels of anthropogenic disturbance (Figure 41). For example, sites 1, 2, 3, 5, 15 were some of the most disturbed along the coast and these sites showed a considerably higher abundance of macrofauna.

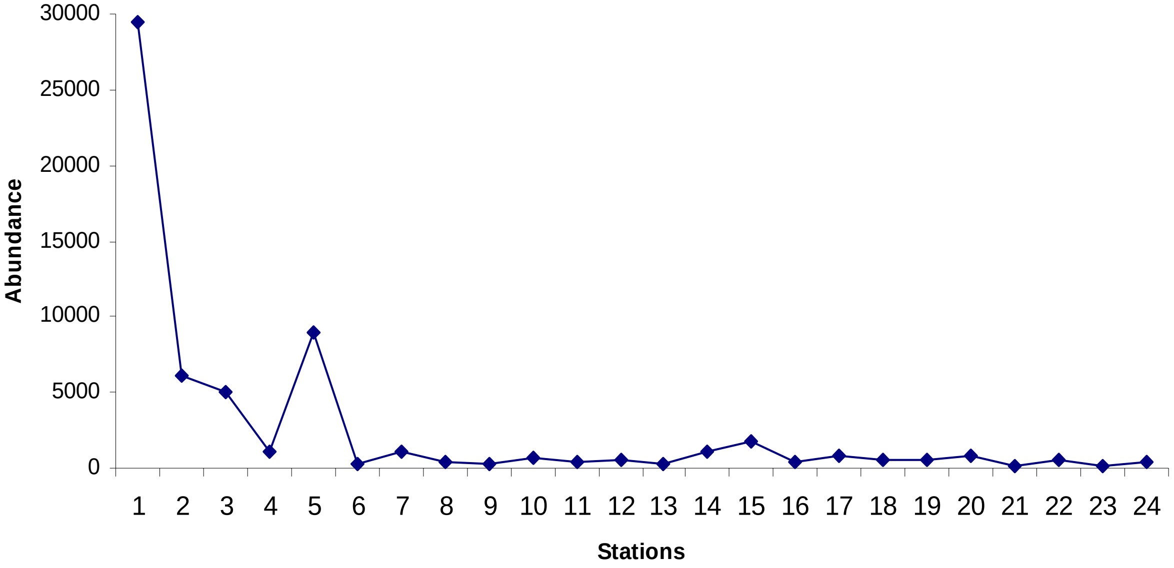

Figure 41. Abundance of macrofauna in various stations (no.s 1-24 on the x-axis correspond to the Sl. No. provided in Table 1 for stations)

5.2.2 Effect of the tsunami on macrofauna

It was interesting to note that areas that were highly impacted by the tsunami had higher abundance, while moderately and less impacted areas had similar abundance (Figure 43). Species richness and evenness did not differ significantly on the basis of tsunami impact (Figure 44, 45). In terms of composition, oligochaetes showed very interesting patterns, reaching very high abundances of approximately 2,000 individuals/m^2 in sites that were highly impacted by the tsunami, while they were quite low in number in areas that were moderately or less impacted (Figure 42). Oligochaetes, archiannelids, polychaetes and nematodes dominated the highly impacted areas, while crustaceans showed no particular change in relation to impacts of the tsunami.

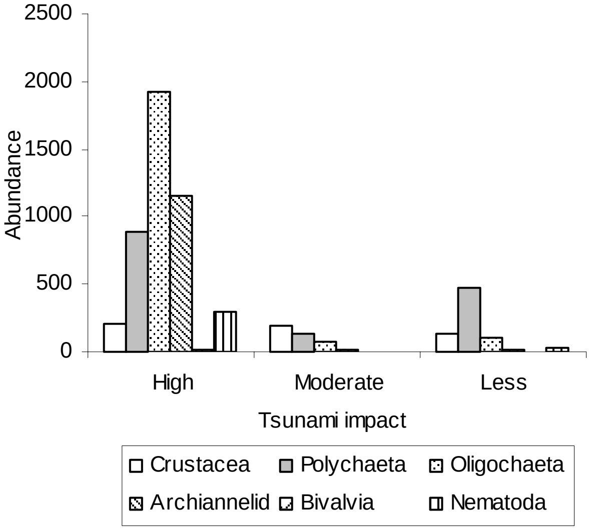

Figure 42. Variation of macrofaunal composition in relation to tsunami impacts

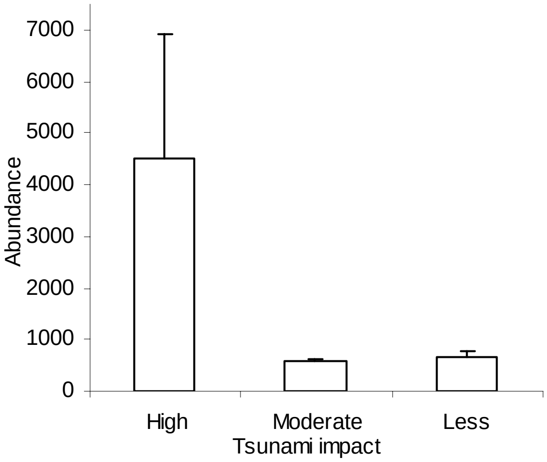

Figure 43. Abundance of macrofauna in relation to tsunami impacts.

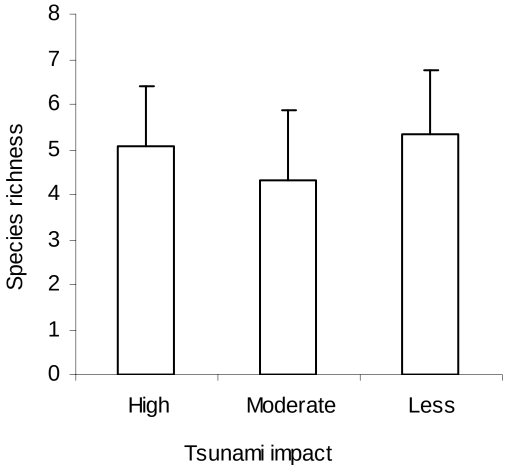

Figure 44. Species richness of macrofauna in relation to tsunami impacts

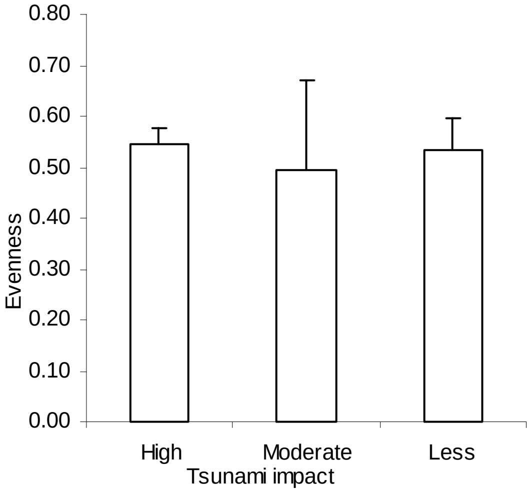

Figure 45. Species evenness of macrofauna in relation to tsunami impacts

5.2.3. Effect of anthropogenic disturbance on macrofauna

Total abundance was higher in highly (human) disturbed areas, followed by moderately disturbed areas and undisturbed areas (Figure 47). Species richness showed some degree of similarity with reference to human disturbances (Figure 48). Undisturbed areas showed the highest values in terms of evenness, while the highly disturbed and moderately disturbed areas were more or less similar (Figure 49). Oligochaetes, archiannelids, polychaetes and nematodes were considerably higher in more disturbed areas (Figure 46). The abundance of crustaceans steadily increased from highly disturbed to undisturbed beaches. Again interesting patterns were noticed with respect to polychaetes, oligochaetes, archiannelids and nematodes. Oligochaete density reached nearly 22,300 individuals/m^2 at Marina Beach, but the second largest value encountered was for Puducherry beach, where it occurred at densities of 436 individuals/m^2. The archiannelid populations were entirely restricted to the continuous stretch between Marina and Puducherry. Elsewhere their numbers were comparatively negligible. Polychaete abundance also increased with increasing human disturbance. Polychaete composition in the highly disturbed areas was dominated by pisionids and spionids.

