Ecological Responses of Intertidal Benthic Communities to Certain Abiotic Factors in Nancowry Islands, Nicobar

Dissertation thesis submitted to Saurashtra University, Rajkot

In partial fulfillment of

The Master of Science Degree in Wildlife Science

By

Samyuktha Rao Kandregula

Under the supervision of

Dr. K. Sivakumar

Dr. Punyasloke Bhadury

Dr. J.A. Johnson

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

June 2017

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

14 July, 2017

Certificate

This is to certify that **Ms. Samyuktha Rao K.** has carried out an original piece of research in partial fulfillment of Master's Degree in Wildlife Science of the Saurashtra University, Rajkot. The topic of her dissertation is **"Ecological Responses of Intertidal Benthic Communities to Certain Abiotic Factors in Nancowry Islands, Nicobar"**. The study was carried out under our supervision from December 2016 to June 2017. We hereby certify that this work is original and has not been submitted for any degree of any university.

Dr. K. Sivakumar
Supervisor

Dr. Punyasloke Bhadury
External co-supervisor

Dr. J.A. Johnson
Co-supervisor

पत्रपेटी सं. 18, चन्द्रबनी, देहरादून - 248001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun- 248001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स : +91-135-2640111 से 2640115, फैक्स : 0135-2640117
EPABX : +91-135-2640111 to 2640115; Fax : 0135-2640117
ई-मेल/Email : wii@wii.gov.in; वेब/website : www.wii.gov.in

Table of Contents

List of Figures:

List of Plates:

List of Tables:

Acknowledgements

My Masters dissertation thesis is a product of nudges, shoves, pulls, cuts and bruises. This endeavor is the result of a massive social network group, each of the nodes integral to the outcome. The thesis would have been very different and difficult to achieve if not for each of these nodes and their support.

Firstly, the support from the **Director, WII** kept reassuring us that we were free to approach him for any help. **Dean, Faculty of Wildlife Science**, with his demeanor of wisdom and dignity was the most patient teacher throughout our two years. Without these two pillars of support and guidance, the two years would have been difficult for us. I would also like to thank **Research Coordinator** for support and guidance.

My supervisors have been pillars of strength and support. Dr. **K. Sivakumar**, I express my deepest sense of gratitude for allowing my tryst with the benthic organisms and also for putting me in touch with Dr. Bhadury. Sitting in that Nicobari goal-ghar at the Guest House in Kamorta, listen to you reminisce about the last time you had come here and how things have changed since then made me realize two things. I wanted to bring people younger than me back to Nicobar and tell them stories and explore the area deeper in different taxa, and I hope against hope that I will not ever have to sigh in resignation about the changes that are happening and about the former glory of Nicobar. I would like to thank Dr. **Punyasloke Bhadury** for his patience and support throughout the speedbreakers and potholes, and mostly throughout each and every one of my panicky fortnightly calls from field. I feel immense relief every time you would reassure me that whatever information I have brought back to lab is workable. I am extremely thankful to Dr. **J. A. Johnson** for being a solid rock of support and help. The Wetland Management module helped in laying a foundation of large-scale processes driving seemingly simple ecosystems.

Shri. **Qamar Qureshi** and Shri. **Manoj Nair** for visiting our field site in the Nicobar islands. Showing you the people who helped us and the plants, animals, and birds that we saw, made us happier than you could have thought of. Night drives, Pit vipers, lying down on the beach (my field site) and staring at the stars, made so unforgettably romantically scientific with you.

Dr. **Bivash Pandav**, our papa Pandav for being our class teacher of sorts and being responsible and answerable for every little "adventure" of ours. Dr. **Gopi G.V.** must have suffered through similar amounts of tension. After all, being Course Coordinator and Associate Course Coordinator of the infamous XV M.Sc. must not have been easy.

Faculty at WII, Dehradun have had to bear our incessant questions and answer keeping our hypothetical and imaginary scenarios in mind. Thank you for letting our mind wander freely and occasionally tapping our shoulder to show us the right direction.

CAMPA Dugong Project for all the support provided. A special mention to **Swapnali Gole** for helping out when nothing seemed positive. Thank you for showing me love and pointing me in the right direction.

A lot of administrative support was provided by Mr. **R Suresh Kumar**, Mr. **Boominathan** and the **District Commissioner, South Andaman** and all support from the team is much appreciated.

The **Andaman and Nicobar Forest Department, Port Blair**, was very approachable and friendly. I am extremely thankful to Dr. **K. Ravichandran**, CCF, Van Sadan, for his support and guidance. A special mention of my gratitude towards the **PCCF, ACF and CF, Van Sadan, Haddo** for smooth processing of permission letters. **Director and Deputy Director of Shipping Services** for allowing us to carry our chemicals on board M.V. Campbell Bay.

Crew and Captain of M.V. Campbell Bay for being super friendly with us, helping out with our inter-island travel and fishing with us at Kamorta Jetty. Special shout-out for the Chief Officer, **Satish Mehta** for explaining to us what lifeboat my cabin-mates and I were supposed to use during an emergency and what the function of a harbor pin is, on every occasion of travel onboard M.V. Campbell Bay.

Dev Adhavan, I am grateful for the fact that you studied at Port Blair. This way you got us in touch with all the influential people while you were just chilling in Dehradun.

However, on a serious note, thank you for introducing us to some great friends of yours. Not only was our dissertation period smooth, but now we can call those people our great friends too.

Dr. **Vaseem Iqbal**, thank you for being famous. I can now brag to all my friends that I know you. Thanks for being there to laugh off all our hiccups in getting the permits, accommodation in Nancowry, or even that time when I got robbed in Port Blair. Moreover, might I just say, your sister is just as sweet as you, if not more. **Basheer** for lugging around our centrifuge tubes and other sample containers and being so nice to not tell us that your car was stuffed with our carton boxes.

Chairperson, Tribal Council, Chowra, made me feel completely welcome and at home on the tiny little island of Chowra. Thank you for chiding me for being a vegetarian as you could not feed me the sacrificial pig that was carried on bamboo poles. I could not have asked for a better place to usher in the New Year. This is the place where I heard some of the finest carol-singing ever. **Village Captains of Raiheon, Taeela, Chongamong, Al-haet, Kuitasuk, Secretary of the Tribal Council** on Chowra Island. I would also like to thank Police Outpost personnel **Suresh, Tarak, Emmanual**, and others. **Junior Engineers of Terassa and Chowra, fisherfolk** of Chowra.

Ono Harry, for making my days at Chowra memorable. Thank you for being extra patient with me while noting down names of the trees, birds and animals. Sitting on the back of your cycle, walking along the coast several times, joking with the old lady in the Nicobari hut, I shall be forever grateful to those memories and will come back for more. Thank you for introducing me to **Christopher, Eglene, Uncle Silvanus, Ekta**, and everyone else and letting me be a part of your tiny world.

Chairperson Tribal Council, Mrs. **Ayesha Majid**, provided us (three absolutely clueless youngsters) with information and showed us what power and kindness looked like.

Village Captains and Second Captains of Kamorta, Kakana, Vikasnagar, Pilpilo, Munak, Chota Enaka and Bada Enaka on Kamorta Island and Champin on Nancowry Island deserve special appreciation

Masters and crew of M.V. Spike and M.T. Kamal for waiting patiently for us at Kamorta Jetty on the days we had to visit other sites for sampling. **Martin, Emmanual, and Masterji from Munak village** for giving us a lot of bananas, chai, and love. Your help is most appreciated, and we are envious of your knowledge of the area and its biodiversity.

Abdul Bhai, for creating lip-smacking food for us at Kamorta. Be it Ashwin's emotional moments with dal, or Naman pleading for the fish fry, or me begging for permission to bathe the cat, your presence has made our field experience very memorable and luxurious. Thank you for teaching us how to tie a hook on the line and chiding us about throwing back fish that local boys said were uneatable ("all fish are eatable!"). Your simplicity, kindness, and love shall forever be remembered. I hope you grow all the beautiful flowers and plants in the garden and that T-Rex and co. do not eat up seedlings.

Aslam Bhai, thank you for considering us a part of your family. All the invitations for birthday parties and festival celebrations are much appreciated. Thank you for making us feel at home. **Munavar, Alex, Isaac, Pandi bhai, Nikhil, and Lambert**, thank you for ferrying us from different parts of the island and rapid responses to our requests for transport throughout our stay at Kamorta. **Pilgrim bhai, Neelam Bhai**, thank you for all the help at RT Office. Tata Sky recharges were never so memorable all my life. Thanks also for the last minute photocopy/ scanning/ printing at the Tribal Council Office. In that moment, we could never express how grateful we felt.

Naseer sir, thank you for letting us stay at your house. It is by far the best base camp many of us have ever seen (Manoj sir, Siva sir, and Qamar sir are in agreement as well) though I regret the fact that half the hall was always occupied by my sediment samples and a centrifuge tube rolling in the corner.

Shri. **Casper James**, Assistant Commissioner, Nancowry, for helping us out with paperwork and introducing us to the other village captains and police personnel which was a blessing in disguise. Many of our seemingly difficult problems were easily solved with the timely help of **Bala sir and Giri sir**. Not once has anyone from the Assistant Commissioner's office been impatient with us despite our strange requests at odd hours, in fact our boat rides, ship rides, helicopter rides were all arranged for promptly. Thank you for everything you have done for us, but most importantly, for allowing me to carry little more luggage than the allowable 5 kg weight on my helicopter journey to Chowra. Thank you for understanding our field, for having a soft corner for us wildlifers and most importantly for being attuned with your environment, your people and all kinds of interactions in this time and era.

Vinod bhai, for accompanying me at Kamorta, for however brief a time, to the PWD Dam. You made me understand how easy every sampling session was going to be if I had someone to just dig the core out. **Anil bhai** for helping out with the intensive sampling and even more intensive packing of samples. **Javed Ali, Robin Paul, Jonah Phillip, Antony, Rajan** and everyone at the **Range Office, Forest Department, Kamorta** for helping us out. **Javed Mohammad, Imran bhai**, thank you for hosting for dinner and helping us out at Sanu Basti.

Ashif Jadwet for answering my incessant calls and despite several hiccups ensuring the safe shipment and delivery of my precious samples onboard M.V. Swarajdweep.

Dr. **Naveen Namboothri** for being my standalone point at a time when I had nothing. You mean a lot to me and have taught me everything I needed to put a foot in the door to marine biology.

A mighty shout-out for **LITME/ITMERG members at IISER-Kolkata** for all their help and support. Dr. **KGMT Ansari** and soon-to-be Dr. **Areen Sen** have been very patient and kind for their invaluable help with macrobenthos and meiobenthos. A relevation that I had during the nutrient analysis was that the samples need the magic touch of **Tarkeshwar Singh** (another soon-to-be Dr.) to give picture perfect readings. **Anwesha**, thanks for being my partner-in-crime and sharing some valuable much needed crazy moments with me. **Asha, Sunita, Indresh, Bandita and Santosh** have been total sweethearts and made my stay at IISER-Kolkata very memorable.

I also want to acknowledge the Shondip, Dibs, Shivam, Nainad, Indoor, Bips, Amrita, Ankita Sinha, Bhatts, Paarsis, Pallavi, Dipak, Devanshi, Harsh, Gogs and many many more (M.Sc. Associates) for their presence, activities and conversations added the spice to our scientific outlook, shopping interests and late night “get-togethers”.

Ashish AP, Justa, Momo, Golu, Churri, Rajwa, Salto, Pohi and Raka-ka-Baka, you guys are the bestest classmates anyone could have ever asked for! Encouragement, love and the fact that we were sailing in the same swaying (sometimes sinking) boat kept me going. **Naman and Ashwin**, thanks for being a part of memories. There could be no other two I would want to form our Isolated Island Idiots’ trio. Niklo to Nicobar!

Baba, Aisa and Moti, thank you for consoling me everytime I thought I’d messed up real bad. Thank you for telling me how much more badly your work was going (not that it made me feel any better). Thank you boo-fallows for missing me and asking me every single time about when I would be back. A heartfelt thank-you to **Enam, Nama and Bangs** for unadulterated love and pure concern that is showered upon me during every phone call. **Sutanu** deserves a super special mention for tolerating and sometimes encouraging the emotional outbursts of mine. Thanks for being a major portion of my support system. I do not want to think what state I would have been in, had it not been for you.

I am surprised and impressed with my parents and brother for not panicking about my wellbeing and whereabouts when network was down which was so often. Dad, that is one degree down and one more to go; I shall catch up to you someday. Mum, thank you for not freaking about the study area and worrying about me being relatively alone there. Shreyu, I do not want to be someone for you to look upto. I’d rather be the one standing by you while you make your own mistakes and learn from them and laugh them off together. Thank you for making me push myself harder. Thank you for understanding and letting me go fly. I hope I make you proud.

Abstract:

1. The intertidal zone is the amphibious niche between the high and low tides. The invertebrate taxa present here lay bare to several influencing factors and facilitate the flow of energy by participating at each trophic level in the marine ecosystem.
2. This study was carried out in order to assess the community structure of intertidal benthic macroinvertebrates. Their associations with various factors known to affect intertidal zones were looked into, in the remote islands of Kamorta and Nancowry in Central Nicobar, Andaman and Nicobar archipelago.
3. Three study sites of varying beach profiles (reflective, intermediate and dissipative) were studied across spatio-temporal scales. Spatial replicates were sampled at the three study sites across tidal zones of High Tide (HT), Mid Tide (MT), and Low Tide (LT) for granulometry (dry sieve method following Wentworth scale), nutrient levels in water (spectrophotometry following Strickland and Parsons protocol) and the macrofauna (light microscopy following the basic taxonomic guides). Temporal replicates were sampled at the dissipative beach over a period of one lunar cycle for nutrient levels in the water (spectrophotometry).
4. In three sites, the major taxon was foraminifera by being the highest in abundance in two sites (reflective and intermediate slopes). At the third site (dissipative slope), gastropods dominated the community. Granulometric analysis showed links with beach profile and taxa encountered. Nutrient profiling showed Nitrate being higher in concentration in the dissipative beach, and Silicate and o-Phosphate showing higher concentrations in the reflective beach. Temporal sampling done for the nutrients (Nitrate, Silicate and o-Phosphate) showed patterns that can be related to the spring tide and neap tide. Soft coral sclerites showed up, at one site in unexpectedly large numbers, at all the sites.
5. Based on the trends seen and the factors measured, the beach slope and the packing of the sediment are key factors in shaping the community. Spatial sampling showed that the reflective and intermediate beach profiles have foraminiferans as their dominant taxa and gastropods dominated the dissipative beach community. This might be due to differential availability of organic matter

and retention of it in the sediment layers for the benthic fauna. This is also seen in the nutrient profiling across the temporal scale where the flushing out the nutrients reduces the concentrations based on the spring tide and neap tide cycle. Soft coral erosion is suspected to be due to the degree of exposure of the beach to harsh wave conditions, among other factors.

6. Baseline information was drawn on the key players of the macrofaunal community signals. Replicates need to be studied to confirm the patterns observed. Comprehensive community level analyses (at species) need to be done along with supplementary data through Total Organic Carbon (TOC) analysis and heavy metal analysis (ICP-MS analysis) needs to be done to ascertain the sources and magnitudes of the signals of influencing factors.

1.0. Introduction:

Oceans are all-encompassing ecosystems that perform many functions that include influencing global climate and supporting diverse life forms. With these life form-influencing factors varying between extremes, life within this spectrum of conditions has managed not just merely to adapt or survive, but to thrive.

The marine benthic zone is the ecological region at the lowest level of a marine ecosystem that includes the sediment surface and the sub-surface layers. The organisms living in this zone and dependent on the sediment are called benthos. These organisms are mostly primary consumers, detritivores or scavengers.

Sediments, be it intertidal or deep sea, make the two most essential resources available for dependent fauna, i.e. space and nutrition. The space that is occupied by the benthic organisms divides benthic organisms into two distinct classes based on where they are mostly found:

a. The group that lives on, in or near the surface of sediments is called epifauna.
b. The group that burrows into the sediment and lives aided by the interstitial space between sediment grain particles is often called as infauna.

