Composition of Intertidal Rock Pool Sedentary Fauna from Select Beaches of Southern Coast of Maharashtra

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(Aided by the Ministry of Environment & Forests, Government of India)

CERTIFICATE

This is to certify that **Ms. Paurnima Vikas Mohite** of Sálim Ali Centre for Ornithology and Natural History (SACON) has carried out an original research work titled, '**Composition of intertidal rock pool sedentary fauna from select beaches of southern coast of Maharashtra**' in partial fulfilment of the M.Sc. (Ornithology & Conservation Biology) degree of Saurashtra University, Rajkot. This investigation was carried out under my supervision from December 2019 to August 2020. I also certify that this research work has not been submitted for any other degree to any University.

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-Paurnima Mohite.

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SUMMARY

Tidepools are common features of rocky shores worldwide. They are poorly studied than the adjacent emergent substratum (rocky patch) and very little information is available about patterns and processes of communities in them.

Considering this paucity of literature, the present study was conducted from January to March, 2020 to know the community composition and structure of rocky intertidal tidepool sedentary fauna (macrobenthos) from two rocky shores – Ladghar and Pajpandhari in Dapoli Taluk, Ratnagiri District, Maharashtra. The objective of the study was to compare the community composition and structure of sedentary organisms present in the tidepools in different intertidal zones as well as shores. By keeping this objective in the mind, answers to following questions were attempted: 1) How do physico-chemical parameters affect community composition and structure of sedentary organisms in tidepools? To test this, correlation analyses were carried out between the physico-chemical variables and the diversity attributes. 2) What is the distribution pattern of organisms within high tide, mid tide and low tide zones of the intertidal regions. 3) What is the effect of anthropogenic disturbance on the community composition and structure of tidepools. For the second and third questions, tests of community similarity like ANOSIM and Hierarchical Cluster Analysis were done.

The correlation analysis revealed very few correlations. Pool depth was shown to be more influencing important for the sedentary macrofauna and Polychaeta abundance and tidepool area was associated with Gastropoda diversity. pH and dissolved oxygen were negatively correlated with both Polychaeta and Gastropoda abundance. In addition, air temperature was found to be negatively correlated with Gastropoda abundance.

Hierarchical cluster analysis and ANOSIM showed no significant variability in community composition of tidepools between two shores as well as between the tidal zones.

Since there was no significant difference observed between the fauna of the two shores, it was concluded that anthropogenic disturbance did not affect the community structure and composition in the study area.

The sedentary faunal community structure in tidepools did not vary consistently with the period of tidal isolation and there is large variability among pools and within intertidal zones. This may be because of the dynamic nature of this ecosystem and the short duration of the study.

This study provided an attempt to understand this ecosystem in a better manner and the findings of which can be used as a base for comparison with studies in the future.

1. INTRODUCTION

1.1. BACKGROUND

Coastal region is a zone of transition between terrestrial and marine ecosystems (Werner & Blanton, 2001). This narrow region is the earth's most complex, diverse, productive and valued ecosystems (Crossland *et al*., 2005; Dethier & Harper, 2011). Various coastal landforms (sandy shores, rocky shores) and habitats (salt marshes, mudflats and mangrove) (Zedler & Callaway, 2001) are present in this region which support a variety of organisms and act as habitat for them. The zone of these landforms and habitats which is under the influence of the tidal cycle is known as the intertidal region.

1.1.1. Rocky Intertidal Region

The intertidal region is a zone of interaction between the sea, land and air (Parulekar, 1981). It is one of the most interesting divisions of the marine ecosystem, the boundary of which is marked by the level of high tide and low tide (Jaiswar & Kulkarni, 2001).

The intertidal region of rocky shores is most densely inhabited which has a greater diversity of animal and plant species as compared to other intertidal regions (Nybakken, 1982). Continuous erosional action of strong waves on rocky shores alters the structure of rocks and boulders into steep rocky cliffs, platforms, tidepools and boulder fields which often are biologically rich environment (Styam & Thiruchitraambalam, 2018). Regular submergence of this heterogeneous regions provides active transportation of the recruitment stock from the nearshore area, but their survival and distribution are limited by environmental stress caused due to periodic emersion and immersion of the intertidal region by tidal cycle (Noel & Jeanne, 2007).

Animals and plants living in the intertidal zone are exposed to varying degree of the desiccating effects of the sun and wind, and the potentially damaging effects of waves. Based on the nature of exposure rocky intertidal region can be divided into various vertical zones. Organisms living in a zone are adapted to environmental conditions of that zone and each

zone has its unique complement of organisms (Styam & Thiruchitraambalam, 2018). Based on the amount and type of inundation, the rocky intertidal region is divided into the following zones (Stephenson & Stephenson, 1949):

Littorina zone (Supra-littoral or High tide zone): The zone submerges only by waves of spring tide or during storms, but not during neap high tide. Very few species inhabit this zone because of comparatively more exposure to air during day and night. The characteristic species of this zone are periwinkles (*Littorina*), neritids (*Nerita*) and lichens.

Balanoid zone (Mid-littoral or Mid tide zone): The zone is exposed to daily ebb and flood of tides. The region is demarcated by the highwater level and low water level of neap tides. It is a species-rich zone than that of the Littorina zone. Balanoid (barnacles), molluscs, crustaceans and rock boring worms like sipunculids are common taxa present in this zone.

Sublittoral springe (Sub-littoral or low tide zone): It is the lowest zone of the shore, experiencing strong wave action and is exposed to air for the relatively small duration only by ebbing of spring tide and rarely dries off. It is typically rich in plant and animal diversity. Organisms present in this region show morphological and behavioural adaptations to withstand strong wave action.

1.1.2. Intertidal Rock Pools

Intertidal rock pools (tidepools henceforth) are one of the ubiquitous and interesting structures present in the intertidal zone of the rocky shores in many parts of the world (Firth *et al*., 2014). These are dynamic and intermittently isolated habitat patches on the rocky intertidal zone and are easily accessible during low tide (Mendonça *et al*., 2018). Because of regular tides, the pools are not stagnant and there is a regular water flux in the pools. As tide pools vary in size, depth, orientation, shading and flushing rate, each pool is physically and biologically distinct (Ganning, 1971; Metaxas & Scheibling, 1993). Similar to the emergent substrata on the rocky intertidal regions; the environment of tidepools is also regulated by tidal cycle, but to a lower extent than that of emergent substrata; and the degree of fluctuation in a tidepool environment is lower near low tide level than that of high tide level (Metaxas & Scheibling, 1993).

Organisms present in tidepools are continually submerged and hence are not subject to the same emersion related stresses like higher temperature amplitude and desiccation rates, as on freely draining substrata (Metaxas & Scheibling, 1993; Mendonça *et al*., 2018). Less harsh environmental conditions in tidepools provide refuges for a variety of marine organisms during low tide and allow organisms to extend their upper limits (Underwood, 1980; Underwood & Jenakoff, 1984). As a result, tidepools are more taxon rich than emergent substrata (Firth, 2014). Tidepools also act as feeding habitats (Wai, 2006; Dias *et al*., 2015) and nursery grounds (Bennett, 1987; Delany, 1998 Dias *et al*., 2015) for many marine organisms. They support huge diversity in a relatively small area which gives rise to a large number of complex food webs. Due to this, such pools can be used as proxies for complex food webs studies which are generally not possible due to logistic difficulties (Mendonça *et al*., 2018). Firth *et al*. (2014) documented that the creation of artificial tidepools of varying dimensions on an intertidal region of artificial coastal defence structures that can provide a range of habitats to promote or increase local biodiversity.

The diversity and distribution of organisms in this dynamic system are determined by tidal amplitude (Batzli, 1969), exposure to wave (Sze, 1982), temperature (Nakamura, 1976), salinity (Ganning, 1971) as well as biological factors such as competition (Zander *et al*., 1999), predation (Dethier, 1980; Trussell *et al*. 2004) and grazing (Noel & Jeanne, 2007).

Apart from these factors, in recent years, the diversity, distribution and health of organisms in the intertidal zone are influenced by various anthropogenic activities (Zedler & Callaway, 2001). This region has a threat of accumulation of pollutants from terrestrial as well as oceanic ecosystems. Organisms living in tidepool are under the threat of pollution as during low tide, pollutants that remain in the tidepool may influence the tidepool ecosystem.

1.2. OBJECTIVE

The objective of the study is to compare the community composition and structure of sedentary organisms present in the tidepools, in different intertidal zones, as well as shores (rocky intertidal region) in order to answer the following questions:

Questions

I. How do physical and chemical factors affect community composition and structure of sedentary organisms in tidepools?

II. What is the distribution pattern of organisms within various zones of the shores?

III. Does anthropogenic disturbance have any effect on the community composition and structure of tidepools?

1.3. LITERATURE REVIEW

Community ecology focuses to describe the patterns of distribution and abundance of species assemblages and to understand the processes that give rise to these patterns (Begon *et al*., 1986). These processes include the effect of the physical environment and biological interaction (Metaxas & Scheibling, 1993). Accordingly, community composition and structure of tidepools are a function of various physical, chemical, biological factors in and around the tidepools.

1.3.1. Factors Affecting Community Composition and Structure of Tidepool Biota

Biotic communities in the tidepools are rather poorly understood and documented as compared to those on the emergent substrata (van Tamelen, 1996; Underwood & Skilleter, 1996). This is because of the variability in physical and structural characteristics of tidepools (Astles, 1993), which poses a challenge for proper replication (Dethier, 1984; Metaxas & Scheibling, 1993).

Internationally, tidepools have been a topic of study since 1855 where a Swedish fishery biologist Sundewall first observed the occurrence of eel in brackish-water tidepools in the archipelago of Stockholm (Ganning, 1971). Subsequently, the tidepool studies have mostly been descriptive and have examined only one or two pools on a shore or recorded only presence or absence of the flora and fauna (Klugh, 1924; Naylor & Slinn, 1958; Ganning, 1971; Ganning & Wulff, 1969; Aleem 1973; Femino & Mathieson, 1980; Preston & Moore, 1988; Brattström, 1990)

Klugh (1924) compared six tidepools having similar depth, bottom character and exposure to wave action, on the New Brunswick coast, wherein, the temperature was found to be the limiting factor in determining the community composition of tidepool biota. Similar results were obtained by Johnson and Skutch (1928) while studying the distribution of algae in intertidal rock pools of Mt. Desert island, Maine, USA. Ambler and Chapman (1950) corroborated with these findings while quantifying the factors affecting flora and fauna of tidepools at the northern end of Narrow Neck Beach, Auckland. However, Ganning (1971) while studying the tidepools from the Swedish west coast, found salinity as a major limiting factor in determining the species composition of tidepool biota. Along with temperature and salinity, it was also reported that the daily changes in dissolved oxygen, pH and alkalinity somewhat influence the biological processes in tidepools (Metaxas & Scheibling, 1993).

Marsh *et al*. (1978) showed that area and depth of the tide pools influence the community structure of the tide pools, but Ranta (1982) and Martins *et al*. (2007) reported that the depth of tidepools irrespective of the area plays a major role in determining the community structure.

1.3.2. Effect of Zonation

Zonation of the intertidal region plays a significant role in the distribution of organisms between tidepools. The abundance, richness and biomass of organisms in the tidepools differs between zones. There are records of such a zonation pattern in diatoms (Metaxas & Lewis, 1992), copepods (Fraser, 1936), Macroalgae (Gross-Custard *et al*., 1979; Kooistra *et al*., 1989), benthic invertebrates (Ganning, 1971; Gross-Custard *et al*., 1979; Huggett & Griffiths, 1986) and fish (Nakamura, 1976; Bennett & Griffiths, 1984; Mgaya, 1992).

Huggett and Griffiths (1986) compared four tidepools situated at different heights at the shore of the Cape Peninsula, South Africa. A linear decrease in the number of species recorded per unit area was observed from the low tide level to the high tide level. Variation in species composition of rockpool biota was also recorded – dominant forms found in pools higher on the shore were algae and grazing gastropods, whereas bivalves and sponges were dominant forms in pools lower on the shore.

1.3.3. Effect of Anthropogenic Factors

Rützler and Sterrer (1970) found that an oil spill 3.7 km away from the Galeta Island, Panama Canal, affected the tidepool biota of the supralittoral spray zone and the mesolittoral zone negatively. This study was conducted two months after the event, but even then tidepools were covered with a layer of oil up to 2 cm deep and were devoid of life.

The earliest experimental studies to assess pollution have been conducted by Bonsdorff and Nelson (1981) and Bonsdorff (1983). Bonsdorff (1984) performed an experimental study to see the impact of oil spills on the fauna associated with *Corallina officinalis* L present in intertidal rock pools in western Norway. About 50 % decrease in faunal abundance was observed within 24 to 48 hours after treatment. The faunal abundance, however, recovered to pre-exposure levels within one to four weeks after treatment.

Tablado *et al*. (1994) found that, in the polluted sites, the density of *Siphonaria lesson* was reduced while their growth rate increased. On the other hand, at the unpolluted site, density was higher and the growth rate was lowered.

In addition to pollution, activities like tourism (Pinn & Rodgers, 2005) trampling (Keoughi & Quinn 1998; Schiel & Taylor, 1999), over collection of living resources (Hockey & Bosman, 1986; Lasiak, 1998; Castilla, 1999) and introduction of alien species (Gross-Custard & Moser, 1988) degrade the biota of the intertidal region. Although the tidepools have not been studied in this context, there is a possibility that such activities may adversely affect the organisms in the tide pools as well (Thompson *et al*., 2002).

1.3.4. Studies in India

Tidepool studies in India have been very few and rare. The first probable study of tidepool fauna from the intertidal rocky habitat is by Parulekar (1981) in Malvan, Maharashtra. In the study, it was found that amongst the various habitats present in the intertidal region, the tidepools proved to be the most species rich supporting 32 animal types (taxa) and 92 species. Also, the species richness of rock pools present in the mid-littoral zone was higher than that of other zones.

Ravinesh and Bijukumar (2013) compared intertidal biodiversity associated with the natural rocky shore at Kovalam and an artificial sea wall at Vizhinjam, Kerala.

Tsering *et al*. (2012) studied fish in ten rockpools on two rocky beaches (5 pools on each beach) of Goa. Nine species belonging to five families were observed in the study.

Kumar *et al*. (2016) studied 100 tide pools of various sizes along the South Andaman coast to know the diversity and distribution patterns of ornamental fishes and their associated flora and fauna. Thirty-five species of ornamental fishes belonging to 22 families were reported and it was found that the assemblage of ornamental fishes was dependent on the water temperature in tidepools. Satyam and Thiruchitrambalam (2018) studied six micro-habitats including tidepools at four sites having similar characteristics and climatic conditions along the rocky coast of Port Blair, South Andaman Islands. It was noticed that the species diversity and evenness were lower in the intertidal region of the beaches having high human activities than the ones with low activity.

Sukumaran *et al*. (2014) studied the impact of 'Chitra' oil spill on the resident macrobenthos in the tidepools present on the rocky intertidal shore of Colaba, Mumbai. The oil spill negatively affected the biotic community structure of the area in the initial months but did not have long-term deleterious effects.

In comparison to international studies on tidepools, the studies in India are few and deal with various ecological aspects of intertidal rocky shores rather than specific tidepools. The studies are mostly restricted to the zonation, diversity, distribution, habitat preference and spatio-

temporal variation of organisms in the intertidal region. Hence considering these aspects the present study is of high academic, ecological and conservation importance.

2. STUDY AREA

The study was conducted on two rocky shores, namely, Ladghar (17˚ 43’ 58’’ N and 73˚ 7’ 40’’ E) and Pajpandhari (17˚ 50’ 3’’ N and 73˚ 5’ 22’’ E) in Dapoli Taluk of Ratnagiri District Maharashtra (Figure 01). The aerial distance between two study sites, Ladghar and Pajpandhari is about 12 km.