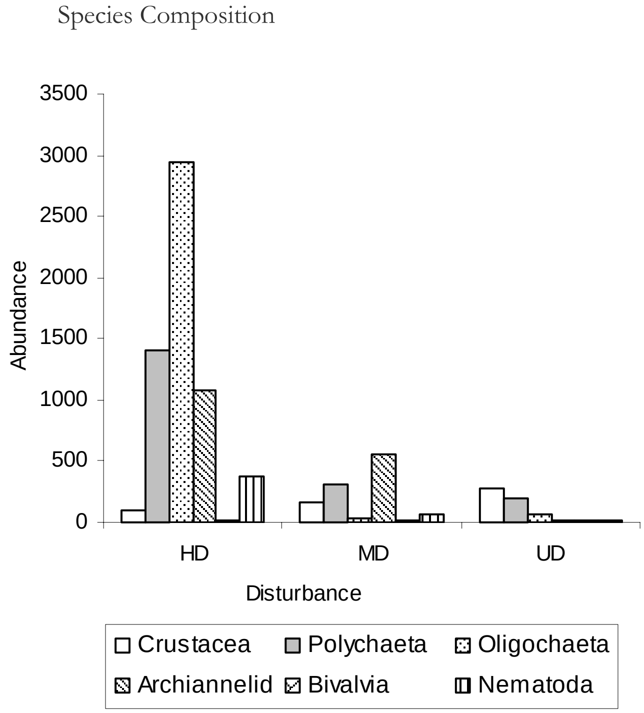

Figure 46. Variation of macrofaunal composition with human disturbance

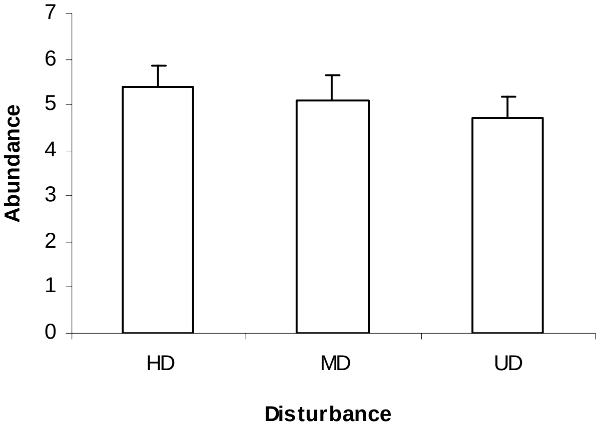

Figure 47. Abundance of macrofauna in relation to human disturbance

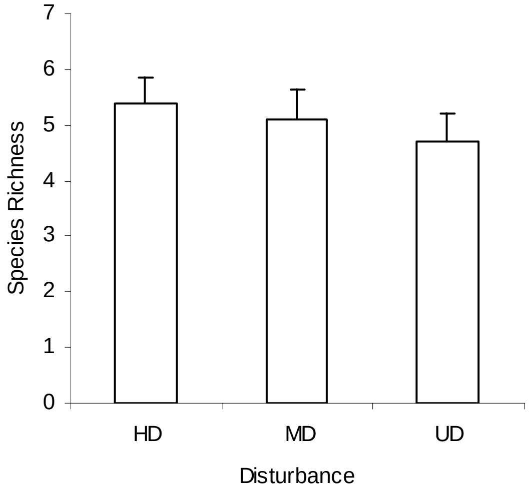

Figure 48. Species richness of macrofauna in relation to human disturbance

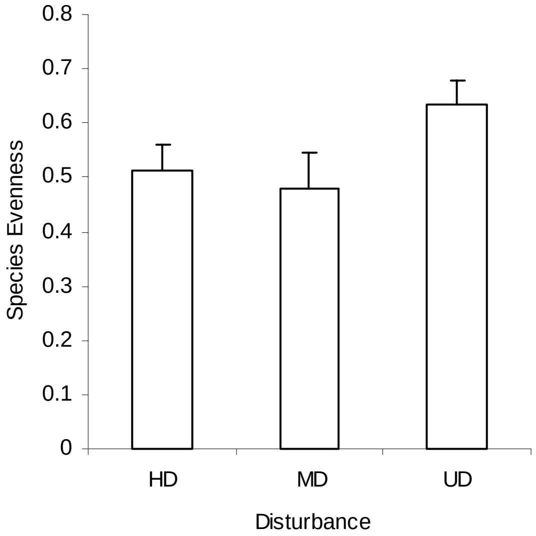

Figure 49. Species evenness of macrofauna in relation to human disturbance

5.2.4. Variation in macrofauna in different ecoregions

Macrofaunal abundance was highest on the Coromandel Coast, followed by the Palk Bay and the Gulf of Mannar (Figure 51). Species richness and evenness on the other hand were higher in the Gulf of Mannar and the Coromandel Coast, followed by Palk Bay (Figures 52 & 53). In terms of group wise composition of macrofauna, the Coromandel Coast populations were dominated by oligochaetes and archiannelids, followed by polychaetes, while nematodes and crustacean abundance was also comparatively high (Figure 50). The Palk Bay had an impoverished population in terms of number of groups present.