Benthic organisms can also be categorized under Macrobenthos, Meiobenthos and Microbenthos classes, based on the size range (Mare 1942). Macrobenthic organisms are retained on 500μ mesh size sieves, meiobenthos on 63μ mesh size sieves. The intertidal region is an amphibious ecosystem that is submerged and exposed in alternation. The fauna and flora that inhabit this distinctive ecosystem are both microscopic and macroscopic and live in synchrony with one of the strongest driving forces operating in this area, the tides.

Intertidal areas are exposed to a wide range of physical and biological parameters of varying intensities and frequencies. Intertidal regions are characterized by the substrate, the nature of which is varied across habitats. Hard-substrate intertidal studies have been focused mostly on rocky shore habitats. Soft-substrate studies span from sandy beaches to mudflats, estuaries to salt marshes.

In the intertidal ecosystem, the most important factors are all of them. This fragile ecosystem has many facets and each of them behaves as its most influential factor. The particle size, the wave action, slope of the beach, the salinity, and much more govern the invertebrate faunal community which is altered by and alters these factors. These factors work in synchrony with the numbers and the kinds (abundances and diversity respectively) and together form the intertidal benthic ecosystem.

Changes that happen on various scales of time, space and ecological parameters are important to understand the working of the ecosystem. Also, the spatio-temporal and ecological changes in an organism are closely related to environmental changes. Benthic fauna, being key players in biogeochemical cycling, nutrient fluxes and energy flow, would hold a pivotal position in monitoring changes in the environment. Identifying limiting or determining factors will help in understanding organisms, which might be hidden keystone species. They can be our look-out for different categories of climatic and environmental change.

1.1 Review of literature:

Interactions between benthic organisms and abiotic variables:
There are scores of abiotic factors that influence and are influenced by creatures of the sea. Temperature exerts an imposing bearing on all metabolic processes. Warmer temperatures accelerate development. In a similar way, each of the factors exercises some control over the other factors in a way that in combination, they either maximize the overall effect or weaken the buildup of the variable (Amend 1997).

The primary physical property of sediment is the grain size and it determines the packing of sediment particles. The packing determines the distribution of the benthic organisms and the categorization of epibenthic organisms and interstitial benthic organisms. In coarse-grained sandy beaches, the large interstitial spaces support many flora and fauna. The sediment layers in coarse sandy beaches are highly oxygenated as every wave drains rapidly back into the sea, causing air to replace the water through the permeable sand layers. In an ecological opposite, fine sand beaches have sediment grain packing in such a way that there is a steep vertical gradient of oxic conditions. This is a multi-stressor environment for benthic organisms, as one of the main physical variable overlays is the morphodynamics of beaches, with physical and chemical conditions working in tandem to make the community what it is (McLachlan and Brown 2006). Altogether, these stressors expose the biotic community to environments that is highly dynamic and harsh (Menn 2002).

Some benthic organisms are subjected to stressful conditions like upper-limit extremes of temperature, wave action, or light intensity (Anandavelu et al. 2013). In particular, the fauna is exposed to adverse conditions if they are the pioneers that eventually act as facilitators and make certain habitat parameters hospitable for colonizing by other species. These facilitators increase the habitat heterogeneity and provide refuge to prey, thereby regulating the occurrence of both the prey and the predator species (Monteiro et al. 2002). Introduced species act as facilitators are assisted by several abiotic factors like the velocity of the currents and water depth. Abundances of these introduced and the linked organisms are extremely high when ideal conditions for their settling and colonizing coincide (Bially and MacIsaac 2000). There can be stark differences in community structures of sediment-associated fauna as a result of powerful winds causing sediment erosion. Winds are one of the driving forces behind the strength and direction of rip currents and shape the faunal assemblages indirectly or sometimes directly (Armonies 1990).

Seasonality, salinity and nutrient:

Seasons play a major role in the abundances of the benthic fauna, as each season is characterized by a certain range of temperature, humidity, salinity level and other abiotic parameters. Even in fauna, that reproduce several times a year, like the mole crab *Emerita talpoida* (Helland et al. 2003, Diaz 1980; Peterson et al. 2006), the overall size of the egg-bearing female and the number of fertile eggs (which is a proxy for energy reserves and fecundity) are richer and better in spring. An example would be salinity which is a seasonally changing abiotic factor. Freshwater inputs to the sea through creeks or ephemeral rivers, hot summers result in stark differences in the salinity levels. These fluctuations in salinity values alter the abundances and the diversity of organisms through an annual cycle of changing seasons and linked environmental parameters (Al-Raei et al. 2009).

The northeastern Australian monsoons are not as powerful, or as prolonged, the densities of meiofauna are highest during the summer wet season. The distance from the equator and the differential timing and features of the seasons influence the benthic infaunal community densities (Alongi 1989). In contrast, Indian monsoons are characterized by intense and drawn out cyclonic weather, and this negatively impacts the meiofaunal numbers which decrease.

The addition of freshwater during the monsoon negatively impacts the infauna in the tropical scenario, but the populations bounce back soon after (Moore et al. 1968, Holm 1978). These studies indicate that intensity of waves and salinity are important factors that govern benthic infaunal communities.

Plankton dispersal:

Certain benthic fauna (for instance, gastropods) in the intertidal region have planktonic larval stages that are highly mobile and undergo two vital processes- Larval dispersal and recruitment. Upon hatching from eggs, the larvae are transported away from their hatching grounds by offshore transport mechanisms, the direction of the currents, tide or the winds that govern it (Shanks 1983), Armonies 1990). Recruitment occurs when the advanced stages of the planktonic form (through some factors that push them shoreward) return to their natal ground to settle and contribute to the population as sexually mature adults. The larvae (also called zoea in some taxa) are laid bare to the elements and factors (biotic, like predators, or abiotic extremes) that maybe harsh during both the onshore and offshore journeys (Morgan and Christy 2011). The factors governing community dynamics themselves fluctuate a lot. This results in an adult population that is a minuscule fraction of the hatched larvae numbers (Amend 1997, Morgan and Christy 2011). Juveniles of certain benthic macrofauna, like crustaceans or gastropod larvae, sometimes hatch in designated nurseries. An example for a nursery would be seagrass beds (Whanpetch et al. 2010*a*). Seagrass beds serve another purpose for juveniles of several small fish that feed or take refuge from predators (Barnes 2013).

The relationship between currents and the dependent organisms has been studied (Armonies 1990), but the temporal aspect of the study is crucial information as certain meiofauna only emerges at night (Armonies 1989). The influence of water currents and tides on faunal communities is because of a differential percolation rate of particulate organic matter and nutrient ions like those of sulfur and nitrogen through sediment layers (Piniak and Lipschultz 2004). The plankton productivity paradox, upwelling of tides and thermal stratification of the water column are patterns that are linked to carbon fixation. Particulate organic matter, which includes macroalgae and other metabolizable organic matter, contributes significantly to the biogeochemical cycles in the microenvironment of intertidal zones (Bode et al. 1997, Al-Raei et al. 2009).

The outcomes of nutrient enrichment experiments on *Tridacna* clams showed that though the responses were quantitatively small, minute changes in the levels of inorganic nutrients alter the clam-zooxanthellae symbioses (Taylor et al. 2010). Growth and calcification rates are influenced by light intensity, water temperature, seasons and differential levels of inorganic nutrient levels (Thomas Jensen 1992, Ambariyanto and Hoegh-Guldberg 1997). The nutrients work in synchrony with other parameters like temperature and current direction and maximize output through the growth or recruitment of organisms (Fitt and Cook 2001, Harrison and Ward 2001, Nordemar et al. 2003).

Interactions amongst benthos:

The two size-classes of benthic organisms, macrofauna and meiofauna, interact both directly and indirectly with each other. Direct influence of macrofauna on meiofauna mostly includes predation. Indirect influences can be seen through alterations in sediment and related characteristics. Meiofaunal groups respond by changing their distribution, community structure, diversity, and density (Urban-Malinga et al. 2014).

Most benthic fauna reflect the environment around them. Be it in numbers, kinds, or even certain aspects of variability or behaviour. Sometimes an off-season weather phenomenon may result in high mortality or a decline in population. A reduction in the population and also delay in the recovery of the population to bounce back was observed during periods of strange weather (Armonies et al. 2001). Certain weather extremes can result in the hatching and recruitment of larvae. Hatching in *Emerita talpoida*, a decapod, has been interpreted to occurring during inner-shelf storm events that are characterized by large waves, warm temperatures and northeasters (Amend 1997). Barnacle recruitment, near California, has been shown (Broitman et al. 2005) to have a positive relationship with abnormal temperature events, but not mussel recruitment.

Closer home, studies have compared benthic faunal communities before and after the tsunami along the Tamil Nadu coast. The assessment of macrofaunal and megafaunal communities was aimed at identifying the major threats to the coastal intertidal ecosystems. Also, than an indicator species approach (Teixeira 2010), a community-based approach is recommended keeping in mind the oligochaete and polychaete diversity (Hutchings 1998) and their tolerance to organic pollution and toxic elements in the water (Sarkar et al. 2005, Berlie et al. 2008*b*).

Disturbances:

Change is inevitable as time is circumlinear, and everything changes with time as it moves forward. Changes, similarly, can also be viewed as disturbances and are mostly of two kinds- natural and humanmade. Certain humanmade disturbances can lead to physical disturbances. At this point in time, we face the impending threat and harsh reality of global change, be it in land use patterns, or even environmental change. Adding to this mixture are extinctions and invasions of entire species (Vitousek et al. 2013).

Natural changes:

After the apocalyptic earthquake and subsequent tsunami of 2004, the low-lying regions of the Nicobar islands were submerged, whereas the low-lying regions of the Andaman were uplifted. This has resulted in a change in intertidal and sub-tidal bathymetry, as the exposure of land to waves and tides was altered (Nehru and Balasubramanian 2012). Littoral drift and the constant cycle of beach erosion and accretion add to the natural changes to the ecosystem and modifies the beach profile by altering granulometric composition.

Anthropogenic changes:

Humans create some of the adverse conditions for benthic invertebrate fauna to exist (Jayaraju et al. 2011) by altering of habitats or by pollution or disturbance/activity. Anthropogenic altering of natural habitats occurs mostly when construction projects (buildings or resorts) come up or beach protection structures like sea-walls, tetrapods, cement blocks or dikes are used (Berlie et al. 2008*a*). Human trampling experiments were conducted to assess the acute impact of human activity (disturbance or tourism). The results showed that all kinds of fauna, irrespective of how they utilized the habitat and the resources, were significantly found in lower abundances as compared to the controls with no trampling (Casu et al. 2006).

Many of the practices are anthropocentric and interrupt natural processes of littoral drift and suspension of sediments (McLachlan and Brown 2006), and the consequences are the conversion of a healthy beach ecosystem into an ecologically dead area. Suspended sediments and how they are transported (Austen et al. 1999) contribute significantly to two processes that are vital to the well-oiled running of the intertidal ecosystem, viz. beach erosion and organic matter.

Primary productivity in the intertidal area is high because many abiotic and biotic factors in optimum levels function in synchrony and maximize output. The secondary productivity is characterized by benthic macrofauna, again in elevated levels of biomass. The perfect combination of abundant nutrients, high light intensity, shallow waters and distinctive nature of sediment are some key players in this ecosystem (Kneib 1984, Warner et al. 2002). Benthic macrofauna forms a crucial link in the food webs of the marine ecosystem (Lubchenco et al. 1984) as they derive nutrition from the phytoplankton and organic matter from the detritus and freshwater inputs into the seas, and form the prey base for many shorebirds, fishes, and other invertebrates. Secondary productivity needs to be measured through respiration and production, which are used as representative values for energy flow to understand self-sustenance of the food web (Asmus and Asmus 1985). Knowledge of all these together constitute the community and its functioning.

The changes in community assemblage due to other factors like human activity, marine debris, toxins in the surroundings and the impacts of these different factors on physiology and energy reserves of marine organisms would not only be interesting knowledge, but also serve as sentinels of climate change, natural disasters, anthropogenic factors, among other phenomena.

Teasing apart the combined effects of temperature and food availability (through phytoplankton) on the meiobenthic community is difficult without controlled and manipulative experimental setups (Olafsson and Elmgren 1997). Keeping all these points in mind, the study has been designed to keep in mind the limitations while addressing the objectives:

1.2 Objectives of Study:

- To understand the qualitative and quantitative relationship amongst macrofauna in intertidal regions of Central Nicobar islands, Andaman and Nicobar Archipelago
- To understand the responses of the macrofaunal groups, with a focus on foraminifera, to an array of environmental and physical variables

- To draw baseline information on relationships between the community and the changes they experience

2. Study Area:

The study was carried out in Nicobar group of Islands, which are part of the Indian Union Territory of Andaman and Nicobar archipelago. The archipelago is part of the saddlebacks of the underwater mountain range that runs between the countries of Myanmar (formerly Burma) and Indonesia. There are several theories of the origin of this mountain range. The mountain range is a manifestation of the fault line that was formed when the Indian tectonic plate collided with the Burmese plate. This also explains the volcanic activity in the area.

Over the last hundred years, human developmental activities have enhanced the effects of natural disturbance regimes in the region. Timber extraction activities, encroachments, and increasing population are the main reasons for radically affecting habitats of various species, and subsequently leading to loss of biodiversity. The increasingly unchecked rates of deforestation in the islands have resulted in silting of coastal waters, posing serious threat to the survival of corals' zone and the mangrove forests.

The two islands, Nancowry and Kamorta, were chosen primarily because of the ease of access. An intriguing future prospect is to study influence of proximity of the two islands which is assumed to push communities towards homogeneity (Rao 1980).

Also, one of the major questions driving the choice of study area was because of the fabled pristine properties. This study was undertaken to look at the biotic community signal and understand if the area would actually be called pristine and untouched. Looking at the Hawaiian islands and how the remotest island had the highest density of garbage ever (Lavers and Bond 2017), there were many doubts about what the outcomes of this study would be. Would this region also be subjected to non-point source of pollution?

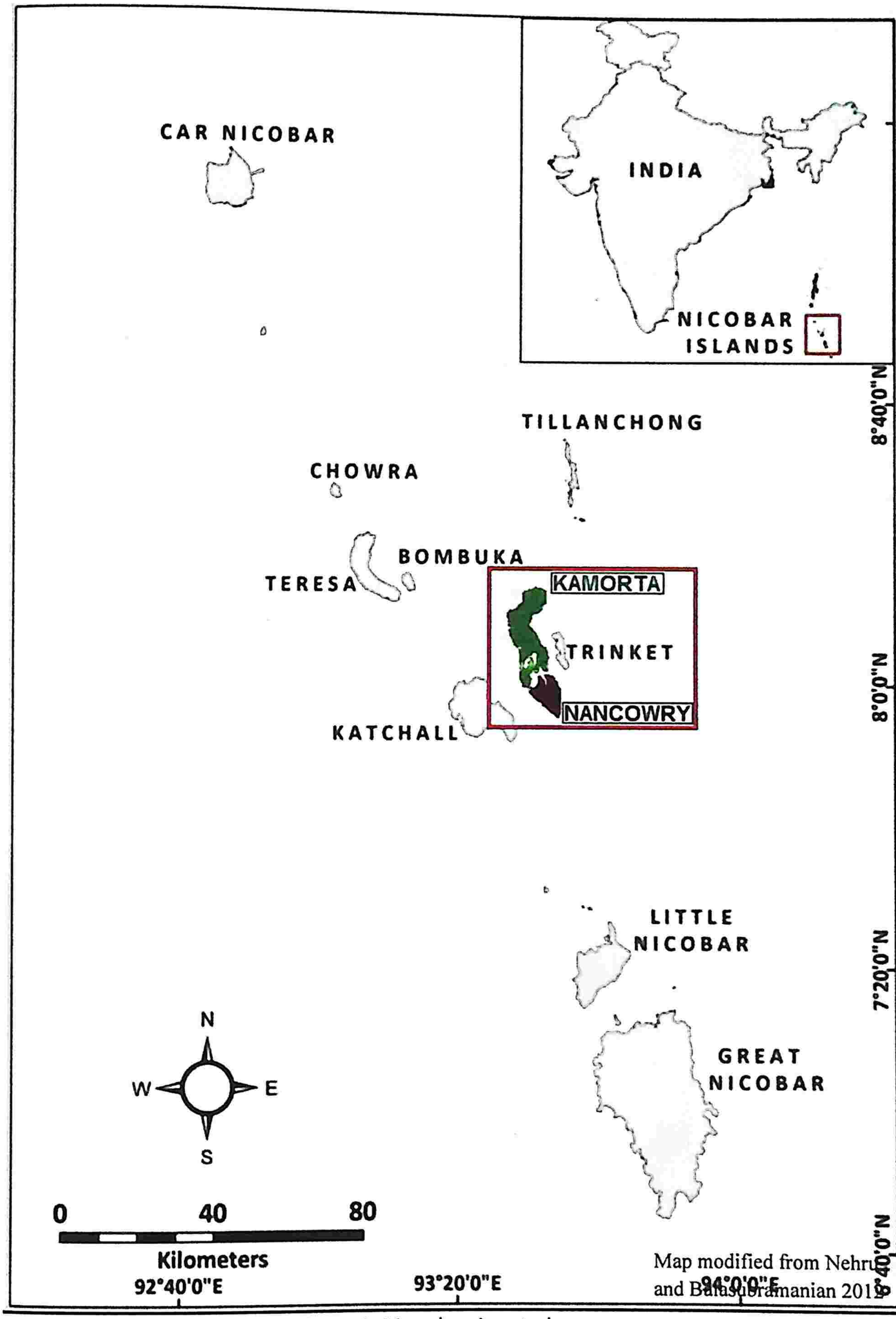


Figure 1: Map showing study area

Figure 2: Map showing sampling stations

<u>Site #1: Pilpilo-</u>

Location: 08.18336 N

93.47476 E

Habitat: It is an exposed beach with several creeks. There are large boulder reefs offshore. There are several gastropod shells, crabs and bivalve shells that are washed ashore. Many water birds are seen around the area, such as Indian Pond Herons, Pacific Reef Egrets, Sand Plovers, Sandpipers, and Terns. Seawater inundated several kilometers inland because of the tsunami and nearly all the vegetation was destroyed.