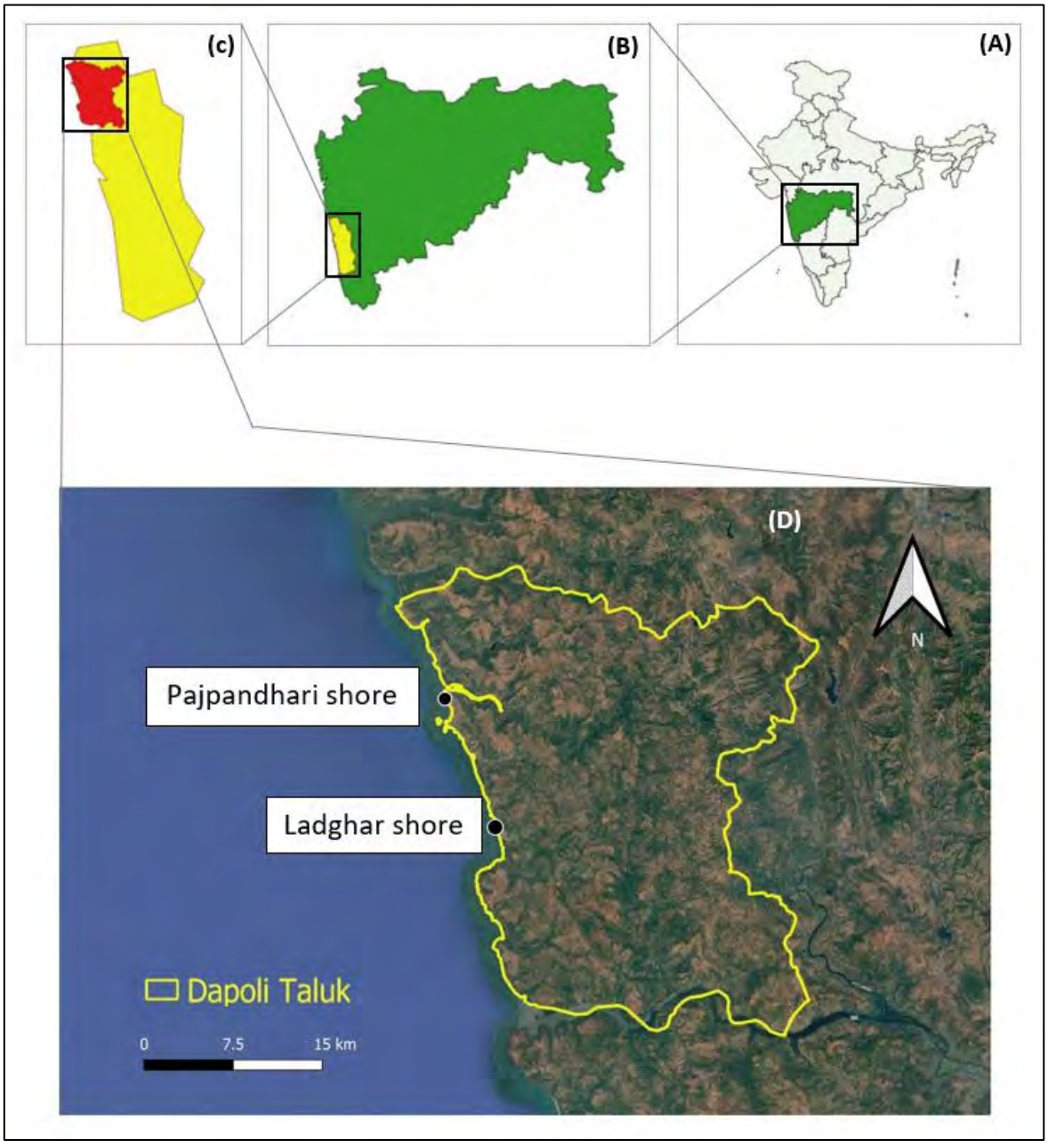


Figure 01: The state of Maharashtra (A), Ratnagiri district (B), Dapoli Taluk (C) and the study sites (Pajpandhari and Ladghar shore).

2.1. KONKAN AND KONKAN COAST

The narrow littoral lowland region between the Arabian sea and the Western Ghats of Maharashtra is known as Konkan. Its average width is 70 km (Nulkar,2014). Seven coastal districts, namely Mumbai City, Mumbai Suburban, Thane, Palghar, Raigad, Ratnagiri and Sindhudurg constitute the Konkan region. The Konkan region is characterized by distinct agroclimatic conditions, soil type, topography, crops and cropping patterns due to its location between the Western Ghats and the Arabian sea (Nulkar, 2014).

2.1.1. Geology of the Konkan Coast

The Konkan coast is formed by various tectonic, fluvial, coastal and aeolian processes during the Quaternary period (Hanamgond, 2008). It is highly dissected by river mouths, estuaries, creeks, rocky headlands, cliffs and islands along its length of 720 km (Wagle, 1991). Morphological features of the Konkan Coast are distinct from the rest of the Indian Coast (Chandramohan *et al*., 1992). The major morphological features include laterite mesas, active and abandoned cliffs, wave-cut platforms, rocky islands, tidal flats, beach rocks, beach ridges, dunes, spits and bars (Wagle, 1991). The prominent landforms in Konkan coastal regions are the laterite capped table-lands with a gentle seaward slope and usually an abrupt fall along the coastline (Wagle, 1989). Erosional and accretional features indicate that the coast is prograding along beaches and retreating along cliffs and headlands. Based on the deposition of landforms, the present coast is neither of emergent nature nor of submergent nature, but it is a combination of both (compound or intermediate coast) (Wagle, 1989; Hanamgond, 2008). To the north of Mumbai, the coastline is predominantly sandy, whereas to its south is an admixture of rocky and sandy.

2.2. RATNAGIRI DISTRICT

Ratnagiri, a land of Varadmuni ‘Parshuram’, is located between 16° 13’ to 18° 04’ N land 73° 02’ to 73° 53’ E, covering an area of 8208 sq km which is 2.7 % of the total geographical area of Maharashtra state. The average North-South length of the district is 180 km and the average East-West extension is about 64 km (National council of Applied Economic Research Report, 2019). The coastal length of the district is 167 km.

2.2.1. Climate and Topography

The climate of Ratnagiri is warm and humid. The temperature fluctuates from 20 ˚C to 33 ˚C, but along the coast, it goes beyond 40 ˚C (Salunkhe, 2014).

Geographically the district can be divided into three zones namely coastal zone, hill area zone and middle zone (Ratnagiri District Administration report). Over 85 % of the land surface of the district is hilly (Ratnagiri District Survey Report for minor mineral other than sand mining or river bed mining, 2019).

a) The coastal zone extends 10-15 km from the seacoast and has low altitude and rainfall about 2,500 mm.
b) The hill zone includes the western slope of the Western Ghats. Its width is 10-15 km and has an altitude ranging between 400 m and 1200 m above mean sea level. The zone experiences high annual rainfall of 3500 mm. All the rivers flowing in the district originate in this region. Vashisthi, Shashtri, Bav, Muchikundi, Jaitapur, Arjuna and Jagbudi are some of the important rivers in the district which ultimately meet the Arabian sea.
c) The Middle zone is the mid-altitude zone between the earlier two zones. The region is important from the point of view of transportation (road and railway).

Majority of the region has laterite rocks and lateritic soil. In the coastal region alluvial and saline soil is present (Landage, 2006).

2.2.2. People and Economy

The total population of Ratnagiri is 16,15,069 (District Census Handbook of Ratnagiri, 2014) out of which 84 % of people stay in rural areas (Salunkhe, 2014).

Agriculture, horticulture and fishing are the major occupations of the people living in Ratnagiri. Though agriculture is a major subsistence activity of 50 % of the population, very less (31.58 %) proportion of the district's land is under agricultural crops due to the rugged and sloping topography. (District Statistical Department Report of Ratnagiri, 2012-13; Salunkhe, 2014).

Ratnagiri is declared as the Horticulture District in Maharashtra and is home to World famous 'Ratnagiri Alphonso Mangoes' and a wide variety of cashew; other plantation crops include coconut and areca nut (National Council of Applied Economic Research Report, 2019).

The fisheries sector plays an important role from the viewpoint of employment generation in the district. It is an important non-agricultural activity in the district; a population of more than 67,000 fisherfolk resides in 99 fishing villages along the coastline (National council of Applied Economic Research Report, 2019). Industrial development in Ratnagiri is comparatively slow (Salunkhe, 2014).

Till 2000, agriculture and fishing were the main occupations in the districts. Due to over exploitation of resources and climatic aberrations, there was a decline in the agriculture and fishing industry leading to the shift of people towards tourism as an alternate source of income (Salunkhe, 2014).

Tourism in Ratnagiri is multi-faceted: cultural, natural (beaches, waterfalls, hot springs, valleys, hill stations, mountains and forest), religious (temples), historical (forts), weekend tourism, new emerging – eco-tourism (turtle festival) and agritourism (National council of Applied Economic Research Report, 2019). Tourism destinations in Ratnagiri are not concentrated but are scattered in remote as well as easily accessible areas and rural as well as urban areas (Salunkhe, 2014).

2.3. DAPOLI TALUK

Dapoli is a northwestern coastal Taluk of the Ratnagiri district having a geographical area of 861 sq km and human population of 1,93,430 (District Census Handbook of Ratnagiri, 2014).

Dapoli town is located on an open plain about 800 ft above mean sea level (Phanse, 2000). The place is covered with thick natural vegetation and extensive cultivation of mango, cashew, areca nut and coconut. It is also known as camp Dapoli as it was one of the places where the British had set up their military camps. Since, those days, it is a famous hill station in Maharashtra attracting lots of tourists every year (Salunkhe, 2014).

Dapoli taluk is identified as a Special Tourism Area by the government of Maharashtra. Annually 50,000 to 1,00,000 tourists visit Dapoli (Annual Report of Hotelier's Association of

Ratnagiri District, 2009-10). It is famous for beaches, ancient temples, forts of historical importance and seafood.

The coastal length of Dapoli Taluk is 35 km. (Socio-Economic Report of Ratnagiri and Sindhudurg District, 2012-13). Dabhol and Harnai are the major fish landing sites in the taluk. The coast here is under the influence of predominantly semi-diurnal tides (Hanamgond, 2008).

2.4. LADGHAR – ROCKY INTERTIDAL REGION

The Ladghar village which is about 12 km from the town, constitutes two beaches, rocky and sandy, totalling to a length of 2.2 km.

It is a small village having an area of 558 ha and a population of 1398 people residing in 391 houses (District Census Handbook of Ratnagiri, 2014). Agriculture is the major occupation of the people. Presently, there are 10 hotels and 7 lodges adjacent to the beach (Salunkhe, 2014) and many more coming up. Most of the tourism is concentrated on the sandy beach and the rocky shore is rarely visited by tourists.

The length of the rocky shore is 712 m. The average width of the rocky intertidal region is 150 m. It has a gentle slope, but towards the landward region, there is an abrupt fall of laterite capped table-land. More than 60 tidepools are present on the rocky shore. It is a relatively less disturbed beach by anthropogenic activities. Only on full moon day and new moon day, the local people collect gastropods for consumption.

2.5. PAJPANDHARI – ROCKY INTERTIDAL REGION

Pajpandhari rocky intertidal region is a 173 m long rocky shore about 18 km from the Dapoli town. The average width of the intertidal region is 90 m. Harnai, a major fish landing site is at a distance of 3.5 km from the village. Pajpandhari village (56.70 ha) is situated almost bordering the intertidal zone. The width of the village is just 50 to 200 m, as it is crammed between the sea on one side and hills on the other. The population density of Pajpandhari

(102 people per hectare) is considerably greater than that of the Ladghar village (3 people per hectare).

The human population of the village is 5780 (District Census Handbook of Ratnagiri, 2014), mostly consisting of the fishing *Koli* community. Men are engaged in actual fishing activities in estuaries and the sea, construction and maintenance of boats and hauling of catch. Women are engaged in the sorting and grading of collected fish, transportation of the fish to the market place, buying and selling of fish, drying of fish (if necessary) and net-weaving (Ulman & Talathi, 2008). Very few fishermen have their fishing boats; most of them are employed in large trawlers owned by other people outside the village. Due to a low fish catch and the presence of large trawlers, the young generation shows a trend of migration to cities (Ulman & Talathi, 2008).

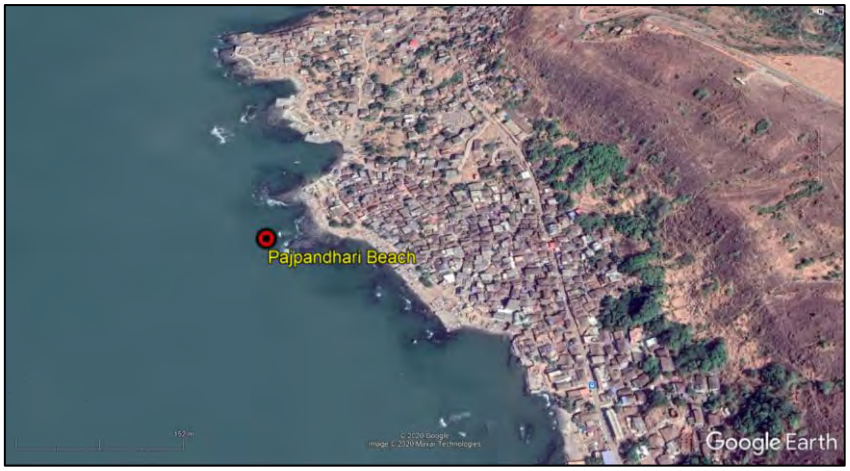
The rocky shore plays important role in the villagers' day to day life as it is used for activities like drying clothes (during low tide), collection of gastropods for consumption, drying fish and dumping of kitchen waste. There are common toilets constructed in the village, but they are out of use, as a result, there is open defecation on the rock patches and there are separate rock patches reserved for gents and ladies. The rock patch is filled with dirt that includes leftover food waste, fish waste and human excreta, which is washed out after the spring tides.

(A)

(B)

(C) **(D)**

Plate 01: (A) Google Earth imagery showing the rocky intertidal region of Ladghar (No human settlement along the beach); (B) Ladghar rocky intertidal region having abrupt fall of laterite capped table-land; (C), (D)Tidepools on Ladghar shore.



(A)

(B)

(C)

Plate 02: (A) Google Earth imagery showing human settlement across the Pajpandhari rocky shore; (B) Pajpandhari rocky shore; (C) Intertidal region used for fish drying.

(A)

(B)

(C)

Plate 03: (A) Presence of garbage on the Pajpandhari shore; (B) Intertidal region used for drying of clothes at Pajpandhari; (C) Algal growth on the plastic present in a tidepool at Pajpandhari.

3. METHODS

3.1. STUDY DESIGN

3.3.1. Selection of Rocky Intertidal Regions

A reconnaissance was carried out prior to the actual sampling, in Ratnagiri and Sindhudurg districts of Maharashtra to observe the presence and proportion of tidepools along the rocky shores. Visual estimates were undertaken by walking the rocky intertidal region based on the Google imagery during the first month of the study. The reconnaissance was done on the days adjoining the full moon and new moon of December, 2019; as during this period, the entire intertidal zone is exposed, due to which the tide pools could be easily located and marked.

3.3.2. Vertical Zonation of Intertidal Region

As the distribution and diversity of intertidal organisms is a function of wave action and exposure to the outside environmental parameters; the zonation was done based on the level of a spring tide. The intertidal zone on each shore was divided into three distinct zones namely low tide zone (exposes only when the water recedes during the spring low tide and not during neap low tide), mid tide zone (subjected to daily ebb and flood of the tides, and demarcated by the high-water level and low water level of neap tides) and high tide zone (pools in this zone flooded during spring high tide, but not during neap high tide) (Figure 02).

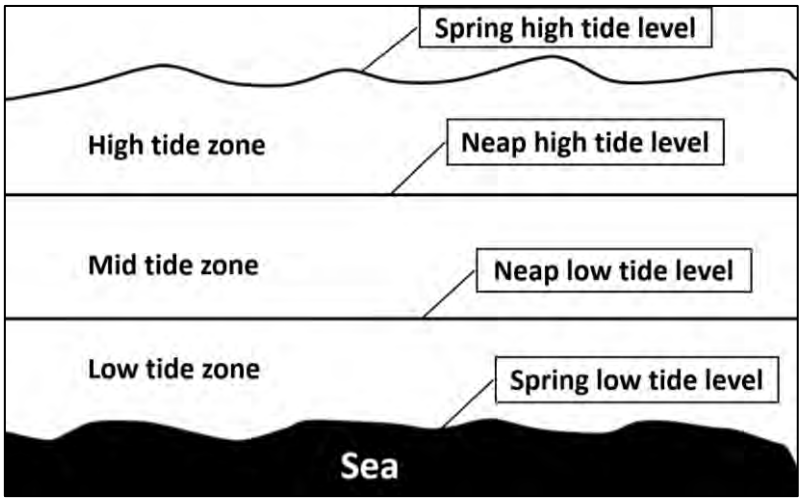


Figure 02: Vertical zonation of the intertidal region based on the tidal levels (diagram not to scale).