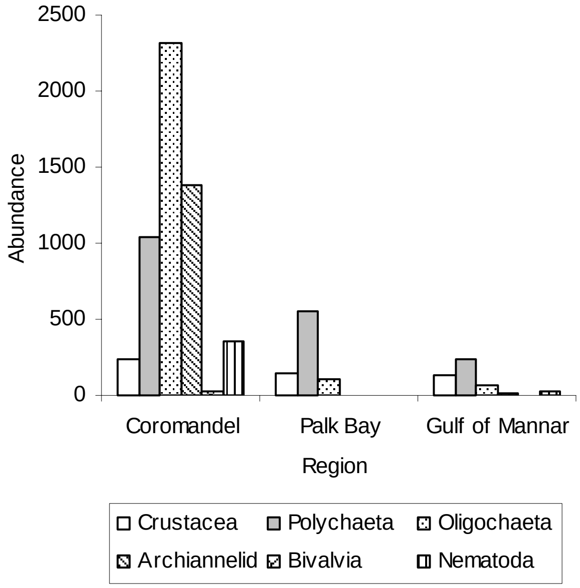

Figure 50. Variation of macrofaunal composition with ecoregions

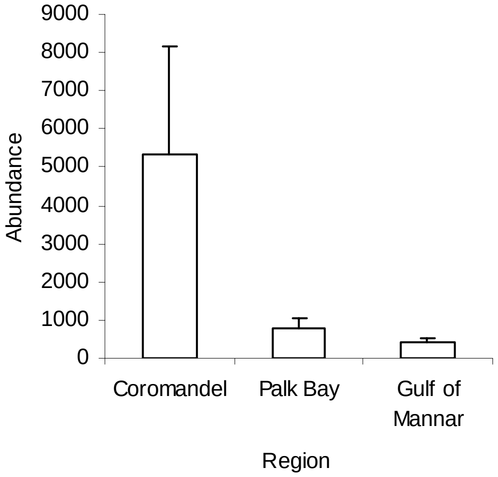

Figure 51. Abundance of macrofauna in relation to ecoregions

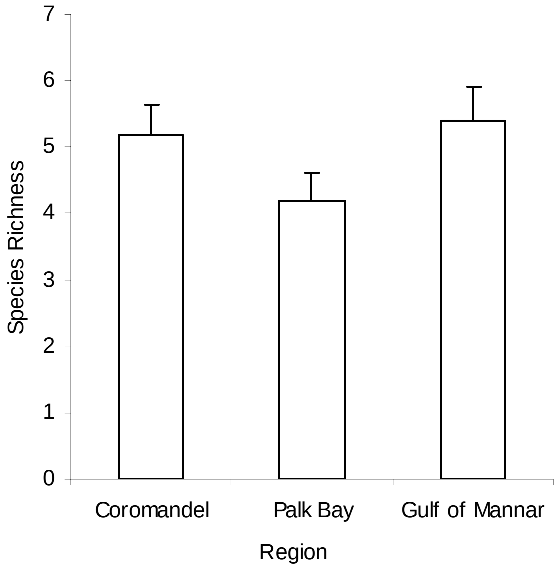

Figure 52. Species richness of macrofauna in relation to ecoregions

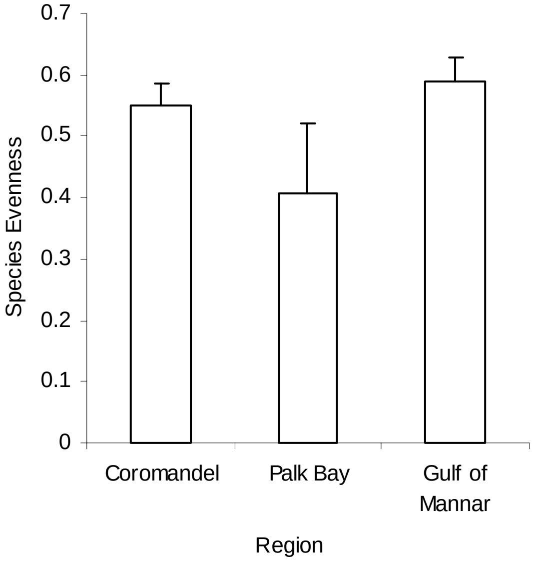

Figure 53. Species evenness of macrofauna in relation to ecoregions

5.2.5. Variation in macrofauna along the latitudinal gradient

Abundance of macrofauna showed an increasing pattern with increasing latitude (Figure 55). Species richness showed no patterns with respect to latitude (Figure 56). The latitudes 9-10ºN and 12-13ºN showed the highest richness and 10-11ºN had the lowest richness. Species evenness was also more or less similar with respect to latitude, with 8-9ºN having the most even macrofaunal composition (Figure 57). In terms of composition, all the groups showed a steady decline with decreasing latitude. Oligochaetes showed a rapid decline in population, falling considerably from 12-13 ºN to 11-12ºN (Figure 54).

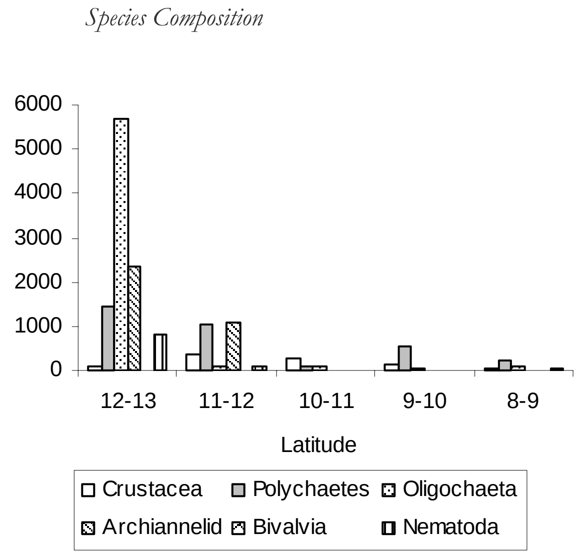

Figure 54. Variation of macrofaunal composition with latitude

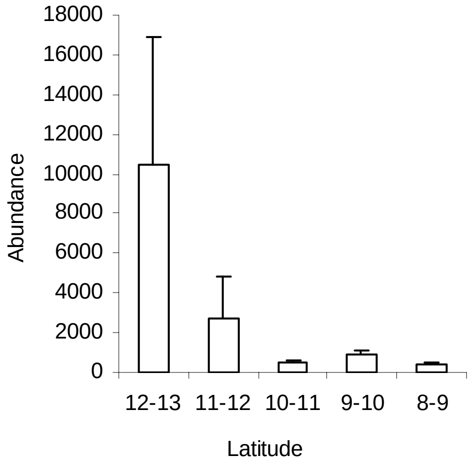

Figure 55. Variation of macrofaunal abundance with latitude

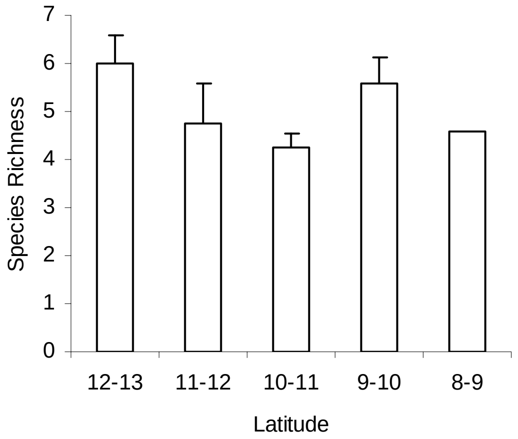

Figure 56. Variation of macrofaunal richness with latitude

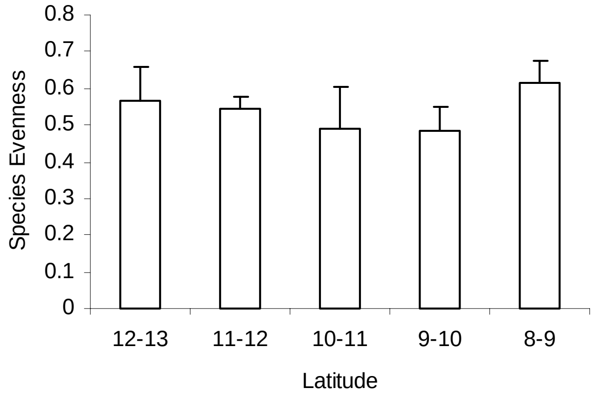

Figure 57. Variation of macrofaunal evenness with latitude

5.3. Analysis of nearshore intertidal megafauna

5.3.1. Effect of the tsunami on megafauna

The tsunami affected areas were divided into 3 categories: highly impacted, moderately impacted and less impacted. Each group consisted of 12, 4 and 9 beaches for which the total megafaunal abundance for each group was averaged. Abundance was highest in less and highly impacted areas followed by moderately impacted areas (Figure 58).

Total species richness showed higher values in areas that were less impacted by the tsunami followed by highly and moderately impacted areas showed similar values (Figure 59). Diversity was highest in areas that were less impacted (H'=0.45) and highly impacted (H'=0.42), followed by areas that were moderately impacted (H'=0.26) (Figure 60). However, species evenness (J') was high in highly impacted area, followed by less impacted and moderately impacted areas (Figure 61).

