4.1 STRUCTURE OF ROCKY LITTORAL ZONE

The geology of Rockpool, Gujarat, is shaped by the area's complex lithological composition and tectonic history. The region is comprised of up of Mesozoic rocks such as dolerite/basalt dykes, laterite, and flood plain deposits (Prajapati, 2020). Rockpool, Gujarat, has distinctive rock formations such as planar cross stratification, trough cross stratification, imbricate structure, and channel structure, all of which indicate a river depositional environment. Geological factors, such as the interaction between climate and geology that determines the shape and hydrology of these ecosystems with varied hydroperiods ranging from several days to a year, are what significantly affect the uniqueness of Rockpool formations (Jocque, 2010).

The rocky littoral zone of selected sites is characterized by quaternary carbonate deposits designated as the miliolite formation are spread all along three sites. The deposits of miliolite formation occur in the form of costal cliffs and shore platforms. The formation is composed of medium to fine grained, well sorted, rounded to sub-rounded allochems like molluscan shell fragments, corals, coralline algae, bryozoans, echinoderms etc. (Bhatt and Patel, 1996).

The Miliolites along the Southern Saurashtra coast of India exhibit land-sea interaction in the form of cliffs, marine terraces, wave-cut platforms, and marine notches (Pant and Juyal, 1993; Bhatt and Bhonde, 2006). Among these, a few observed during the study are as follows: (Plate 4.1).

A. **Contorted cross laminae** refer to a type of sedimentary structure found in sedimentary rocks, characterized by the complex, irregular folding or twisting of cross-bedded layers (laminae). These laminae, which are typically formed by the deposition of sediment in a cross-bedding pattern and typically form in environments with varying current or flow conditions (Plate 4.1(A)).

Cliff profile of rocky littoral zone

B. Solution channels formed by infiltration of meteoric water into the porous Miliolites abound over the top surface of the cliffs rendering a honey-comb appearance. It can develop within the Miliolites (Plate 4.1(B)).

C. Tidal pools of varying sizes abound the shore platform. The floor of the tidal pools is inhabited by Barnacle and algae (Plate 4.1(C)). Hammer (encircled) for scale (length 32 cm).

D. Limpets colonizing the shell limestone unit occurring over the shore platform in Veraval and Chhara (Plate 4.1 (D)).

E. Trending vertical joint passing along the shore platform. The joint aperture is very narrow with highly irregular joint walls (Plate 4.1 (E)).

Marine Notches

F. Littorinids inhabiting the notch roof. The notch roof is intensely pitted due to spray action and bioerosion (Plate 4.1 (F)).

Bioerosion and Bioconstruction

G. Algae and Lichens inhabit the upper intertidal and the supratidal zones, respectively. Contrasting difference in the appearance of the fresh Miliolite located away from the reaches of the wave and tide actions and those infested by algae and lichens is quite evident (Plate 4.1 (G)).

H. Littorinids inhabiting the shell limestone on the shore platform (Plate 4.1 (H)).

I. Barnacles colonizing the shore platform (Plate 4.1 (I)).

Marine and sub-aerial erosion

J. Large portions of the shore platform get eroded by the breaking waves and tidal currents (Plate 4.1 (J)).

K. Mass wasting of the Miliolite cliffs is caused by widening of the vertical joints by dissolution processes due to passage of meteoric water along them (Plate 4.1(K)).

L. Filamentous algae occur over the intertidal portions of the shore platform (Figure 4.1 (L)).

Plate 4.1: Land-sea interaction in the form of cliffs, marine terraces, wave-cut platforms, and marine notches at study sites

This littoral zone often includes exposed rocky outcrops, consisting of various types of rocks like basalt, granite, and sedimentary rocks. These rocks can be eroded by wave action, creating different textures and habitats for marine life. The zonation pattern of rocky shores describes the distribution and arrangement of different intertidal communities along a gradient from high to low tide. Intertidal zone of these sites are divided into Supralittoral zone, upper littoral zone, mid littoral zone and lower littoral zone. The topography of this rocky littoral zone of these sites are uneven, featuring elements such as ledges, crevices, and pools. These topographical characteristics create a variety of microhabitats.

During the study total 18 different types of microhabitats have been recorded along the three sites such as, large boulders (BR), Platform rock (PR), Flat rock pools/ puddles (FRP), Pointer rock pools/puddles (PRP), Zoanthid bed (ZB), Barnacle bed (BB), Coral pool (CP), Hanging on rock (HR), pits, Underneath of rock (UR), Dry hole at the base (DH), Micro pool (MP), Algal bed (AB), Flat rock caves/crevices (FRC) and Sandy substratum (Plate 4.2).

Each microhabitats play a crucial role in supporting and enhancing marine communities. Microhabitats create a variety of niches and ecological roles within a marine community. Each microhabitat, such as tide pools, crevices, or algal bed, provides specific conditions and resources that different species are adapted to exploit. This diversity helps support a wide range of organisms. Microhabitats offer critical shelter and protection for marine organisms. For instance, crevices in rocky shores provide refuge from predators and harsh environmental conditions. Tide pools can offer a stable environment for small organisms during low tides. Many species have evolved specialized adaptations to thrive in particular microhabitats. For example, organisms living in tide pools are adapted to withstand variable salinity and temperature, while those in high-energy zones may have features that help them cling to rocks and resist wave action.

Plate 4.2: Microhabitats recorded from selected study sites

Different microhabitats support different food sources and nutrient cycles. For example, algae and seaweeds in tide pools and intertidal zones contribute to primary production, supporting herbivores and, consequently, higher trophic levels. Some microhabitats serve as important breeding and nursery grounds. For instance, sheltered areas and tide pools can provide a safe environment for juvenile fish and invertebrates to grow and develop before they move to more open waters. Microhabitats often support high levels of biodiversity due to their varied conditions and resources. For example, a single tide pool might host a diverse community of algae, invertebrates, and small fish, all interacting in complex ways. Microhabitats facilitate various ecological interactions, such as symbiosis, competition, and predation. These interactions are crucial for maintaining balanced and functioning ecosystems.

Veraval

This rocky littoral zone is 3 Km long and has regular tidal exposure of about 50-80 m. The substrate composition of this rocky littoral zone is typically composed of large boulders and bedrock with a relatively gentle to moderate slope. This means that the transition from high tide to low tide areas is gradual rather than abrupt. The coast is primarily composed of sedimentary rocks, including sandstone and limestone, which influence the overall slope and terrain. The topography of this rocky littoral zone these sites are uneven, featuring elements such as ledges, crevices, and pools. These topographical features create a variety of microhabitats. The zonation pattern of rocky shores describes the distribution and arrangement of different intertidal communities along a gradient from high to low tide. Intertidal zone of Veraval is divided into Supralittoral zone, upper littoral zone, mid littoral zone and lower littoral zone.

In the supralittoral zone, extreme desiccation, high salinity, and temperature fluctuations occur. This zone having different micro habitats such as boulders, shallow tidepools, puddles, pointer rock, platform rock, vertical crevices which provides good habitat for gastropods like *Echinolittorina malaccana*, *Lunella* spp., *Chiton* spp., *Cellana karachiensis, Cellana radiata* etc.

Mid littoral zone of this site having medium to large tidepools, flat crevices with various assemblages such as zoanthid assemblage, *Cerithium* assemblage and *Porites* assemblage, due to presence of large sized Zoanthid, *Cerithium* and patchy *Porites* colonies, provides microhabitats to *Timarete* spp*., Daylithos parmatuss, Branchiomma* spp*, Sabellidae, Ophiuroidea* spp., and *Halichondria panicea* etc.

Lower littoral zone is submerged during high tide and exposed during lowest low tide, creates an environment conducive to the attachment and growth of Bivalves, Barnacles and echinoderms. The high-pitched vertical crevices likely offer protection from predators and exposure to nutrients carried by the water, making them attractive habitats for these sessile organisms. Tidepools of this zone are medium and having more depth.

Mul Dwarka

Rocky littoral zone is 2.5 Km long and has tidal exposure of about 40- 75m. Substratum composition of this site is hard flat rocky littoral area having small sized depression in interspersed with many small and large shallow tidepools and puddles.

The spray zone is covered by sand and dead molluscan shells. Upper littoral zone of this site having flat rockpools with small crevices which provided habitat to *Cerithium zonatum, Gyrineum natator*, *Nerita albicilla* and other gastropod spp.

Mid littoral zone mainly flat rocky substratum with small and large tidepools and caves & crevices. Many species such as *Palythoa mutuki*, *Trochus stellatus*, many Vermetid spp., Bivalvia spp., *Gobius niger* and other *Gobius* spp. have been observed in this zone. A big tidepool present in this zone having 1900 cm length.

Lower littoral zone of this site is covered with sargassum and coralline algae and zoanthids colony mainly *Palythoa mutuki* and *Palythoa heliodiscus*, Vermetids spp. Tidepools present in this zone having more depth but small in size compared to middle and upper littoral zone of this site.

Chhara

Rocky littoral zone is 4 Km long and has tidal exposure of about 60-65 m. The topography of the rocky littoral zone these sites are uneven, featuring elements such as large boulders with slope elevation, rugged rock faces, cliffs, and sharp transitions from high to low tide.

Upper littoral zone having different types of microhabitats such as micro pools, puddles, dry hole at base. Tidepools of this zone mainly shallow and small which support variety of species such as habitat for many actiniarian colony and small rock acorn barnacles, *Grapsus* spp., and *Echinolittorina malaccana*.

Mid littoral zone is large and deep tidepools with coralline bed. Which provided good habitat to *Pseudoceros susanae*, *Eulalia viridis*, *Sabellastarte spectabilis*, Nereididae spp., *Callionymus reticulatus* and *Gymnothorax pseudothyrsoideus* etc. tidepools of this zone having more depth compared to the upper and lower littoral zone.

Lower littoral zone of this site is covered by sargassum bed and with many small and deep tidepools and hole. Which provided habitat for many gastropod spp., *Pilumnus* spp., and fish etc.

4.2 STRUCTURE OF TIDEPOOL

During the study total - tidepools have been studied in three sites. From these sites 18 tidepools from Veraval, 14 tidepools from Mul Dwarka and 18 tidepools from Chhara coast have been studied using GIS technique using point scale maps (Figure 4.1 to 4.3).