3.3.3 Selection of Tidepools

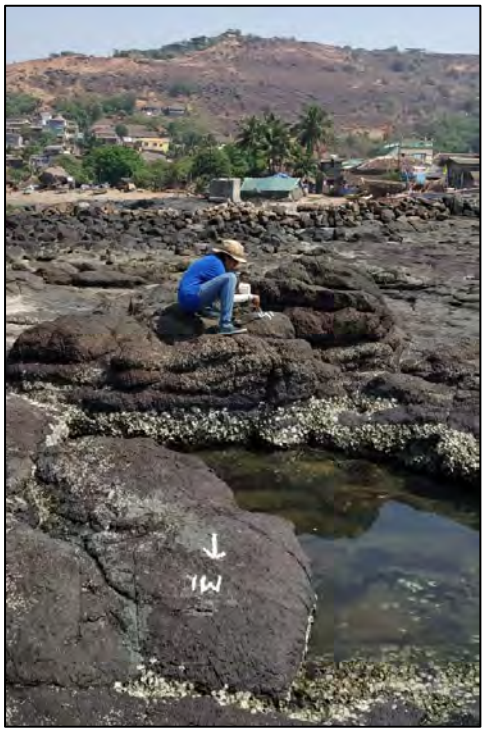
Three separate tidepools having a definite boundary were selected in each of the above-mentioned zones on both the shores. Each pool was given a unique name 'pool ID' consisting of two letters and a number for the identification and analysis purpose. The first letter stands for Ladghar (L) or Pajpandhari (P) rocky shore; the second letter stands for the tidal zone – low (L) or mid (M) or high (H) and a number stands for one of the three pools in each zone. These pools were marked with oil paint and their GPS location was recorded.

3.3.4. Measurement of Tidepool characteristics

The selected tide pools were measured for the surface area and depth.

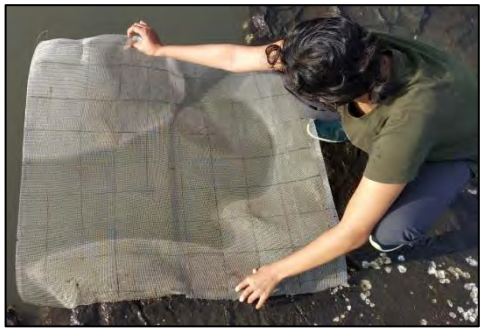
Surface area: The surface area was measured by using a net marked with 80 cm X 70 cm grids further divided into 10 cm X 10 cm. The area was calculated by placing the net slightly above the water level in each tide pool and counting the number of 10 cm X 10 cm squares.

Pool depth: Depth was recorded by lowering a calibrated plastic rod approximately at the centre of the pool.



(A)

(B)



(C)

Plate 04: (A), (B) Marking of tidepool; (C) Measurement of tidepool surface area using a gridded net.

3.2. SAMPLING

Sampling was done one day before and after spring tide once in a month from January to March on both the locations. A random 1m X 1m grid was picked in the pool and water and faunal samples were collected from the centre of the grid.

3.2.1. Water Sampling

Only one water sample was collected from each pool as the pool sizes were relatively small when compared to Ward (1983). One hundred ml of water was collected using a clean reusable plastic container at a depth of 10 cm from each pool. The physico-chemical (Table No. 1) parameters were assessed from the sampled water using calibrated instruments and standard protocols.

Table 1: Water parameters estimated from the water sample.

Water parameters	Instrument/Method	Field/Laboratory
Temperature	Handheld probe (Multi-Parameter Testr^{TM} 35 Series)	Field
pH		
Salinity	Refractometer (VISTA A366ATC)	
Dissolved oxygen	Winkler test (Trivedi *et al*., 1986)	Laboratory
Sodium	Flame photometer (Trivedi & Goel, 1986; Grasshoff *et al*., 1999)	
Calcium		
Potassium		

3.2.2. Sedentary Fauna (Benthos) Sampling

Gastropods present in a grid were counted, photographed in the field and were again placed at the same location from where they were collected.

The benthic sampling was done using a grab of 10 cm X 10 cm from the centre of a grid. The samples were sieved through a sieve of 500 micron. The samples present on the sieve were kept in a polythene bag containing sea water and were fixed and preserved by adding Rose Bengal solution and 10 % formaldehyde, respectively. After each sampling, all the samples were washed repeatedly to remove the attached sediment and debris, in the laboratory. Specimens were identified up to family level using a compound microscope following the

available identification keys (Fauvel, 1953; Fauchald, 1977; Apte, 2012) and experts' help (S. K. Sivadas, *in litt*.; P. Murugesan, *in litt*.; S. Sautya, *in litt*.). Organisms were enumerated and expressed as number of individuals per m^2 (no. m^{-2}).

(A) **(B)**

Plate 05: Photographs of field sampling at the two shores. (A) Water parameter estimation using the handheld probe; (B) Salinity estimation using the refractometer.

3.3. STATISTICAL ANALYSIS

Species number and abundance data from all the three replicates were pooled for each pool for statistical analysis.

A two-step approach was followed during the analysis. Initially, the analysis was conducted at a higher taxonomic level for the four orders or groups – Polychaeta (a class), Amphipoda (an order), Gastropoda (a class) and Actinaria (an order) recorded in the study. Then in the next step, the analysis was conducted at the family level for Polychaeta and Gastropoda separately. The organisms of the orders Amhipoda and Actinaria could not be identified up to the family level and hence, were not considered for this analysis. For both the steps, the following analyses were done.

Simpson index of diversity (1-D) was used for the diversity estimation, as it provides a good estimate of diversity at a relatively small sample size (Mugurran, 2004). Simpson's Index measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species). The D was calculated by using the following formula

$$\text{Simpson Index (D)} = \sum \left(\frac{n_i[n_i - 1]}{N[N-1]} \right)$$

Where,

n_i= number of individuals of the i^{th} species

N= total number of individuals.

The greater the value of D, the greater is the dominance.

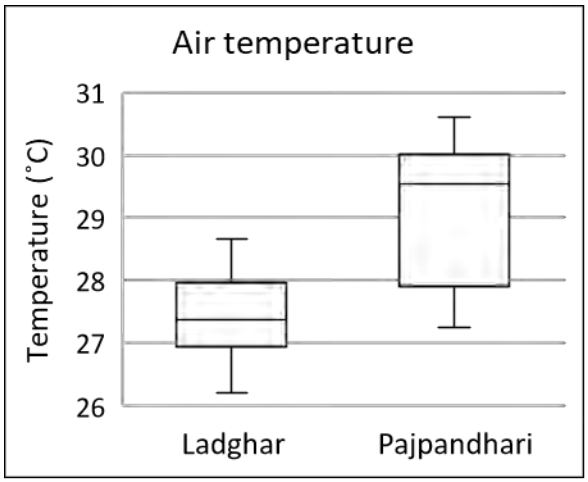
Spearman's rank-order correlation coefficients (ρ) were estimated between macrobenthic richness, abundance, Simpson diversity index and physico-chemical variables. Analysis of similarity (ANOSIM) was used to compare the community composition within (i.e. between the tidal zones) and between shores. Hierarchical Cluster analysis using UPGMA algorithm and Bray-Curtis similarity measure was conducted to know the similarity of the tide pool biota across each pool. For conducting the ANOSIM and the Cluster Analyses for the polychaetes and gastropods families, square root transformation of the raw data was done after adding the value ‘1’ to each cell. This was because the raw data had extreme values and many zero

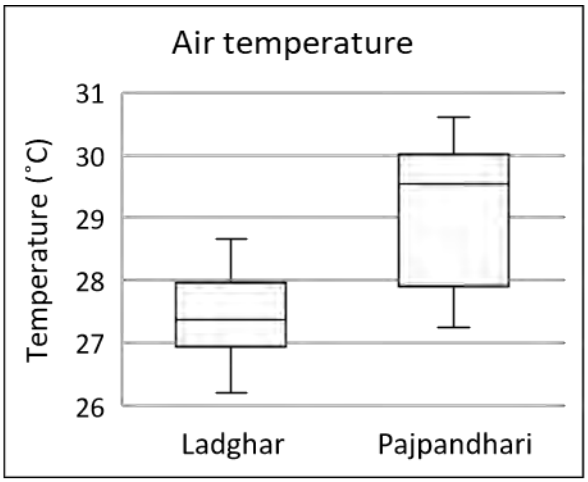
values. The Univariate and multivariate analyses of macrobenthic data were carried out using Paleontological Statistics (PAST) (v4.03) (Hammer *et. al.*, 2001) and Statistical Package for Social Sciences (SPSS) (v21) (George & Mallary, 2019) software.

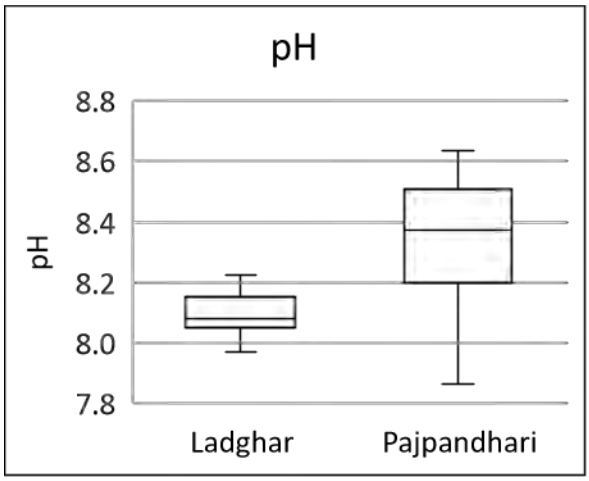
4. RESULTS

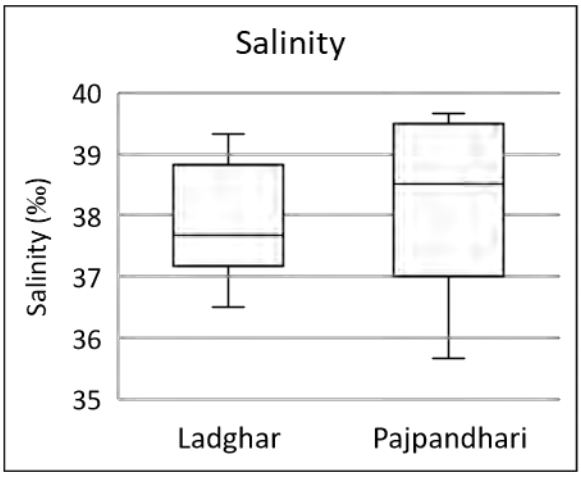
4.1. PHYSICO-CHEMICAL PARAMETERS

It was found that the average values of physico-chemical parameters (air temperature, water temperature, pH, salinity, dissolved oxygen (DO), sodium, calcium and potassium) were higher on the Pajpandhari shore than that of the Ladghar shore, except water depth and pool area which was more of tidepools on Ladghar shore (Figure 03). Due to the dynamic nature of this ecosystem, two tide pools in low tide zone of the Ladghar shore and the Pajpandhari shore were not exposed during the second and third sampling respectively, hence sampling could not be conducted from those tide pools. Physico-chemical parameters recorded during the study are given in Appendix 1.









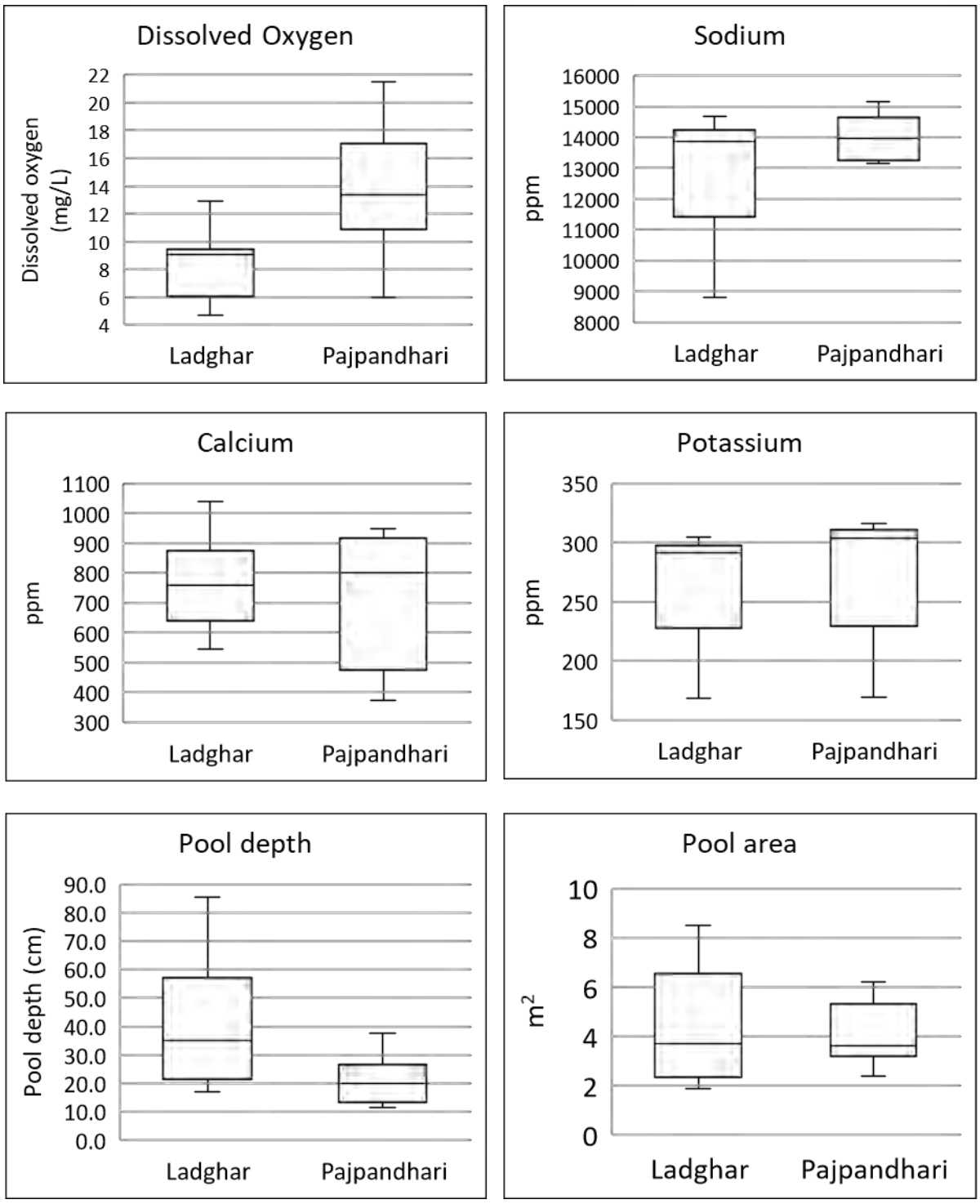
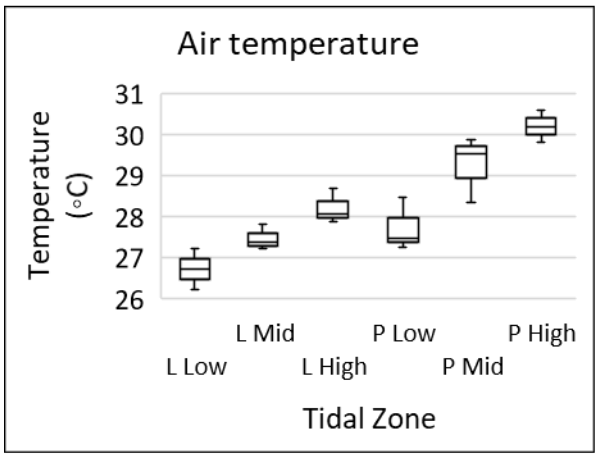
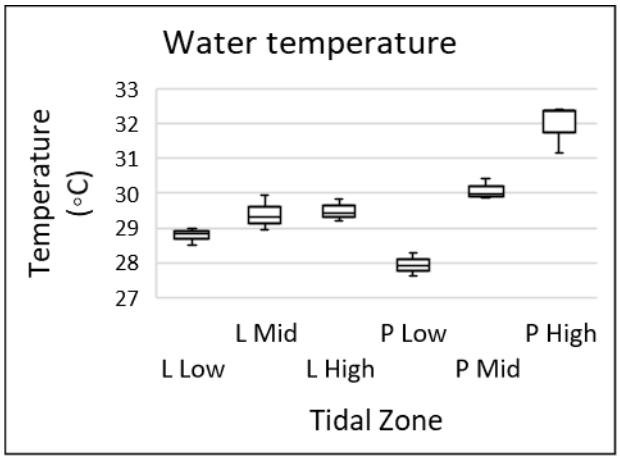
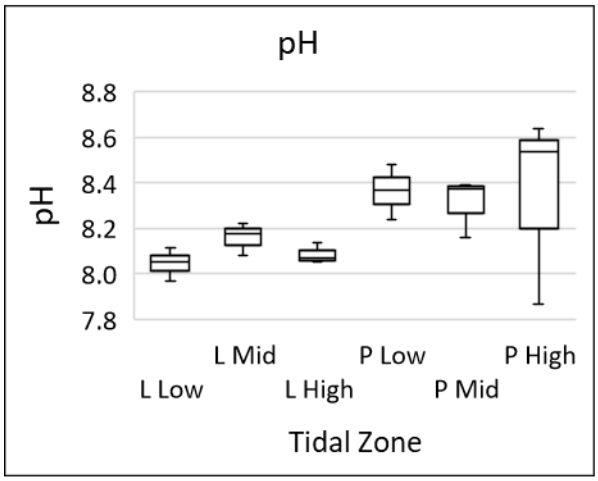