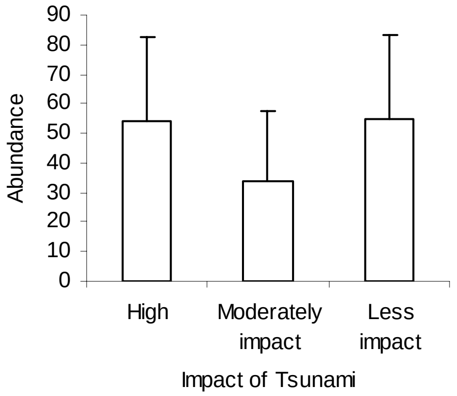

Figure 58. Abundance of megafauna in relation to impacts of the tsunami

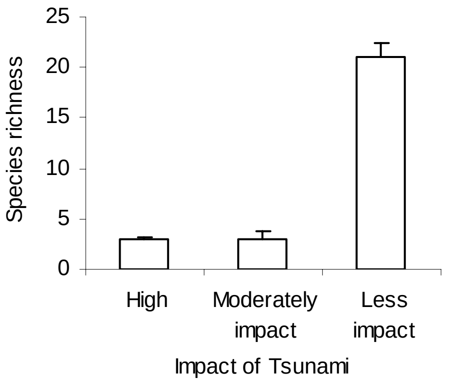

Figure 59. Species richness of megafauna in relation to tsunami impacts

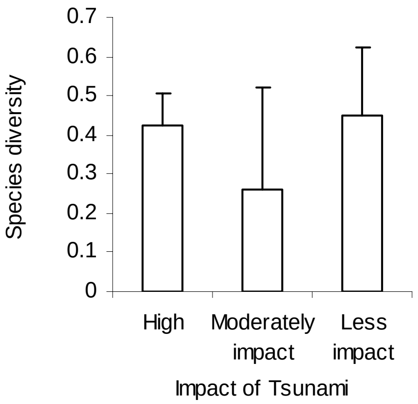

Figure 60. Species diversity of megafuna in relation to tsunami impacts

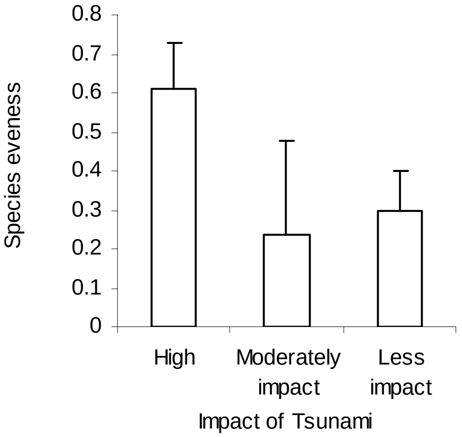

Figure 61. Species evenness of megafuna in relation to tsunami impacts

5.3.2. Effect of anthropogenic disturbance on megafauna

Moderately disturbed areas showed the highest values in abundance, species richness and species diversity, while species evenness was higher in the highly disturbed beaches (Figures 62-65). Abundance of megafauna is highest in areas that are moderately disturbed, followed by highly disturbed and undisturbed areas (Fig. 62). The total species richness for each group was the highest in moderately disturbed areas with 20 species, ranging from 0 to 13 for each beach. The undisturbed areas had 6 species ranging from 1 to 4 per beach, and highly disturbed areas had 5 species ranging from 0 to 3 per beach. Species diversity was highest in moderately disturbed areas (H'=0.46), followed by undisturbed (H'=0.39) and highly disturbed (H'=0.37) beaches. Species evenness did not vary with levels of distrurbance.

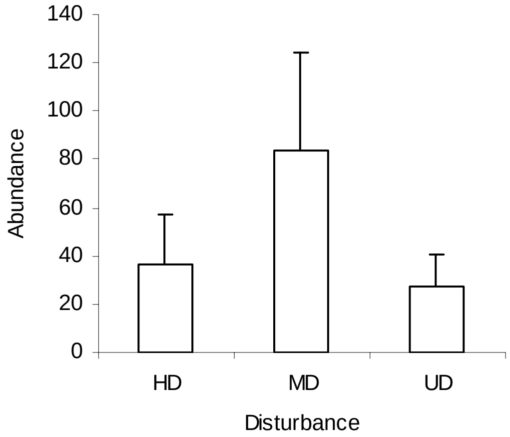

Figure 62. Abundance of megafuna in relation to anthropogenic disturbance

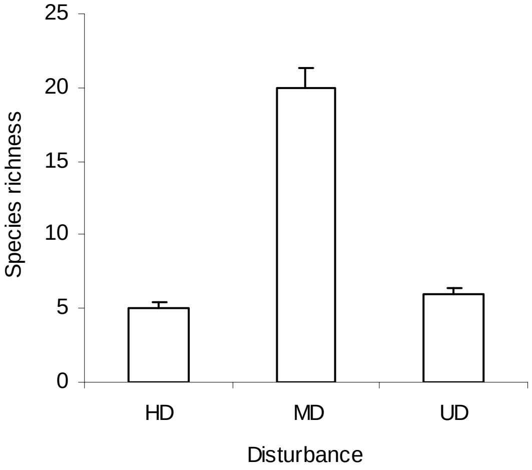

Figure 63. Species richness of megafuna in relation to anthropogenic disturbance

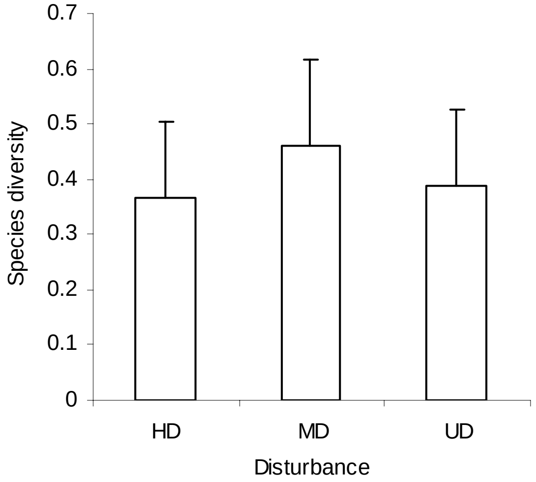

Figure 64. Species diversity of megafuna in relation to anthropogenic disturbance

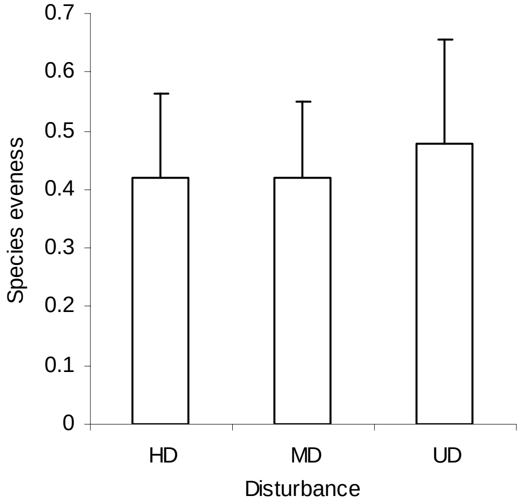

Figure 65. Species evenness of megafauna in relation to anthropogenic disturbance

5.3.3. Variation in megafauna in different ecoregions

Abundance was more or less similar in the Coromandel and the Palk Bay (63), followed by much lower values for the Gulf of Mannar (Figure 66). The Palk Bay had the highest species richness followed by the Gulf of Mannar and the Coramanadel Coast (Figure 67). The Coromandel Coast showed higher diversity (H'=0.51), followed by the Palk Bay (H'=0.41) and the Gulf of Mannar (H'=0.30) (Figure 68). Species evenness was the highest along the Coromandel Coast (J'=0.73), followed by the Gulf of Mannar (J'=0.25) and Palk Bay (J'=0.21) (Figure 69).