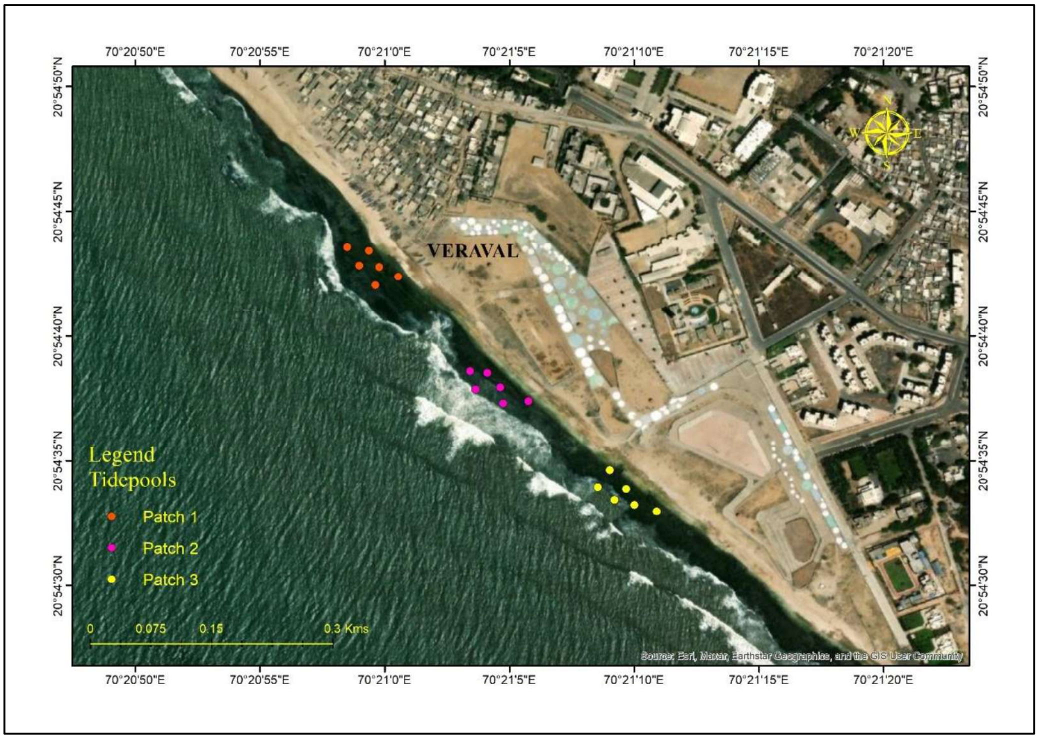


Figure 4.1: Location of selected tidepools at Veraval coast

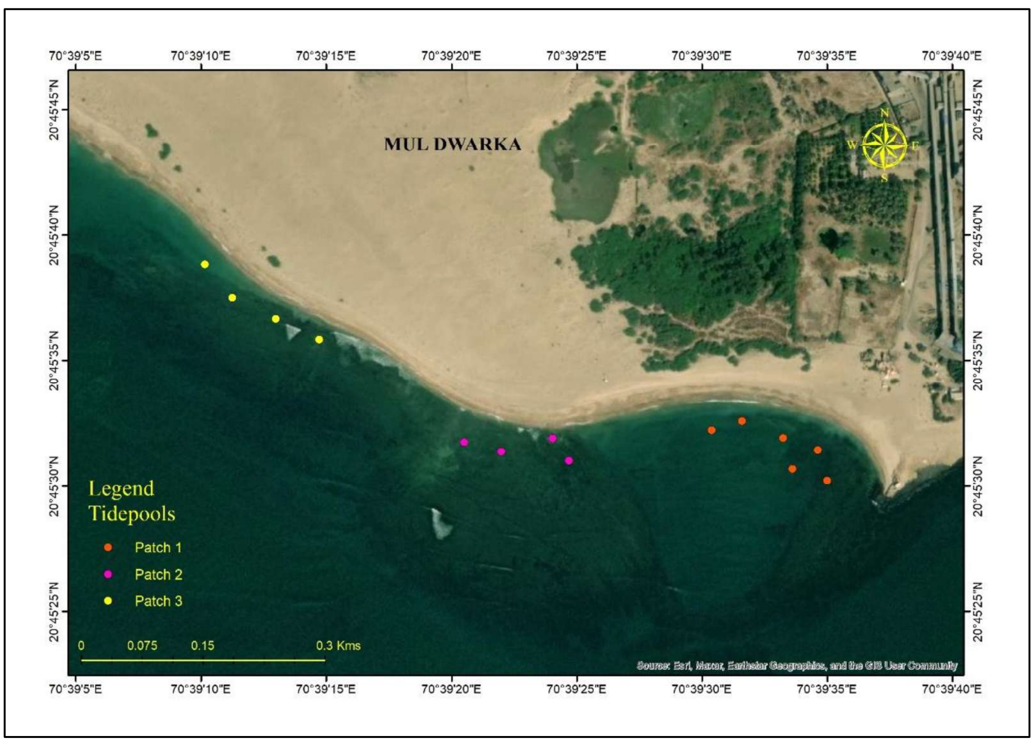


Figure 4.2: Location of selected tidepools at Mul Dwarka coast

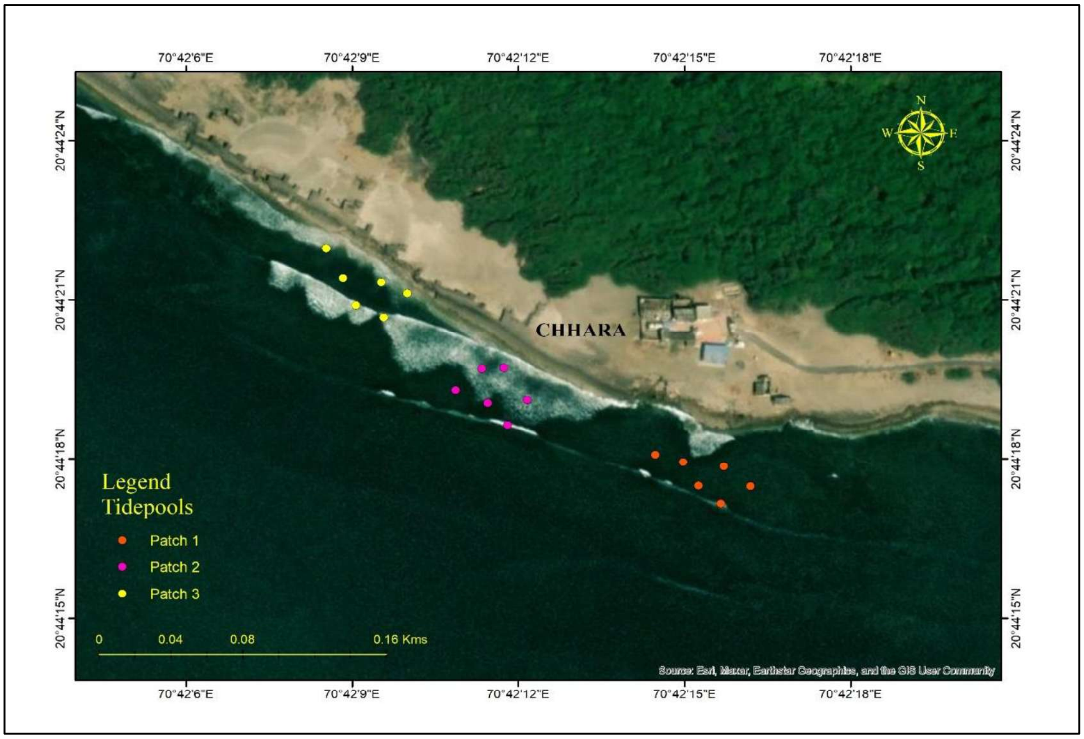


Figure 4.3: Location of selected tidepools at Chhara coast

4.2.1 Studies of the physical characteristics and tidepool structure at the Veraval coast

For the study of tidepool structure, physical characteristics related to the size of tidepools were measured which include length, depth, width, radius and shape (Table 1).

Table 1: Physical characteristics of selected tidepools at Veraval coast

SITE	TIDEPOOL	LENGTH (cm)	DEPTH (cm)	WIDTH (cm)	RADIUS (cm)	SHAPE (cm)
Veraval	1	52	21	95	26	Elongated
	2	35	33	42	17.5	Elongated
	3	240	38	100	120	Elongated
	4	300	55	210	150	Elongated
	5	240	30	300	120	Irregular
	6	190	32	260	95	Elongated
	7	520	90	650	260	Irregular
	8	235	55	240	117.5	Irregular
	9	340	24	450	170	Irregular
	10	500	32	700	250	Irregular
	11	510	26	530	255	Elongated
	12	240	34	400	120	Elongated
	13	50	29	38	25	Pointed oval
	14	42	31	60	21	Irregular
	15	230	120	210	115	Irregular
	16	160	74	170	80	Elongated
	17	130	43	200	65	Irregular
	18	100	36	190	50	Elongated

Tidepools are distinct coastal ecosystems shaped by a range of physical factors. Studying the ecological processes in these ecosystems requires an understanding of these characteristics. The length, depth, breadth, radius, and form of the tidepools along the Veraval coast are the main physical characteristics that are examined in this study. Outlining the link between these aspects and how they could affect or reflect environmental and ecological circumstances is the aim.

Measurements of length, depth, width, radius, and shape for eighteen tidepools are among the data gathered. Three forms show out as particular: "Elongated," "Irregular," and "Pointed oval."

Eighteen tidepools measurements at Veraval have been included in the dataset (Table 1):

- **Length:** Ranges from 35 cm to 520 cm.
- **Depth:** Ranges from 21 cm to 120 cm.
- **Width:** Ranges from 38 cm to 700 cm.
- **Radius:** Ranges from 17.5 cm to 260 cm.
- **Shape:** Includes Elongated, Irregular, and Pointed oval.

A. Length and Width relationship

Tidepools differ significantly in length and width, with some (such as 3 & 4) having incredibly large dimensions. Tidepool 4, for example, is 300 cm long and 210 cm wide, suggesting a sizable and perhaps intricate ecological structure. lower tidepools, such as those in 2 and 14, on the other hand, have considerably lower diameters. Larger tidepools, as those in 7 and 11, are often longer and broader, indicating that the more surface space available in these habitats may sustain dense or more diversified populations.

B. Depth variation

The depth ranges from 21 cm to 120 cm; deeper tidepools (15 cm) probably offer more stable microhabitats than shallower ones. Increased depth may affect the variety of species that live in these pools and assist create a more stable ecosystem. Compared to deeper tidepools, shallow tidepools (such as 1 and 2) may sustain a different variety of flora and fauna and are susceptible to temperature fluctuations.

C. Radius and shape

- **Radius**

In larger tidepools, in particular, the radius values exhibit a positive correlation with both length and width. For example, tidepool 7 has large radius of 260 cm relates to its considerable dimensions of 650 cm for width and 520 cm for length.

The surface area and variety of biological niches inside the pool are affected by the tidepools' variable shapes. Long pools (1 and 16) are often narrower and longer, whereas irregular pools (7 and 10) can provide a variety of microhabitats but have less predictable proportions.

D. Ecological implications of shape

- **Shapes**

1. Elongated shapes

Longer lengths compared to widths characterize elongated tidepools. This form may have an impact on the pool's water flow patterns, which may have an impact on how nutrients and organisms are distributed. The extended form may help microalgae proliferate and organisms move more easily.

2. Irregular shapes

Irregular pools might lead to a more diverse ecosystem because of their variable sizes and unpredictable borders. A wider variety of species may be supported by microhabitats with a higher degree of diversity as a result of this variability.

3. **Pointed oval shapes**

Tidepool 13 is a tiny tidepool that could harbour a more specialized group of organisms that are suited to these particular environmental circumstances.

4.2.2 Studies of the physical characteristics and tidepool structure at the Mul Dwarka coast

14 tidepools measurements at Mul Dwarka have been included in the dataset (Table 2):

- **Length:** Ranges from 48 cm to 1900 cm.
- **Depth:** Ranges from 7 cm to 52 cm.
- **Width:** Ranges from 90 cm to 3170 cm.
- **Radius:** Ranges from 24 cm to 950 cm.
- **Shape:** Includes Elongated, Irregular, and Oval

Table 2: Physical characteristics of selected tidepools at Mul Dwarka coast

SITE	TIDEPOOL	LENGTH (cm)	DEPTH (cm)	WIDTH (cm)	RADIUS (cm)	SHAPE (cm)
Mul Dwarka	1	150	9	300	75	Irregular
	2	300	7	370	150	Irregular
	3	390	19	410	195	Oval
	4	1900	52	3170	950	Irregular
	5	200	38	330	100	Irregular
	6	430	34	470	215	Elongated
	7	200	18	220	100	Irregular
	8	170	21	130	85	Irregular
	9	190	32	190	95	Elongated
	10	300	28	220	150	Elongated
	11	120	24	90	60	Irregular
	12	200	20	110	100	Irregular
	13	48	34	46	24	Elongated
	14	112	41	120	56	Irregular

A. Length and Width relationship

The tidepools range in length from 48 cm to 1900 cm, which is a significant variation. Additionally, there is a wide variation in breadth, ranging from 90 to 3170 cm. large tidepools, like the one in the middle zone with dimensions of 4, have significant surface that might support a variety of microhabitats and a higher level of ecological complexity. Smaller tidepools, such as number 13, on the other hand, have far more limited geographical coverage.