Human Activities: Occasional small vessel movement goes on, mostly leaving to deeper waters to harvest large and more fish. Small scale spear fishing occurs in shallow waters offshore.

Sampling: The site has semi-diurnal tides. Samples were collected around the Low Tide (0.45m, around 1500 hours) on 27th February 2017.

Impact of tsunami: The beach is relatively unsheltered and unprotected and waters are deep. The beach faces Teressa and Bompoka Islands, which are about 15 nautical miles away from the site. The site was severely affected as there were long stretches of low-lying areas and no shielding structures. Tsunami run-up and inundated several kilometers inland. Severe beach erosion occurred when the entire coastal region was submerged and new creeks have formed after the tsunami.

Morphodynamic nature of beach: Intermediate

Site #2: Champin-

Location: 08.02666 N

93.54509 E

Habitat: Some houses of locals are present close to the beach. The boats are beached a few meters from the high tide line. There are few old seagrass beds at sea and small boulder corals about ten meters offshore. The beach is less sheltered compared to Site #3. There was a loss of coastal vegetation due to the tsunami.

Human activities: Small-scale fishing is carried out here along with moderate levels human activity around sunset like children playing. This site is the best natural harbor in these islands; large ships and small- and medium-sized boats operate frequently from here.

Sampling: The tides at this site are semi-diurnal in nature. Samples were collected around the Low Tide (0.44m, around 1610 hours) on 1st March 2017.

Impact of tsunami: This site experienced a submergence of about 1.5-1.75 m and was among the most affected sites due to the subsidence phenomenon and the tsunami run-up. This is in spite of the fact that it is shielded in different directions by Kamorta Island, Trinket Island and Katchall Island in increasing order of distance. Mangroves and associated coastal vegetation was completely wiped out.

Morphodynamic nature of beach: Reflective type

Site#3: PWD Dam-

Location: 08.04703 N

93.54206 E

Habitat: It is a sheltered dissipative beach with one freshwater creek supplied from the rainwater harvesting reservoir for drinking water. The site was submerged after the tsunami of 2004, due to subduction and seawater inundation. There was a forested patch near the study site called Lanthakadi and a settlement called Denghibasti, both of which are now under water. The dominant vegetation on land is the planted *Casuarina equisetifolia*, which shows allelopathy and degrades slowly. Thereby beach has a very forest-floor visual characteristic to it. Small patches of *Nypa fructicans* and tall *Rhizophora* mangrove trees (planted by the forest department) are seen very close to the freshwater reservoir. Towards the low tide zone soil texture is muddy and clayey. Coarse grained sand is present in the high tide zone. The eastern side of the island, of which this beach is a part of, was safeguarded by Trinket Island which bore the brunt of the waves. Despite this, the devastation left behind by the tsunami is evident even after more than a decade. Coral rubble and wooden logs (mostly mangroves) found upto several inches below the surface of soil, indicative of the level and impact of the submergence. Stumps and snags of dead mangroves were present in the entire intertidal region. Young seagrass beds are exposed only during the LTs of spring tides. Seawrack is washed ashore, and the high tide line is usually marked with gastropod shells occupied by hermit crabs, bivalve shells and occasional cuttlefish bone. Several water birds frequent the area, some of which include Whimbrel, Spotted Redshanks, Pacific Reef Egrets, Sandpipers, Sand Plovers and Terns.

Human activities: Fishing activities are carried out using gill nets on traditional canoes in shallow waters and line fishing and finer mesh size nets (usually mosquito nets) from the shore to catch sardines and prawns. Tree lopping and felling happens regularly for firewood. Minor sand mining happens from high tide zone.

Sampling: The tides at this site are mesotidal and semi-diurnal in nature. Samples were collected around the Low Tide (0.49m, around 1650 hours) on 2nd March 2017 for spatial sampling. For temporal scale sampling, samples were collected for one month starting from 11th January 2017 to 11th February 2017.

Morphodynamic nature of beach: Dissipative beach

3. Methods

To understand changes in the community assemblage, sampling was done across spatio-temporal scales. Spatial replicates were taken from three sites: Pilpilo, Champin and PWD Dam. The sampling was done on days with similar tidal inundation levels. The choice was due to the fact that these three sites had distinct human signs as well as beach profiles. This gives a good distinctive demarcation between sites to look at signals of natural changes as well as human pressures.

Temporal replication was carried out at one site and this was repeated over a period of one lunar cycle, i.e. one month. This site was chosen because of the severe impact of the tsunami on the site.

3.1. Field

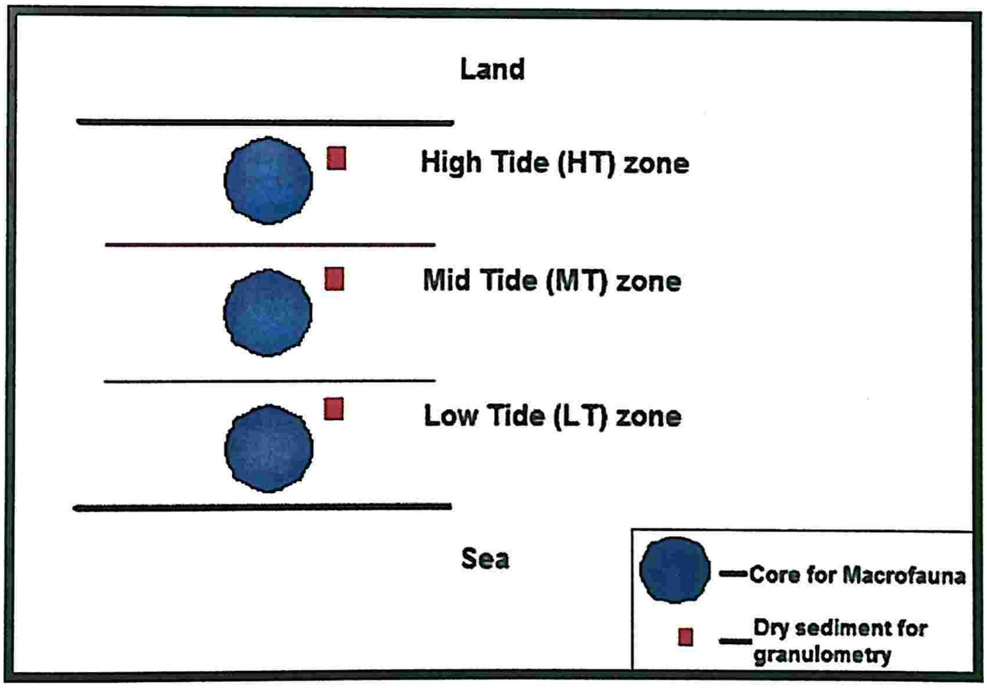


Figure 3: Sampling collection strategy for macrofaunal and sediment analysis

3.1.1. Biotic parameters:

a) Sampling of macrobenthos: A metal hand-held corer was used of dimensions of 15 cm diameter and 20 cm depth (Berlie et al. 2008*a*).

Plate 1: Core collection being done for macrofaunal sampling in Site #3: PWD Dam

b) Collection of dry sediment for granulometry: The sediment was collected from the base of the cavity (formed after extracting core of macrobenthos).

c) Collection of water for Nutrient: 50 mL Falcon tubes were used to collect about 40 mL of surface water from beyond the Low Tide zone. Samples were fixed using 4% Formaldehyde.

Sample processing:

Sieving: Macrobenthos samples were sieved on 500μ and the retained portions were transferred into plastic containers and 4% Formaldehyde was added as a fixative.

Plate 2: Sieving of macrofaunal sediment on 500µ sieve and stored in plastic containers

Meiobenthos samples were sieved on 63µ and the retained portions were transferred into plastic containers and 4% Formaldehyde was added as a fixative.

Storing and Transport: Samples were labeled and stored in polystyrene boxes. They were sealed and transported to lab.

3.1.2. Abiotic parameters:

3.1.2.1. Environmental factors:

In situ environmental parameters were measured using a hand-held digital instrument, PCSTestr 35 (Eutech) for used for measurement for pH, temperature and salinity.

3.1.2.2. Nutrient complexes:

Nitrate, o-Phosphate and Silicate concentrations were measured spectrophotometrically in the fixed samples following the standard protocols (Strickland and Parsons 1972) after returning to the lab.

3.1.3. Physical parameters:

About 50g sediment was collected on field after the coring for biotic samples was done. This sediment samples were not sieved, not fixed and sundried on field and dried again the hot air oven overnight.

4. Results:

Taxa commonly encountered:

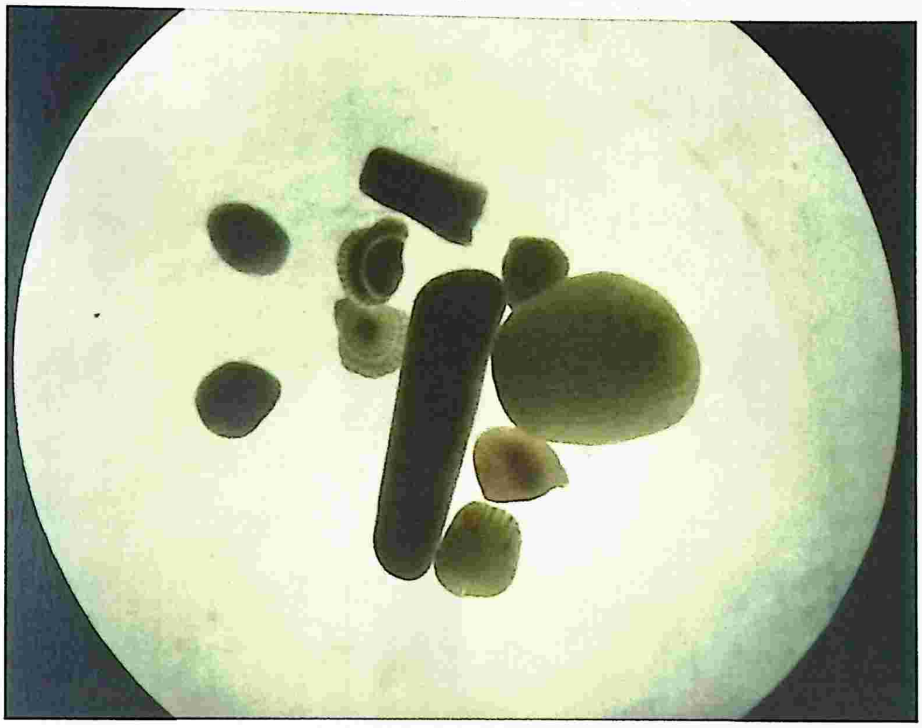


Plate 3: Corals separated out from the sediment at 20X zoom

Plate 4: Soft coral sclerites separated out from sediment at 20X zoom

Plate 5: High abundance of Soft coral sclerites separated out from 10g of sieved

Plate 6: Foraminifera separated out from sediment at 10X zoom

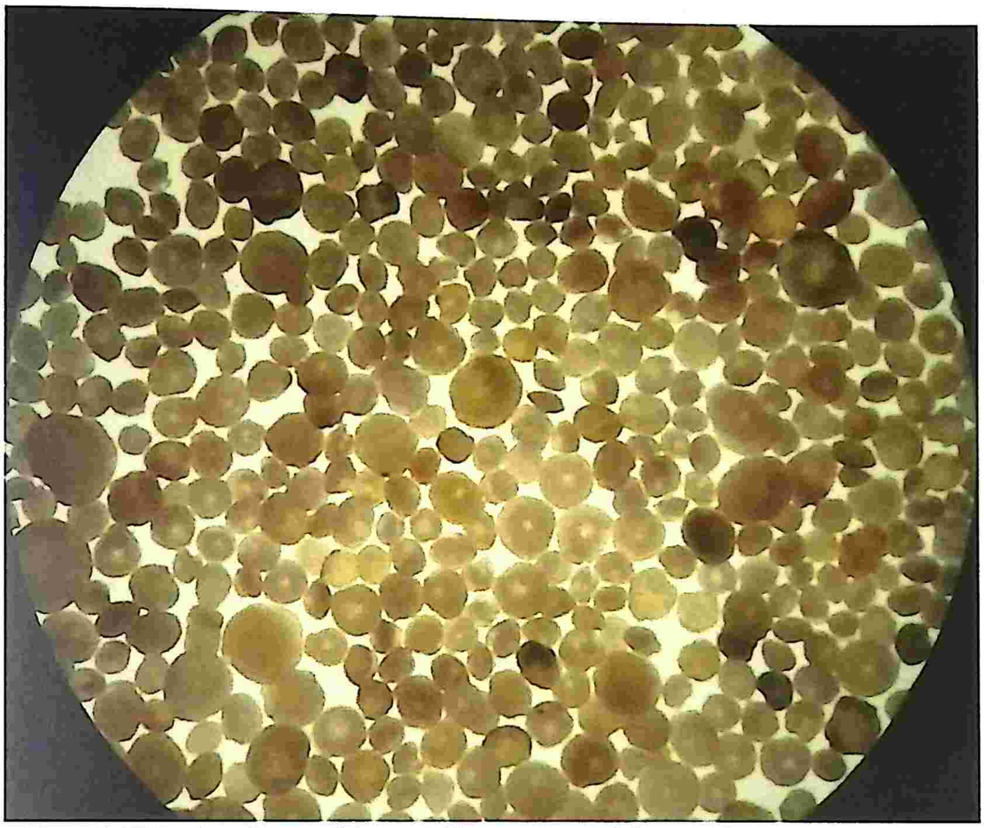


Plate 7: High abundance of Foraminifera separated from sediment at 10X zoom

Plate 8: Intact Gastropods separated out at 32X zoom

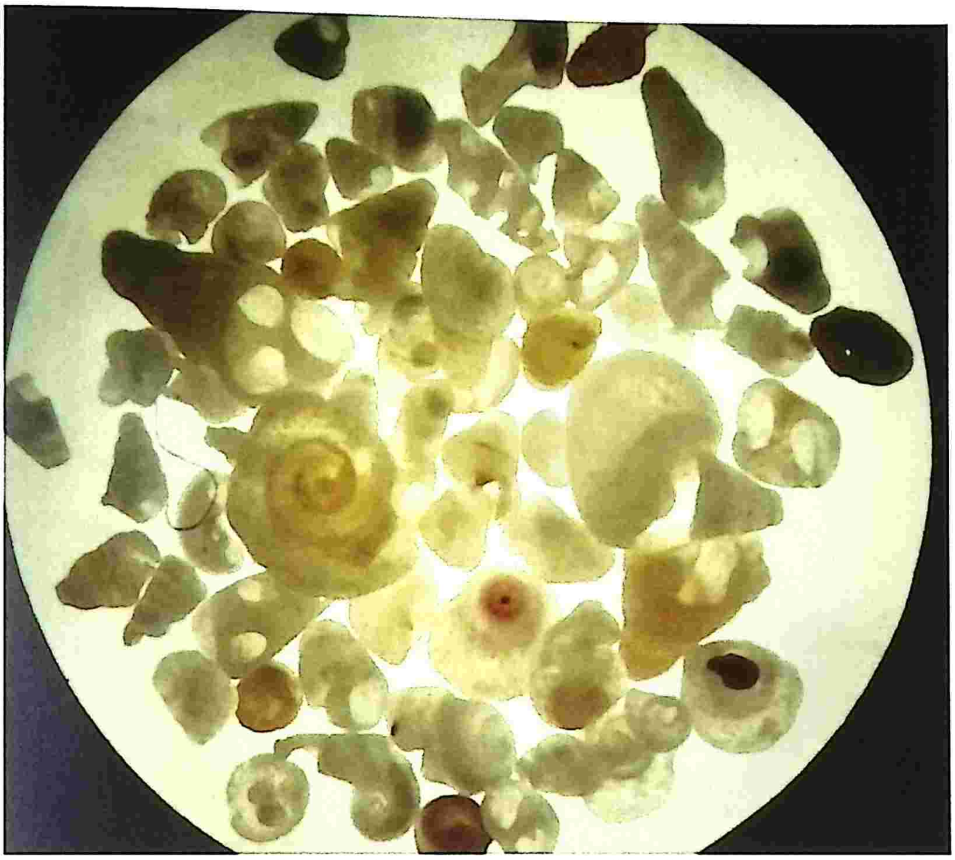


Plate 9: Broken Gastropods separated at 20X zoom

4.1. Macrofauna:

Comparison of overall abundances:

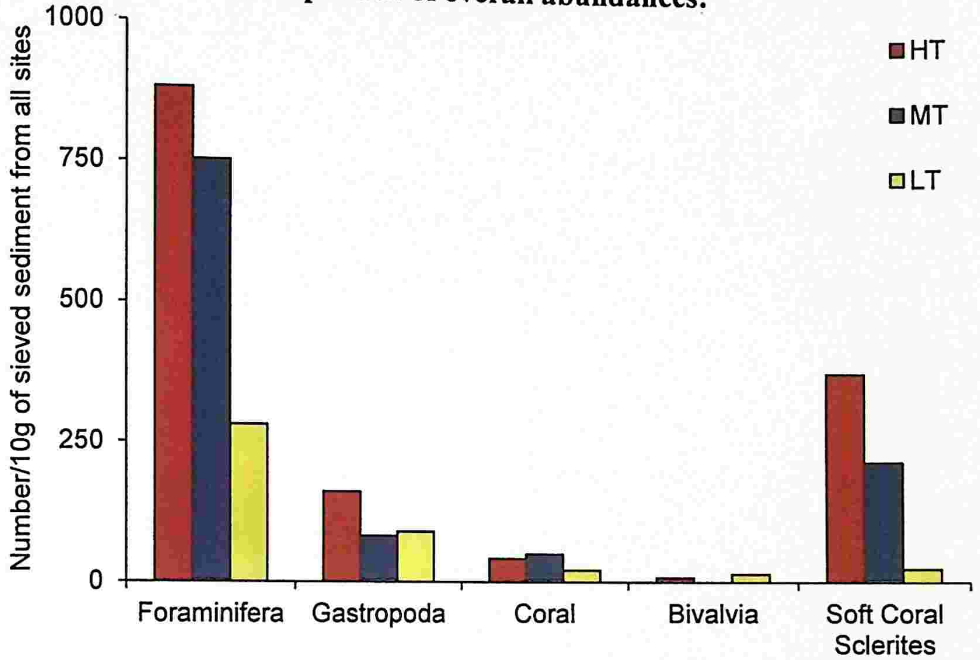


Figure 4: Overall abundances of taxa across zones

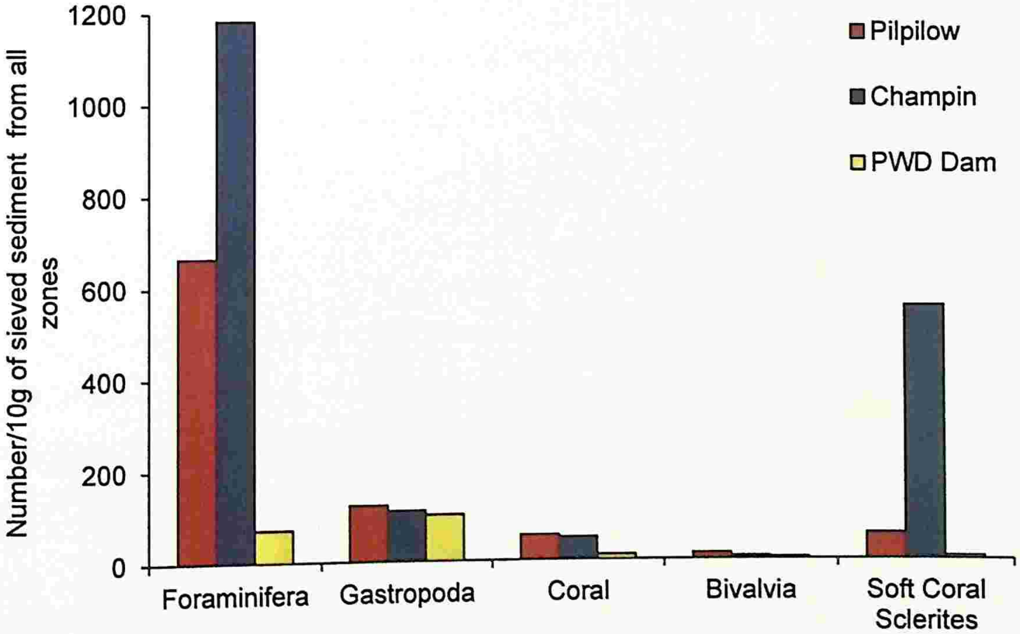


Figure 5: Overall abundances of taxa across sites

Site#1: Pilpilo:

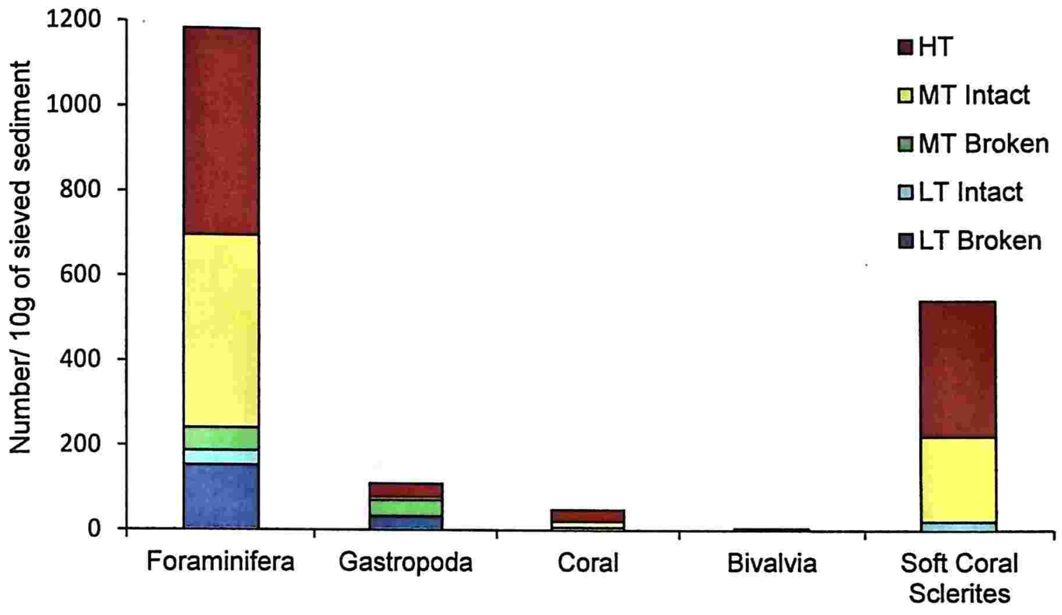


Figure 6: Abundances of taxa at Site #1: Pilpilow

High Tide (HT) Zone:

This zone showed dominance by foraminifera groups (487 foraminifera were counted), and this was closely followed by soft coral sclerites (329 sclerites were counted). Though there were other groups present (like gastropods, corals and bivalves), they were comparatively fewer.

Mid Tide (MT) Zone:

This zone of Site #1 was dominated by foraminifera and the number broken was several times lower than the number intact (455 were intact and 54 were broken). Soft coral sclerites were again found in plenty (207). An interesting observation would be the number of broken gastropods is higher than that of intact gastropods.

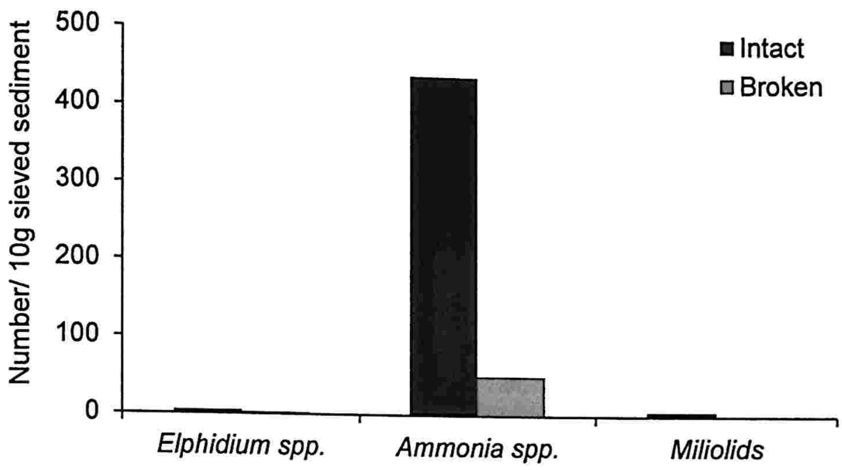


Figure 7: Abundances of Foraminifera taxa at MT Zone of Site #1- Pilpilow

When the foraminifera groups were looked into, *Ammonia spp.* numbers were very high(445 intact tests and 52 broken tests) in comparison to others. No live foraminifera were present. Only benthic, calcareous tests were encountered.

Low Tide (LT) Zone:

In the low tide zone, the foraminifera group was dominant over other groups. An interesting observation is the number of broken foraminifera is more than four times the number of intact foraminifera. Even the intact gastropod numbers are several times lesser compared to broken gastropod numbers. The other taxa encountered were corals and soft coral sclerites.

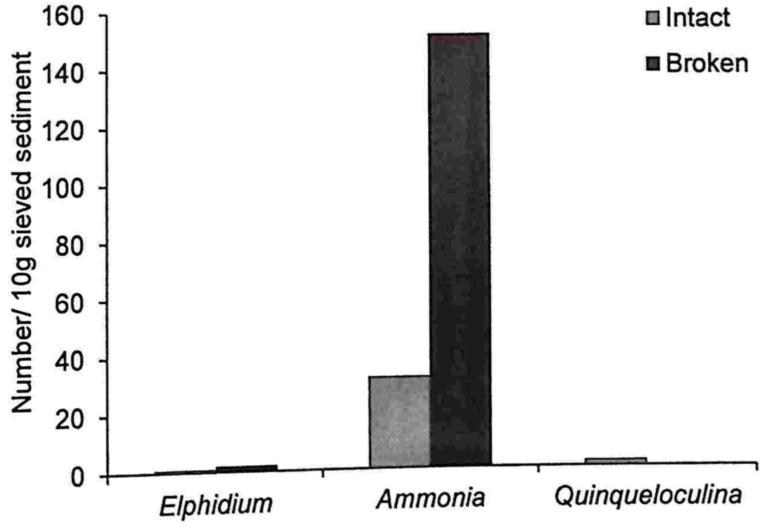


Figure 8: Abundances of Foraminifera taxa at LT Zone of Site #1- Pilpilow

Upon dividing the foraminifera group, the *Ammonia spp.* was dominant, with the broken tests outnumbering the intact tests.

Site#2: Champin:

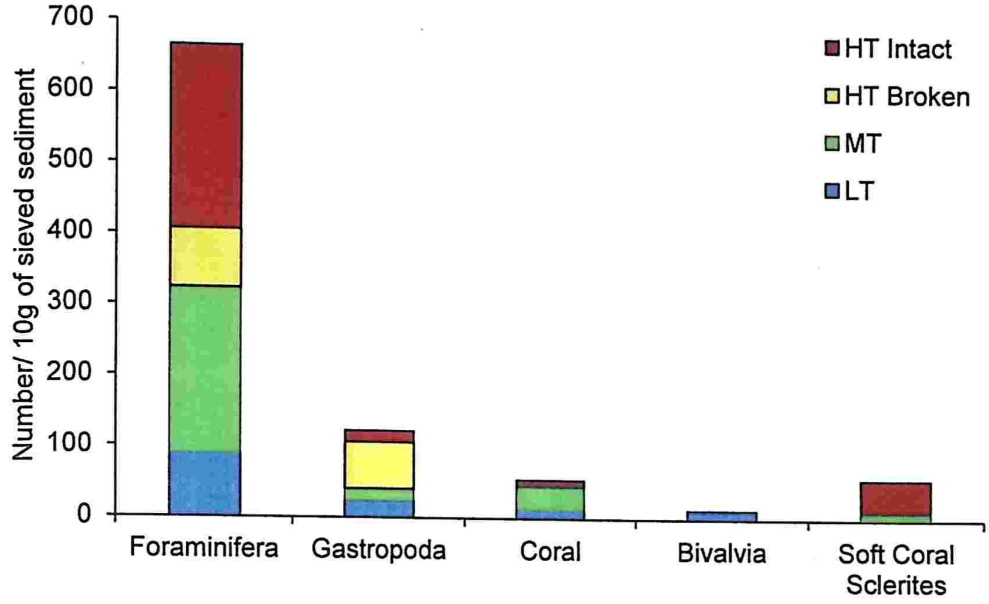


Figure 9: Abundances of taxa at Site #2: Champin

High Tide Zone:

Dominant group in the high tide zone is foraminifera, with the intact tests (259) more than three times the number of broken tests found (82). The gastropod group shows a reverse trend where the number of broken gastropods (65) is almost four times the number of intact gastropod shells (17). Other taxa encountered were corals, bivalves and soft coral sclerites. Sclerites were 46 in number.

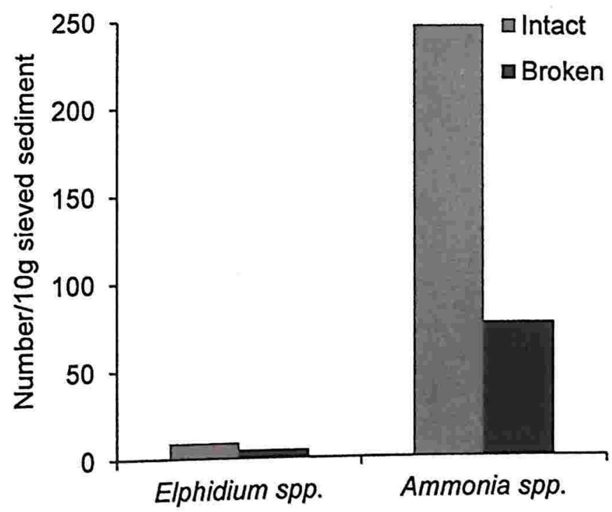


Figure 10: Abundances of Foraminifera taxa at HT Zone of Site #2- Champin

The number of intact *Ammonia spp.* tests (248) of was more than the number of broken tests (77). The number of intact tests of *Elphidium spp.*(9) also outnumber the broken *Elphidium spp.* tests (5).