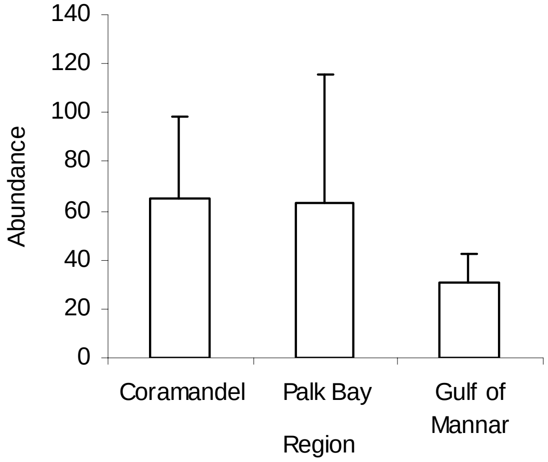

Figure 66. Variation of megafaunal abundance in relation to ecoregions

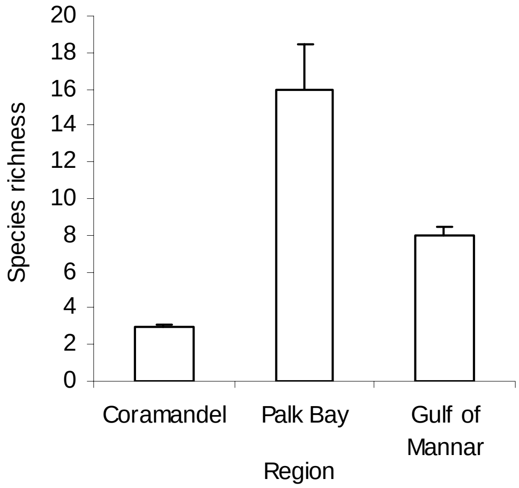

Figure 67. Species richness of megafauna in relation to the ecoregions

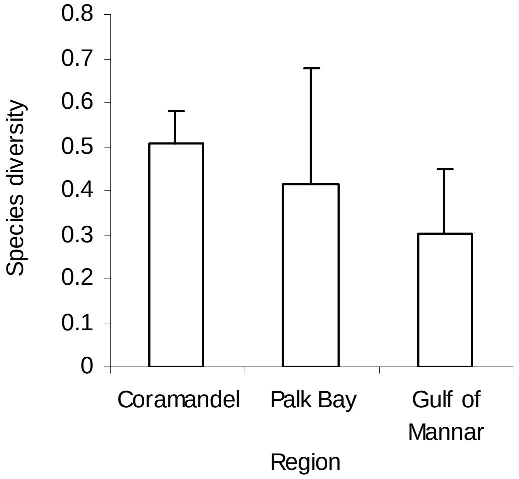

Figure 68. Species diversity of megafauna in relation to the ecoregions

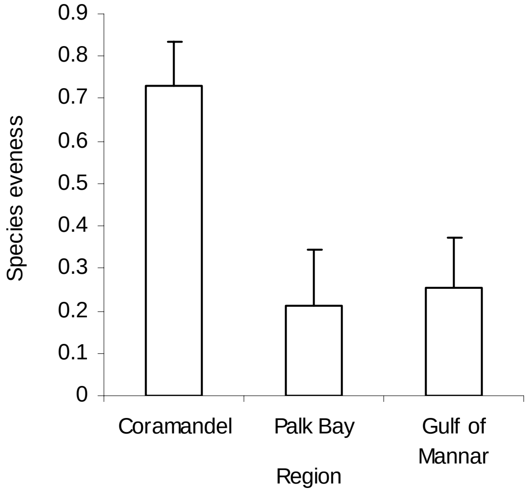

Figure 69. Species evenness with respect to the ecoregions

5.3.4. Variation in megafauna along the latitudinal gradient

The abundance of megafauna was the maximum at the highest latitude 13-12ºN, followed by 9ºN (Figure 70). Species richness showed a significant correlation with latitudinal gradient, decreasing as latitude increased (r= 0.66) (Figure 71). Species evenness and diversity did not show a pattern with latitude (Figure 72, 73).