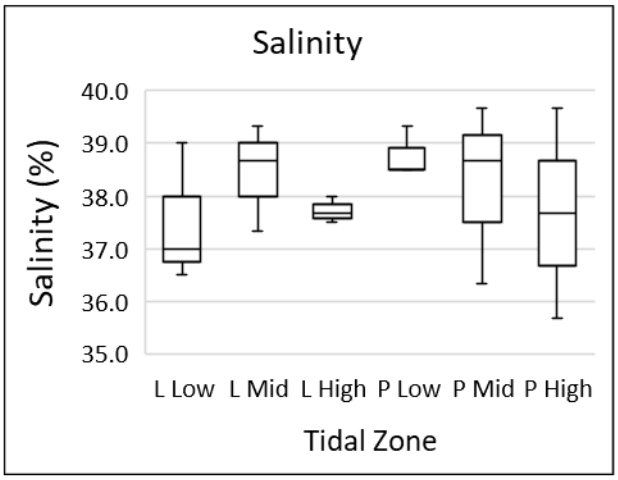
Figure 03: Box and Whisker plots of physico-chemical variables recorded from the tidepools at the Ladghar and Pajpandhari shores during the study period.

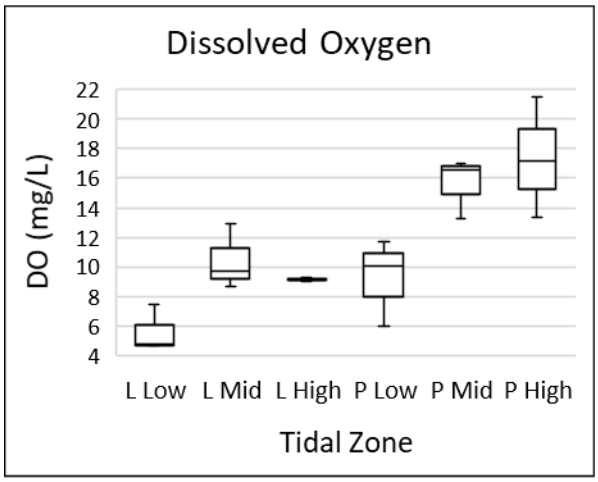
There was very high variation observed in the abiotic variables among the tidepools. Air and water temperature increased from low tide zone to high tide zone on both the shores, but the values of other parameters did not show any pattern (Figure 04).

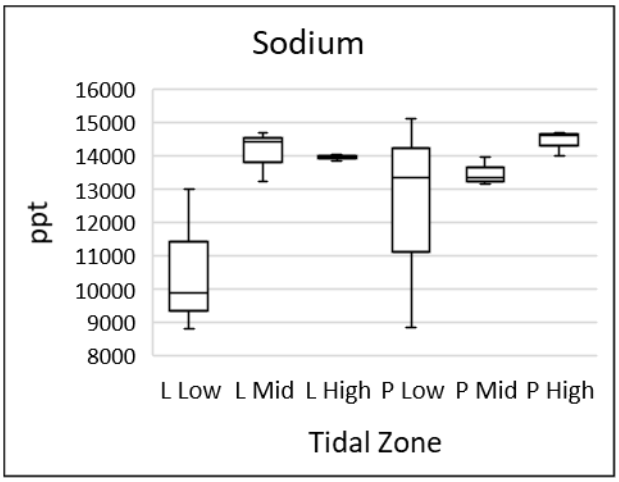












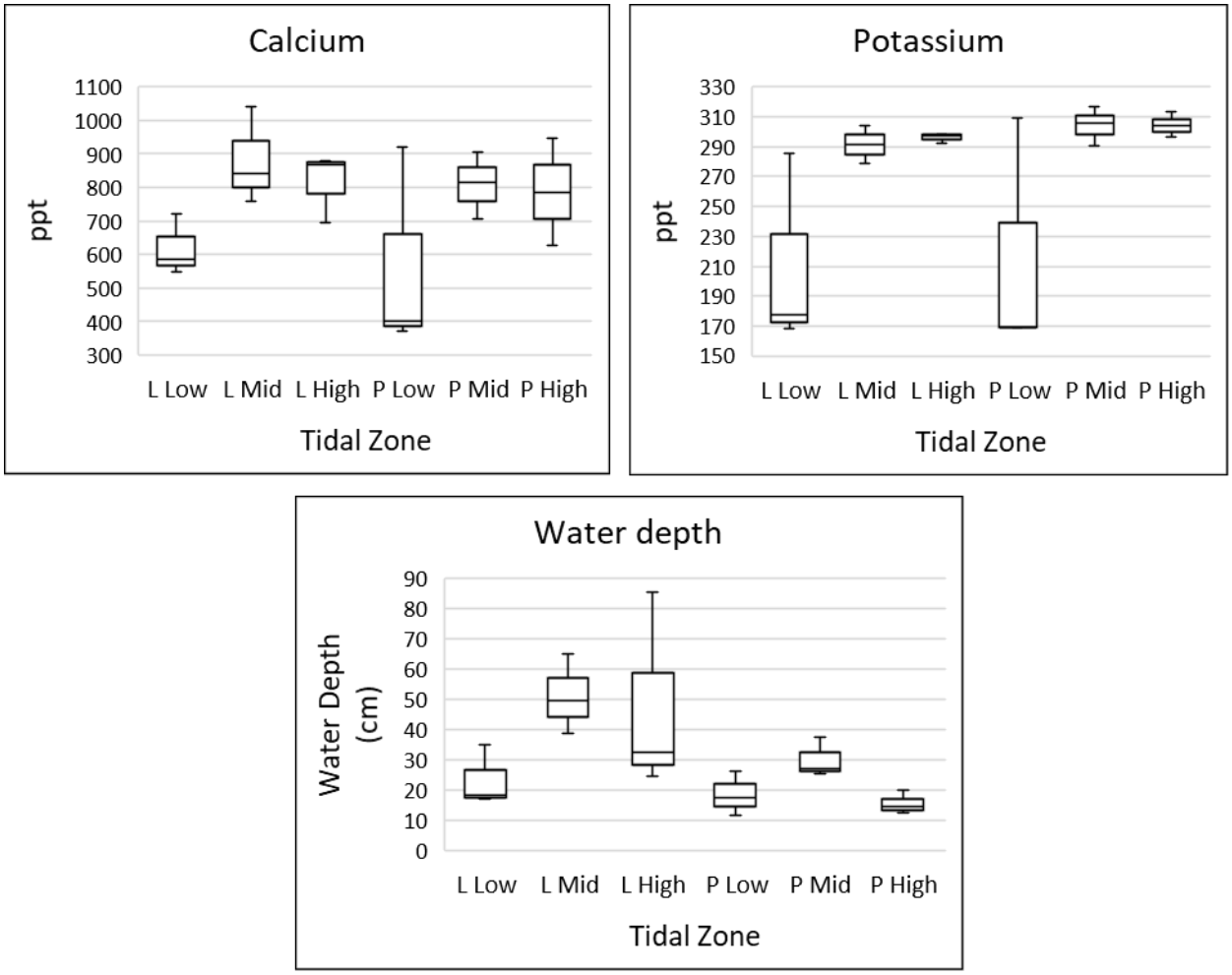


Figure 04: Box and Whisker plots showing the variation of abiotic characters across various tidal zones (L- Ladghar shore; P- Pajpandhari shore) at the two locations.

4.2. ORDER LEVEL ANALYSES

4.2.1. Community Description

Four taxa of benthic organisms, namely, Polychaeta, Amphipoda, Gastropoda and Actinaria (Sea anemones), were recorded during the study. Macrobenthic abundance ranged from 2 no. m^{-2} (PH2 pool) to 4524 no. m^{-2} (LM2 pool). The average abundance (represented as 'mean ± standard deviation' henceforth) of macrobenthic organisms on both the shores was 1271 ± 1314 no. m^{-2}. The average abundance of macrobenthic organisms on the Ladghar rocky shore (1595 ± 1342 no. m^{-2}) was more than that of the Pajpandhari rocky shore (947 ± 774 no. m^{-2}). Polychaetes (66.2 %) and amphipods (32.5 %) were the major groups accounting for 98.7 % of the macrobenthic abundance. Gastropods (1.2 %) and Sea anemones (0.1 %) comprised very less proportion of the macrobenthic population. All the four taxa were recorded on the

Ladghar shore in all the zones except sea anemones which were recorded only in low tide zone and mid tide zone. On Pajpandhari shore, apart from sea anemones, all other taxa were recorded. Figure 05 describes the community structure of each pool.

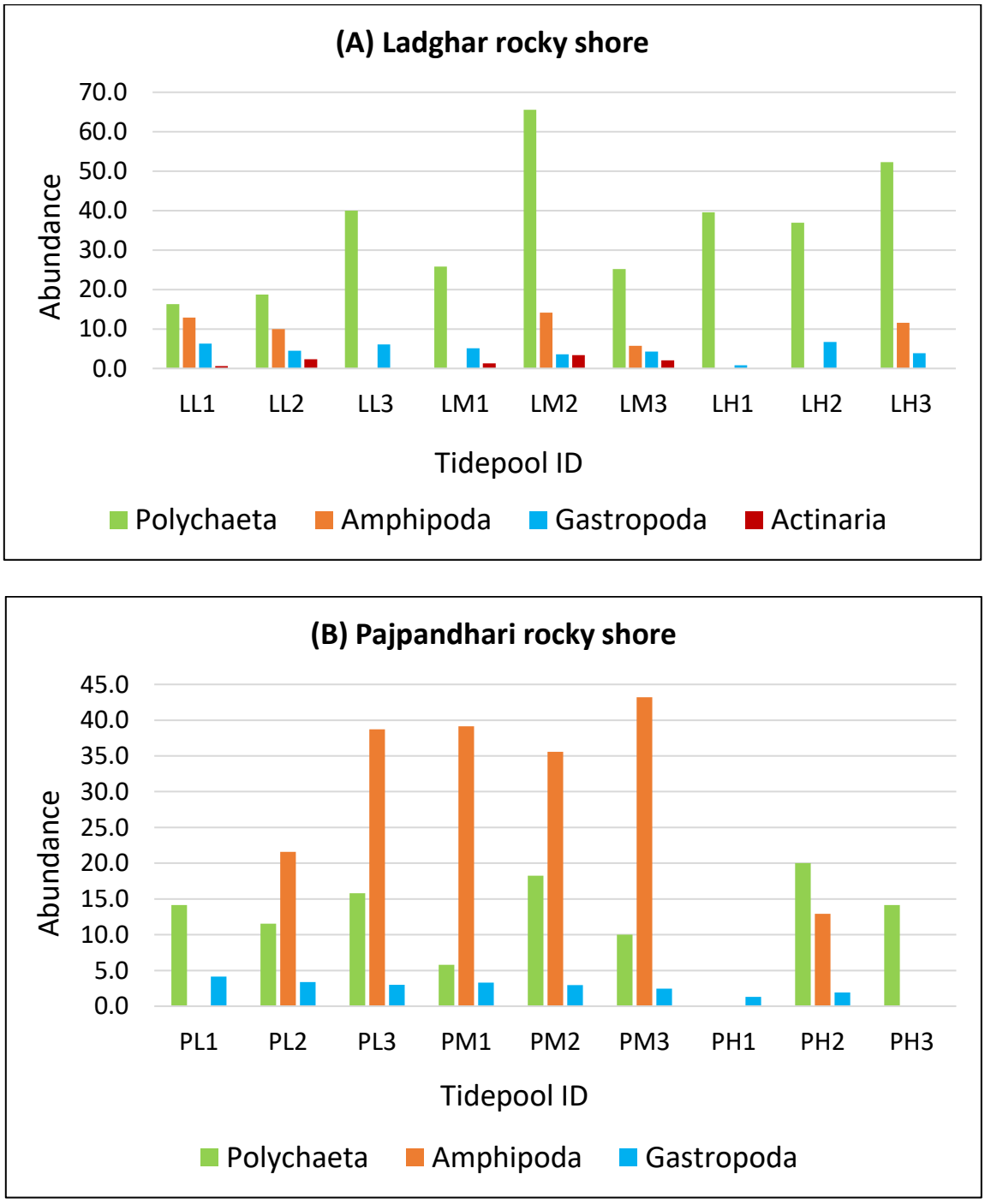


Figure 05: The community structure of the tide pools at (A) Ladghar and (B) Pajpandhari rocky shores (The first letter stands for Ladghar (L) or Pajpandhari (P) rocky shore; the second letter stands for the tidal zone – low (L) or mid (M) or high (H) and a number stands for one of the three pools in each zone). Note - The abundance values are square root transformed for better representation.

4.2.2. Correlation Analysis

Spearman correlation analysis of macrobenthic fauna with measured physico-chemical parameters showed that pool depth was positively correlated with macrobenthic abundance ($r = 0.585$; $p < 0.05$) (Figure 06).

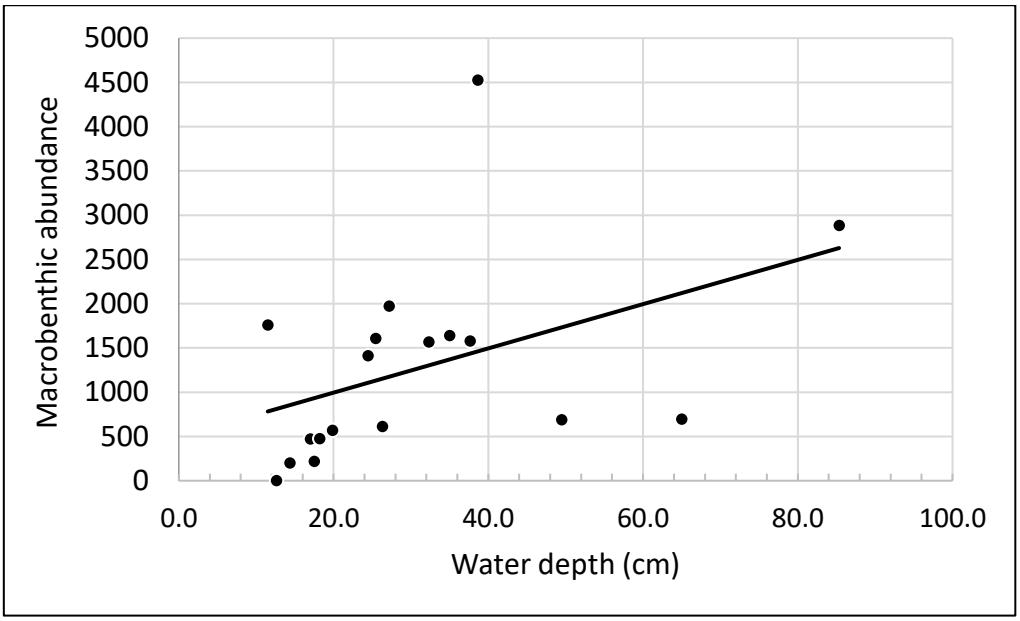


Figure 06: Scatter plots depicting significant association between macrobenthic abundance and water depth.