B. Depth variation

Depth varies significantly, from 7 to 52 cm, suggesting a wide range. More stable conditions might be provided by deeper tidepools (such as the four that are 52 cm deep), which may offer as a buffer against desiccation and temperature variations. Shallower tidepools (such as the two at a depth of 7 cm) are more susceptible to changes in the surrounding environment, but they could still be inhabited to specialized ecosystems that have adapted to them.

C. Radius and Shape

- **Radius**

The width and length of the tidepools have a positive correlation with the radius values. Larger tidepools, like number 4, have a 950 cm radius, indicating a considerable total area and perhaps intricate underlying structure.

- **Shape**

The tidepools' varied shapes have an effect on their ecological characteristics.

1. Irregular shapes

Most tidepools (e.g., 1, 2, & 4) have irregular shapes. Diverse microhabitats and intricate edge ecosystems are frequently the result of irregular forms. This species may contribute to biodiversity by offering a range of refuge sites and niches.

2. Elongated shapes

Long and narrow shapes are characteristics of elongated tidepools (e.g., 6 & 9). These forms might have an impact on the pool's water flow patterns, which could change the distribution of nutrients and allow for the growth of various organisms.

3. Oval shapes

Compared to irregular pools, Tidepool 3 is oval shape might offer a more symmetrical environment. By providing a balance between area and form complexity, oval shapes may be able to host a variety of organisms that are adapted to relatively stable environments.

D. Ecological implications of shape

1. Large tidepools

The most stable and complex ecosystems are probably found in large tidepools (such as those 4, which have a considerable depth and surface area). They could be able to sustain more complex ecological interactions and a wider variety of species.

2. Shallow and Smaller tidepools

Even though they are more exposed to external stresses, smaller and shallower tidepools (e.g. 13) can nevertheless sustain specialized ecosystems. The organisms that have evolved to these circumstances may find significant niches in these tidepools.

4. Shape effects

The distribution of habitats inside the pool and the flow of water and nutrients are influenced by the tidepool's structure. While oval forms may provide more stable but less adaptable habitats, irregular and elongated shapes might offer a variety of microenvironments

4.2.3 Studies of the physical characteristics and tidepool structure at the Chhara coast

Table 3. Physical characteristics of selected tidepools at Chhara coast

SITE	TIDEPOOL	LENGTH (cm)	DEPTH (cm)	WIDTH (cm)	RADIUS (cm)	SHAPE (cm)
Chhara	1	45	12	60	22.5	Oval
	2	52	18	72	26	elongated
	3	75	17	68	37.5	Elongated
	4	95	36	92	47.5	Elongated
	5	53	10	80	26.5	Elongated
	6	130	16	100	65	Irregular
	7	130	23	210	65	Irregular
	8	180	32	270	90	Elongated
	9	230	42	340	115	Irregular
	10	290	57	470	145	Irregular
	11	180	48	290	90	Irregular
	12	600	60	1300	300	Elongated
	13	95	24	125	47.5	Irregular
	14	190	44	164	95	Elongated
	15	140	32	250	70	Irregular
	16	210	48	290	105	Irregular
	17	180	56	185	90	Irregular
	18	110	21	68	55	Irregular

Eighteen tidepools measurements at Chhara have been included in the dataset (Table 3):

- **Length:** Ranges from 45 cm to 600 cm.
- **Depth:** Ranges from 10 cm to 60 cm.
- **Width:** Ranges from 60 cm to 1300 cm.
- **Radius:** Ranges from 22.5 cm to 300 cm.
- **Shape:** Includes Oval, Elongated, and Irregular.

A. Length and Width relationship

The length of tidepools ranges greatly from 45 to 600 cm, while their corresponding widths vary from 60 to 1300 cm. Greater surface area for habitat is provided by larger tidepools, like 12 (600 cm long and 1300 cm wide), which may be able to sustain a wider variety of organisms than smaller tidepools, like 1 (45 cm long and 60 cm wide).

There appears to be a proportionate relationship between both dimensions since the tendency shows that the width of tidepools tends to rise along with their length.

B. Depth variation

Tidepools range depths that vary from 10 to 60 cm. In comparison to shallower pools (e.g., five with a depth of 10 cm), deeper tidepools (12 with a depth of 60 cm) probably offer a more stable environment in terms of salinity and temperature. Increased depth might sustain more stable microhabitats and act as a buffer against environmental extremes.

C. Radius and shape

- **Radius**

The radius is between 22.5 and 300 cm, larger radius usually indicating larger tidepools. Tidepool 12, for example, has a radius of 300 cm, which reflects its large size. The radius serves as a key indication of the tidepool's total size and possible degree of habitat complexity.

- **Shape**

At Chhara, the tidepool forms are oval, elongated, and irregular, and they each have a distinct impact on the ecological characteristics:

1. **Oval shape**

Tidepool 1 is oval shape, and more consistent proportions may contribute to a more stable environment with well-balanced water circulation.

2. **Elongated shapes**

Several tidepools have elongated shapes (see 2, 8, and 14 for examples), suggesting a long, narrow form. Longitudinal tidepools may promote particular patterns of water movement, which might impact the distribution of nutrients and possibly provide a niche for a particular group of organisms that are suited to these circumstances.

3. **Irregular shapes**

Boundaries of irregular tidepools, such as those in 6, 9, and 16, are generally intricate and variable. Different biological niches and a higher quantity of microhabitats might be produced by these forms. Because there is a greater range of habitats accessible, shape variability can lead to increased biodiversity.

D. Ecological implications

1. Large and Deep tidepools

The largest and deepest tidepools, such as tidepool 12, which are 600 cm long and 60 cm deep, provide considerable, stable habitats that probably sustain a wide variety of species. These pools give organisms more steady survival circumstances and an extensive space to reside.

2. Smaller and Shallow tidepools

Tidepool 1 and other smaller, shallower tidepools are more vulnerable to changes in the surrounding environment. Compared to larger pools, these pools may host fewer or different species, frequently favouring those suited to more variable environments.

SHAPE IMPACT

A tidepool's form affects how its microhabitats are distributed. When it comes to their ecological advantages, extended tidepools may differ from irregular pools. More complex habitats with a wider range of circumstances are frequently produced by irregular shapes, which may increase species richness.

4.3 COMMUNITY STRUCTURE OF TIDEPOOLS

151 macrofaunal species have been recorded from these 50 tidepools during the study period (Table 4). Included in nine distinct phyla, Porifera, Cnidaria, Platyhelminthes, Nemertea, Annelida, Arthropoda, Mollusca, Echinodermata and Chordata. The Veraval coast have been has the maximum number of species, 114 while the coasts of Mul Dwarka and Chhara have the lowest number 68 and 94. At the genus/species level, each organism that was recorded was categorized. Table 4 & 5 provides a comprehensive taxonomy of all the documented species.

PORIFERA

Eight species belonging to the phylum Porifera were recorded throughout the study period. Among these, the South Saurashtra coast was inhabited to significant populations of *Cliothosa delitrix*, *Cliona* spp., and *Halichondria panicea* (Sabapara and Poriya, 2023). While *Cliothosa delitrix* showed a wider range of habitat preference, occurring not only in shallow high tide pools and upper mid-littoral zones but also extending to deeper mid-littoral and lower littoral pools, *Cinachyrella* spp. was primarily found in shallow high tide pools and upper mid-littoral zones. In contrast to *Cinachyrella* spp., which have a more limited range of habitat, *Cliothosa delitrix* exhibits a distribution pattern which highlights its ecological diversity and adaptability.

CNIDARIA

22 Cnidaria species, comprising seven sea anemones, seven zoantharians, five corals, two hydrozoans, and one jellyfish species, were found during the study from three distinct types of tidepools. *Zoanthus sansibaricus* has been identified along the slopes and edges of tidepools, whereas *Actinia equina* was only found in shallow high tidepools (Shah, 2017; Pandya, 2015). Significantly, large areas of the upper and intermediate littoral zones along rocky shore have seen a significant increase in the dominance of zoantharian colonies, displacing the algal vegetation that was previously abundant in these zones (Desai, 1987). Furthermore, it was noted that *Porites* spp. were prominent in patches across the middle and lower littoral zones of the tidepools, suggesting a notable presence and possible ecological influence in these environments.

PLATYHELMINTHES

Two Platyhelminthes species have been found throughout this study. Along the Chhara coast, *Pseudoceros susanae* was commonly seen in deep mid- and lower littoral pools. Coralline algae predominates in these habitats. Other Polycladida species, on the other hand, were only found in the same location in shallow high tidepools. With *Pseudoceros susanae* preferred the more complex, algal-dominated environments of deeper pools and Polycladida species being adapted to the unique conditions of the shallower tidepools, this distribution pattern shows habitat-specific preferences among the Platyhelminthes.

NEMERTEA

During the study, *Evelineus mcintoshii* and *Baseodiscus hemprichii*, two species of Nemertea, were identified. Remarkably, neither species could be found in the tidepools along the Mul Dwarka shore. *Evelineus mcintoshii*, however, was only found in the tidepools of Veraval, suggesting that this species has a particular affinity for habitat or that its range is restricted. However, no *Baseodiscus hemprichii* was found in any of the tidepools that were studied at either location. This suggests that either it may not exist in these habitats or that more research is necessary to determine the extent and distribution of its habitat.

ANNELIDA

Sixteen species in the phylum Annelida have been recorded during the study. Furthermore, subtidal regions in the Gulf of Kutch support a diverse range of macrobenthic organisms, with polychaetes being the most common, followed by gastropods and crustaceans, all including to the region's overall biodiversity (Shivanagouda, 2013).

These included *Branchiomma* spp. and *Sabellastarte spectabilis*, which were only found in the upper mid-littoral pools of Chhara, suggesting that these species preferred a particular type of environment. Nonetheless, it was discovered that Serpulidae worms were widespread in all of the places that were examined. Typically, these worms formed dense colonies that were linked to zoanthid colonies in tidepools. Furthermore, this preference for such types of microhabitats has been shown by the frequent attachment of solitary tubes of Sabellidae spp. to coral substrates. *Branchiomma* spp., *Sabellastarte spectabilis*, and Sabellidae spp. have distinct habitat linkages with tidepool environments, which are highlighted by this distribution pattern, which also demonstrates the ecological adaptability of the Serpulidae.

ARTHROPODA

With a total of 27 species recorded, Arthropoda was the second most diverse phylum in the study area. Of these, the high tidepools in Chhara were particularly inhabited to large populations of *Clibanarius rhabdodactylus* and *Clibanarius zebra*. On the other hand, *Pilumnus* spp. were often seen along the Mul Dwarka coastline. More specifically, *Clibanarius rhabdodactylus* was identified in significant numbers along Veraval's rocky coastlines, where it lives in the upper and middle intertidal zones in shallow tidepools and rock crevices (Patel et al., 2023). Additionally, in the shallow high tidepools and upper mid-littoral pools at Mul Dwarka, *Atergatis ocyroe* was observed. This species is distinguished by its brown blotches and patches surrounded by white lines on the carapace, with similar dark brown spots on the chelipeds, abdomen, maxillipeds, and thoracic sternum (Trivedi, 2016). This distribution reveals the distinct ecological niches and environmental preferences that various arthropod species occupy in the studied area.

MOLLUSCA

A total of 56 species from 20 family were recorded throughout the study. Intertidal habitats in Gujarat support a diverse range of species, particularly in rock pools and subtidal zones. Studies in the region showed the presence of a complex ecology, including limpets, barnacles, macrobenthos, and gastropods (Vakani and Kundu, 2020; Trivedi et al., 2021; Shivanagouda, 2013; Temkar, 2014).

The class Gastropoda showed out among them all as the most diverse and prominent in all tidepool habitats. The gastropod population along the Veraval shore contributes to the variety, with species such as Turbo coronatus and Cerithium morus in abundance. (Teremkar, 2014).