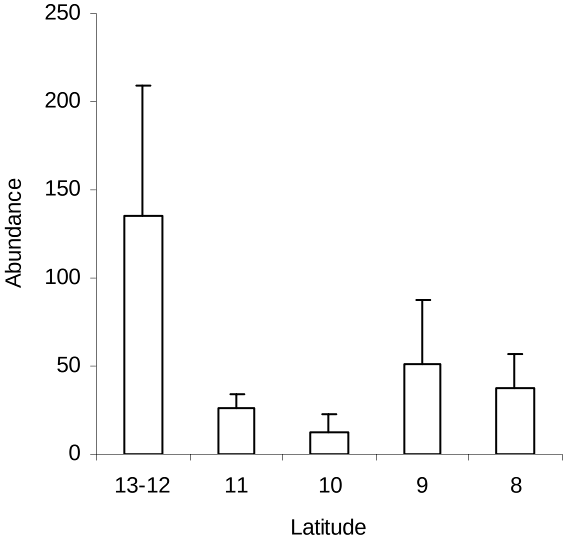

Figure 70. Variation in abundance of megafauna with latitude

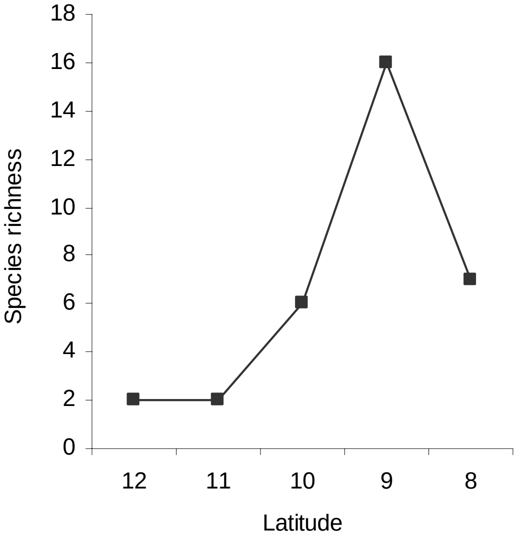

Figure 71. Species richness of megafuna with respect to latitude

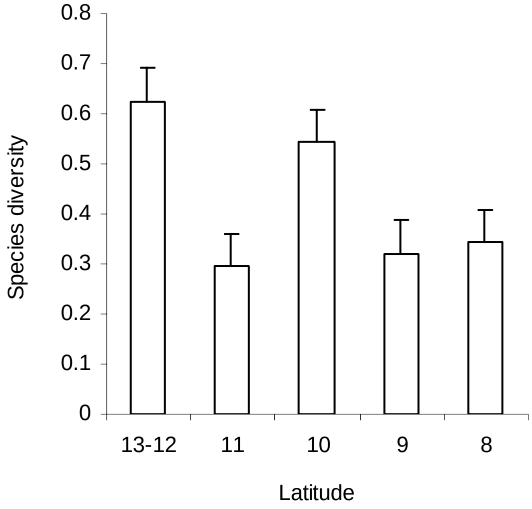

Figure 72. Species diversity of megafuna with respect to latitude

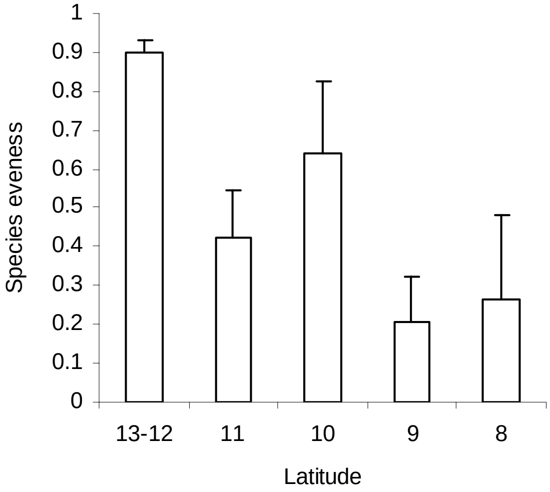

Figure 73. Species evenness of megafuna with respect to latitude

6. Discussion

6.1. Disturbance (tsunami and anthropogenic)

In the absence of reliable pre-tsunami data, characterising the impact of a large scale disturbance like the tsunami on coastal ecosystems is difficult. Further, segregating tsunami induced disturbance from other natural and human induced variations is even more challenging, considering the study was undertaken three years post-tsunami. We are therefore discussing the impacts of human and tsunami related disturbances together.

A healthy benthic ecosystem is characterised by a balanced community with a few well established species. Frequent disturbance affect the structure of the ecological communities by removing the well established species and allowing opportunistic species to colonise disturbed areas (White 1979). Connell (1978) concluded that certain levels of disturbance are important to maintain higher levels of biodiversity in an ecosystem. Known as the intermediate distrubance hypothesis, diversity trends have been found to show an increase with increasing disturbance till a certain threshold, beyond which, there is a sudden drop in diversity (Connell 1978). The Tamil Nadu coastline, which has the longest stretch of sandy beach in India, was exposed to a major natural disturbance. The tsunami of December 2004 wreaked major havoc in the coastal areas of Tamil Nadu, and the intertidal coastline bore the brunt of this impact. While disturbance theory was proposed for a disturbance of small and localised intensities, not many studies exist on responses of ecosystems to disturbances with intensities as powerful and widespread as that of the tsunami. The east coast of India from Srikakulam in Andhra Pradesh to Kodiakkarai in Tamil Nadu was the most severely affected (Madhusudan *et al.* 2007). The major impacts of the tsunami on the intertidal sandy shore communities are by large scale physical damage, dislodging and subsequent removal from the ecosystem, changing sediment structure/texture and also availability of nutrients and other food resources (Altaff *et al.* 2005; Chaudhary *et al.* 2006).

The current study was conducted 3 yrs after the tsunami hit the Indian mainland and the high abundance of megafauna in areas that were highly impacted could suggest that these areas have been re-colonised since. Recolonisation of sandy shores is inevitable as the fauna associated with them are highly mobile, plastic and opportunistic and will colonise any area that is defaunated (McLachlan and Brown 2006). It was interesting to note that Marina, Kovallam, Mahabalipuram and Puducherry showed the highest abundance for both macrofauna and megafauna.

Studies in the past have shown that depending on the intensity of the disturbances, the coastal ecosystems are capable of being recolonised within a day, month or year (Coull 1969; Pequegnat 1975; Thistle 1980). The only study pertaining to recovery and reestablishment of intertidal communities from the east coast of mainland India after the tsunami was by Altaff *et al.* (2005). They studied meiofauna of the Marina Beach along with certain abiotic and physical parameters of the beach. They observed that the sediment characteristics of the beach returned to its original state in five days, while the profile of the beach was restored to its original state in fifteen days. They observed that the meiofaunal populations declined drastically immediately after the tsunami, but during the third and fourth days their densities increased to more than pre-tsunami levels and later returned to normal pre-tsunami levels from the fifth day onwards.

With respect to macrofaunal communities, the current study revealed that sites that had been considerably impacted by the tsunami showed considerable difference in terms of abundance and species richness. As the present study deals only with a taxonomic magnification up to the group level, variations in species richness in relation to tsunami impacted and non-impacted beaches are not available. However, the macrofauna show higher abundance with higher degree of human disturbance rather than with the impact of the tsunami. For example, beaches that were both considerably impacted by tsunami and also have significant anthropogenic stress had the highest abundance. This is explained by the dominance of certain groups of macrofauna like the oligochaetes, nematodes, polychaetes and nemerteans in such severely disturbed areas.

An excellent example for this is the Marina Beach. The beach was considerably impacted by the tsunami and the receding waves had lasted for nearly 24 hours (Altaff *et al.* 2005). In addition, Marina also faces the maximum human induced stress among the beaches of the Tamil Nadu coast. High foot traffic, usage of the beach for domestic purposes and pollution from sewage influx from the metropolitan city of Chennai are some of the major disturbances on the beach. The beach had a considerably higher abundance of macrofauna (up to 30,000 individuals/m^2) than other beaches. Nearly 99.5% of the abundance comprised oligochaetes, nemerteans, nematodes and polychaetes; oligochaetes dominated the populations (nearly 76%). One possible explanation for this high level of dominance is that oligochaetes, nematodes and certain species of polychaetes are species capable of surviving or thriving in disturbed conditions. The impact of the tsunami waves could have removed well established species from the beach, and usually, disturbed sediments are commonly invaded by opportunistic species (McLachlan and Brown 2006). When an area becomes disturbed, and chronic human or other natural variations (in this case excessive faecal and sewage pollution) prevent the natural inhabitants from recolonising, species diversity declines and pollution-tolerant organisms such as oligochaetes replace pollutant-sensitive species (Lafont 1984; Farara and Burt 1993). Oligochaetes are also reported to adapt and thrive in areas with oxygen deficiency caused by excess sewage and faecal pollution (Giere 2006). In other freshwater ecosystems, Howmiller and Scott (1977) and Wright (1955) suggested that the degree of pollution could be summarised by aquatic oligochaete abundance. Worm densities of 100-999/m^2. were said to indicate light pollution, moderately polluted areas supported 1,000-5,000 worms/m^2, and densities of worms exceeding 5,000/m^2 were representative of heavily polluted areas. The current study reveals that the density of oligochaetes at Marina Beach far exceeds the densities proposed for heavily polluted areas by Wright (1955).

With regard to megafauna, *Donax cuneatus* and *Emerita asiatica* dominated the tsunami affected regions (especially the Coromandel Coast). The type of beach explains this occurrence better than the impact of tsunami. Nearly all the sampled sites in the Coromandel Coast are exposed sandy beaches of high wave energy. *D. cuneatus* and *E. asiatica* are typical representatives of such beaches and prefer high wave energy, exposed surf beaches. On the other hand, the absence of other common sandy shore megafaunal species is probably explained by the increased anthropogenic disturbance on the beaches of the Coromandel Coast, thereby allowing only stress tolerant species to recolonise.

Species richness and diversity was highest in areas less impacted by the tsunami, while moderately impacted and highly impacted areas showed similarity in species richness. Theory suggests that disturbance within thresholds are ideal to maintain high diversity and while retaining vital ecosystem processes. The tsunami as a disturbance is likely to have been of much higher magnitudes, thereby leading to a rapid decline in species richness. This also explains why areas like the Palk Bay and northern half of the Gulf of Mannar that were less impacted by the buffering action of the Sri Lankan landmass, had a much higher diversity of megafauna.