4.2.3. Community Similarity Analysis

One-way ANOSIM demonstrated no significant differences ($p > 0.05$) in the macrobenthic community composition observed between three zones (low tide zone, mid tide zone and high tide zones) of each shore and between same zone (i.e. between low tide zone of Ladghar and Pajpandhari shore and same for mid tide zone and high tide zone) of the two shores.

Hierarchical cluster analysis of macrobenthic abundance data using Bray-Curtis similarity index, defined three clusters. PH1 was completely outside of the cluster (Figure 07).

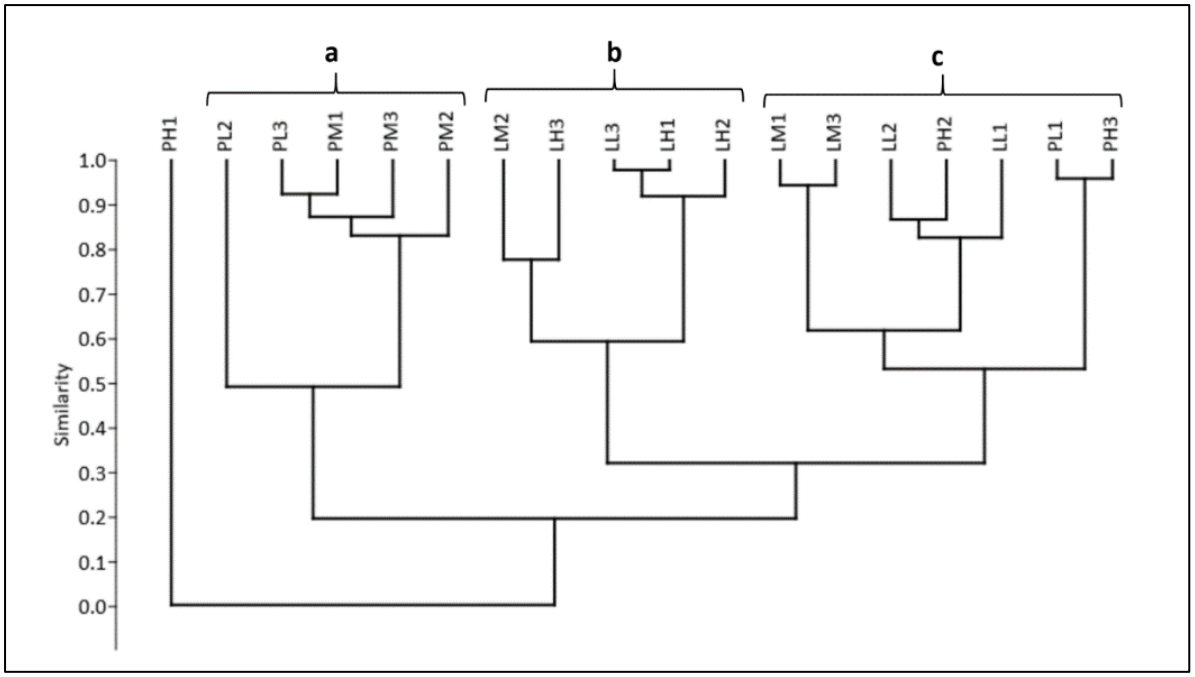


Figure 07: Dendrogram showing the community similarity of macrobenthos in all the tide pools in the study area.

4.3. ORDER - POLYCHAETA

4.3.1. Community Description

Thirteen families of the order Polychaeta were recorded from the two shores. The average number or richness of families in each pool was 2.5 ± 1. No polychaete was recorded in the PH1 pool. A tabular description of the distribution and abundance of Polychaeta families is given in Table 02. A list of Polychaeta families present in the tidepools is given in Appendix 2.

Table 02: Community Composition and Structure of Polychaetes and the major families found in the pools.

Location	Number of total families recorded	Percent composition of dominant families (%)	Average abundance of polychaetes per pool (no. m^{-2})
On both the shores	13	Spionidae (54.8 %) Capetellidae (30.4 %) Nereididae(4.6 %) Syllidae (3.5 %)	841 ± 1127
Ladghar shore	6	Spionidae (61 %) Capetellidae (32 %)	1498 ± 1308
Pajpandhari shore	11	Nereididae (40.4 %) Capetellidae (14.4 %) Phyllodocidae (8 %) Terebellidae (8 %) Spionidae (6 %) Syllidae (6 %)	183 ± 132

4.3.2. Correlation Analysis

pH and Dissolved Oxygen were negatively correlated with the abundance of polychaetes, whereas tidepool depth was positively correlated with the abundance (Table 03) (Figure 08).

Table 03: Spearman's correlation coefficient for the significant correlations ($p < 0.05$) between the physico-chemical variables and polychaete abundance.

Physico-chemical variables	Polychaete abundance
pH	-0.634
Dissolved Oxygen	-0.531
Water Column Depth	0.488

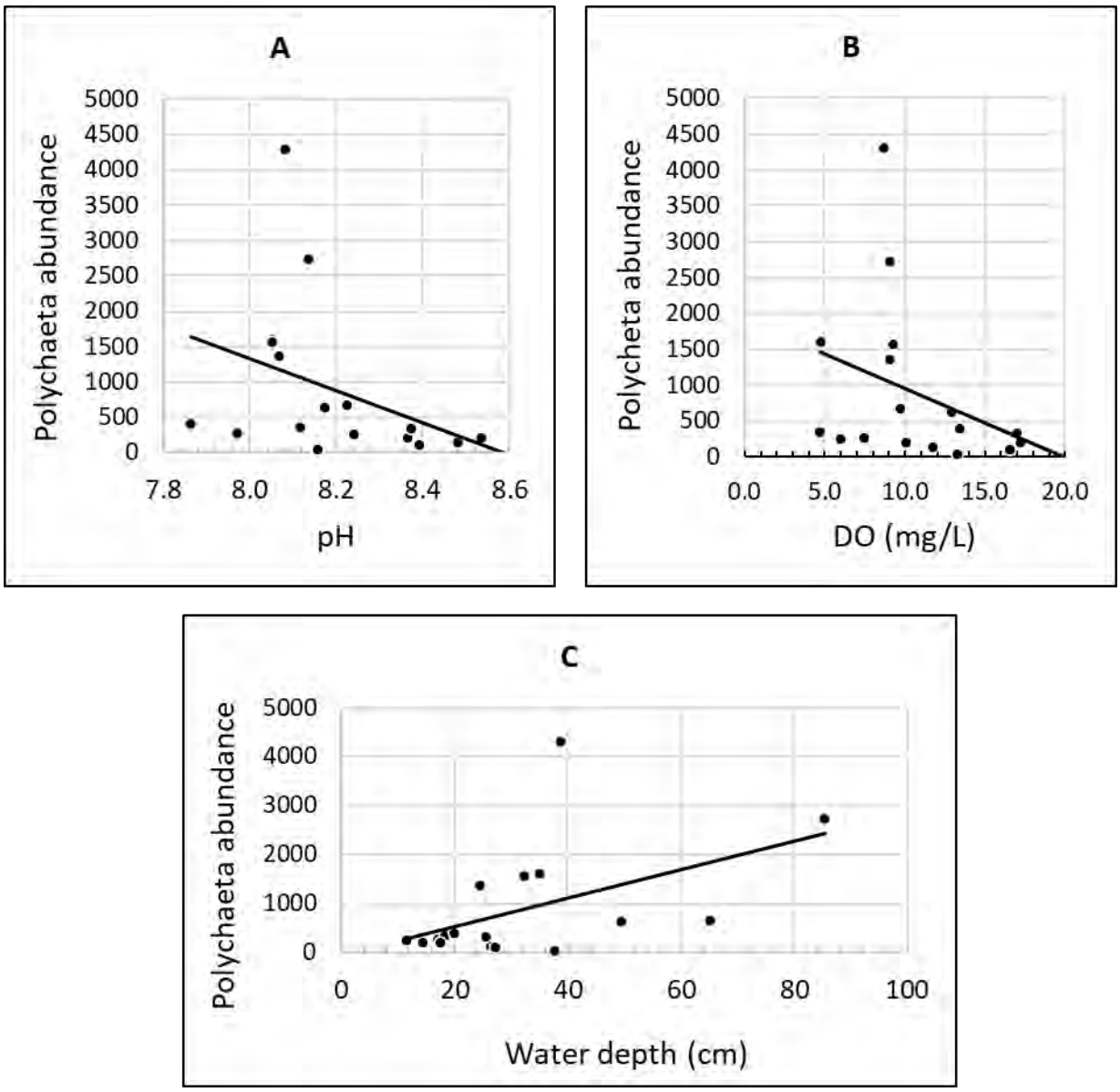


Figure 08: Scatter plots depicting significant relationships between Polychaeta abundance and pH (A), DO (B) and water depth (C).

4.3.3. Community Similarity Analysis

One-way ANOSIM demonstrated no significant differences ($p > 0.05$) observed between community composition of the three zones (low tide zone, mid tide zone and high tide zone) of each shore and between same zone (i.e. between low tide zone of Ladghar and Pajpandhari shore and same for mid tide zone and high tide zone) of two shores.

Hierarchical cluster analysis clearly showed two distinct groups. Group 'a' contained all the tidepools on Ladghar shore except PH2 and group 'b' consists of all the pools of Pajpandhari shore (Figure 09).

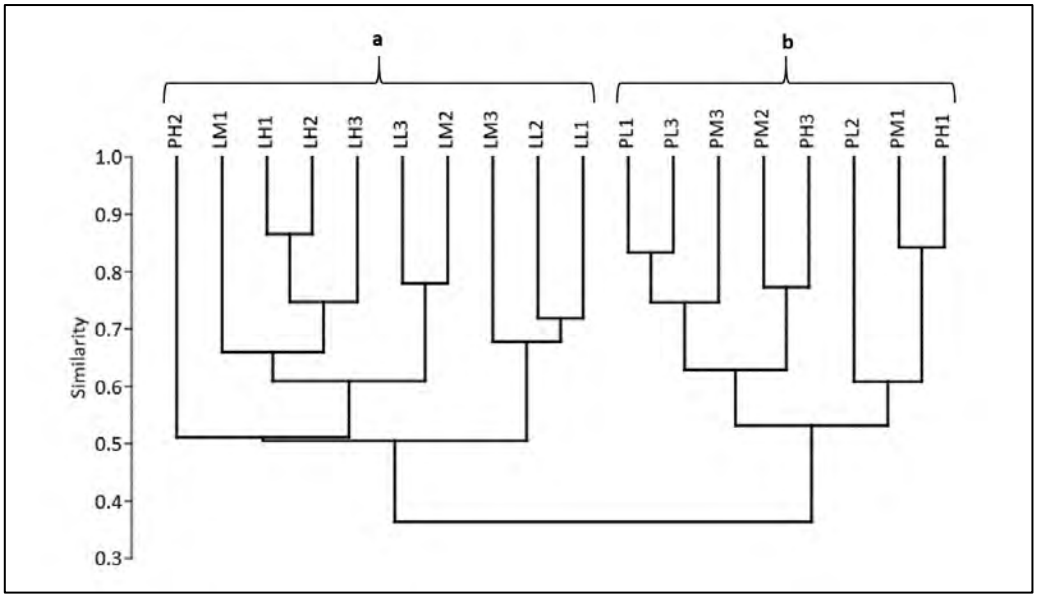


Figure 09: Dendrogram showing the community similarity of polychaetes in all the tide pools in the study area.

4.4. CLASS - GASTROPODA

4.4.1. Community Description

Total 22 families of gastropods were recorded from two shores during the study period. The average number of families recorded in a pool were 4.33± 2.22 m^{-2}. No gastropod was recorded in PH3 pool. Table 04 describes the community composition and structure in brief. List of Gastropoda families present in the tidepools is given in Appendix 3 with the average abundance.

Table 04: Community Composition and Structure of Gastropods of the major families found in the pools.

Location	Number of total families recorded	Percent composition of dominant families (%)	Average abundance of gastropods per pool (no. m^{-2})
On both the shores	22	Ranellidae (43.5 %) Muricidae (20.7 %) Neritidae (17.9 %)	15 ± 12
Ladghar shore	20	Ranellidae (40.9 %) Neritidae (22.1 %) Muricidae (21.4 %)	22 ± 14
Pajpandhari shore	10	Ranellidae (51.3 %) Muricidae (18.5 %) Littoridae (12.7 %)	8 ± 4

4.4.2. Correlation Analysis

Air Temperature, pH and Dissolved Oxygen were negatively correlated with the abundance of gastropods and tidepool area was positively correlated with the gastropod diversity (Table 05) (Figure 10).

Table 05: Spearman's correlation coefficients for the significant correlations ($p < 0.05$) between the physico-chemical variables and gastropod richness, abundance and diversity.

Variables	Abundance	Diversity
Air Temperature	-0.613	-
pH	-0.582	-
Dissolved Oxygen	-0.514	-
Tide Pool area	-	0.58

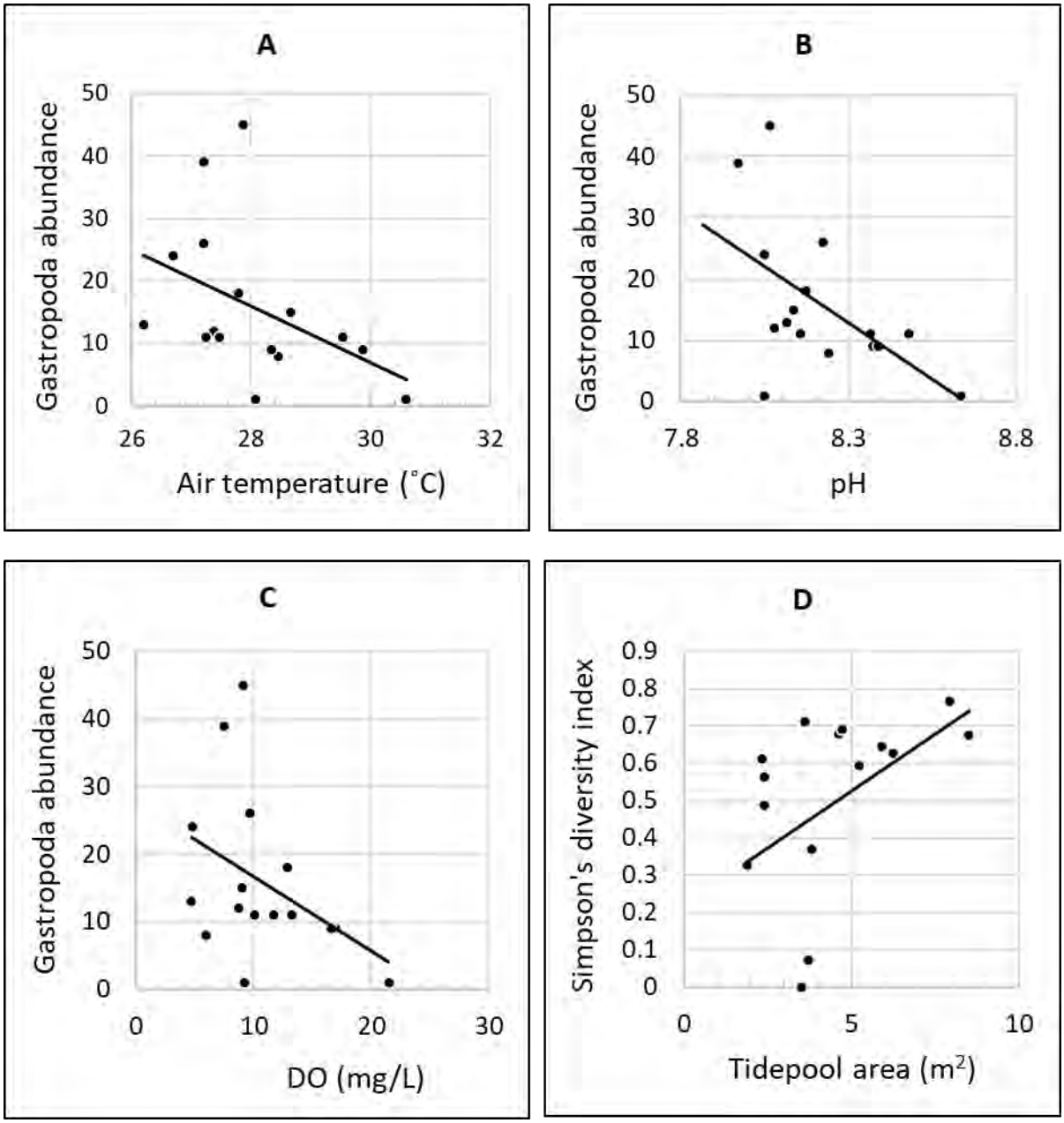


Figure 10: Scatter plots depicting significant relationships between Gastropoda abundance and Air temperature (A), pH (B), DO (C); and Simpson diversity and tidepool area (D).