Interestingly, *Thylacode*, a species of Vermetid, was found mostly in deep mid- and lower littoral pools at Mul Dwarka, and in shallow high tidepools at Chhara. Joshi (2015) has conducted the first comprehensive examination of these gastropods' substrate preferences and densities in Gujarat. A rich and diverse gastropod community was evident in the shallow high tidepools, where a number of gastropod species, including *Lunella coronata*, *Rhyssoplax peregrina*, *Astralium semicostatum*, *Cellena karanchiensis*, *Turbo bruneus*, *Cellena radiata*, and *Turbo intercoastalis*, predominated.

ECHINODERMATA

Seven Echinodermata species were identified across three study locations, including three brittle stars, one sea urchin, and three sea stars. Sea stars were found mostly in deep mid- and lower littoral pools. *Amphipholis squamata* and *Ophiactis savignyi* were particularly frequent among brittle stars in the middle and lower littoral zones, often found in zoanthid colonies and seaweed holdfasts. *Amphipholis squamata* was the most common species found along the Veraval coast (Baroliya, 2022). This distribution pattern demonstrates various echinoderm species' affinity for certain microhabitats within tidepools and littoral zones, showing their ecological role and interactions with local marine population.

CHORDATA

A total of 11 species from 20 family were recorded throughout the study. The distribution of species across the three sites; Veraval, Mul Dwarka, and Chhara, reveals varying patterns of presence (P) and absence (A). Species such as *Gobius paganellus*, *Abudefduf* spp., and *Pomacanthus annularis* are present at all three sites, indicating broad habitat suitability across the locations for these species. Conversely, some species like *Gobius bucchichi* and *Gobius* spp. 1 are present only at Veraval and Mul Dwarka but absent at Chhara, suggesting site specific ecological conditions or environmental factors that support their presence at those locations but not at Chhara. In the case of *Gobius* spp. 2 and *Gobius* spp. 3, the species show a pattern of presence at two sites, indicating some level of habitat preference or competitive advantage in those environments, with absence in one site possibly due to factors such as food availability, water quality, or interactions with other species. The Andaman coast revealed 35 species of ornamental fishes across 100 tide pools, indicating a significant diversity in these environments (Kumar et al., 2016). The observed variations in species distribution can be attributed to environmental heterogeneity, differences in habitat preferences, and possibly interspecific competition, which collectively influence species occurrence at these sites.

Table 4: The taxonomic classifications of the tidepool macrofauna reported throughout the study period are consistent with the recent updates from WoRMS (World Register of Marine Species) regarding scientific nomenclature and taxonomic positions

Sr. No.	PHYLUM	CLASS	ORDER	FAMILY	*SPECIES*
1	Porifera	Demospongiae	Clionaida	Clionaidae	*Cliothosa delitrix*
2				Clionaidae	*Cliona* spp.
3			Tetractinellida	Tetillidae	*Cinachyrella* spp.
4			Suberitida	Halichondriidae	*Halichondria* spp. 1
5				Halichondriidae	*Halichondria* spp. 2
6				Halichondriidae	*Halichondria panicea*
7			Haplosclerida	Chalinidae	*Haliclona cinerea*
8				Chalinidae	*Haliclona tubifera*
1	Cnidaria	Anthozoa	Actiniaria	Actiniidae	*Anthopleura sola*
2					*Anthopleura elegantissima*
3					*Anthopleura* spp.
4					*Actinia equina*
5					*Urticina clandenstina*
6				Aiptasiidae	*Exaiptasia diaphana*
7				Phymanthidae	*Phymanthus crucifer*
8			Zoantharia	Zoanthidae	*Zoanthus kuroshio*

9					*Zoanthus vietnamensis*
10					*Zoanthus sansibaricus*
11				Sphenopidae	*Palythoa caesia*
12					*Palythoa mutuki*
13					*Palythoa heliodiscus*
14		Scyphozoa	Semaeostomeae	Ulmaridae	*Aurelia* spp.
15		Hydrozoa	Siphonophorae	Physaliidae	*Physalia physalis*
16			Anthoathecata	Porpitidae	*Porpita porpita*
17		Anthozoa	Scleractinia	Poritidae	*Porites compressa*
18					*Porites* spp.
19					*Goniopora columna*
20					*Goniopora* spp.2
21				Dendrophylliidae	*Turbinaria peltata*
22				Hexacorallia	*Isaurus tuberculatus*
1	Platyhelminthes	-	-	Pseudocerotidae	*Pseudoceros susanae*
2			Polycladida	-	Polycladida spp.

1	Nemertea	Pilidophora	Heteronemertea	Lineidae	*Evelineus mcintoshii*
2				Valenciniidae	*Baseodiscus hemprichii*
1	Annelida	Polychaeta	Sabellida	Sabellidae	*Branchiomma* spp.
2					*Sabellastarte spectabilis*
3					Sabellidae spp. 1
4					Sabellidae spp. 2
5					Sabellidae spp. 3
6					Sabellidae spp. 4
7					Sabellidae spp. 5
8				Serpulidae	*Serpula* spp.
9			Phyllodocida	Phyllodocidae	*Eulalia viridis*
10				Nereididae	Nereididae spp.1
11					Nereididae spp. 2
12					Nereididae spp. 3
13			Terebellida	Cirratulidae	*Timarete* spp.
14					*Cirriformia* spp.
15					*Daylithos parmatus*

16			-	-	*Polychaete* spp.
1	Mollusca	Gastropoda	Littorinimorpha	Cymatiidae	*Gyrineum natator*
2				Littorinidae	*Echinolittorina leucostica*
3					*Echinolittorina malaccana*
4				Cypraeidae	*Naria ocellata*
5					*Mauritia arabica asiatica*
6					*Mauritia eglantina*
7					*Mauritia histrio*
8					*Mauritia* spp.
9				Vermetidae	*Thylacode* spp.1
10					*Thylacode* spp.2
11					*Thylacode* spp.3
12				Rostellariidae	*Tibia curta*
13			Neogastropoda	Muricidae	*Mancinella armigera*
14				Conidae	*Conus* spp. 1
15					*Conus* spp. 2
16					*Conus* spp. 3

17				Muricidae	*Maculotriton serrialis*
18					*Lataxiena bombayana*
19				Columbellidae	*Mitrella scripta*
20			Caenogastropoda	Cerithiidae	*Cerithium zonatum*
21					*Cerithium* spp. 1
22					*Cerithium* spp. 2
23					*Clypeomorus batillariaeformis*
24			Trochida	Trochidae	*Trochus stellatus*
25					*Turbo bruneus*
26					*Turbo intercoastalis*
27					*Astralium semicostatum*
28					*Astralium stellare*
29					*Lunella coronata*
30			Nudibranchia	Samlidae	*Samla bicolor*
31				Chromodorididae	*Hypselodoris maritima*
32				Facelinidae	*Phidiana militaris*
33			Chitonida	Chitonidae	*Rhyssoplax peregrina*
34					*Chiton* spp. 1

35					*Chiton* spp. 2
36			Aplysida	Aplysiidae	*Aplysis oculifera*
37			Cycloneritida	Neritidae	*Nerita albicilla*
38					*Nerite* spp.
30			-	-	*Cowrie* spp.
40		Cephalopoda	Octopoda	Octopodidae	*Octopus vulgaris*
41					*Octopus* spp.1
42					*Octopus* spp. 2
43		Gastropoda	Systellommatophora	Onchidiidae	*Peronia verruculata*
44			-	-	Gastropod spp. 1
45			-	-	Gastropod spp. 2
46			-	-	Gastropod spp. 3
47			-	-	Gastropod spp. 4
48			-	-	Gastropod spp. 5
49			-	-	*Patella* spp.1
50			-	-	*Patella* spp. 2
51		Bivalvia	-	-	Bivalvia spp. 1
52			-	-	Bivalvia spp. 2

53			-	-	Bivalvia spp. 3
54		Gastropoda	-	Nacellidae	*Cellena radiata*
55			-		*Cellena karanchiensis*
56			-	-	*Siphonaria* spp.
1	Arthropoda/Crustacea	Thecostraca	Balanomorpha	Balanidae	*Balanus* spp.
2					*Amphibalanus amphrite*
3				Chthamalidae	*Chthamalus stellatus*
4				Tetraclitidae	*Tetraclita squamosa rufotincta*
5					*Tetraclitella purpurascens*
6		Malacostraca	Stomatopoda	Gonodactylidae	*Gonodactylus chiragra*
7					*Gonodactylus viridis*
8			Scalpellomorpha	Lapadidae	*Lepas anatifera*
9			-	-	*Shrimp* spp.
10			Decapoda	Xanthidae	*Atergatis ocyroe*
11				Oziidae	*Epixanthus* spp.
12				Cancridae	*Cancer pagurus*
13					*Eriphia* spp.

14				Portunidae	*Charybdis annulata*
15					*Charybdis* spp.
16				Diogenidae	*Clibanarius rhabdodactylus*
17					*Clibanarius zebra*
18					*Clibanarius* spp.
19				Palaemonidae	*Palaemon serratus*
20				Porcellanidae	*Petrolisthes* spp.
21				Pilumnidae	*Pilumnus* spp. 2
22					*Pilumnus vesoertilio*
23				Grapsidae	*Grapsus* spp. 1
24					*Grapsus* spp. 2
25					*Grapsus* spp. 3
26				-	Crab spp. 1
27				-	*Lobster* spp.
1	Echinodermata	Ophiuroidea	Amphilepidida	Amphiuridae	*Amphipholis squamata*
2				Ophiactidae	*Ophiactic savignyi*
3				-	Ophiuroidea spp. 1

4		Echinoidea	Camarodonta	Echinometridae	*Echinometra* spp.
5		Asteroidea	Valvatida	Asterinidae	*Aquilonastra lorioli*
6					*Aquilonastra* spp.1
7					*Aquilonastra* spp. 2
1	Chordata	Teleostei	Gobiiformes	Gobiidae	*Gobius paganellus*
2					*Gobius* spp.1
3					*Gobius vittatus*
4					*Gobius niger*
5					*Gobius bucchichi*
6					*Gobius* spp. 2
7					*Gobius* spp. 3
8					*Gobius* spp. 4
9			Ovalentaria incertae sedis	Pomacentridae	*Abudefduf* spp.
10			Acanthuriformes	Pomacanthidae	*Pomacanthus annularis*
11			Anguilliformes	Muraenidae	*Gymnothorax pseudothyrsoideus*

Table 5: List of macrofauna observed in tidepools at selected study sites (abbreviations: "P" for Present, "A" for Absent)

No.	Name of species	Sampling sites		
		Veraval	**Mul Dwarka**	**Chhara**
	Porifera			
1	*Cliothosa delitrix*	P	P	P
2	*Cliona* spp.	P	A	A
3	Cinachyrella spp.	P	P	P
4	*Halichondria* spp. 1	P	A	A
5	*Halichondria* spp. 2	A	P	P
6	*Halichondria panicea*	P	P	P
7	*Haliclona cinerea*	P	A	P
8	*Haliclona tubifera*	P	A	A
	Cnidaria			
1	*Anthopleura sola*	P	A	P
2	*Anthopleura elegantissima*	P	P	P
3	*Anthopleura* spp.	A	A	P
4	*Actinia equina*	P	A	P
5	*Urticina clandenstina*	P	A	P
6	*Exaiptasia diaphana*	P	P	P
7	*Phymanthus crucifer*	A	P	A
8	*Zoanthus Kuroshio*	A	A	P
9	*Zoanthus vietnamensis*	P	P	P
10	*Zoanthus sansibaricus*	P	P	P
11	*Palythoa caesia*	P	A	P
12	*Palythoa mutuki*	P	P	P
13	*Palythoa heliodiscus*	A	P	A
14	*Aurelia* spp.	A	A	P
15	*Physalia physalis*	P	P	P
16	*Porpita porpita*	P	P	P
17	*Porites compressa*	P	A	A