Mid Tide Zone:

Dominating group of the Mid Tide zone is foraminifera (235) and followed by corals (32). Other taxa encountered are gastropods and soft coral sclerites.

Low Tide Zone:

Dominant group of the Low Tide zone is foraminifera. Other groups encountered include gastropods, corals and bivalves.

Site#3: PWD Dam:

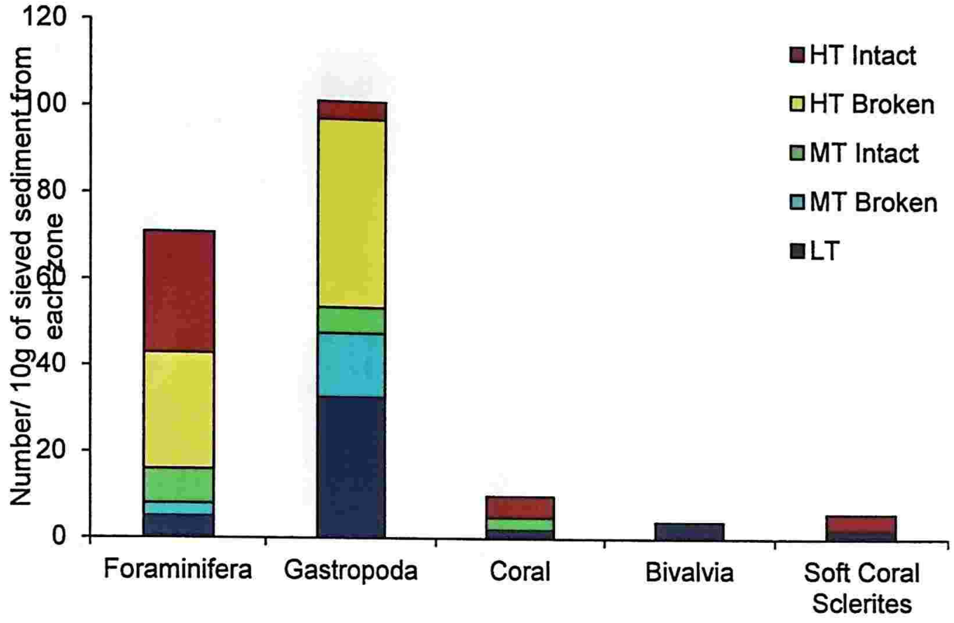


Figure 11: Abundances of taxa at Site #3: PWD Dam

High Tide Zone:

Dominant group is foraminifera, followed by gastropods. Broken (28) and intact tests (27) were almost equal, whereas the number of broken gastropod shells (44) was more than ten times that of intact shells (4). Corals and Soft Coral Sclerites were encountered as well.

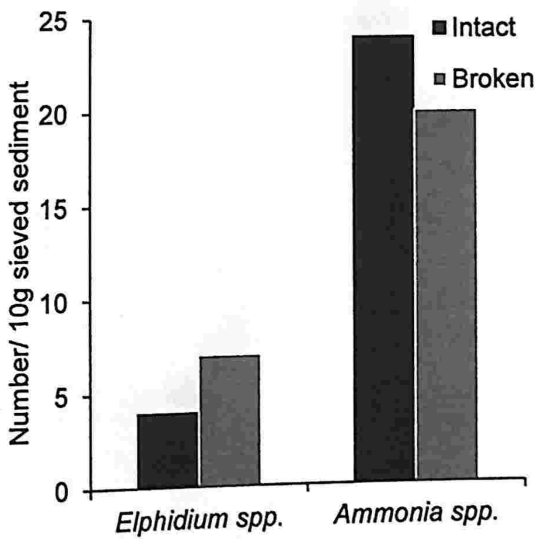


Figure 12: Abundances of Foraminifera taxa at HT Zone of Site #3- PWD Dam

There were two genera that were encountered, *Elphidium spp.* and *Ammonia spp.*, and *Ammonia spp.* was dominant. Intact *Elphidium spp.* tests (4) were fewer than broken *Elphidium spp.* tests (7). Intact *Ammonia spp.* tests (24) were more than broken *Ammonia spp.* tests (20).

Mid Tide Zone:

There were three groups that were encountered in the Mid Tide Zone. Of them, Gastropods were dominant with broken shells (15) outnumbering the intact shells (6). Gastropods are followed by foraminifera, in which intact tests (8) are more than broken tests (3). Corals (3) were also present in this zone.

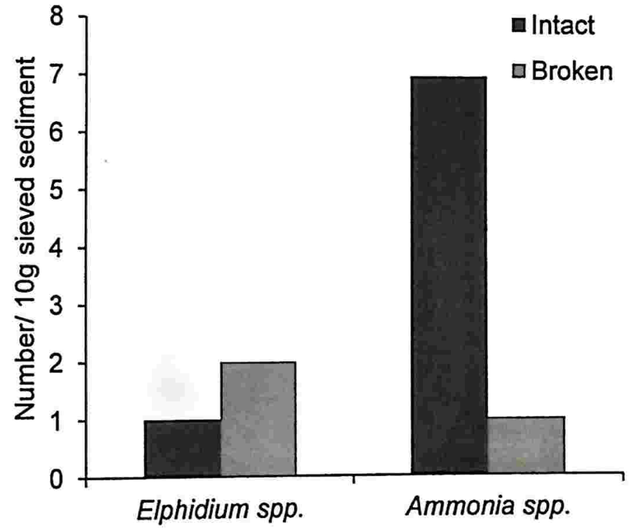


Figure 13: Abundances of Foraminifera taxa at MT Zone of Site #3- PWD Dam

The two foraminifera genera encountered are *Elphidium spp.* and *Ammonia spp.*, and *Ammonia spp.* was dominant. Intact *Elphidium spp.* tests (1) were fewer than broken *Elphidium spp.* tests (2). Intact *Ammonia spp.* tests (7) were more than broken *Ammonia spp.* tests (1).

Low Tide Zone:

Gastropods were the dominant group at the Low Tide region of the PWD Dam, followed by bivalves and then by foraminiferans. Soft coral sclerites were found too, but they were not found in as high numbers as in the other sites.

4.2. Abiotic parameters:

Table 1: Abiotic factors across the three sites

	Site#1	Site#2	Site#3
Salinity	30.33	28.00	29.67
Temperature (°C)	26.77	27.27	29.07
pH	7.77	7.53	7.98

Nutrient:

a. Nitrate:

Spatial replicates:

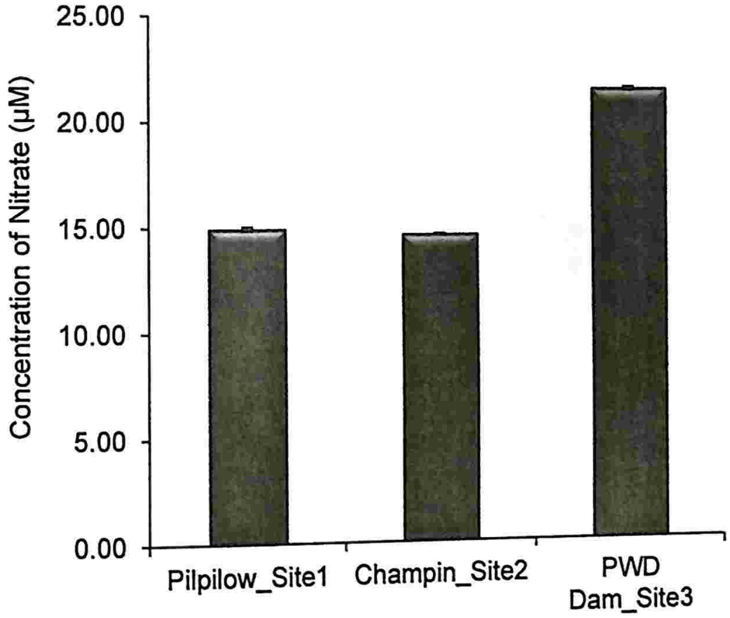


Figure 14: Nitrate concentrations (µM) across three sites

Nitrate concentrations between Site#1 (14.95) and Site #2 (14.71) are not very different, but Site #3 (21.67) has a higher value in comparison.

Temporal replicates:

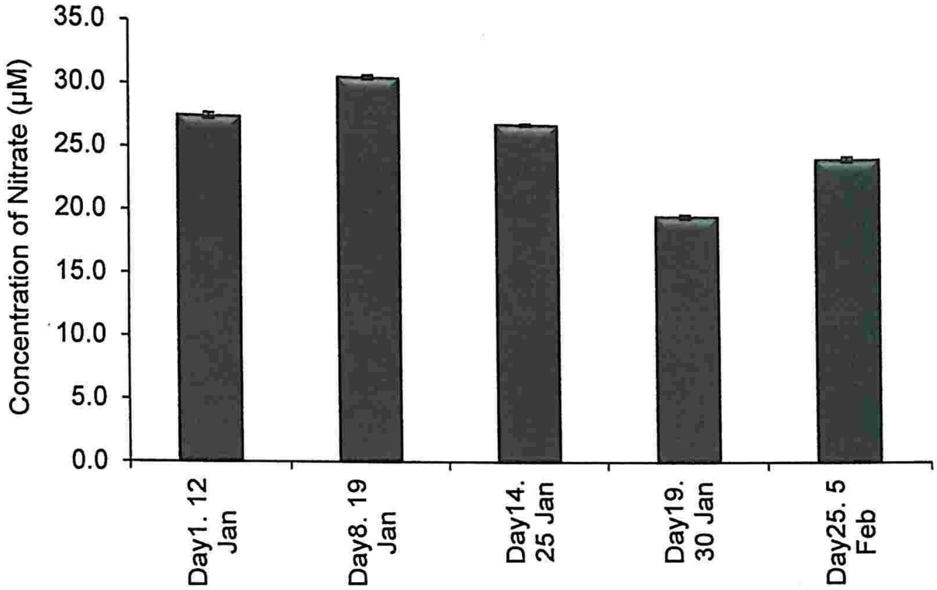


Figure 15: Nitrate concentrations (µM) across the lunar cycle

Silicate:

Spatial replicates:

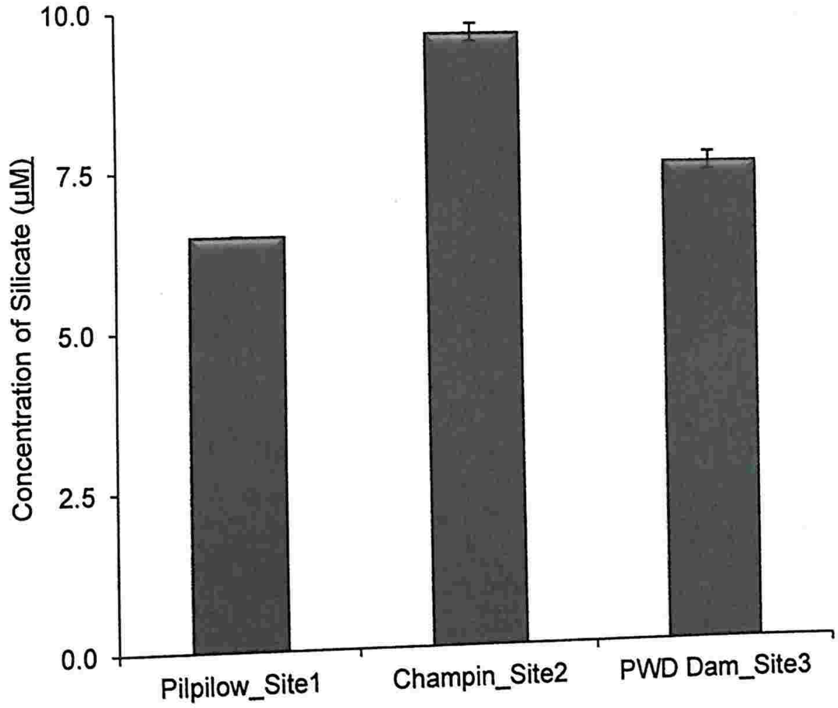


Figure 16: Silicate concentrations (µM) across three sites

Temporal replicates:

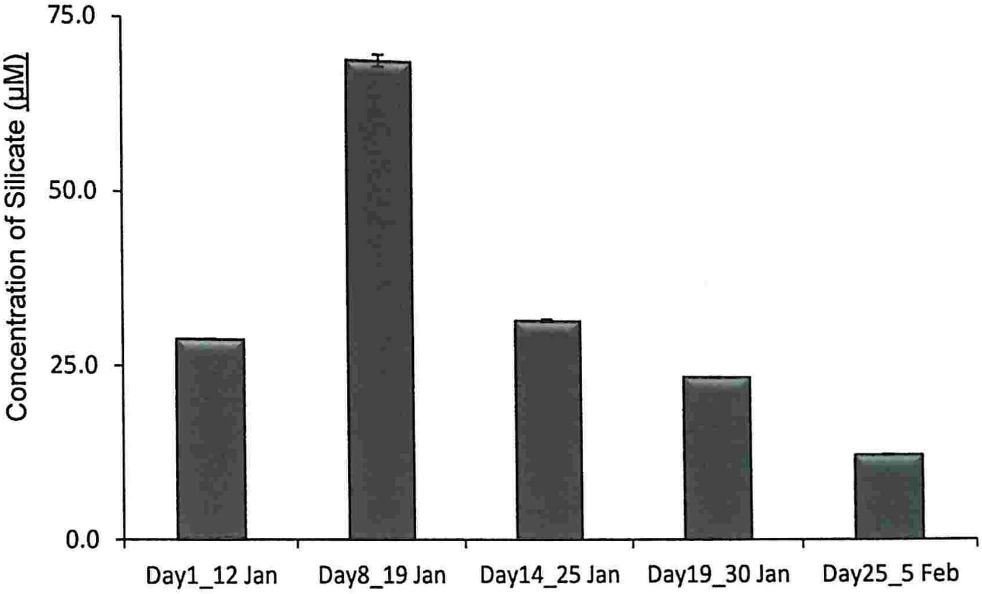


Figure 17: Silicate concentrations (µM) across the lunar cycle

Phosphate:

Spatial replicate:

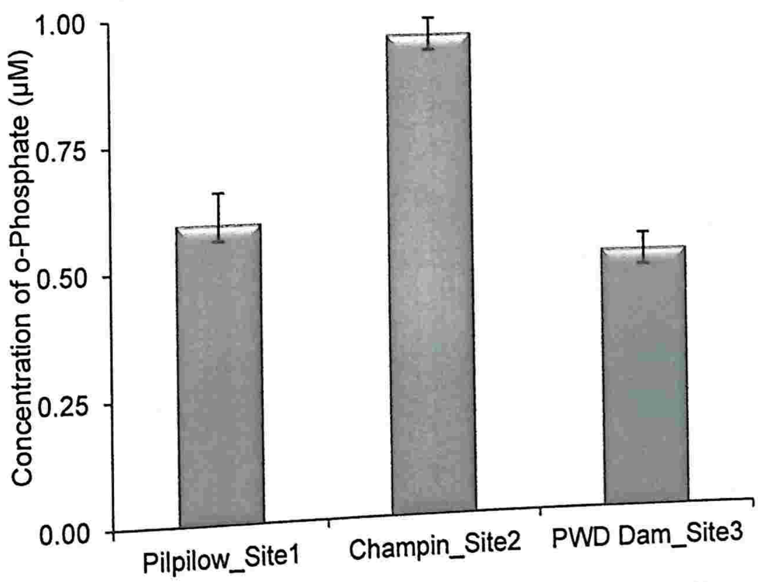


Figure 18: o-Phosphate concentrations (µM) across three sites

Temporal replicate:

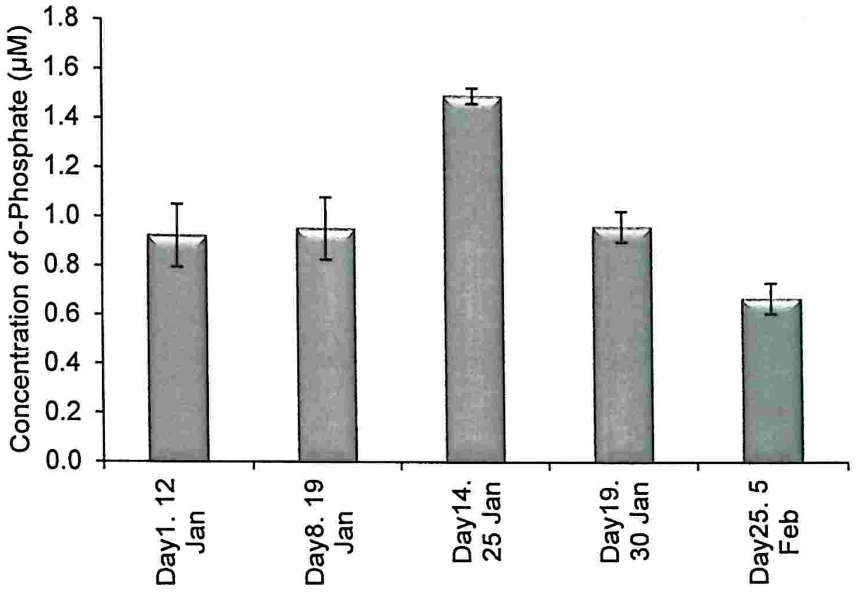


Figure 19: o-Phosphate concentrations (µM) across the lunar cycle

4.3. Physical parameters:

Site#1: Pilpilow

Morphodynamic nature of beach: Intermediate type

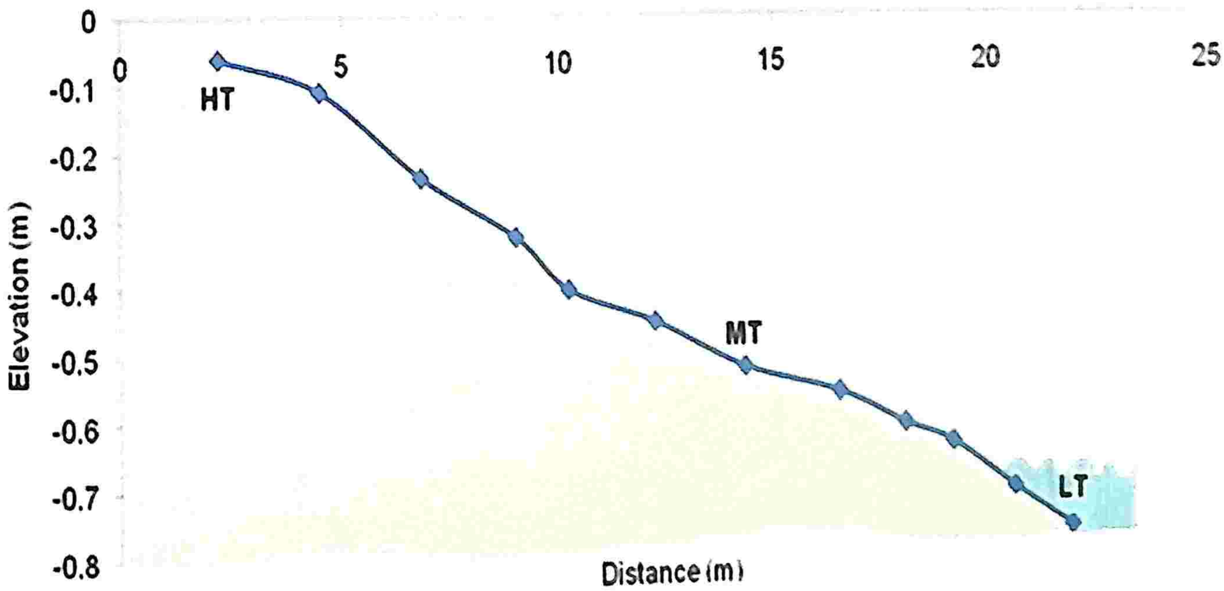


Figure 20: Beach Profile of Site #1- Pilpilow

Site#2: Champin

Morphodynamic nature of beach: Reflective type

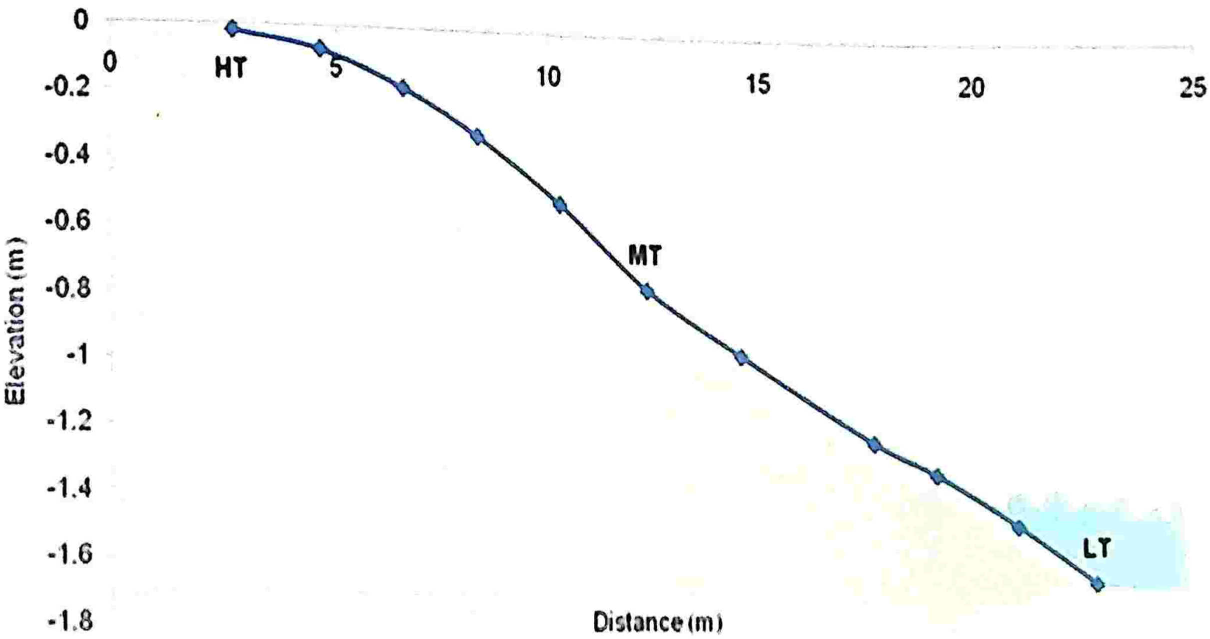


Figure 21: Beach Profile of Site #2- Champin

Site#3: PWD Dam

Morphodynamic nature of beach: Dissipative type

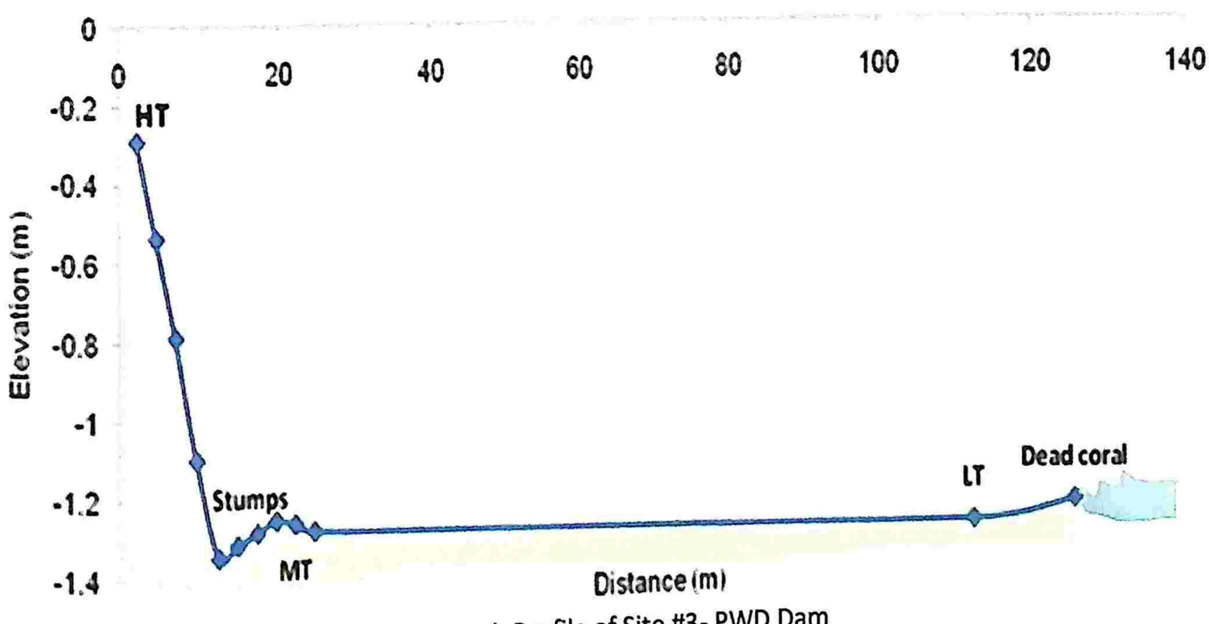


Figure 22: Beach Profile of Site #3- PWD Dam

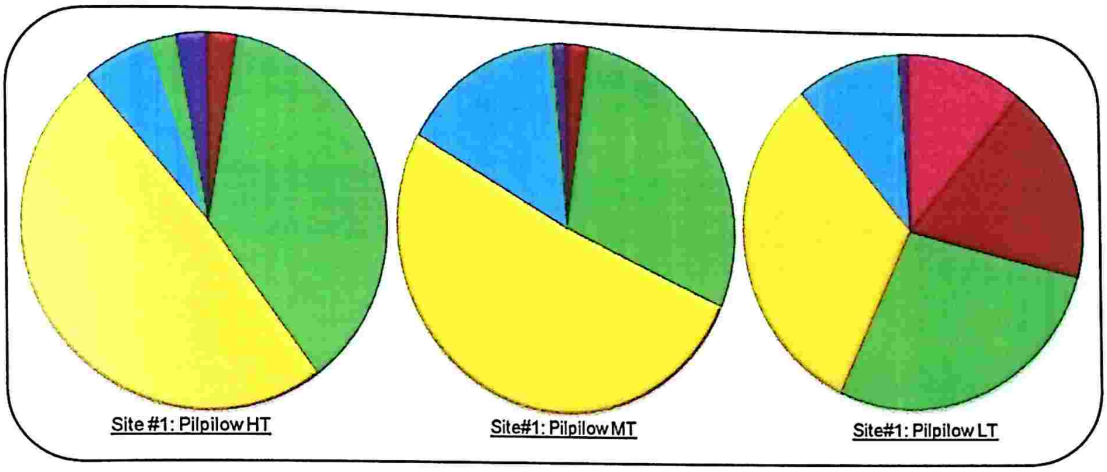
A dissipative beach is wide and flat in profile, and dissipates the force of the waves far from the intertidal region.

Sediment Granulometric analysis:

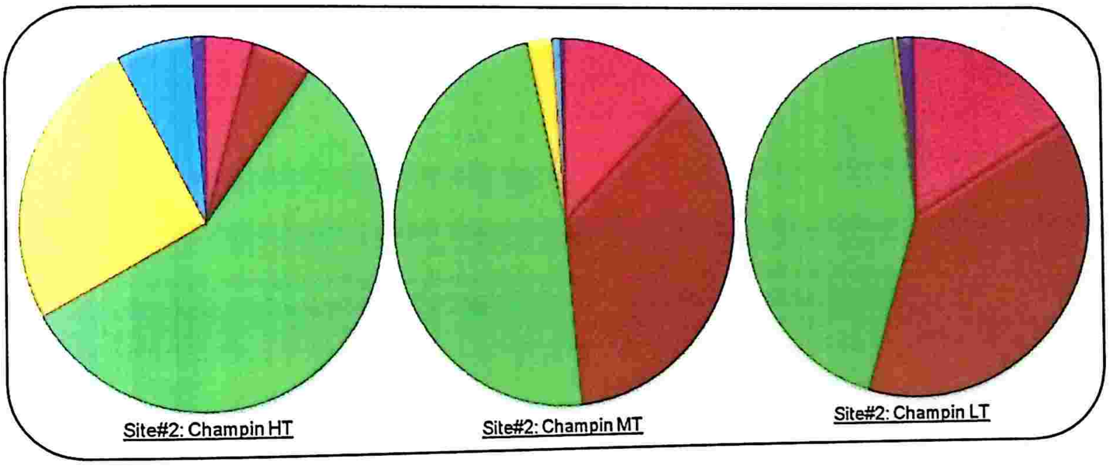
Granulometric analysis was done following a dry sieve-shaker method and modified Wentworth 1922, Berlie et al. 2008 classification of grain size categories.

This series of pie-charts shows how the weight retained on different category of sieves is different:-