4.4.3. Community Similarity Analysis

The ANOSIM test revealed no significant differences observed between the two shores. Even zonation between and within the shores did not affect the community composition of the gastropods.

The dendrogram generated by the Hierarchical Cluster Analysis, showed no distinct groupings with respect to shores or zonation (Figure 11).

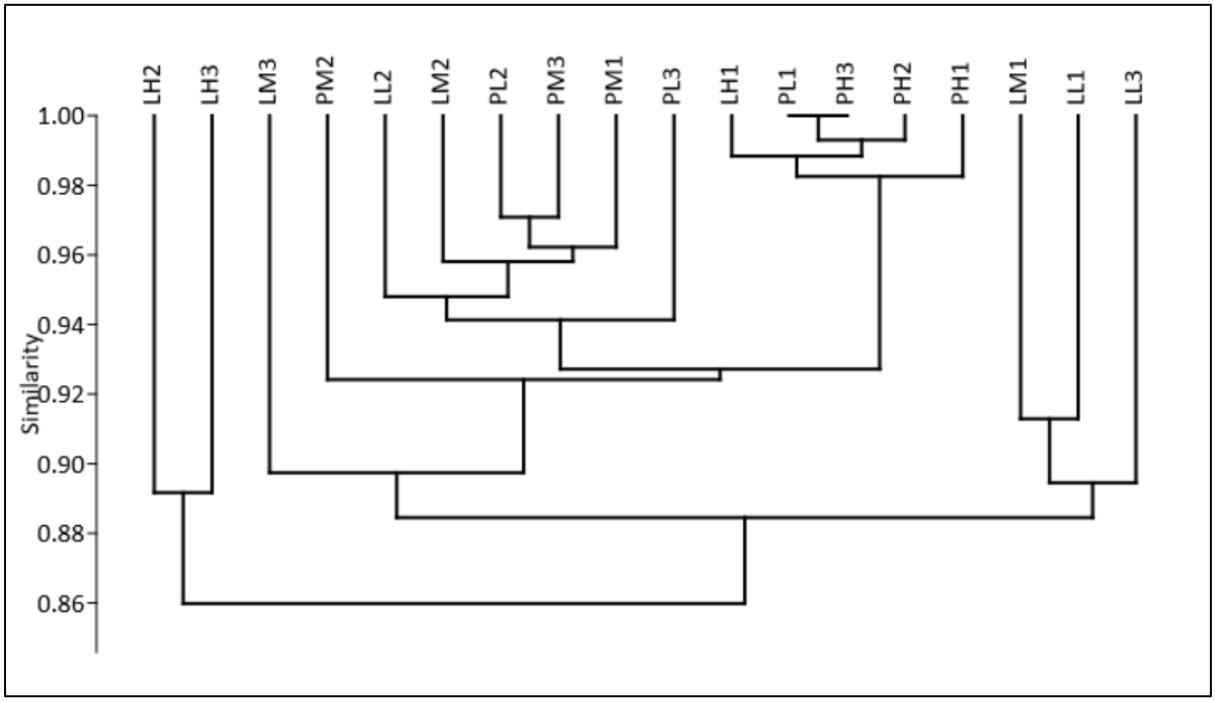


Figure 11: Dendrogram showing the community similarity of gastropods in all the tide pools in the study area.

4.5. Other Observations

Other than the above-mentioned observations, various natural and anthropogenic changes were recorded on the shores. This section gives a general overview and comparison between the two sites with respect to their rockpools and emergent substrata. The observations mentioned here are ocular or written after interviewing local people.

Distinguishable changes could be observed on both the shores from January to March. A total of 30 algal species were recorded from the tidepools. Out of which 21 and 18 algal species were found on the Ladghar and Pajpandhari shore respectively. The area occupied by algae

on each shore was 20 to 30 % and 40 to 50 % respectively (ocular estimate). Algal richness and abundance were correlated with physico-chemical parameters and macrobenthos, but no significant associations were observed.

There were some visible temporal changes in the algae of the sites. At Ladghar shore, the colour of the algae changed from green to brownish-yellow from January to March. The percent cover of algae was also reduced during the same period. At Pajpandhari, in January, the mid and low tide zones were very abundant in algae which were totally absent in February and March.

Sponges were observed in the low tide zone of the Ladghar shore. Barnacles were present in the mid tide zone of the Ladghar and Pajpandhari shore. Sea slugs (Order - Gastropoda) of varying sizes (2-15 cm) were observed at on both the shores.

Waders like Kentish Plover (*Charadrius alexandrinus*) and Lesser Sand Plover (*Charadrius mongolus*) were observed foraging in the intertidal region and the tide pools of Ladghar shore. Other birds like Intermediate Egret (*Ardea intermedia*) and Little Cormorant (*Microcarbo niger*) were also observed. Brahminy Kites (*Haliastur indus*) and White-bellied Sea Eagles (*Haliaeetus leucogaster*) were seen soaring along the Ladghar coast during the sampling durations. No shorebirds were observed on the Pajpandhari rocky shore. Only House crows (*Corvus splendens*) were seen scavenging on leftover food waste and fish waste.

Plate 06: Algae present on the emergent substrata of the Ladghar intertidal region.

(A)

(B)

(C)

(D)

Plate 07: (A), (B), (C) Sea slugs observed on the Ladghar and Pajpandhari shores; (D) Dead snake observed on the intertidal region of Pajpandhari.

(A)

(B)

(C)

(D)

(E)

(F)

Plate 08: (A) Bubble formation in a tidepool; (B) Algae present in a tidepool; (C), (D) Fishes caught by the local boys of Pajpandhari from the tidepools; Gastropods and sea anemone observed in a tidepool of Ladghar.

(A)

(B)

(C)

(D)

(E)

(F)

Plate 09: (A), (B)Sponges observed in the low tide zone of the Ladghar shore; (C) Crows observed at Pajpandhari shore; (D) Kentish plover (*Charadrius alexandrinus*), (E) Little Cormorant (*Microcarbo niger*) and (F) Intermediate Egret (*Ardea intermedia*) observed on the Ladghar shore.

5. DISCUSSION

5.1. PHYSICO-CHEMICAL PARAMETERS

Only three of the physico-chemical parameters namely - Air, water temperature and Dissolved Oxygen (DO), showed some pattern with respect to the zonation. Hence, only these three are explained here.

5.1.1. Air and Water Temperature

A high positive correlation was observed between air and water temperature ($r = 0.756$; $p = 0.000$). This is because the water temperature is closely related to air temperature and a number of sunshine hours per day (Ganning, 1971). It was observed that air and water temperature increased from low tide zone to high tide zone on both the shores. Variation in exposure to the sunlight might have resulted in the heating of rock differently, generating such a pattern. Since the pools in mid and high tide zones are exposed more than those of the low tide zone, such a trend of temperature was observed.

5.1.2. Dissolved Oxygen (DO)

The values of dissolved oxygen ranged from 4.7 to 21.5 mg/L during the study duration. This observed DO range is relatively high as compared to other studies where it ranged from 1.2 to 12.3 mg/L (Crabtree & Dean, 1982; Nair *et al*., 1984; Musale *et al*., 2015).

Such high values of DO can be caused by a phenomenon called Dissolved Oxygen supersaturation. Due to an excess of solar energy, warming of sea beds and bottom waters occurs, which induces gaseous supersaturation. Due to such conditions, excessive bubble formation takes place (Marks, 2008). In the case of tide pools, the effect of solar energy may be enhanced owing to the shallow depth as compared to the subtidal zone. Hence, dissolved oxygen supersaturation can be the reason for such high DO values in the study. The pool in which the highest values of DO were recorded was PH1 on the Pajpadhari shore. Interestingly, the Air temperature, water temperature, pH and salinity of this particular pool is the highest among the 18 pools in the study. Hence, if we go by the logic of the Dissolved Oxygen Supersaturation phenomenon, the high temperatures, are ideal for such an effect.

Furthermore, due to such high temperatures, the evaporation rates are also high, which leads to an increase in the salinity, which was observed as expected. In addition, the depth of this pool is comparatively lesser than the other pools, further proving the point.

5.2. COMMUNITY COMPOSITION AND STRUCTURE

Very few studies are available which have concentrated exclusively on polychaetes and gastropods of tidepools. Hence, other studies that have looked at other intertidal habitats are used for comparison in the following sections.

5.2.1. Macrobenthos

Four benthic groups, Polychaeta (66.2 %), Amphipoda (32.5 %), Gastropoda (1.2 %) and Sea anemone (0.1 %) were recorded during the present study and their average abundance was 1271 ± 1314 no. m^{-2}.

In a study on the tidepools of Colaba, Mumbai, Polychaeta (44 %), Amphipoda (30 %) and Gastropoda (14 %) were the predominant groups (Sukumaran *et al*., 2014). In a study conducted in the subtidal region of Dabhol, Maharashtra showed that the community was numerically dominated by Polychaeta, followed by Amphipoda, Bivalvia, Oligochaeta and Gastropoda (Ingole *et al*., 2002). In a study conducted at the Vellar Estuary, Tamil Nadu, the macrobenthic community comprised of Polychaeta, Crustacea, Bivalvia, Gastropoda and other groups (anemones, planarians, polyclads and phoronids). Among the macrobenthic groups, Polychaeta predominated (75 %) followed by Crustacea and Gastropoda; the contribution of other groups was relatively less (Chandran, 1987). A study conducted near the Visakhapatnam harbour found that polychaetes were dominant both in richness and abundance (except monsoon) and amphipods were the second abundant group (Musale *et al*., 2015). Similar results were found in a study conducted at the Ashtamudi estuary in Kerala (Nair *et al*., 1984). The results of the present study and those mentioned above are in corroboration with the statement that Polychaetes are an important component of macrobenthic community, as they are often dominant in terms of abundance (Sivadas *et al*., 2010).

The mean macrobenthic abundance or range of the abundance recorded from various habitats when compared, {1331 ± 925 no. m^{-2} (tidepool) (Sukumaran *et al*., 2014), 488 ± 188 no. m^{-2} (subtidal region) (Ingole *et al*., 2002), 123 ± 50 no. m^{-2} (estuary) (Govindan *et al*., 1983), 4177 ± 6743 no. m^{-2} (estuary) (Nair *et al*., 1984), 0 to 900 no. m^{-2} (estuary) (Chandran, 1987), 402 ± 424 no. m^{-2} (harbour) (Musale *et al*., 2015)} reveals high abundance in the tidepool ecosystem. Though in the present study the habitats were not studied, the values are comparable to the tide pool data of Sukumaran *et al.* (2014) along the west coast of India.

5.2.2. Polychaeta

Total 13 families were recorded during the study among which Spionidae (54.8 %), Capetellidae (30.4 %) and Nereididae (4.6 %) were dominant families. The average abundance of polychaetes recorded per pool was 841 ± 1127 no. m^{-2}.

Parulekar (1981) had recorded 12 polychaete families in the intertidal region of the Malvan coast, Maharashtra. The intertidal region of that study focused on a variety of habitats such as rocky shores, rock-pool and gravel bed, sandy shores, mudflats and mangroves. Six families of polychaetes recorded there were common with the present study. Addition of six families viz - Capitellidae, Onuphidae, Phyllodocidae, Polynoidae, Sabellidae, Saccocirridae and Sigalionidae were recorded in the present study. Thirteen polychaete families were recorded from tidepools present on the intertidal region of Colaba, Mumbai during the one-year study period. In the same study Orbiniidae (39.8 %), Capitellidae (22.2 %) and Spionidae (8.6 %) were the dominant families (Sukumaran *et al*., 2014). Nephtyidae, Pilargidae, Lumbrineridae, Glyceridae and Capitellidae were the dominant families in Vellar estuary, Tamil Nadu (Chandran, 1987). Capitellidae and Neredidae were the dominating families found in a study conducted in Chilika lake, a brackish water lagoon in Orissa (Mahapatro *et al*., 2015). Total 30 Polychaeta families were recorded in and around Mormugao harbour, Goa out of which Spionidae (58 to 1008 no. m^{-2}) and Capitellidae (77 to 453 no. m^{-2}) were the dominant families (Sivadas *et al*., 2010). In a study conducted in and around Visakhapatnam harbour polychetes (60 out of 84) were dominant both in richness and abundance (except monsoon); Cossuridae and Cirratulidae were the composition wise dominant families (Musale *et al*., 2015). In a two years study (1980 and 1981) conducted in tidepools of Quebec salt marsh, Canada, polychaetes were reported only during 1981 and that too in few pools closer to the estuary; the abundance recorded was 800 no. m^{-2} (Ward & FitzGerald, 1983).

In the above-mentioned studies, the Polychaeta abundance was 585 no. m^{-2} (Sukumaran *et al*., 2014), 8669 ± 9826 no. m^{-2} (Nair *et al*., 1984), 0 to 738 no. m^{-2} (Chandran, 1987), 652 to 4096 no. m^{-2} (Sivadas *et al*., 2010).

The dominant family and polychaete abundance in each of the studies is different.

In the present study, *Prionospio pinnata* (Spionidae) and *Capitella capitata* (Capitellidae) were the two predominant species with respect to abundance. At Ladghar shore, *Prionospio pinnata* was found in all the pools, while *Capitella capitata* was found only in seven pools. At Pajpandhari, they were found in two and three pools respectively. Also, the average abundances of both these species were higher at Ladghar than at Pajpandhari (Table 06).

Table 06: The average abundances with standard deviation of *Prionospio pinnata* and *Capitella capitata* at Ladghar and Pajpandhari shores.

Location	***Prionospio pinnata*** **(no. m^{-2})**	***Capitella capitate*** **(no. m^{-2})**
Ladghar shore	911 ± 1276	624 ± 1276
Pajpandhari shore	50 ± 24	78 ± 51

Both these species are established as pollution indicators (Grassle & Grassle, 1974; Pearson & Rosenburg, 1978), which implies that they occur in high abundances at places where there is a prevalence of pollution. In the present study, Pajpandhari shore is more prone to anthropogenic activities and hence, can be said to be more prone to pollution than Ladghar shore. Hence, the abundances of these two species were higher at Ladghar than at Pajpandhari which is unusual.

The reason for this abundance could be the accretion of sand in tidepools. During the present study, one of the pools on Ladghar shore was totally filled with sand, which indicates accretion is more on Ladghar shore. Pollutants could have been transported from the nearshore area of Ladghar and tidepool being microcosm the pollutants might have been accumulated.

5.2.3. Gastropoda

In the present study, total 22 families of gastropods were recorded. Parulekar (1981) also recorded 22 families at Malvan, whereas, Sukumaran *et al*. (2014) recorded 10 families from tidepools present on the intertidal region of Colaba, Mumbai.

In the present study total, 22 families of gastropods were recorded, out of which Ranellidae (43.5 %), Muricidae (20.7 %) Neritidae (17.9 %) were the abundance wise dominant families. Muricidae and Neritidae have been found as dominant in other studies (Suresh *et al*., 2012; Khade & Mane, 2012; Sakthivel & Fernando, 2014), but the most dominant family found in the present study was not found dominant in these studies.

5.3. CORRELATION

Very few significant relationships were found between the physico-chemical parameters and richness, abundance and Simpson diversity index.