18	*Porites* spp.	P	A	A
19	*Isaurus tuberculatus*	P	A	P
20	*Turbinaria peltata*	A	A	P
21	*Goniopora* spp.1	P	A	P
22	*Goniopora* spp.2	A	A	P
		Platyhelminthes		
1	*Pseudoceros susanae*	P	P	P
2	Acotylea	A	A	P
		Nemertea		
1	*Evelineus mcintoshii*	P	A	A
2	*Baseodiscus hemprichii*	P	A	P
		Annelida		
1	*Branchiomma* spp.	A	A	P
2	*Sabellastarte spectabilis*	A	A	P
3	Sabellidae spp. 1	P	P	P
4	Sabellidae spp. 2	P	P	P
5	Sabellidae spp. 3	P	A	A
6	Sabellidae spp. 4	A	A	P
7	Sabellidae spp. 5	P	P	P
8	*Serpula* spp.	P	A	A
9	*Eulalia viridis*	P	P	P
10	Nereididae 1	P	P	P
11	Nereididae 2	P	A	P
12	Nereididae 3	P	A	P
13	*Timarete* spp.	P	P	P
14	*Cirriformia* spp.	P	A	A
15	*Daylithos parmatus*	P	A	A
16	*polychaete* spp.	A	A	P

Mollusca				
1	*Gyrineum natator*	P	A	A
2	*Echinolittorina leucostica*	A	P	P
3	*Echinolittorina malaccana*	P	A	P
4	*Naria ocellata*	P	A	A
5	*Mauritia arabica asiatica*	A	P	P
6	*Mauritia eglantina*	P	P	P
7	*Mauritia histrio*	P	A	P
8	*Mauritia* spp.	P	A	A
9	*Thylacode* spp.1	P	P	P
10	*Thylacode* spp.2	A	P	A
11	*Thylacode* spp.3	A	P	A
12	*Tibia curta*	P	A	P
13	*Mancinella armigera*	P	A	A
14	*Conus* spp. 1	P	A	P
15	*Conus* spp. 2	P	A	P
16	*Conus* spp. 3	P	P	P
17	*Maculotriton serrialis*	P	P	P
18	*Lataxiena bombayana*	P	A	P
19	*Mitrella scripta*	A	P	P
20	*Cerithium zonatum*	P	P	P
21	*Cerithium* spp.1	P	P	P
22	*Cerithium* spp. 2	P	P	P
23	*Clypeomorus batillariaeformis*	P	P	P
24	*trochus stellatus*	P	P	P
25	*Turbo bruneus*	P	P	P
26	*Turbo intercoastalis*	P	P	P
27	*Astralium semicostatum*	A	P	P
28	*Astralium stellare*	P	P	P
29	*Lunella coronata*	P	P	P

30	*Samla bicolor*	P	P	A
31	*Hypselodoris maritima*	P	A	A
32	*Phidiana militaris*	P	A	A
33	*Rhyssoplax peregrina*	P	P	P
34	*Chiton* spp. 1	P	A	P
35	*Chiton* spp. 2	P	A	A
36	*Aplysia oculifera*	P	P	P
37	*Aplysia* spp. 1	P	A	P
38	*Nerita albicilla*	P	P	P
39	*Nerita* spp.	P	P	P
40	Cowrie spp.	A	P	A
41	*Octopus vulgaris*	A	A	P
42	*Octopus* spp.1	P	A	A
43	*Octopus* spp.2	P	A	A
44	Peronia verruculata	P	P	P
45	gastropod spp.1	P	A	A
46	gastropod spp.2	P	A	A
47	gastropod spp.3	P	A	A
48	gastropod spp.4	P	A	A
49	gastropod spp.5	A	P	A
50	Gastropod spp.6	A	P	A
51	Bivalvia spp. 1	P	A	P
52	Bivalvia spp. 2	P	A	A
53	Bivalvia spp. 3	P	P	A
54	*Cellena radiata*	P	P	P
55	*Cellena karanchiensis*	P	P	P
56	*Siphonaria* spp.	P	A	A
Arthropoda				
1	*Balanus* spp.	P	A	P
2	*Amphibalanus amphrite*	P	P	P

3	*Chthamalus stellatus*	P	A	P
4	*Tetraclita squamosa rufotincta*	P	P	P
5	*Tetraclitella purpurascens*	A	A	P
6	*Gonodactylus chiragra*	P	P	A
7	*Gonodactylus viridis*	P	P	P
8	*Lepas anatifera*	P	A	A
9	shrimp spp.	A	A	P
10	*Atergatis ocyroe*	P	A	A
11	*Epixanthus* spp.	P	A	A
12	*Cancer* spp.	P	A	A
13	*Eriphia* spp.	A	P	A
14	*Charybdis annulata*	P	A	P
15	*Charybdis* spp.	A	P	A
16	*Clibanarius rutilus*	P	A	A
17	*Clibanarius zebra*	P	P	P
18	*Clibanarius* spp.	P	A	A
19	*Palaemon serratus*	A	P	A
20	*Petrolisthes* spp.	A	A	P
21	*Pilumnus* spp.	P	P	P
22	*Pilumnus vespertilio*	P	P	P
23	*Grapsus* spp. 1	A	A	P
24	*Grapsus* spp. 2	A	A	P
25	Crab spp. 1	P	A	A
26	lobster spp.	A	A	P
27	*Leptodius* spp.	P	A	A
Echinodermata				
1	*Amphipholis squamata*	P	P	P
2	*Ophiactic savignyi*	P	P	A
3	Ophiuroidea spp.	A	P	A

4	*Echinometra* spp.	P	A	A
5	*Aquilonastra lorioli*	P	A	A
6	*Aquilonastra* spp.1	P	A	P
7	*Aquilonastra* spp.2	A	A	P
Chordata				
1	*Gobius paganellus*	P	P	P
2	*Gobius xanthocephalus*	P	P	P
3	*Gobius niger*	P	A	P
4	*Gobius bucchichi*	P	P	A
5	*Gobius* spp. 1	P	A	A
6	*Gobius* spp. 2	A	P	A
7	*Gobius* spp. 3	A	P	A
8	*Abudefduf* spp.	P	P	P
9	*Pomacanthus annularis*	P	A	A
10	*Gymnothorax pseudothyrsoideus*	P	A	P
11	*Callionymus reticulatus*	P	A	P

4.3.1 Community composition of tidepools macrofauna

Significant differences in the distribution of species were found across the three sampling sites in a thorough assessment comprising 151 species distributed over 50 tidepools (Figure 4.4). With 56 species, 37% of all species, the Phylum Mollusca was found to be the most dominating. Arthropoda was the second most common phylum, which comprises around 18% of all species with 27 species. Cnidaria was following with 22 species (14%), Annelida was with 16 species (11%), and Chordata was with 11 species (7%). There were seven (5%), eight (6%), two (1%), and two (1%) species each representing Echinodermata, Porifera, Nemertea, and Platyhelminthes. This varying macrofaunal composition, which represented the heterogeneous characteristics of the tidepool ecosystems, differed among assemblages at distinct locations (Figure 4.5, 4.6 & 4.7).

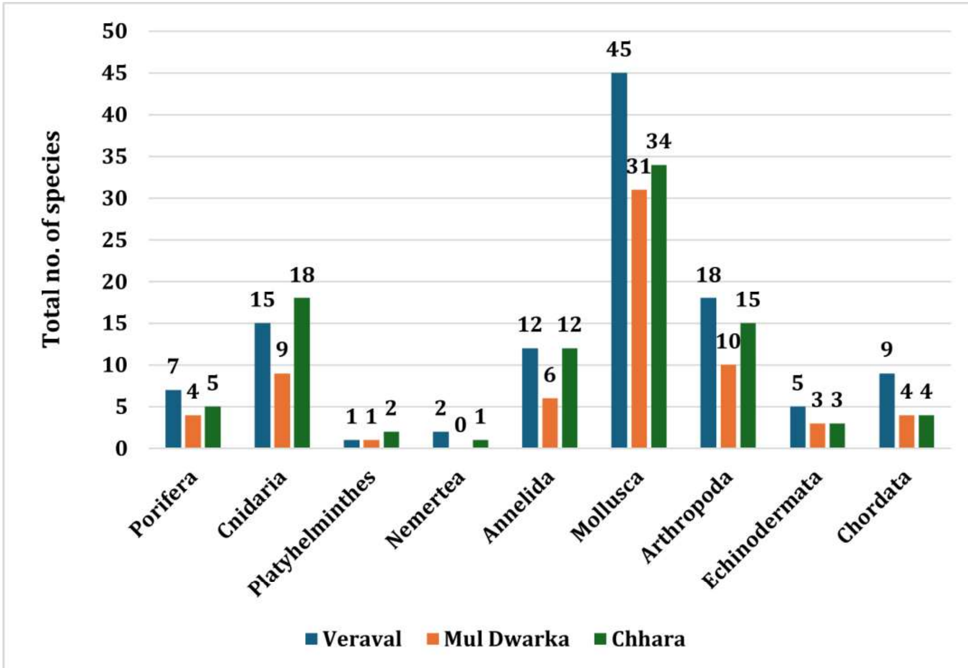


Figure 4.4: Phylum wise distribution of tidepool fauna at all sampling locations

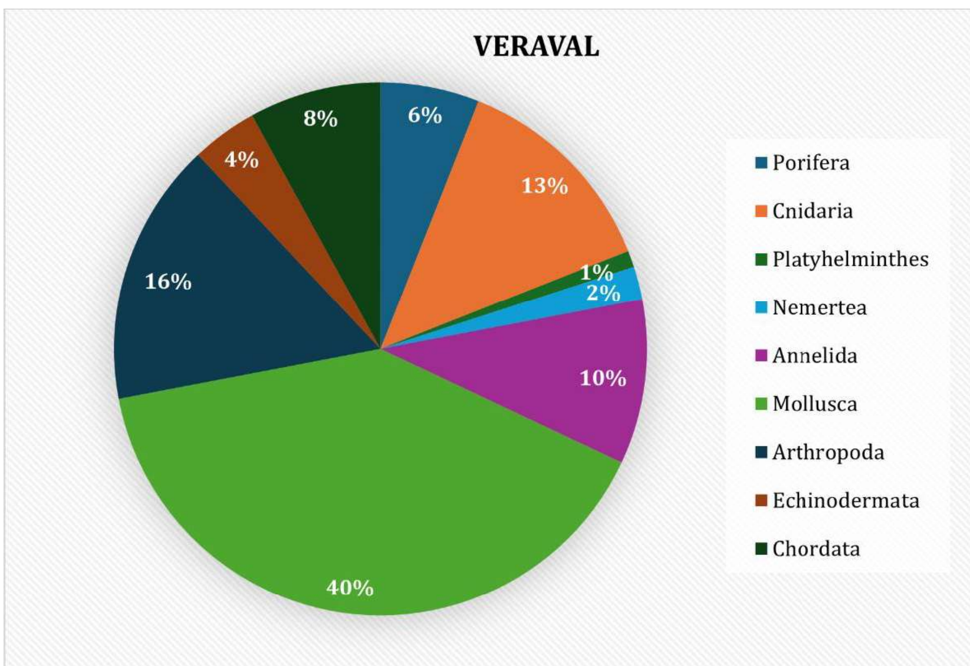


Figure 4.5: Community composition of tidepool fauna at the Veraval. Numbers on the plot indicate each phylum's contribution to the community