Site#1: Pilpilow



Site#2: Champin



Site#3: PWD Dam

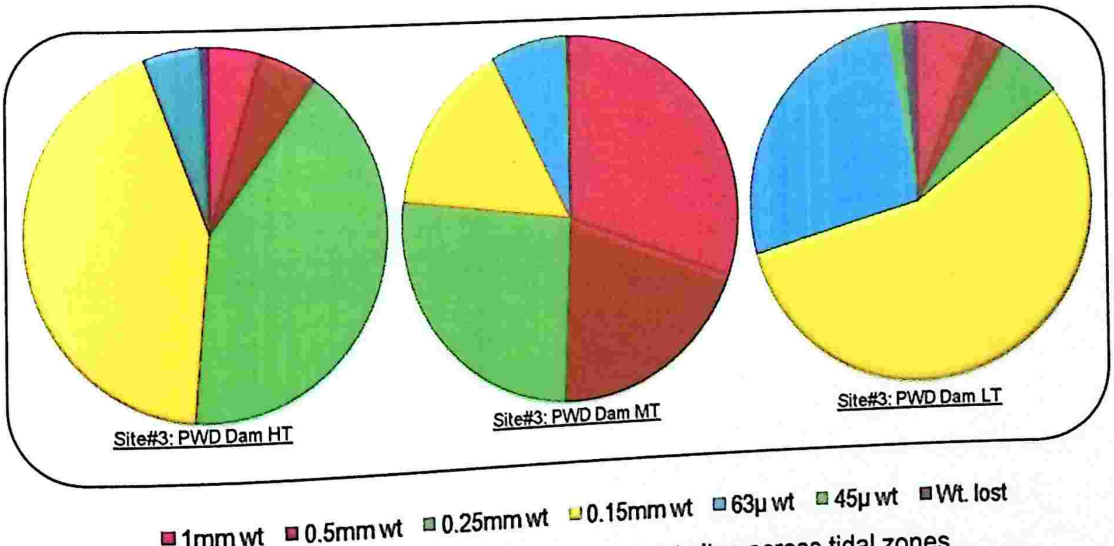


Figure 23: Granulometric composition at sites across tidal zones

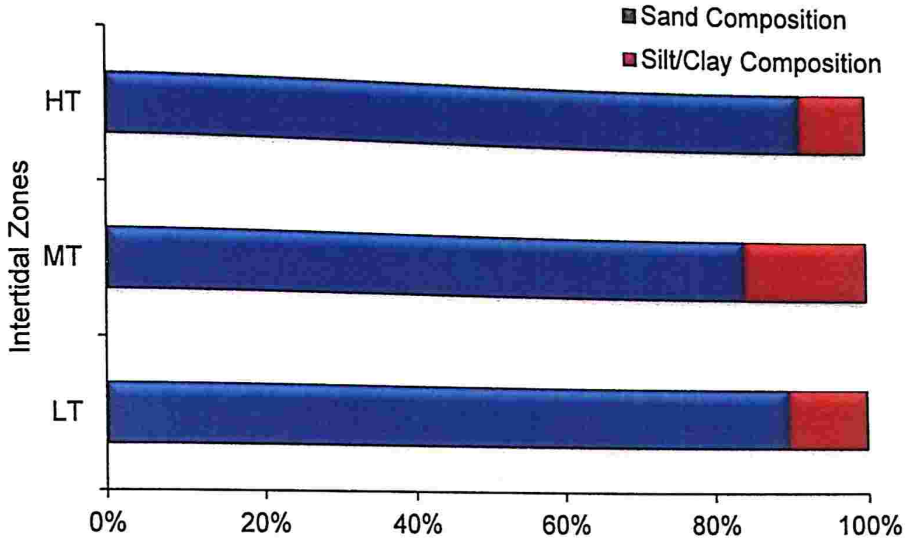


Figure: Sand-Silt/Clay Composition at Site #1: Pilpilow

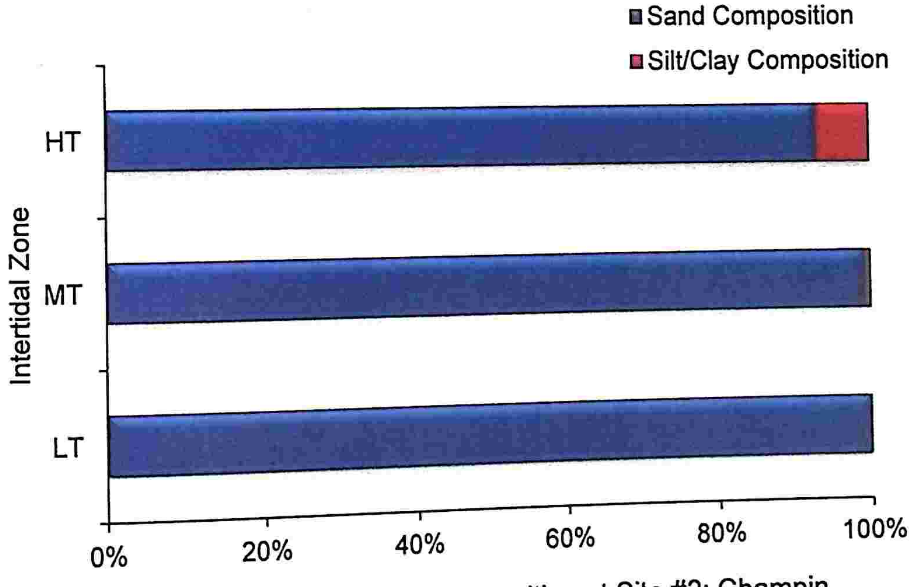


Figure 24: Sand-Silt/Clay Composition at Site #2: Champin

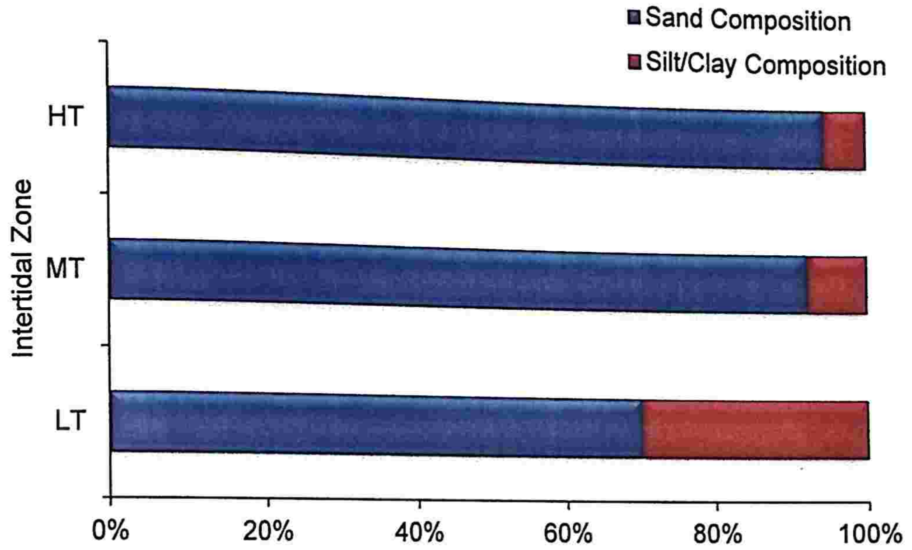


Figure 25: Sand-Silt/Clay Composition at Site #3: PWD Dam

Particle sizes of sands range from coarse sands (0.5-1mm), medium (0.25-0.5mm) and fine sands (0.063-0.25mm), with the substratum structure being rarely homogenous and having a low sorting coefficient, i.e., it is often well sorted. The sorting will be the result of the prevailing hydrodynamic regime including long-shore drift and coastal gyres, in the case of intertidal sediments, and headland gyres in the case of subtidal sandbanks. The sand grains of beaches and subtidal sandbanks are usually quartz (silica) particles derived from erosion (McLachlan and Brown 2006). The ratios of different grain sizes are supposed to vary in the long run, and this is what will be a vital aspect in the beach erodibility, facilitation and colonizing by other intertidal fauna (Armonies and Reise 1999).

Discussion:

Beach profiles noted at same place, but over different time points will give completely different profile slopes. This is due to storms, seasonal surges, anthropogenic activities nearby, etc. This can help making the right prospective management practices or the conservation course of action (Berlie et al. 2008*a*).

All the foraminiferans encountered were modern, benthic, and calcareous forms. No live foraminifera were encountered, all were dead tests. This remains the same for all three sites. There were also a noteworthy number of gastropod shells. This is mostly because of the severe physical factors influencing the sediments and subsequently the benthic communities. Beach erosion and harsh wave action and tidal surges are some examples. Beach erosion is interrupted and slowed down by biofilms and algal mats (Connell 1961, Reise et al. 1989, Gorgula and Connell 2004) which hold the sediments together, more so near the shores. It has also been studied in a mudflat in the Danish Wadden Sea that the tidal surges and ebbing is a weaker eroding factor as compared to the constant wave action (Austen et al. 1999). However, overall, sediments and nutrition act in sync to determine the community structure and distribution based on energy reserves (Dittmann 2002).

Site #1: Pilpilow:

Benthic fauna:

The proportion of broken Gastropod shells or broken tests of foraminiferans is lesser compared to Site #2, as the beach profile is less steep. The number of broken shells and tests could also be a result of harsh wave action and intense physical forces like thixotropy and dilatancy properties of the sediments.

Nevertheless, you have a significant number of soft coral sclerites to show how harsh wave action is and how erosion is causing damage to these sensitive species. It is the highest number of soft coral sclerites found in all of the samples, and the sclerites which represent damage to the coral have been found in all the zones. This could also mean that there is a constant physical damage happening at the coral reef offshore (where the soft corals would mostly be attached). Since it is exposed to the open sea, the eroded sclerites land up on the shore.

Granulometric analysis:

Interstitial space inside the sediment layers provides nutrition and space to infauna. If there is a higher proportion of silt/clay content, the sediment layers will be densely packed, reducing the interstitial space. This causes the groups of macrofauna to compete for the limited resource: nutrition.

Since Site #1 beach is an Intermediate beach, there is a small amount of silt/clay composition in the overall sediment. This means that there is some amount of microhabitats and niches available for benthos of various sizes. Also, keeping in mind the exposure to open sea and the harsh, unchecked waves, the grain size and the beach profile indicate the dynamic nature of erosion here (McLachlan and Brown 2006).

Site #2: Champin:

Benthic fauna:

Site #2 is sheltered by islands on three sides. Despite this, the beach profile is the steepest and forms a reflective beach. The biotic community is mostly dominated by foraminiferans, in all the zones. Despite the sheltered nature of the beach, there is a noteworthy number of soft coral sclerites that have been found here. Contrary to Site #1, this might not entirely be due to natural causes. There is frequent vessel movement, the erosion of the soft corals might have happened due to that. The slowly recovering offshore seagrass habitat might be exerting some change on the community (Leduc and Probert 2011).

Granulometric analysis:

Having a largely sand-dominated granulometric data would mean that it is a coarse-grained beach and that the interstitial spaces are large. This means it is a well-oxygenated system as the coarse-grained sediments and the beach profile allow the complete flushing of the water and organic matter. This would have provided a perfect habitat for infauna, except that the beach profile (reflective morphodynamic type) makes the wave action and tidal impact rough and subsequently fauna actively burrow deeper into the sediment.

Site #3: PWD Dam:

Benthic fauna:

Gastropoda dominate the taxa of Site#3 as they can rasp on the plant matter using their radula and there is a heavy organic matter load at this site. Also, since there are not really harsh physical conditions that would play an influential role in shaping the community, gastropods are unaffected. They are mostly epifauna, and being a dissipative beach, they are not adversely affected by the higher silt/clay content. There have also been a lot of papers (Whanpetch et al. 2010*b*, Leduc and Probert 2011, Barnes 2013) that talk about the impact of seagrass beds and other biotic communities have on the meiofaunal diversity and abundance. Since this site has young seagrass beds, the community is of particular interest to us.

Granulometric analysis:

Due to the submergence after the tsunami, the beach retained a lot of properties of the forest floor it once was. Also, there is a source of freshwater, sediment and organic matter from the creek. These could potentially be reasons as to why the site shows higher levels of silt/clay composition in comparison to the two other sites. Typically, sediment where the packing is dense with silt/clay playing an important role, the fauna found are mostly epifauna.

Temporal sampling:

This site is a dissipative beach, where the substrate does not get completely devoid of water due to the slope. This results in nutrient complexes forming trends over the period of temporal sampling. This stagnancy of nutrients at neap tides is overcome when dilution and ultimately flushing out during the spring tides takes place. With a representative sampling from each week, five time points have represented the gradual shift over the moon period. This is an important aspect of the study because the cyclic fluctuations in the nutrient concentrations would be important in driving the benthic communities which form a crucial role in the nutrient cycling as well as the energy flow through trophic levels.

According to these aspects, if we had to classify the three sites based on disturbances, we can draw the following conclusions:

- Site#1 Pilpilow has physical forces as a major influencing, which might also be the reason for erosion of soft corals and also the broken tests and mollusc shells. Since this is an intermediate type of beach and also an open exposed beach, the combined effect might be too harsh for certain fauna. Also the impact of the tsunami and the constant dynamism due to storms is a major driving force at this site.
- Site#2 Champin is sheltered from harsh natural forces by several islands on all the sides. Despite this, there are certain forces driving the community here. These include the harsh beach profile and the vessel movement around the region. The reflective beach profile has a steep beach face. The biodiversity here is trying to bounce back, be it through boulder corals or seagrass beds. These seagrass beds provide a microniche for a lot of benthic fauna by slightly altering the sediment characteristics. Such microniches are high priority conservation areas as they promote specialized biotic communities to thrive there. Also a lot of trophic levels are dependent on them directly or indirectly.
- Site #3 PWD Dam was severely affected by the tsunami so much so that the terrestrial ecosystem was turned into an aquatic ecosystem. This has severely altered soil chemistry (as is observed in the peaks and dips in the concentrations of nutrients). The beach is a dissipative beach going on for almost 200m at neap tide. The lunar cycle clearly affects the sites by altering the submerged and exposed area. This would directly reflect on the benthic communities which have to depend on the nutrient and the interstitial space (which is affected by water content).

References:

Al-Raei, A. M., K. Bosselmann, M. E. Böttcher, B. Hespenheide, and F. Tauber. 2009. Seasonal dynamics of microbial sulfate reduction in temperate intertidal surface sediments: controls by temperature and organic matter. Ocean Dynamics 59:351–370.

Alongi, D. M. 1989. Ecology of tropical soft-bottom benthos: A review with emphasis on emerging concepts. Rev. Biol. Trop. 37:85–100.

Ambariyanto, and O. Hoegh-Guldberg. 1997. Effect of nutrient enrichment in the field on the biomass, growth and calcification of the giant clam Tridacna maxima. Marine Biology 129:635–642.

Amend, M. R. 1997. A time series analysis of larval release and larval recruitment of the mole crab, emerita talpoida. University of Oregon.

Anandavelu, I., R. Jayabarathi, G. Padmavati, and K. A. Jayaraj. 2013. Epifaunal assemblage on morphologically distinct intertidal seaweeds of Kodiyaghat (South Andaman), India. Proceedings of the International Academy of Ecology and Environmental Sciences 3:229–237.

Armonies, W. 1989. Meiofaunal emergence from intertidal sediment measured in the field: significant contribution to nocturnal planktonic biomass in shallow waters. Helgoländer Meeresunters 43:29–43.

Armonies, W. 1990. Short-term changes of meiofaunal abundance in intertidal sediments. Helgoländer Meeresunters 44:375–386.

Armonies, W., E. Herre, and M. Sturm. 2001. Effects of the severe winter 1995/96 on the benthic macrofauna of the Wadden Sea and the coastal North Sea near the island of Sylt. Helgoland Marine Research 55:170–175.

Armonies, W., and K. Reise. 1999. On the population development of the introduced razor clam Ensis americanus near the island of Sylt (Nort Sea). Helgoländer Meeresunters 52:291–300.

Asmus, H., and R. Asmus. 1985. The importance of grazing food chain for energy flow and production in three intertidal sand bottom communities of the northern Wadden Sea. Helgoländer Meeresunters 39:273–301.

Austen, I., T. J. Andersen, and K. Edelvang. 1999. The influence of benthic diatoms and invertebrates on the erodibility of an intertidal a mudflat, the Danish Wadden Sea. Estuarine Coastal and Shelf Science 49:99–111.

Barnes, R. S. K. 2013. Distribution patterns of macrobenthic biodiversity in the intertidal seagrass beds of an estuarine system, and their conservation significance. Biodiversity and Conservation 22:357–372.

Berkeley, A., C. T. Perry, S. G. Smithers, B. P. Horton, and K. G. Taylor. 2007. A review of the ecological and taphonomic controls on foraminiferal assemblage development in intertidal environments. Earth-Science Reviews.

Berlie, T., N. Namboothri, A. Mohan, and K. Shanker. 2008*a*. A Protocol for Ecological Monitoring of Sandy Beaches and Intertidal Fauna on the Indian Coast. UNDP/ UNTRS, Chennai and ATREE, Bangalore, India. p 37.

Berlie, T., N. Namboothri, and K. Shanker. 2008*b*. Beyond the Tsunami Macro and Mega Faunal Communities of Intertidal Ecosystems on the Tamil Nadu Coast, India. UNDP/UNTRS, Chennai and ATREE, Bangalore, India. p 52.

Bially, A., and H. J. MacIsaac. 2000. Fouling mussels (Dreissena spp.) colonize soft sediments in Lake Erie and facilitate benthic invertebrates. Freshwater Biology 43:85–97.

Bode, A., J. A. Botas, and E. Fernández. 1997. Nitrate storage by phytoplankton in a coastal upwelling environment. Marine Biology 129:399–406.

Broitman, B. R., C. a. Blanchette, and S. D. Gaines. 2005. Recruitment of intertidal invertebrates and oceanographic variability at Santa Cruz Island, California. Limnology and Oceanography 50:1473–1479.

Casu, D., G. Ceccherelli, and A. Castelli. 2006. Immediate effects of experimental human trampling on mid-upper intertidal benthic invertebrates at the Asinara Island MPA (NW Mediterranean). Pages 271–279 *in*. Hydrobiologia. Volume 555.

Connell, J. H. 1961. The Influence of Interspecific Competition and Other Factors on the Distribution of the Barnacle Chthamalus Stellatus. Ecology 42:710–723. <http://www.jstor.org/stable/1933500?seq=1&cid=pdf-reference#references_tab_contents>.

Diaz, H. 1980. The Mole Crab Emerita talpoida (Say): A Case of Changing Life History Pattern.

Ecological Monographs 50:437–456. <http://www.jstor.org/stable/1942652>.

Dittmann, S. 2002. Benthic fauna in tropical tidal flats–a comparative perspective. Wetlands Ecology and Management 10:189–195. <http://link.springer.com/article/10.1023/A:1020119512225>.

Fitt, W. K., and C. B. Cook. 2001. The effects of feeding or addition of dissolved inorganic nutrients in maintaining the symbiosis between dinoflagellates and a tropical marine cnidarian. Marine Biology 139:507–517.

Gorgula, S. K., and S. D. Connell. 2004. Expansive covers of turf-forming algae on human-dominated coast: The relative effects of increasing nutrient and sediment loads. Marine Biology 145:613–619.

Harrison, P. L., and S. Ward. 2001. Elevated levels of nitrogen and phosphorus reduce fertilisation success of gametes from scleractinian reef corals. Marine Biology 139:1057–1068.