Megafaunal populations corresponded to the intermediate disturbance hypothesis which proposes that diversity is highest when disturbance levels are moderate. High disturbance in areas causes species that can tolerate high levels of stress to exist whereas low disturbance leads to competition for limited resources and survival of only a few species (Connell 1978). This fact is also reflected in the species evenness showing the highest value in undisturbed areas.

Healthy and resilient ecosystems are capable of returning to their pre-disturbance levels provided there is minimal or no additional (man-made or anthropogenic) stress on the ecosystem (McCook *et al.* 2007). The term ecosystem resilience refers to 'the capacity of the ecosystem to absorb shocks, resist dramatic changes in condition, and maintain or recover key functions and processes, without undergoing phase shifts'. Beyond a certain level of disturbance (threshold), in spite of adaptive capacities and resilience, the ecosystem may not return to its original state but may reach a different state, with different species composition and dominance (Holling 1973, Walker *et al.* 2002). The presence/absence of such stressors and the intensity of the disturbance determine how the ecosystem recovers. The present study indicates that many sites of the Coromandel Coast were severely impacted by the tsunami, and though the abundance of fauna was high, species richness was quite poor and was dominated by certain species, suggesting that additional human stress may preventing the beaches from returning to normal.

6.2. Ecoregions

There were distinct differences in the abundance, species composition and richness of macro and megafauna in different ecoregions. The Coromandel Coast, predominantly a sandy shore region had exposed beaches with high wave energy, considerably well oxygenated sand and the profiles showed considerable variations from steep (reflective) microtidal beaches to flat (dissipative) beaches, with many intermediate forms. The beaches of the Coromandel Coast had the highest abundance of macrofauna, followed by the Palk Bay and the Gulf of Mannar. But interestingly, more macrofaunal groups were represented in the Gulf of Mannar region. The higher densities of macrofauna in Coromandel Coast are attributed to the occurrence of certain groups like oligochaetes, archiannelids and nematodes in large numbers.

The Palk Bay region, with flourishing seagrass beds, is a sheltered and productive ecosystem. Seagrass beds provide a sheltered environment, as they dissipate wave energy and reduce sediment re-suspension (Gambi *et al.* 1990). The total organic carbon percentage in the Palk Bay was the highest of the three ecosystems. The high level of organic carbon in the sediment, owing to the increased amount of detritus associated with seagrass, is reported to serve as a major food source for benthic forms (Wolff *et al.* 1993). In the current study however, the Palk Bay was represented by lower densities and groups of macrofauna. The high organic content in the sediment (due to decaying seagrass), higher levels of clay content, and considerably low wave energy (low oxygen mixing in the interstitial water) lead to poor oxygen levels to prevail in the sediments of the Palk Bay. Though larger benthic fauna, capable of making tubes and burrows and capable of reaching the water column thrive in these conditions, the smaller macrofaunal communities typical of sandy shore ecosystems do not survive well here. This probably accounts for the impoverished macrofaunal community in the Palk Bay. On the other hand, the megafaunal communities (represented by bivalves, large eunicids, muricid gastropods and *Cerithidia cingulata* etc.) were found to be quite abundant.

The beaches of the Gulf of Mannar were well sheltered by the coral reef formations and the adjacent islands, and also were sandy, well mixed beaches. Sheltered beaches have been reported to support higher diversity of macrofauna (Dexter 1992; McLachlan and Brown 2006). These conditions are ideal for species that cannot adapt to a changing environment. Among the beaches sampled, the highest value of organic carbon was seen in Devipattinam as the seagrass bed extended into the intertidal area. The species eveness however was the highest in the Coromandel Coast, showing the presence of *Donax cuneatus*, *Emerita asiatica* and *Sunetta scripta*. This trend has been explained previously. The species *Emerita asiatica* was not found in the Palk bay or the Gulf of Mannar suggesting that it preferred areas that had sandy beaches.

6.3. Latitudinal gradient

In the present study, nearshore megafauna showed some trends with respect to latitude. Species richness was found to increase with decreasing latitude. There is now ample evidence that sandy beach communities display similar responses to latitude as those found in other communities, namely, greater diversity toward the tropics if the same beach types are compared (McLachlan and Brown 2006). Some species like the bivalves *Donax incarnatus* and *Donax faba* were entirely restricted to the southern latitudes. This trend in species richness has been documented for many groups of organisms, both marine and terrestrial, and despite a few exceptional taxa is widely accepted for biota as a whole (e.g. Fischer 1960; Pianka 1966; Rhode 1992; Gaston 1996; Willig *et al*. 2003; Roy *et al*. 2007).

However, latitudinal influences are weaker than the effects of physical factors (Bird, 2005; Brazeiro 1999; McLachlan and Dorvlo 2005). In the present study, there was a peaking of species richness towards the mid latitudes and again a gradual decline towards the tropics. But this may be attributed more to the type of ecosystem rather than latitude. The Palk Bay, for example, had the highest species richness and this is accounted by the larger diversity of species associated with intertidal seagrass beds. But in general, even if the Palk Bay were to be excluded, there was a gradual increase in species richness toward the tropics. This can be attributed to a greater species pool (Soares 2003; McLachlan and Dorvlo 2005). However, the abundance of megafauna decreased, probably because of lower inshore productivity and this has also been reported in sandy shore fauna from other parts of the world (McLachlan and Dorvlo 2005).

Latitudinal differences are also said to affect physical features and beach types (Ricciardi and Bourget 1999; McLachlan and Brown 2006). Wave energy is greater at higher latitudes, and the prevalence of finer river-borne sands results in more dissipative beaches than in the tropics. Since profiles of beaches have not been made in the current study, it is hard to tell if there were changes in physical patterns of beaches with respect to latitude. But generally, the more dissipative and macrotidal beaches were encountered in the northern latitudes (Cuddalore, Parangipettai, Karaikkal and Nagapattinam) though further north, the beaches again became more reflective in nature. This could be attributed to lack of major rivers bringing in sediment and sand to enrich the beaches.

Among the three main groups of sandy beach benthos (crustaceans, molluscs, and polychaetes), latitudinal patterns are found (Soares 2003). Soares (2003) found that crustaceans, for example amphipods, are generally more prevalent at higher latitudes with more dissipative, macro-tidal beaches. In the present study, the same pattern was observed in the case of crustaceans that were more abundant on macrotidal dissipative beaches such as Cuddalore, Parangipettai, Karaikkal.

7. Conclusions

1. In the absence of published baseline pre-tsunami literature on nearshore ecosystems, it is not possible to comment on the recovery and recolonisation of these ecosystems. General patterns show abnormal occurence of macrofaunal and megafaunal elements in the tsunami hit and disturbed regions of the Coromandel Coast. This we attribute to the considerable human stress to these coastlines.
2. Macrofaunal and megafaunal communities (especially oligochaetes, nematodes, archiannelids, certain species of polychaetes and *Emerita asiatica*) are sensitive to human disturbance and can be used as excellent indicators of disturbance along coastal ecosystems.
3. There are definite patterns in the composition of species in relation to ecoregions, as shown by the megafaunal composition.

8. Recommendations

Milbrink (1983) developed an environmental index based on oligochaete abundance and species diversity, arguing that it is more useful to examine oligochaete community composition than to use a single indicator species on its own. Milbrink's environmental index classifies organisms according to their tolerance to organic pollution in streams. Considering the occurrence of oligochaetes commonly in the organically polluted beaches of the Tamil Nadu coast and considering the strong evidence of its potential as an ideal indicator community[2], it would be worthwhile to develop a long-term monitoring strategy for oligochaetes along the Indian coast. Oligochaete monitoring needs to be conducted yearly to identify precise temporal patterns in their densities. Sampling methods (collection times, site locations, number of sites sampled) should be standardised among years to improve the precision for estimating health of the nearshore intertidal communities. It would also be interesting to investigate other physical and abiotic parameters (exposure of the beach, profile of beach, oxygen availability, grain size, etc.) that control oligochaete populations.