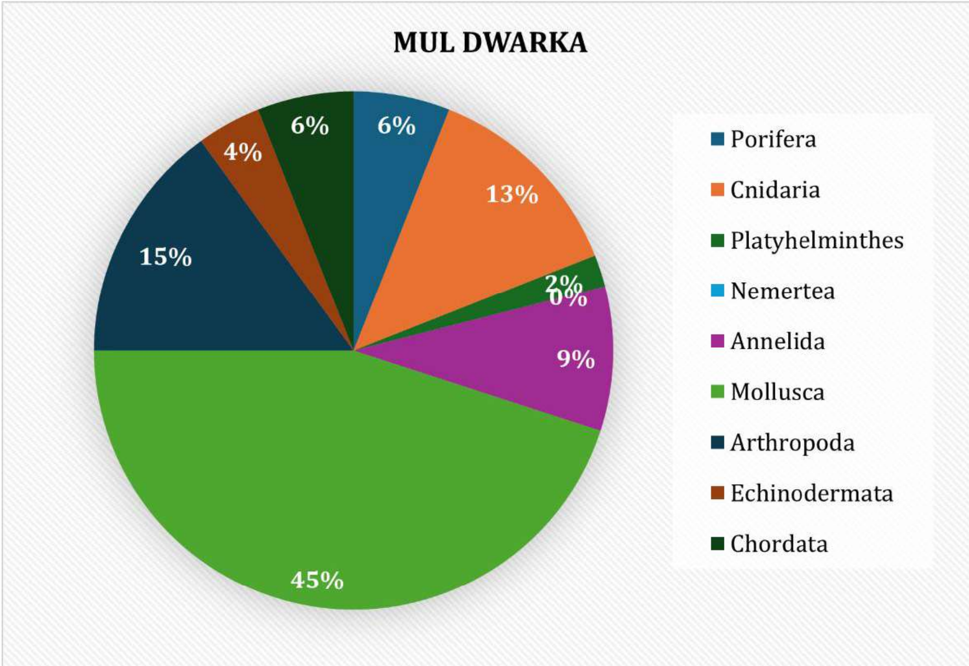


Figure 4.6: Community composition of tidepool fauna at the Mul Dwarka. Numbers on the plot indicate each phylum's contribution to the community

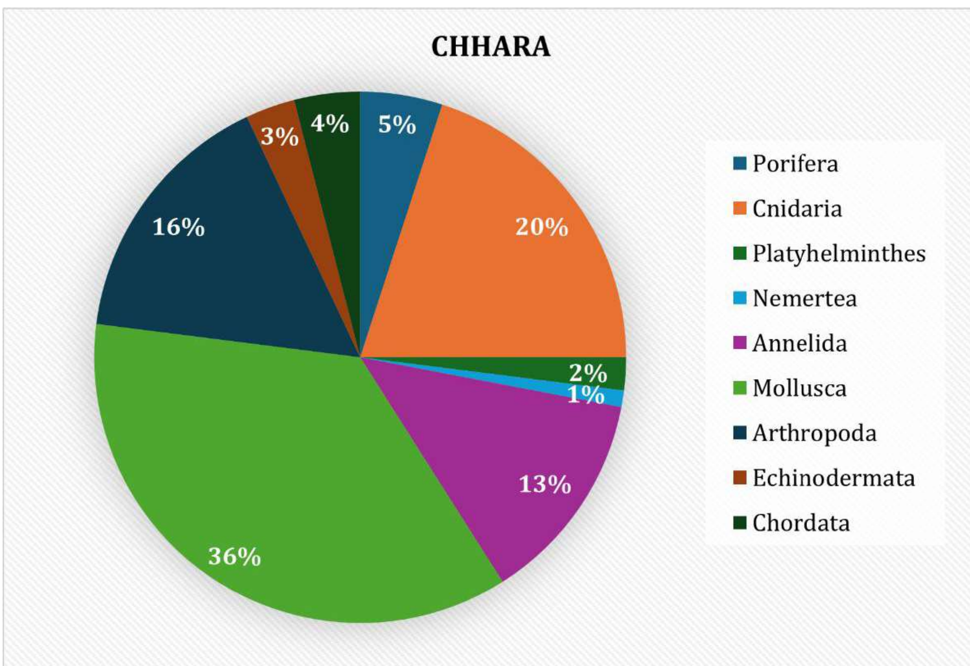


Figure 4.7: Community composition of tidepool fauna at the Chhara. Numbers on the plot indicate each phylum's contribution to the community

4.3.2 Diversity Indices

A. Shannon-Wiener diversity index

The Shannon Index, a measure of community biodiversity, was estimated for three sampling locations: Chhara, Mul Dwarka, and Veraval over a three-year period (2021-2023). This index measures diversity in a community by combining species richness and evenness.

Study, the mean Shannon Index, a measure of biodiversity, differed throughout the three locations. Chhara has an average Shannon Index of 1.83 and a standard deviation of 0.145, suggesting substantial heterogeneity in biodiversity. Mul Dwarka had a lower mean Shannon Index of 1.72 with a standard deviation of 0.125, indicating less biodiversity than Chhara. Veraval had a similar mean Shannon Index of 1.81, but with less fluctuation, as demonstrated by a standard deviation of 0.107, suggesting more stable biodiversity in this location.

The yearly percentage change in biodiversity across the three locations showed unique tendencies. Chhara's biodiversity decreased significantly from 2021 to 2022, by 9.30%, followed by a lower fall of 5.60% in 2023, showing a continued negative trend. Mul Dwarka, on the other hand, had a significant increase in biodiversity, with a 12.79% growth from 2021 to 2022, followed by a stabilization with a slight increase of 1.52% in 2023, indicating a favourable trend. Veraval followed a similar pattern to Chhara, with an 8.22% fall from 2021 to 2022 and a 2.55% decline through 2023, indicating a gradual decline in biodiversity during the investigated period (Figure 4.8).

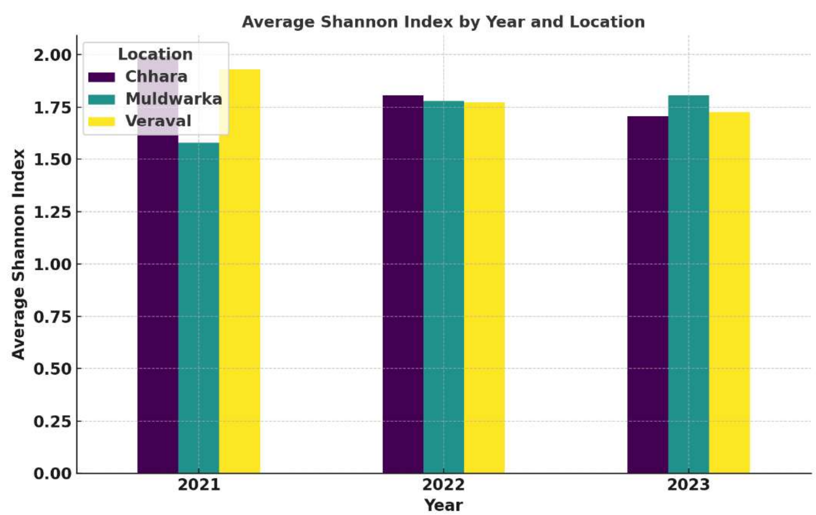


Figure 4.8: Yearly variation of Shannon index for tidepool fauna at sampling sites

The observed Shannon Index changes between years and locations can be linked to a number of ecological and environmental variables that impact species distribution and abundance. The significant increase in biodiversity in Mul Dwarka in 2022 might be attributed to environmental conservation efforts or natural seasonal fluctuations that encourage a broader range of species. In contrast, the declines seen in Chhara and Veraval might be attributed to anthropogenic pressures such as habitat destruction, pollution, or climate changes that affect marine ecosystems.

B. Pielou's Evenness Index (J')

This index is based on the Shannon Diversity Index (H′), where S is the total number of species and H′ is the Shannon Diversity Index. The Shannon Diversity Index measures the uncertainty in predicting the species identity of an individual randomly selected from a dataset.

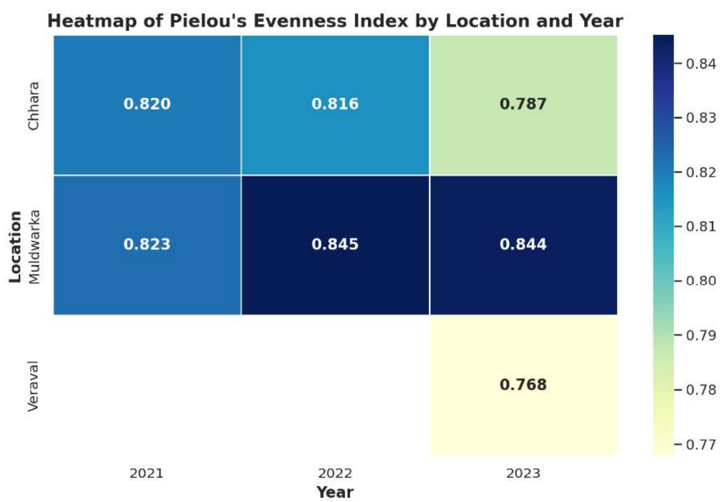


Figure 4.9: Yearly variation of Pielou's Evenness index for tidepool fauna at sampling sites

Across various locations and years, the Pielou's Evenness Index (J') values varied from around 0.76 to 0.82, suggesting moderate to high evenness in the distribution of species. An ecosystem that is healthier and more stable is linked to a more equal distribution of individuals among species, as shown by higher values of J'. Temporal patterns in J' at each site can show changes in the environment over time that may be caused by natural succession, conservation initiatives, or environmental changes. Differences in ecological stresses, management strategies, or habitat characteristics can be highlighted by spatial variation in J' between sites, offering insights into the fundamental causes affecting ecosystem health and biodiversity (Figure 4.9).

C. Berger-Parker Index

To determine the dominant pattern throughout the duration of the months, the Berger-Parker Index was displayed. The variation in species dominance for each month is depicted in a bar plot, which shows how the percentage of the most abundant species varies over time.

The Berger-Parker Index plot has been used to interpret when a single species was significantly dominating the environment. Months with a high index correspond to these types of eras. Lower Berger-Parker Index months, on the other hand, indicate more biodiversity since they indicate a more balanced distribution of individuals among different species. With its important insights on the ecological balance and changes in biodiversity over time, this study is essential to comprehending the dynamics of species dominance within the dataset. These trends attest to the health and stability of the ecosystem and can help guide conservation efforts (Figure 4.10).

The analysis's findings show times of high and low biodiversity, which represent the changes in the environment during a period of several months. Investigating the variables affecting these differences, such as the environment or human activity, may require more research.

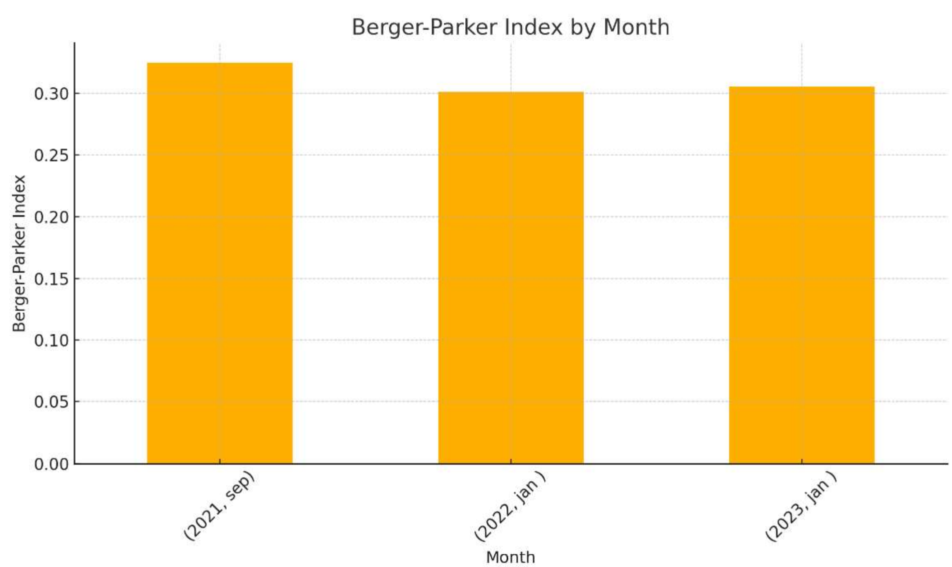


Figure 4.10: Yearly variation of Berger- Parker index for tidepool fauna at sampling sites

4.3.3 Diversity of Animal Taxa and Comparative Study of Sites

Investigate both motile and sessile organisms in order to analyse taxonomic diversity of tidepools in three distinct locations: Veraval, Chhara, and Mul Dwarka, during the specified period of time (September 2021 to September 2023). The data reveals differences in the abundance and distribution of various species at both temporal and spatial scales. The four seasons are as follows: summer (March to May), monsoon (June to August), post-monsoon (September to November), and winter (December to February).