5.3.1. Benthos

A positive relationship was observed between pool depth and total abundance of macrobenthic organisms ($r = 0.585$; $p < 0.05$). A similar relationship was observed in other studies (Droop, 1953; Ranta, 1982; Metaxas, 1993; Underwood & Skilleter, 1996; Therriault, 1999; Martins, 2007). This is because pool depth provides an extra habitat dimension to the pool area and increases the water volume (effectively a larger 'island'), which eventually increases habitat availability to aquatic organisms. In addition to this, the depth increases the survival of tidepool fauna by minimizing daily fluctuations in desiccation frequency, temperature and salinity (Therriault, 1999).

5.3.2. Polychaeta

It was found that Polychaete abundance was negatively correlated with pH ($r = -0.634$; $p < 0.01$) and dissolved oxygen ($r = - 0.531$; $p < 0.05$) and positively correlated with the pool depth ($r = 0.488$; $p < 0.05$).

The pH of seawater plays an important role in the marine ecosystem because many biochemical reactions take place within a narrow range of pH (Shepherd, 1988). In the present

study, a positive correlation was observed between pH and DO ($r = 0.676$, $p < 0.002$); the pH increased due to the increased alkalinity associated with high DO supersaturation impacting the diversity and abundance.

The dissolved oxygen was negatively correlated to the polychaete abundance. Oxygen supersaturation increased the tolerance levels of six phyla (Giomi *et al*., 2019), an entirely opposite pattern was observed in this study conducted in coastal habitats of the Red Sea. The above-mentioned study, however, did not consider polychaetes in their analysis, and it would be interesting to see whether such a pattern holds good with polychaetes as well.

The depth increases the survival of tidepool fauna by minimizing daily fluctuations in desiccation frequency, temperature and salinity (Therriault, 1999).

5.3.3. Gastropoda

Gastropod abundance was negatively correlated with air temperature ($r = -0.613$; $p < 0.05$). Due to increased temperature, gastropods enter into a condition known as heat coma. In this condition, depending on their location, two types of respiratory patterns are seen. If gastropods are submerged the respiratory rate falls, whereas if they are in air respiratory rate shows an initial rise followed by a fall prior to thermal death (Sandison, 1967).

pH was negatively correlated to gastropod abundance ($r = -0.582$; $p < 0.05$). This could be because many biochemical reactions take place within a narrow range of pH (Shepherd, 1988).

DO was negatively correlated to gastropod abundance ($r = -0.514$; $p < 0.05$). As mentioned in the case of polychaetes, no specific reason could be attributed for such an occurrence.

Pool surface area was found to be positively correlated with gastropod diversity ($r = 0.58$; $p < 0.05$). No studies could be found which have mentioned about the relationship between area and gastropod diversity. Gastropod density was high in large tidepools (Ward, 1983), if this statement combined with the theory of island biogeography (MacArthur and Wilson, 1967), as an island area increases species richness increases, then it can be said that as the pool surface area increases, the gastropod diversity also increases.

5.4. COMMUNITY SIMILARITY

5.4.1. Benthos

Cluster analysis of benthic abundance showed three clusters, but one pool (PH1) was totally outside this cluster. No relationship could be ascertained for the clustering.

No strong cluster was observed between the pools of the same intertidal region, because of the large variability in macrobenthic abundance among pools. Similarity among tidal zones was very less pronounced for macrofaunal communities in a study conducted at a rocky shore in Nova Scotia, Canada (Metaxas *et al*.,1994). In a study carried out at Three Anchor Bay, Cape Peninsula, South Africa, cluster analysis showed that three distinct vertical zones were attributed to the exposure of the intertidal region by tides, but the results were concluded by studying only four pools situated at different heights with respect to the tidal range for five days (Huggett & Griffiths 1986).

5.4.2. Polychaetes

For the polychaete abundance, two distinct clusters representing the tide pools of the two shores were observed except one pool. The reasons for such clustering may be attributed to the formation of distinct microclimatic conditions on each shore due to an integrated effect of the physico-chemical parameters. The reason behind one pool being clustered differently could not be ascertained.

5.4.3. Gastropods

No prominent pattern could be identified of gastropod distribution, with respect to tidal zones from the cluster analysis.

5.5. CONCLUSION

Pool depth and pool area were found to be positively correlated with macrobenthic and polychaete abundance, and gastropod diversity respectively. While air temperature, pH and dissolved oxygen were found to be negatively correlated with the benthos, polychaete and gastropod abundance.

Very few statistically significant correlations were observed during the study. This may be because of the dynamic nature of this ecosystem and the short duration of the study. The present study shows that macrobenthic community structure in tidepools does not vary consistently with the period of tidal isolation and there is large variability among pools within intertidal zones. The variability is larger in the tide pools than that of the emergent substrata because of the interaction of several physical factors (Metaxas & Scheibling, 1993). Due to this variability, the tide pools are a unique ecosystem.

The study on Tide pool ecology has not been attempted in India and the present brief study shows that there are variations among the individual pools located at different zones. Variations based on the disturbance were also observed between the two beaches although it was not quantified during the study. Long duration studies would help generate data that can help in management of the tide pools. Nevertheless, this study is a first attempt to document the difference in the faunal composition in the tidepool of an individual beach and understand the similarity if any amongst two spatial located beaches. The data generated in this study can be used as a base for comparison with studies in the future.

REFERENCES

Aleem, A.A. 1973. Contribution to the study of littoral diatoms on the west coast of Sweden. *Botanica marina*, *16*(4):193-200.

Ambler, M.P., and V.J. Chapman. 1950. A quantitative study of some factors affecting tide pools. *Transactions of the Royal Society of New Zealand*, 75(4):394-409.

Apte, D. 2012. *Field guide to the marine life of India*. First Edition. Published by Deepak Apte and co-published and distributed by Animesh Apte. 502pp.

Astles, K.L. 1993. Patterns of abundance and distribution of species in intertidal rock pools. *Marine Biological Association of the United Kingdom*, 73:555-569.

Batzli, G.O. (1969). Distribution of biomass in rocky intertidal communities on the Pacific coast of the United States. *The Journal of Animal Ecology*, 38(3):531-546.

Begon, M., J.L. Harper, and C.R. Townsend. 1986. Ecology: Individuals, populations and communities. *Blackwell scientific publications*. 876pp.

Bennett, B.A. 1987. The rock-pool fish community of Koppie Alleen and an assessment of the importance of Cape rock-pools as nurseries for juvenile fish. *South African Journal of Zoology*, *22*(1):25-32.

Bennett, B.A. and Griffiths, C.L. 1984. Factors affecting the distribution, abundance and diversity of rock-pool fishes on the Cape Peninsula, South Africa. *African Zoology*, 19(2):97-104.

Bibby, R., P. Cleall-Harding, S. Rundle, S. Widdicombe, and J. Spicer. 2007. Ocean acidification disrupts induced defences in the intertidal gastropod *Littorina littorea*. *Biology letters*, *3*(6): 699-701.

Bonsdorff, E. 1983. Effects of experimental oil exposure on the fauna associated with *Corallina officinalis* L. in intertidal rock pools. *Sarsia*, *68*(2):149-155.

Bonsdorff, E. 1984. Effects of experimental oil spills in intertidal rock pools. *Ecological Bulletins*, 36:159-164.

Bonsdorff, E., and W.G. Nelson. 1981. Fate and effects of Ekofisk crude oil in the littoral of a Norwegian fjord. *Sarsia*, *66*(3):231-240.

Brattström, H. 1990. Intertidal ecology of the northernmost part of the Chilean Archipelago: Report no. 50 of the Lund University chile expedition 1948-49. *Sarsia*, *75*(2):107-160.

Castilla, J.C. 1999. Coastal marine communities: trends and perspectives from human-exclusion experiments. *Trends in Ecology & Evolution*, *14*(7):280-283.

Chandramohan, P., N.M. Anand, and B.U. Nayak. 1992. Surfzone dynamics of the Konkan Coast, India. B. N. Desai (Ed.) Oceanography of the Indian Ocean. pp. 751-759. New Delhi India Oxford and IBH.

Chandran, R., G.S. Thangaraj, V. Sivakumar, B. Srikrishnadhas, and K. Ramamoorthi. 1982. Ecology of macrobenthos in the Vellar Estuary. *Indian Journal of Marine Sciences*, 11:122-127.

Chouikh, N.E., P. Gillet., W.J. Langston, M. Cheggour, A. Maarouf, and A. Mouabad. 2020. Spatial distribution and structure of benthic polychaete communities of Essaouira intertidal rocky shores (Atlantic coast of Morocco). *Journal of Oceanology and Limnology*, *38*(1):143-155.

Crabtree, R.E., and J.M. Dean. 1982. The structure of two South Carolina estuarine tide pool fish assemblages. *Estuaries*, 5:2-9.

Crossland, C.J., H.H. Kremer, H.J. Lindeboom, M. Crossland, J.I., and Le Tissier, M.D.A. (Ed). 2005. *Coastal fluxes in the Anthropocene: the land-ocean interactions in the coastal zone project of the International Geosphere-Biosphere Programme*. Springer-Verlag, Berlin. 232 pp.

Delany, J., A.A. Myers, and D. McGrath. 1998. Recruitment, immigration and population structure of two coexisting limpet species in mid-shore tidepools, on the West Coast of Ireland. *Journal of Experimental Marine Biology and Ecology,* 221(2):221-230.

Dethier, M.N. 1980. Tidepools as refuges: predation and the limits of the harpacticoid copepod *Tigriopus californicus*. *Journal of Experimental Marine Biology and Ecology*, *42*(2):99-111.

Dethier, M.N. 1984. Disturbance and recovery in intertidal pools: maintenance of mosaic patterns. *Ecological monographs*, *54*(1):99-118.

Dethier, M.N., J. Harper. 2011. Classes of Nearshore Coasts. *Reference Module in Earth Systems and Environmental Sciences: Treaties on Estuarine and Coastal Science*. Volume 1. Elsevier Limited. pp. 61-74.

Dias, M., A. Silva, H.N. Cabral, and C. Vinagre. (2014). Diet of marine fish larvae and juveniles that use rocky intertidal pools at the Portuguese coast. *Journal of Applied Ichthyology, 30*(5):970-977.

Droop, M.R. 1953. On the ecology of flagellates from some brackish and fresh water rockpools of Finland. *Acta Botanica Fennica*, 51:1-52

Fauchald, K. 1977. The polychaete worms - Definitions and keys to the orders, families and genera. *Natural History Museum of Los Angeles County, Science Series*, (28). 188pp.

Fauvel, P. 1953. Annelida Polychaeta. *The fauna of India, including Pakistan, Ceylon, Burma and Malaya*, The Indian Press, Allahabad. 507pp.

Femino, R.J., and Mathieson, A.C., 1980. Investigations of New England marine algae. IV: The ecology and seasonal succession of tide pool algae at Bald Head Cliff, York, Maine, USA. *Botanica Marina*, 23(5):319-332.

Firth, L.B., M. Schofield, F.J. White, M.W. Skov, and S.J. Hawkins. 2014. Biodiversity in intertidal rock pools: Informing engineering criteria for artificial habitat enhancement in the built environment. *Marine Environmental Research*, 102:122-130.

Fraser, J.H. 1936. The distribution of rock pool copepoda according to tidal level. *The Journal of Animal Ecology*, 5(1)23-28.

Ganning, B. 1971. Studies on chemical, physical and biological conditions in Swedish rockpool ecosystems. *Ophelia*, *9*(1):51-105.

Ganning, B., and Wulff, F. 1969. The effects of bird droppings on chemical and biological dynamics in brackish water rockpools. *Oikos*, 20(2)274-286.

George, D., and P. Mallery. 2019. *IBM SPSS Statistics 26 step by step: A simple guide and reference*. Routledge. Psychology Press. 671pp.

Giomi, F., A. Barausse, C.M. Duarte, J. Booth, S. Agusti, V. Saderne, A. Anton, D. Daffonchio, and M. Fusi. 2019. Oxygen supersaturation protects coastal marine fauna from ocean warming. *Science advances*, 5(9):eaax1814.

Goss-Custard, J.D., and Moser, M.E. 1988. Rates of change in the numbers of dunlin, *Calidris alpina*, wintering in British estuaries in relation to the spread of *Spartina anglica*. *Journal of Applied Ecology*, 25(1)95-109.

Goss-Custard, S., Jones, J., Kitching, J.A., and T. A. Norton. 1979. Tide pools of Carrigathorna and Barloge Creek. *Philosophical Transactions of the Royal Society of London*. *Biological Sciences*, *287*(1016):1-44.

Govindan, K., P.K. Varshney, and B. Desai. 1983. Benthic studies in south Gujarat estuaries. *Mahasagar - Bulletin of National Institute of oceanography*, 16:349-356.

Grasshoff, K., K. Kremling, and M. Ehrhardt. 1999. *Methods of seawater analysis*. Third Edition. John Wiley and Sons. 600pp.

Grassle, J.F., and J.P. Grassle. 1974. Opportunistic life histories and genetic systems in marine benthic polychaetes. *Journal of Marine Research*, 32:253-284.

Hammer, Ø., D.A. Harper, and P.D. Ryan 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, *4*(1): 9.

Hanamgond, P.T. 2008. Dynamics of Konkan Coast - A Review. Paper presented at National Seminar Konkan Coast DEED (Dynamics, Evolution, Ecosystem and Development) at G. S. Science Degree College, Belgaum, Karnataka (12-13 Sept. 2008).

Hockey, P. A., and A. L. Bosman. 1986. Man as an intertidal predator in Transkei: disturbance, community convergence and management of a natural food resource. *Oikos*, 46(1)3-14.

Huggett, J., and C.L. Griffiths. 1986. Some relationships between elevation, physico-chemical variables and biota of intertidal rock pools. *Marine Ecology Progress Series*, *29*:189-197.

Ingole, B.S., N. Rodrigues, and Z.A. Ansari. 2002. Macrobenthic communities of the coastal waters of Dabhol, west coast of India. *Indian Journal of Marine Sciences*, 31(2):93-99.

Jaiswar, A.K., and B.G. Kulkarni. 2001. Vertical distribution of molluscs in the intertidal area in and around Mumbai, India. *Journal of the Indian Fisheries Association*, 28:93-100.

Johnson, D.S., and A.F. Skutch. 1928. Littoral vegetation on a headland of Mt. Desert Island, Maine. II. Tide-pools and the environment and classification of submersible plant communities. *Ecology*, *9*(3):307-338.

Keough, M.J. and G.P. Quinn. 1998. Effects of periodic disturbances from trampling on rocky intertidal algal beds. *Ecological Applications*, 8(1):141-161.

Klugh, A.B. 1924. Factors controlling the biota of tide-pools. *Ecology*, *5*(2):192-196.

Kooistra, W.H.C.F., A.M.T. Joosten, and C. van den Hoek. (1989). Zonation Patterns in Intertidal Pools and their Possible Causes: A Multivariate Approach. *Botanica Marina*, *32*(1):9-26.

Kumar, C.S., J.K. Mishra, and N.P. Kumar. 2016. Diversity and distribution of tide pool ornamental fishes along the Andaman coast (Andaman Sea), India. *Marine Biodiversity,* 46(2): 433-441.

Landage, P.B. 2006. The role of Ratnagiri district central co operative bank in the development of co operative movement in Ratnagiri district. Unpublished Ph.D. thesis submitted to Shivaji University, Kolhapur, India. 288pp.

Lasiak, T. (1998). Multivariate comparisons of rocky infratidal macrofaunal assemblages from replicate exploited and non-exploited localities on the Transkei coast of South Africa. *Marine Ecology Progress Series*, *167*:15-23.

MacArthur, R. H. and E. O. Wilson. 1967. *The theory of island biogeography*. Princeton University Press, Princeton, New Jersey, USA. 203pp.

Magurran, A.E. 2004. *Measuring Biological Diversity.* John Wiley and Sons. 264pp.

Mahapatro, D., R.C. Panigrahy, S. Panda, and R.K. Mishra. 2015. An Updated Checklist of Benthic Polychaetes of Asia's Largest Brackish Water Coastal Lagoon - The Chilika Lake. *Journal of Coastal Zone Management*, 18(3):406.

Marks, R. 2008. Dissolved oxygen supersaturation and its impact on bubble formation in the southern Baltic Sea coastal waters. *Hydrology Research*, 39(3):229-236.