Further, many of the beaches that were facing considerable anthropogenic stress were found to be dominated by stress tolerant species. Three years after the tsunami, it seems like the nearshore intertidal communities have not reached pre-tsunami status in terms of species composition and abundance. The dominance of these stress tolerant species suggests that the natural resilience of these ecosystems has been considerably weakened by anthropogenic impacts. Though the current study is a preliminary rapid assessment of the intertidal communities, the results indicate that the natural resilience and inherent adaptive capacity of these ecosystems are considerably reduced. More thorough and intensive research needs to be invested into understanding these ecosystems properly and the current study could serve as a platform.

Sandy beaches have been given short shrift in coastal management, and efforts need to be made to raise their profile in policy and implementation. They serve a variety of ecological and socio-cultural functions, and serve as critical habitats for many fauna. Given the potential impact of coastal development, climate change and sea level rise, the need for a long term coastal conservation programme seems more critical than ever.

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[2] http://www.epa.gov/med/grosseile_site/indicators/oligochaetes.html

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10. Appendices

Appendix 1

Types of coastline in different maritime states of India (adapted from Kumar et al. 2006)

State	Total length of Sandy beach (%)	Total length of Sandy beach (km)	Total length (km)	Coast affected by erosion (km)
Gujarat	28	340.1	1214.7	36.4
Maharashtra	17	110.9	652.6	263.0
Goa	44	66.4	151.0	10.5
Karnataka	75	210.0	280.0	249.6
Kerala	80	455.8	569.7	480.0
Tamil Nadu	57	516.9	906.9	36.2
Andhra Pradesh	38	370.0	973.7	9.2
Orissa	57	271.5	476.4	107.6
West Bengal	–		157.5	49.0
Daman and Diu			9.5	–
Puducherry			30.6	6.4
Total mainland	43	2331.7	5422.6	1247.9
Lakshadweep			132.0	132.0
Andaman and Nicobar			1962.0	–
Total			7516.6	1379.9

Appendix 2

Grain size scale adopted in the GRADISTAT program, modified from Udden (1914) and Wentworth (1922)

Types	Generic Name	Particle diameter (mm)	phi (Ø)
Sand	Very Coarse	1 to 2	0 to -1
	Coarse	0.5 to 1	1 to 0
	Medium	0.25 to 0.5	2 to 1
	Fine	0.125 to 0.25	3 to 2
	Very Fine	0.0625 to 0.125	4 to 3
Mud	Silt	0.0039 to 0.0625	8 to 4
	Clay	< 0.0039	> 8

Appendix 3

Calculation of levels of various types of human disturbance using a scale of 0-3 points depending on the levels of disturbance for each beach

S. No.	Station	Fishing	Foot traffic	Domestic use	Other use	Total	Disturbance
1.	Marina	3	3	3	0	9	HD
2.	Kovalam-C	1	2	1	3	7	MD
3.	Mahabalipuram	3	3	2	2	10	HD
4.	Kadapakam	1	1	1	0	3	UD
5.	Puducherry	3	3	3	3	12	HD
6.	Cuddalore	2	2	2	0	6	MD
7.	Parangipettai	1	1	0	0	2	UD
8.	Poompuhar	3	2	2	3	10	HD
9.	Karaikkal	0	2	0	2	4	UD
10.	Nagapatinam	2	2	2	0	6	MD
11.	Kodiakarai	2	2	0	1	5	MD
12.	Eripurakarai	1	1	0	0	2	UD
13.	Thondi	3	3	2	2	10	HD
14.	Devipatinam	2	2	2	2	8	MD
15.	Rameswaram	3	3	3	2	11	HD
16.	Dhanushkodi	1	2	1	1	5	MD
17.	Mandapam	3	2	3	2	10	HD
18.	Valinokam	2	2	0	0	4	UD
19.	Vembar	3	3	0	0	6	MD
20.	Vellapati	3	2	0	0	5	MD
21.	Punnakayal	0	1	0	0	1	UD
22.	Alanthali	3	3	3	0	9	HD
23.	Ovari	3	3	3	3	12	HD
24.	Vattakotai	0	1	1	3	5	MD
25.	Kovalam-K	0	1	1	1	3	UD

Appendix 4

Latitudes and abiotic parameters in different sites along the Tamil Nadu coast

S. No.	Station	Latitude	% Org carbon	Cond. (mS)	TDS (ppt)	pH	Grain Size in Ø	Sample
1.	Marina	N 13° 02. 315'	0.06	53.1	33.30	7.82	1.30	Medium sand
2.	Kovalam-C	N 12° 47. 357'	0.1	55.62	36.23	8.01	1.32	Medium sand
3.	Mahabalipuram	N 12° 37. 105'	0.2	53.1	33.30	7.82	1.12	Medium sand
4.	Kadapakam	N 12° 16. 061'	0.07	55.62	36.23	8.01	1.66	Medium sand
5.	Puducherry	N 11° 55. 386'	0.22	55.125	36.44	8.18	0.95	Coarse sand
6.	Cuddalore	N 11° 43. 315	0.24	50.37	33.50	7.33	1.95	Medium sand
7.	Parangipettai	N 11° 31. 602'	0.17	48.1	29.61	7.64	2.14	Fine sand
8.	Poompuhar	N 11° 08. 685'	0.16	52.875	33.67	7.62	1.92	Medium sand
9.	Karaikkal	N 10° 54. 938'	0.21	57.66	36.61	7.27	2.36	Fine sand
10.	Nagapatinam	N 10° 44. 694'	0.22	55.95	32.96	7.64	2.56	Fine sand
11.	Kodiakarai	N 10° 16. 481'	0.17	55.14	36.86	7.37	2.69	Fine sand
12.	Eripurakarai	N 10° 18. 911'	0.38	52.08	35.82	8.06	1.43	Medium sand
13.	Thondi	N 09° 44. 559'	0.88	56.19	38.46	8.39	1.83	Medium sand
14.	Devipatinam	N 09° 28. 529'	1.48	54.63	37.26	8.39	2.33	Fine sand
15.	Rameswaram	N 09° 16. 573'	0.39	45.15	29.79	7.86	1.56	Medium sand
16.	Dhanushkodi	N 09° 11.930'	0.22	47.01	29.02	7.61	1.82	Medium sand
17.	Mandapam	N 09° 16.611'	0.2	49.98	30.98	7.64	1.73	Medium sand
18.	Valinokam	N 09° 09.772'	0.21	49.245	30.67	7.89	2.02	Fine sand
19.	Vembar	N 09° 04.549'	0.11	55.92	36.15	7.83	1.64	Medium sand
20.	Vellapati	N 08° 51.170'	0.34	54.48	36.18	8.07	1.67	Medium sand
21.	Punnakayal	N 8° 32.283'	0.24	50.58	34.47	7.98	2.16	Fine sand
22.	Alanthali	N 08° 29.284'	0.17	55.98	36.31	7.89	1.04	Medium sand
23.	Ovari	N 08° 16.528'	0.08	56.25	37.44	7.92	1.37	Medium sand
24.	Vattakotai	N 08° 07.394'	0.24	53.22	34.36	8.01	1.49	Medium sand
25.	Kovalam-K	N 08° 04.947'	0.09	55.35	35.87	7.95	1.52	Medium sand

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