Diversity of Motile Organisms

1. **Veraval**

Mollusca and Arthropoda are the most dominant phyla in the tidepools of Veraval coast. During the winter months (December to February), there is high diversity of these organisms, with Mollusca and Arthropoda in especial abundance. Summer (March to May) shows a persistent presence of these taxa, while total diversity were lower than in winter. The monsoon season (June to August) results in a significant decrease in motile organism diversity, with the most apparent declines observed in June and July. However, the post-monsoon season (September to November) marks a slow recovery, with an increase in the number of Mollusca. This seasonal fluctuation highlights the adaptive adaptations and ecological dynamics of motile organisms in the Veraval area (Figure 4.11).

2. **Mul Dwarka**

Mollusca taxa have been the most dominant frequent motile organisms along the tidepools of Mul Dwarka coast, and their numbers are consistent but low throughout the year. During the winter months (December to February), both Mollusca and Chordata have been shows regular presence, with January being the most diverse month. As the season continues into summer (March to May), there was notable decrease in diversity, especially in May. The monsoon season (June to August) significantly reduces the presence of motile species, with minimum representation at this time. However, the post-monsoon months (September to November) saw a slow recover, with an increase in the number of motile organisms, notably Mollusca, have been increased in November (Figure 4.12).

3. **Chhara**

The tidepools of Chhara coast has a distinct pattern of diversity, with Mollusca predominating and Annelida and Arthropoda have been observed rare. During the winter months (December to February), this taxa's diversity ranges from moderate to high, with notable peaks in January and February. However, as the season continues into summer (March to May), diversity decreases noticeably, with the decrease being noticeable in May. The monsoon season (June to August) has the lowest diversity, with few motile taxa. Following the monsoon, the post-monsoon season (September to November) is a time of recovery, with increased biodiversity, particularly between September and November. This seasonal variation demonstrates the biological dynamics and resilience of the aquatic environment in the tidepools of Chhara area ((Figure 4.13).

Diversity of Sessile Organisms

1. **Veraval**

Cnidaria and Porifera are the most dominant sessile organisms in the tidepools of Veraval coast. During the winter months (December to February), both Cnidaria and Porifera have been observed in abundance. As the season progresses to summer (March to May), their number stays modest, with a minor decrease in May. The advent of the monsoon season (June to August) causes a large fall in the population of these sessile organisms, with the most visible decreases happening in June and July. However, during the monsoon (September to November), there is a noticeable decline, with an increase in the number of sessile taxa. This seasonal variation highlights the role of environmental conditions on the distribution and abundance of sessile species of tidepools in Veraval (Figure 4.14).

2. **Mul Dwarka**

Porifera taxa are the most dominant sessile organisms along the tidepools of Mul Dwarka coast. During the winter months (December to February), these organisms have high percentages, with the peak observed in January. As the season proceeds into summer (March to May), Porifera presence decreases, reaching a low in May. Because of the difficult climatic conditions during the monsoon season (June to August), Porifera numbers were significantly reduced. However, in the post-monsoon season (September to November), there is a steady recover, with higher percentages observed in November. This cyclical pattern highlights how seasonal environmental fluctuations affect the distribution and abundance of Porifera in the Mul Dwarka coast (Figure 4.15).

3. **Chhara**

Cnidaria and Porifera taxa represent the majority of sessile organisms in the tidepools of Chhara area. During the winter months (December to February), several taxa have moderate to high percentages, with January having been the highest. As the season progresses into summer (March to May), their populations decrease noticeably, with the largest drop occurring in May. The monsoon season (June to August) has the lowest percentages of sessile species due to poor environmental circumstances. However, in the post-monsoon season (September to November), there is a recovery phase, with higher percentages of Cnidaria and Porifera observed in September and November. This pattern demonstrates how seasonal fluctuations in environmental conditions affect the distribution and abundance of sessile fauna of tidepools in Chhara (Figure 4.16).

4.3.4 Seasonal and Spatial Variations

Winter (December to February)

During the winter months (December to February), unique patterns of seasonal and spatial variations in marine biodiversity are found at all three sites. Veraval's maritime habitat has the highest total variety, with both motile and sessile organisms prospering. The constant presence of Mollusca and Arthropoda among motile taxa, as well as higher percentages of Cnidaria and Porifera among sessile taxa, indicates a stable and productive environment. In contrast, Chhara has modest variety, with a notable presence of Mollusca and sessile Cnidaria, with peak diversity occurring in January, indicating suitable winter conditions. Mul Dwarka, despite likewise experiencing great variety, has a little lower level than Veraval. The consistent presence of motile Mollusca and sessile Porifera, particularly in January, highlights seasonal stability but indicates a lower overall richness in comparison to Veraval. These variations reflect the impact of specific climatic scenarios and ecological factors on the distribution and abundance of marine organisms throughout the winter months.

Summer (March to May)

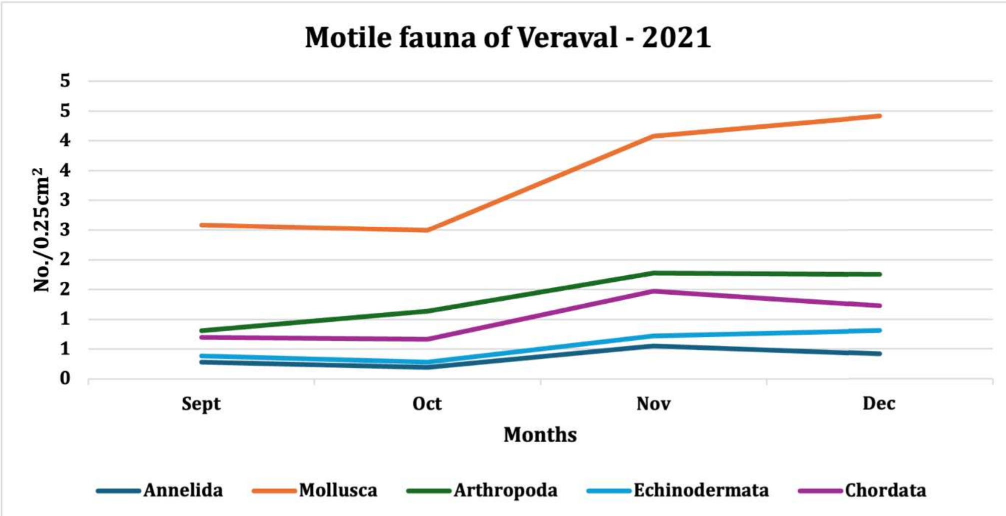
During the summer (March to May), the marine ecosystems of Veraval, Chhara, and Mul Dwarka have been observed significant biodiversity changes. Although motile organisms, notably Mollusca, have been consistently present in Veraval, overall biodiversity was lower than during the winter months. The sessile community also shows a minor decrease, notably in May, indicating changes in the environment or nutrition availability. In Chhara, there was large fall in the richness of motile species, notably in May, as well as a decline in sessile taxa, indicating a significant shift in ecological dynamics. Mul Dwarka displays the most significant fall, with both motile and sessile organisms reaching their lowest diversity in May, which might be attributed to increased environmental stress or changes in habitat conditions.

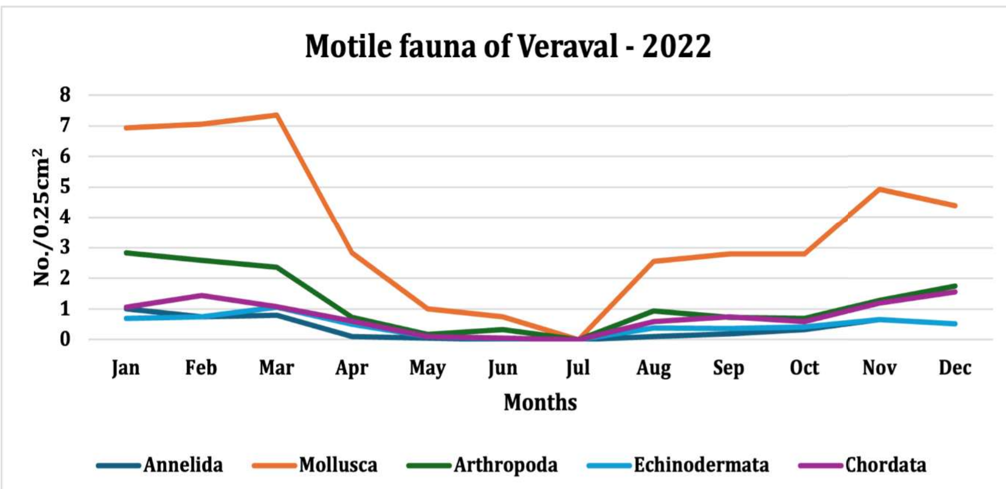
Monsoon (June to August)

During the monsoon season (June to August), all three study sites Veraval, Chhara, and Mul Dwarka, show large decreases in marine biodiversity, while the scale and reason for this decline differ. At Veraval, both motile and sessile species have been significantly reduced, particularly in June and July, owing to increased sedimentation, turbid water conditions, and changed nutrient dynamics caused by monsoon rains. Chhara has the lowest levels of diversity for both motile and sessile organisms, indicating high environmental stress caused by the monsoon's extreme conditions, which are expected to damage marine ecosystems and resource availability. Mul Dwarka also finds a low prevalence of both motile and sessile species, showing that the monsoon has a significant influence on local marine biodiversity, which may be enhanced by harsh water conditions and reduced habitat quality. These findings highlight the significant impact of monsoon-related processes on marine ecosystems, underlining the seasonal difficulties that marine life challenge during this time.

Post-monsoon (September to November)

In the post-monsoon season (September to November), all three study sites; Veraval, Chhara, and Mul Dwarka highlight a phase of recovery in marine biodiversity. At Veraval, there is a noticeable recovery of both motile and sessile species, with increasing population of Mollusca and other sessile taxa indicating that environmental conditions have gradually stabilized following the monsoon. Chhara also indicates a recovery pattern, with both motile and sessile organisms displaying increasing diversity in September and November, indicating better habitat conditions and less stress from monsoon impacts. Similarly, Mul Dwarka's marine life is gradually increasing, with more motile Mollusca and sessile Porifera, indicating a favourable response to the less severe post-monsoon climate. These changes collectively represent a time of ecological recovery and growing stability, as marine ecosystems recover from monsoon-induced disturbances.