Helland, S., J. Christian Nejstgaard, H. J??rgen Fyhn, J. K. Egge, and U. B??mstedt. 2003. Effects of starvation, season, and diet on the free amino acid and protein content of Calanus finmarchicus females. Marine Biology 143:297–306.

Hilborn, R. C. 2004. Sea gulls, butterflies, and grasshoppers: A brief history of the butterfly effect in nonlinear dynamics. American Journal of Physics 72:425–427. <http://scitation.aip.org/content/aapt/journal/ajp/72/4/10.1119/1.1636492>.

Holm, R. F. 1978. The community structure of a tropical marine lagoon. Estuarine and Coastal Marine Science 7:329–345.

Hutchings, P. 1998. Biodiversity and functioning of polychaetes in benthic sediments. Biodiversity and Conservation 7:1133–1145.

Jayaraju, N., B. C. S. Raja Reddy, and K. R. Reddy. 2011. Anthropogenic impact on Andaman coast monitoring with benthic foraminifera, Andaman Sea, India. Environmental Earth Sciences 62:821–829.

Kneib, R. T. 1984. Patterns of Invertebrate Distribution and Abundance in the Intertidal Salt Marsh: Causes and Questions. Estuaries 7:392.

Lavers, J. L., and A. L. Bond. 2017. Exceptional and rapid accumulation of anthropogenic debris on one of the world's most remote and pristine islands. Proceedings of the National Academy of Sciences 201619818. <http://www.pnas.org/lookup/doi/10.1073/pnas.1619818114>.

Leduc, D., and P. K. Probert. 2011. Small-scale effect of intertidal seagrass (Zostera muelleri) on meiofaunal abundance, biomass, and nematode community structure. Journal of the Marine Biological Association of the United Kingdom 91:579–591. <http://www.journals.cambridge.org/abstract_S0025315410001645>.

Lubchenco, J., B. A. Menge, S. D. Garrity, P. J. Lubchenco, L. R. Ashkenas, S. D. Gaines, R. Emlet, J. Lucas, and S. Strauss. 1984. Structure, persistence, and role of consumers in a tropical rocky intertidal community (Taboguilla Island, Bay of Panama). Journal of Experimental Marine Biology and Ecology 78:23–73.

Mare, M. F. 1942. A study of a marine benthic community with special reference to the micro-organisms. Journal of the Marine Biological Association of the UK 25:517–554.

McLachlan, A., and A. C. Brown. 2006. The Ecology of Sandy Shores. The Ecology of Sandy Shores. <http://www.sciencedirect.com/science/article/pii/B978012372569150015X>.

Menn, I. 2002. Ecological comparison of two sandy shores with different wave energy and morphodynamics in the North Sea. Volume 417.

Monteiro, S. M., M. G. Chapman, and A. J. Underwood. 2002. Patches of the ascidian Pyura stolonifera (Heller, 1878): Structure of habitat and associated intertidal assemblages. Journal of Experimental Marine Biology and Ecology 270:171–189.

Moore, H. B., L. T. Davies, T. H. Fraser, R. H. Gore, and N. R. Lpez. 1968. Of marine science 1968.

Morgan, S. G., and J. H. Christy. 2011. Adaptive Significance of the Timing of Larval Release by Crabs Author (s): Steven G . Morgan and John H . Christy Published by : The University of Chicago Press for The American Society of Naturalists Stable URL : http://www.jstor.org/stable/2463029 . d. 145:457–479.

Nehru, P., and P. Balasubramanian. 2012. Sonneratia ovata Backer (Lythraceae): Status and Distribution of a Near Threatened Mangrove Species in Tsunami Impacted Mangrove

Habitats of Nicobar Islands, India. Journal of Threatened Taxa 4:3395–3400.

Nordemar, I., M. Nystrom, and R. Dizon. 2003. Effects of elevated seawater temperature and nitrate enrichment on the branching coral Porites cylindrica in the absence of particulate food. Marine Biology 142:669–677.

Olafsson, E., and R. Elmgren. 1997. Seasonal dynamics of sublittoral meiobenthos in relation to phytoplankton sedimentation in the Baltic Sea. Estuarine Coastal and Shelf Science 45:149–164.

Peterson, C. H., M. J. Bishop, G. A. Johnson, L. M. D'Anna, and L. M. Manning. 2006. Exploiting beach filling as an unaffordable experiment: Benthic intertidal impacts propagating upwards to shorebirds. Journal of Experimental Marine Biology and Ecology 338:205–221.

Piniak, G. A., and F. Lipschultz. 2004. Effects of nutritional history on nitrogen assimilation in congeneric temperate and tropical scleractinian corals. Marine Biology 145:1085–1096.

Rao, G. C. 1980. On the zoogeography of the interstitial meiofauna of the Andaman and Nicobar Islands, Indian Ocean. Rec. Zool. Surv. India 77:153–178.

Reise, K., E. Herre, and M. Sturm. 1989. Historical changes in the benthos of the Wadden Sea around the island of Sylt in the North Sea. Helgoländer Meeresunters 43:417–433.

Sarkar, S. K., A. Bhattacharya, S. Giri, B. Bhattacharya, D. Sarkar, D. C. Nayak, and A. K. Chattopadhaya. 2005. Spatiotemporal variation in benthic polychaetes (Annelida) and relationships with environmental variables in a tropical estuary. Wetlands Ecology and Management 13:55–67.

Shanks, A. L. 1983. Surface slicks associated with tidally forced internal waves may transport pelagic larvae of benthic invertebrates and fishes shoreward. Mar. Ecol. Prog. Ser. 13:311–315.

Strickland, J. D. H., and T. R. Parsons. 1972. A Practical Handbook of Seawater Analysis. A practical handbook of seawater analysis 167:185. <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:A+PRACTICAL+HANDBOOK+OF+SEAWATER+ANALYSIS#0>.

Taylor, P., D. Apte, and S. Dutta. 2010. Ecological determinants and stochastic fluctuations of

Tridacna maxima survival rate in Lakshadweep Archipelago. Systematics and Biodiversity 8:461–469.

Teixeira, H. 2010. Benthic Macroinvertebrates as Ecological Indicators for Estuarine and Coastal Ecosystems : Assessment and Intercalibration. University of Coimbra.

Thomas Jensen, K. 1992. Dynamics and growth of the cockle, Cerastoderma edule, on an intertidal mud-flat in the Danish Wadden sea: Effects of submersion time and density. Netherlands Journal of Sea Research 28:335–345.

Urban-Malinga, B., A. Drgas, S. Gromisz, and N. Barnes. 2014. Species-specific effect of macrobenthic assemblages on meiobenthos and nematode community structure in shallow sandy sediments. Marine Biology 161:195–212.

Vitousek, P., L. L. Loope, and H. Adsersen. 2013. Islands: biological diversity and ecosystem function. Volume 115.

Warner, M. E., G. C. Chilcoat, F. K. McFarland, and W. K. Fitt. 2002. Seasonal fluctuations in the photosynthetic capacity of photosystem II in symbiotic dinoflagellates in the Caribbean reef-building coral Montastraea. Marine Biology 141:31–38.

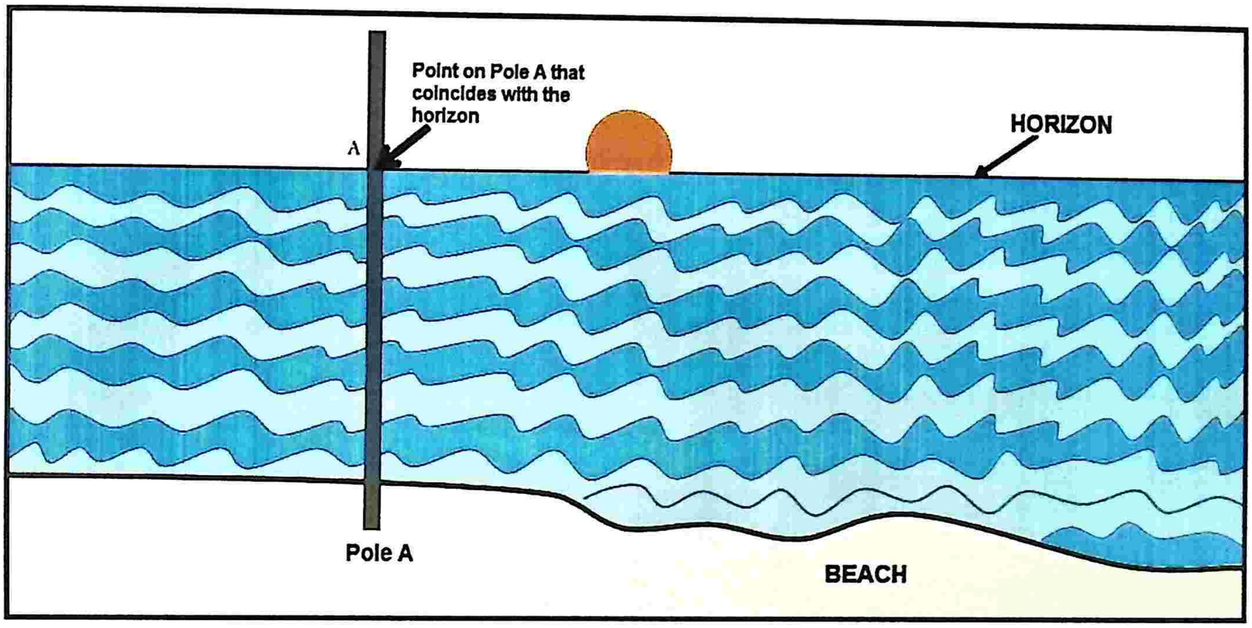
Wentworth, C. K. 1922. A Scale of Grade and Class Terms for Clastic Sediments. The Journal of Geology 30:377–392. <http://www.journals.uchicago.edu/doi/10.1086/622910>.

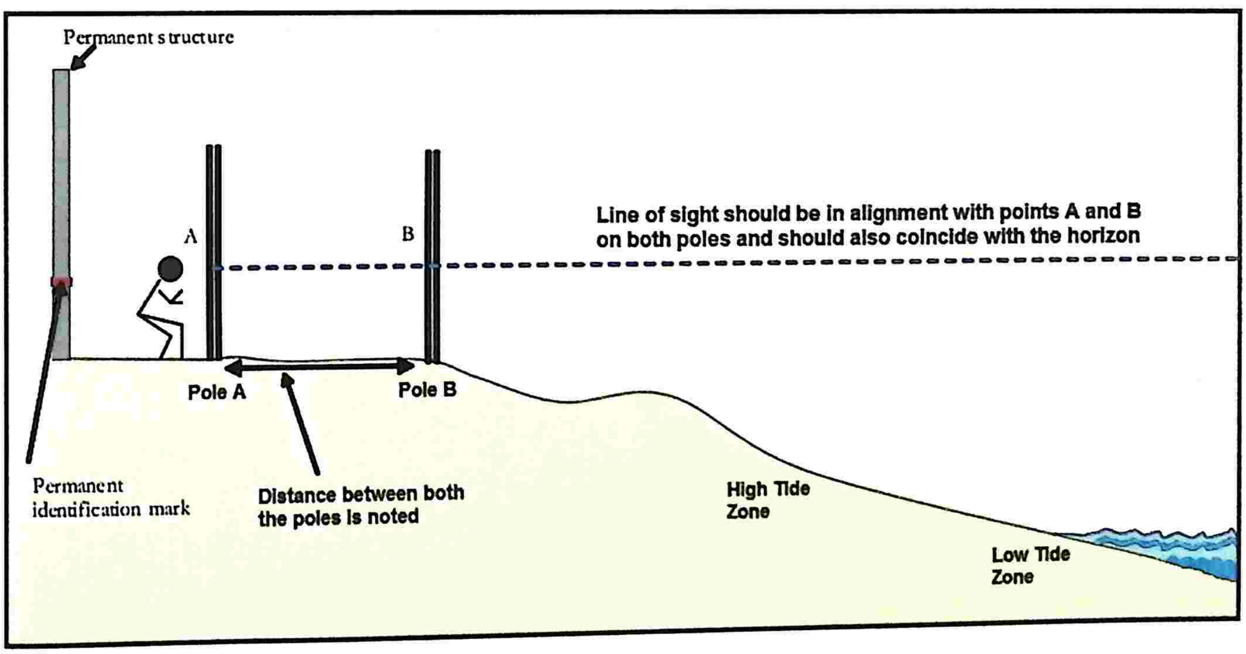
Whanpetch, N., M. Nakaoka, H. Mukai, T. Suzuki, and S. Nojima. 2010*a*. Estuarine , Coastal and Shelf Science Temporal changes in benthic communities of seagrass beds impacted by a tsunami in the Andaman Sea , Thailand. Estuarine, Coastal and Shelf Science 87:246–252. Elsevier Ltd. <http://dx.doi.org/10.1016/j.ecss.2010.01.001>.

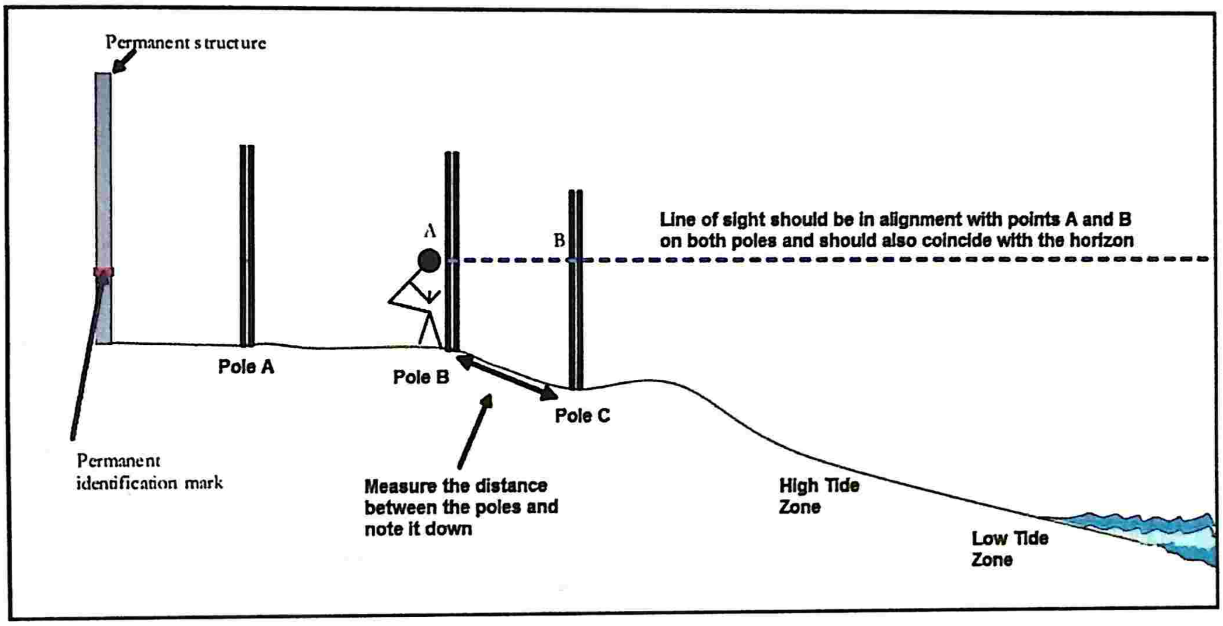
Whanpetch, N., M. Nakaoka, H. Mukai, T. Suzuki, S. Nojima, T. Kawai, and C. Aryuthaka. 2010*b*. Temporal changes in benthic communities of seagrass beds impacted by a tsunami in the Andaman Sea, Thailand. Estuarine, Coastal and Shelf Science.

APPENDICES

Annexure 1A: Beach Profiling







{**Modified from** (Andrade and Ferreira 2006, Berlie et al. 2008)}

Annexure 1B: **Beach Profile Datasheet**

Point	Distance between pole A and B	Readings on current and successive pole (cm)		Elevation (cm) = B - A	Elevation (m) = (cm) X 0.01	Cumulative distance	Cumulative elevation	Notes
I		A						
		B						
II		A						
		B						
III		A						
		B						
IV		A						
		B						
V		A						
		B						
VI		A						
		B						
VII		A						
		B						
VIII		A						
		B						
IX		A						
		B						
X		A						
		B						
XI		A						
		B						
XII		A						
		B						