Marsh, B., T.M. Crowe, and W.R. Siegfried. 1978. Species richness and abundance of clinid fish (Teleostei; Clinidae) in intertidal rock pools. *African Zoology,* 13 (2):283-291.

Martins, G.M., S.J. Hawkins, R.C. Thompson, and S.R. Jenkins. 2007. Community structure and functioning in intertidal rock pools: effects of pool size and shore height at different successional stages. *Marine Ecology Progress Series,* 329:43-55.

Mendonça, V., C. Madeira, M. Dias, F. Vermandele, P. Archambault, A. Dissanayake, J. Canning-Clode, A.A.V. Flores, A. Silva, and C. Vinagre. 2018. What's in a tide pool? Just as much food web network complexity as in large open ecosystems. *PloS ONE*, *13*(7),e0200066.

Metaxas, A., and A. G. Lewis. 1992. Diatom communities of tidepools: the effect of intertidal height. *Botanica Marina*, *35*(1):1-10.

Mgaya, Y.D. 1992. Density and production of *Clinocottus globiceps* and *Oligocottus maculosus* (Cottidae) in tidepools at Helby Island, British Columbia. *Marine Ecology Progress Series*, 85(3):219-225.

Metaxas, A., and R.E. Scheibling. 1993. Community structure and organization of tidepools. *Marine Ecology Progress Series*, 98:187-198.

Musale, A.S., D.V. Desai, S.S. Sawant, K. Venkat, and A.C. Anil. 2015. Distribution and abundance of benthic macroorganisms in and around Visakhapatnam Harbour on the east coast of India. *Journal of the Marine Biological Association of the United Kingdom*, *95*(2):215-231.

Nair, N.B., P.A. Azis, K. Dharmaraj, M. Arunachalam, K.K. Kumar, and N.K. Balasubramanian. 1984. Ecology of Indian estuaries - V: Primary productivity of the Ashtamudi estuary, south-west coast of India. *Proceedings: Animal Sciences*, *93*(1):9-23.

Nakamura, R. 1976. Temperature and the vertical distribution of two tidepool fishes (*Oligocottus maculosus, O. snyderi*). *Copeia*, 1976(1):143-152.

Naylor, E., and Slinn, D.J. 1958. Observations on the ecology of some brackish water organisms in pools at Scarlett Point, Isle of Man. *The Journal of Animal Ecology*, 27(1)15-25.

Noel, L., and L. Jeanne. 2007. Species interactions during succession in rockpools: role of herbivores and physical factors. Unpublished Ph. D. thesis submitted to University of Plymouth, England. 210pp

Nulkar, G. 2014. Lessons from Velas: Assessment of Eco-tourism as a Model for Conservation in Konkan. *Journal of Ecological Society*, 26-27.

Nybakken, J.W. 1982. *Marine Biology, An Ecological Approach*. Fourth Edition. Addison Wesley Longman Inc., pp. 219-301.

Orr, J.C., V.J. Fabry, D. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishinda, F. Jacobs, and others. 2005. Anthropogenic ocean acidification over the twenty-first century and its impacts on calcifying organisms. *Nature*, 437:481–486.

Parulekar, A.H. 1981. Marine fauna of Malvan, central west coast of India. *Mahasagar*, 14:33-44.

Peacor, S.D., and E.E. Werner 2001. The contribution of trait-mediated indirect effects to the net effects of a predator. *Proceedings of the National Academy of Sciences*, 98(7):3904-3908.

Pearson T.H., and R. Rosenberg. 1978 Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and marine biology annual review*. 16:229–311.

Phanse, S.S. 2000. The biology of marine algae of Konkan. Unpublished Master's thesis submitted to K. V. Pendharkar College, Dombivli, University of Mumbai, India. 62pp.

Pinn, E. H., and M. Rodgers. 2005. The influence of visitors on intertidal biodiversity. *Journal of the Marine Biological Association of the United Kingdom*, *85*(2):263-268.

Preston, A., and P. G. Moore. (1988). The flora and fauna associated with *Cladophora albida* (Huds.) Kütz. from rockpools on Great Cumbrae Island, Scotland. *Ophelia*, *29*(3):169-186.

Ranta, E. 1982. Animal Communities in rock pools. *Annales Zoologici Fennici, 19:337-347.*

Ravinesh, R., and A. Bijukumar. 2013. Comparison of intertidal biodiversity associated with natural rocky shore and sea wall: A case study from the Kerala coast, India. *Indian Journal of Geo-Marine Sciences*, 42(2):223-235.

Rützler, K., and W. Sterrer. 1970. Oil pollution: damage observed in tropical communities along the Atlantic seaboard of Panama. *BioScience*, *20*(4):222-224.

Salunkhe, P. 2014. A study of impact of tourism on socio-economic development in Ratnagiri district. Unpublished Ph.D. thesis submitted to Tilak Maharashtra Vidyapeeth (Deemed University), Pune, India. 320pp.

Sandison, E.E. 1967. Respiratory response to temperature and temperature tolerance of some intertidal gastropods. *Journal of Experimental Marine Biology and Ecology*, *1*(2):271-281.

Satyam, K., and G. Thiruchitrambalam. 2018. Habitat Ecology and Diversity of Rocky Shore Fauna. *Biodiversity and Climate Change Adaptation in Tropical Islands*, Academic Press. pp. 187-215.

Schiel, D.R., and D.I. Taylor. 1999. Effects of trampling on a rocky intertidal algal assemblage in southern New Zealand. *Journal of experimental marine biology and ecology*, *235*(2):213-235.

Shepherd, J. 1988. Fish health and disease. In: J. Shephered and N. Bromage (Ed.), Intensive Fish Farming. pp*. 198-238. BSP Professional Books, Oxford.*

Shepherd, J. and N. Bromage. 1992. *Intensive Fish Farming*. Oxford Blackwell Scientific Publications, London.

Sivadas, S., B. Ingole, and M. Nanajkar. 2010. Benthic polychaetes as good indicators of anthropogenic impact. *Indian Journal of Marine Sciences*, 39(2):201-211.

Stephenson, T. A., and A. Stephenson. 1949. The universal features of zonation between tide-marks on rocky coasts. *The Journal of Ecology*, 37(2):289-305.

Sukumaran, S., J. Mulik, M.A. Rokade, and A. Kamble. 2014. Impact of 'Chitra' Oil Spill on Tidal Pool Macrobenthis Communities of a Tropical Rocky Shore (Mumbai, India). *Estuaries and Coasts*, 37(6):1415-1431.

Sze, P. 1982. Distributions of macroalgae in tidepools on the New England coast (USA). *Botanica Marina*, *25*(6):269-276.

Tablado, A., J.L. Gappa, and N.H. Magaldi. 1994. Growth of the pulmonate limpet *Siphonaria lessoni* (Blainville) in a rocky intertidal area affected by sewage pollution. *Journal of Experimental Marine Biology and Ecology*, *175*(2):211-226.

Therriault., T.W., and J. Kolasa. 1999. Physical determinants of richness, diversity, evenness and abundance in natural aquatic microcosms. *Hydrobiologia*, 412:123-130.

Thompson, R.C., T.P. Crowe, and S.J. Hawkins. 2002. Rocky intertidal communities: past environmental changes, present status and predictions for the next 25 years. *Environmental conservation*, 29(2)168-191.

Trivedy, R.K., P.K. Goel, and C.L. Trisal. 1987. *Practical methods in ecology and environmental science*. Enviro Media Publications. 340pp.

Trussell, G.C., P.J. Ewanchuk, M.D. Bertness, and B.R. Silliman. 2004. Trophic cascades in rocky shore tide pools: distinguishing lethal and nonlethal effects. *Oecologia*, 139(3):427-432.

Tsering, L., H.B. Pawar, R.A. Sreepada, S.V. Sanaye, and U. Suryavanshi. 2012. Ichthyofaunal diversity and ecology of intertidal rock pools of Goa, west coast of India. *Fishing Chimes, 38(8):56-59*

Ulman, Y.N., V.G. Naik, and J.M. Talathi. 2008. Traditional fishing practice and socio-cultural activities of Koli community in Konkon region of India. *Asian Agri-History*, *12*(4):311-319.

Underwood, A.J. 1980. The effects of grazing by gastropods and physical factors on the upper limits of distribution of intertidal macroalgae. *Oecologia*, *46*(2):201-213.

Underwood, A.J., and G.A. Skilleter. 1996. Effects of patch-size on the structure of assemblages in rock pools. *Journal of Experimental Marine Biology and Ecology*, 197(1):63-90.

Underwood, A.J., and P. Jernakoff. 1984. The effects of tidal height, wave-exposure, seasonality and rock-pools on grazing and the distribution of intertidal macroalgae in New South Wales. *Journal of Experimental Marine Biology and Ecology*, *75*(1):71-96.

van Tamelen, P.G. 1996. Algal zonation in tidepools: experimental evaluation of the roles of physical disturbance, herbivory and competition. *Journal of Experimental Marine Biology and Ecology*, *201*(1-2):197-231.

Wagle, B.G. 1989. Morphology and evolution of the central west coast of India. *Mahasagar*, *22*(1):13-21.

Wagle, B. G. 1991. Shores of the Central West coast of India – A Case study using remote sensing data. *Mahasagar*, 24(1):13-20.

Wai, T.C., and G.A. Williams. 2006. Monitoring spatio-temporal variation in molluscan grazing pressure in seasonal, tropical rock pools. *Marine biology, 149*(5):1139-1147.

Ward, G., and G.J. FitzGerald. 1983. Macrobenthic abundance and distribution in tidal pools of a Quebec salt marsh. *Canadian Journal of Zoology*, *61*(5):1071-1085.

Werner, F.E., and B.O. Blanton. 2001. Coastal Circulation Models. *Encyclopedia of Ocean Sciences*. Second Edition. Volume 1. Academic Press. pp. 572-580.

Zander, C.D., J. Nieder, and K. Martin. 1999. Vertical Distribution Patterns. In: M. H. Horn, K. L. M. Martin, and M. A. Chotkowski (Ed). *Intertidal fishes*. Pp. 26-53. Academic Press, New York.

Zedler, J.B., and John C.C. 2001 Tidal wetland functioning. *Journal of Coastal Research*, Special issue No 27:38-64.

Appendix 1: Physico-chemical parameters (mean ± standard deviation) of each tidepool in the study.

Pool ID	Air temperature (°C)	Water temperature (°C)	pH	Salinity (‰)	DO (mg/L)	Pool Depth (cm)	Sodium (ppm)	Calcium (ppm)	Potassium (ppm)	Pool area (m^2)
LL1	27.2±0.9	28.5±1.0	8.0±0.1	39.0±1.7	7.4±1.6	17.0±2.6	12989.2±262.1	720.0±346.4	285.5±122.8	5.21
LL2	26.2±1.7	28.9±0.4	8.1±0.1	37.0±0.0	4.7±4.1	18.2±0.3	8805.5±7628.7	546.7±582.9	168.4±179.3	8.5
LL3	26.7±0.4	29.0±0.4	8.1±0.0	36.5±0.7	4.7±4.2	35.0±4.2	9867.0±8573.6	586.7±646.6	177.4±194.6	2.31
LM1	27.2±1.7	28.9±0.8	8.2±0.1	38.7±1.5	9.7±2.1	65.0±4.4	14411.8±775.5	760.0±280.0	278.7±180.7	3.7
LM2	27.4±2.0	29.3±1.0	8.1±0.1	39.3±0.6	8.7±1.7	38.7±1.5	14683.2±1096.0	1040.0±520.0	304.3±137.3	2.4
LM3	27.8±1.0	29.9±0.2	8.2±0.2	37.3±2.1	12.9±4.3	49.5±1.8	13236.7±566.6	840.0±355.5	291.2±126.4	4.62
LH1	28.1±2.2	29.8±1.0	8.1±0.1	37.5±0.7	9.2±2.1	32.3±2.5	14052.5±436.6	880.0±486.6	298.0±129.8	3.46
LH2	27.9±2.8	29.2±1.3	8.1±0.1	38.0±1.0	9.1±2.0	24.5±2.2	13975.5±208.9	693.3±272.3	297.4±139.3	1.87
LH3	28.7±0.7	29.4±0.8	8.1±0.2	37.7±2.5	9.1±1.5	85.3±3.5	13860.0±798.0	866.7±266.3	292.6±129.9	7.91
PL1	27.3±1.8	27.6±0.8	8.4±0.0	38.5±2.1	10.1±0.5	17.5±0.7	13365.0±13431.5	400.0±355.5	169.2±180.8	6.22
PL2	27.5±1.2	28.3±0.6	8.5±0.2	39.3±1.2	11.7±1.0	26.3±1.5	15139.7±1630.1	920.0±567.1	308.7±138.8	3.6
PL3	28.5±2.6	27.9±1.3	8.2±0.3	38.5±2.1	6.0±5.2	11.5±2.1	8858.7±7673.6	373.3±344.9	169.2±180.1	2.4
PM1	29.5±1.7	29.9±0.2	8.2±0.2	38.7±2.3	13.3±0.6	37.7±3.2	13141.3±358.4	906.7±349.5	290.3±119.1	5.9
PM2	28.3±0.3	30.0±2.2	8.4±0.2	39.7±5.5	17.0±2.9	25.5±1.0	13948.0±726.1	813.3±440.6	305.8±137.0	3.8
PM3	29.9±2.3	30.4±0.6	8.4±0.1	36.3±2.1	16.6±4.4	27.2±2.3	13341.2±856.2	706.7±257.2	316.2±105.2	4.7
PH1	30.6±3.2	32.4±0.4	8.6±0.4	39.7±6.4	21.5±4.2	12.6±1.7	14615.3±1446.5	946.7±369.5	303.9±132.9	3.5
PH2	29.8±1.6	31.2±0.3	7.9±0.1	37.7±0.6	13.4±8.9	19.9±0.8	14010.3±971.6	786.7±205.3	296.5±127.2	2.9
PH3	30.2±2.5	32.4±0.4	8.5±0.2	35.7±4.0	17.2±11.4	14.4±0.9	14696.0±1611.8	626.7±122.2	312.9±146.6	3.5

Appendix 2: Distribution of polychaete families with the average abundance (no. m^{-2}) in the 18 tidepools in the study area.

Location	Ladghar									Pajpandhari								
Tidal zone	Low			Mid			High			Low			Mid			High		
Family \ No	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Aphroditidae										50								
Capitellidae		50	50	500	233		633	567	2333					33			133	67
Eunicidae													33					
Nereididae				33						150		250		100	67			100
Onuphidae																	67	
Phyllodocidae											67			33				33
Polynoidae														67				
Sabellidae	67																	
Saccocirridae						367		167										
Sigalionidae											67							
Spionidae	100	250	1550	67	4067	200	933	633	400						33		67	
Syllidae	100	50		67		67								100				
Terebellidae																	133	

Appendix 3: Distribution of gastropod families with the average abundance (no. m^{-2}) in the 18 tidepools in the study area.

Location	Ladghar									Pajpandhari								
Tidal zone	Low			Mid			High			Low			Mid			High		
Family \ No	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Babylonidae	0.7																	
Buccinidae	2.7	3.3		0.7				0.7	0.7			1.0		0.3				
Cassidae						1.0												
Cerithidae		0.3																
Costellariidae			1.3															
Epitonidae			0.7	0.3		1.3												
Fasciolariidae												0.7						
Littoridae										1.7	3.0			1.0	0.7	1.3	0.3	
Littorinidae									1.7									
Mitridae	0.3				0.7													
Muricidae	11.3	3.0	4.0		3.3	8.7		8.0	3.3	2.3	4.3	1.3		1.0	2.3		0.3	
Nassariidae			3.3		0.3													
Naticidae				0.3	0.3	1.3								0.3				
Neritidae		1.0					0.7	35.7	5.7				1.3		1.7			
Planaxidae	0.7																	
Pyrinidae	0.3		0.3										1.0					
Ranellidae	22.3	5.7	13.7	24.7	8.0	3.7		0.3	1.3	6.3	3.3	5.3	5.7	7.0	4.3	0.3		
Terebridae	1.0								1.0									
Trochidae									1.0		0.7		1.0					
Turbinidae			1.3			2.0				1.0			2.0					
Turridae									0.3									
Vassidae						0.3												