Motile fauna of Veraval - 2021
5
5
4
4
3
3
2
2
1
1
0
No./0.25cm²
Sept
Oct
Nov
Dec
Months
Annelida
Mollusca
Arthropoda
Echinodermata
Chordata


Motile fauna of Veraval - 2022
8
7
6
5
4
3
2
1
0
No./0.25cm²
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
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Nov
Dec
Months
Annelida
Mollusca
Arthropoda
Echinodermata
Chordata

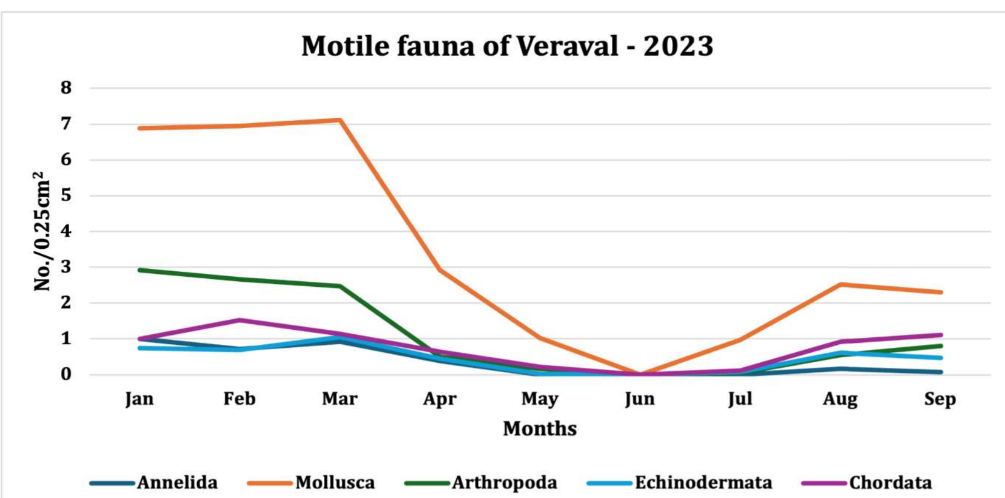
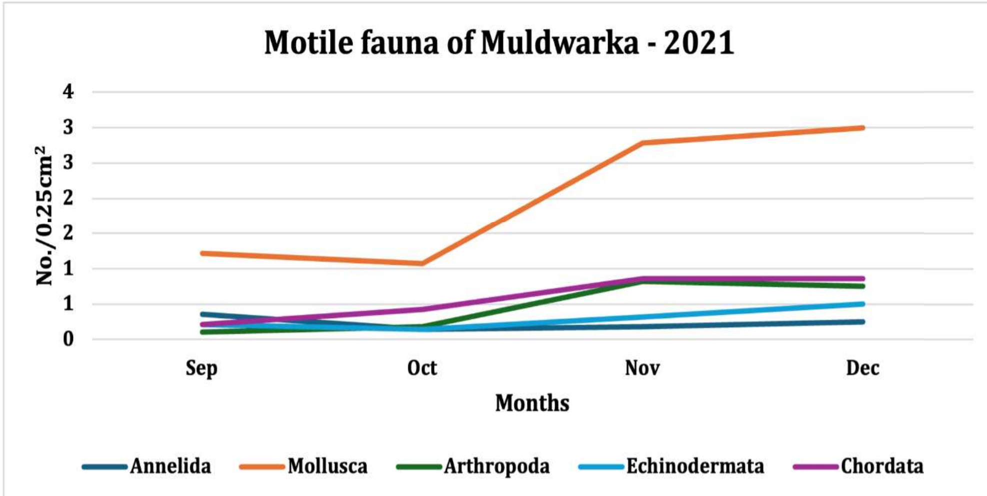
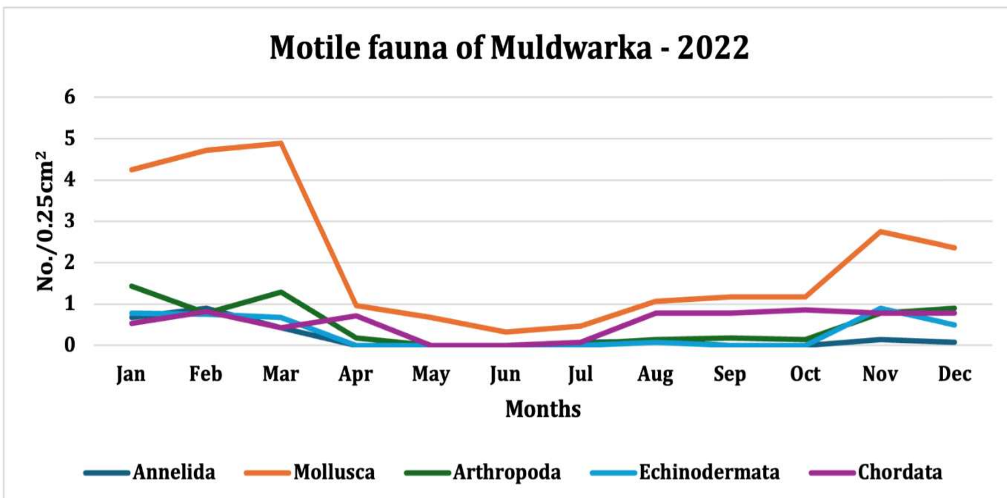

Motile fauna of Veraval - 2023
8
7
6
5
4
3
2
1
0
No./0.25cm²
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Months
Annelida
Mollusca
Arthropoda
Echinodermata
Chordata

Figure 4.11: Seasonal and Spatial variations in the abundance value of tidepool's motile fauna at Veraval (2021, 2022, 2023)





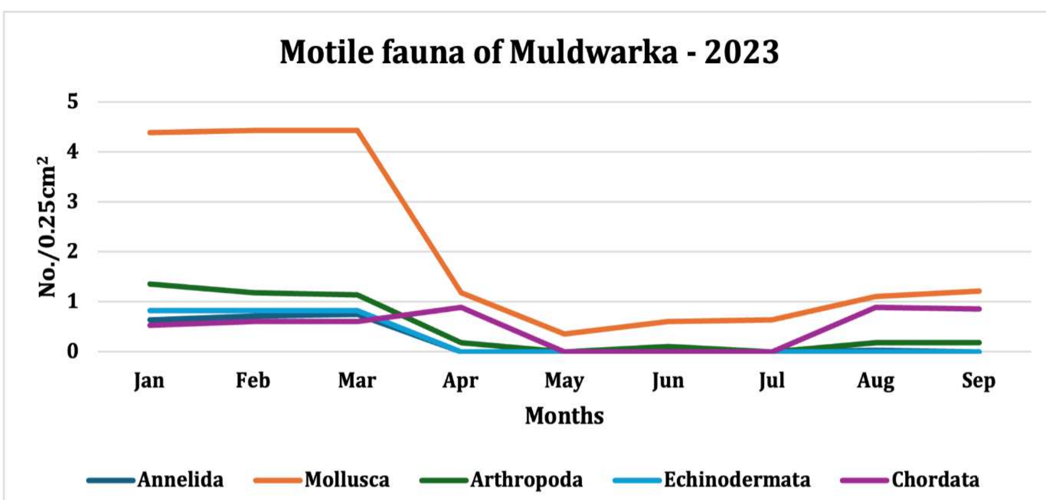
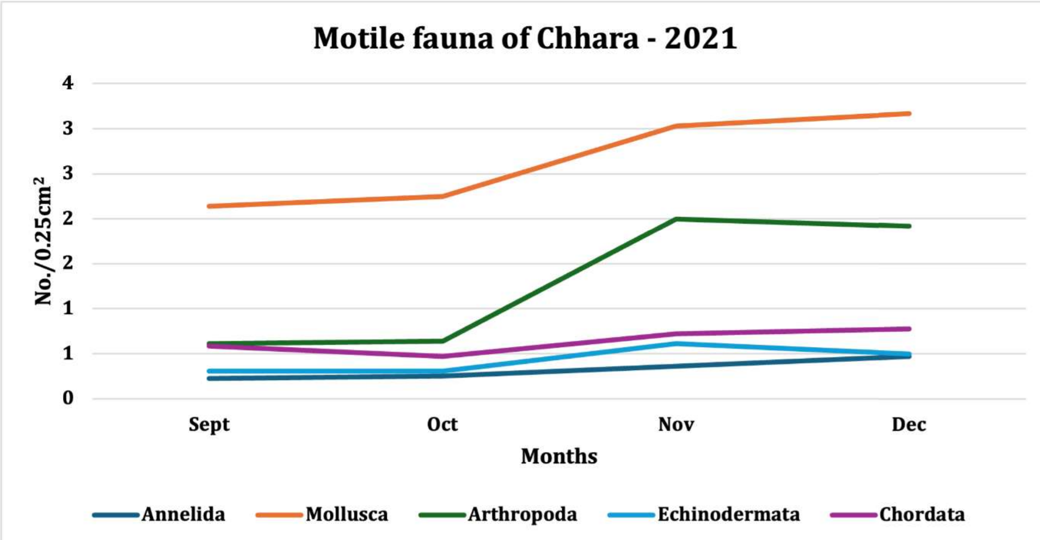
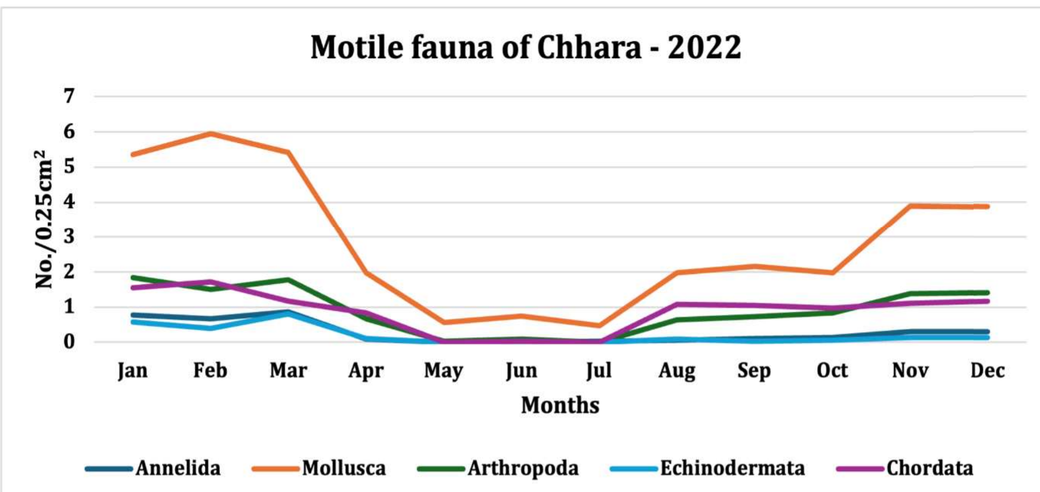


Figure 4.12: Seasonal and Spatial variations in the abundance value of tidepool's motile fauna at Mul Dwarka (2021, 2022, 2023)





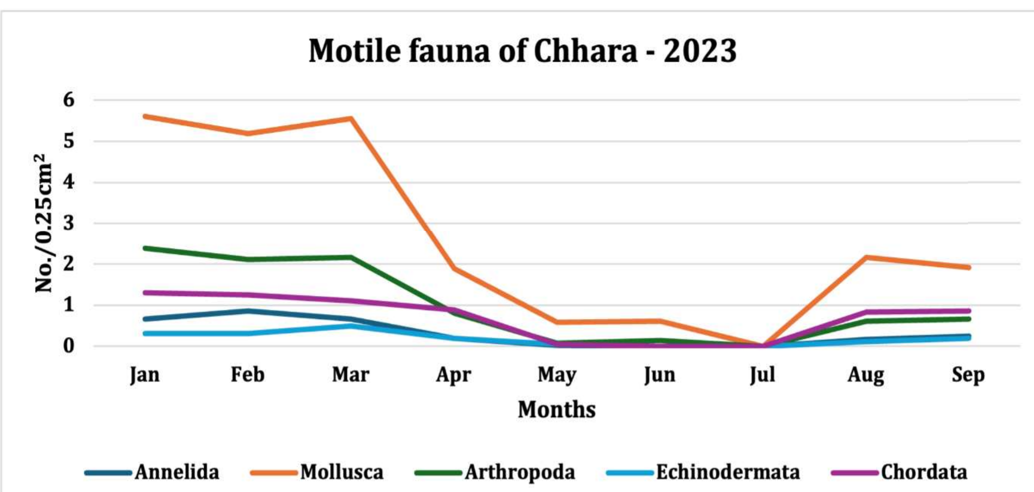
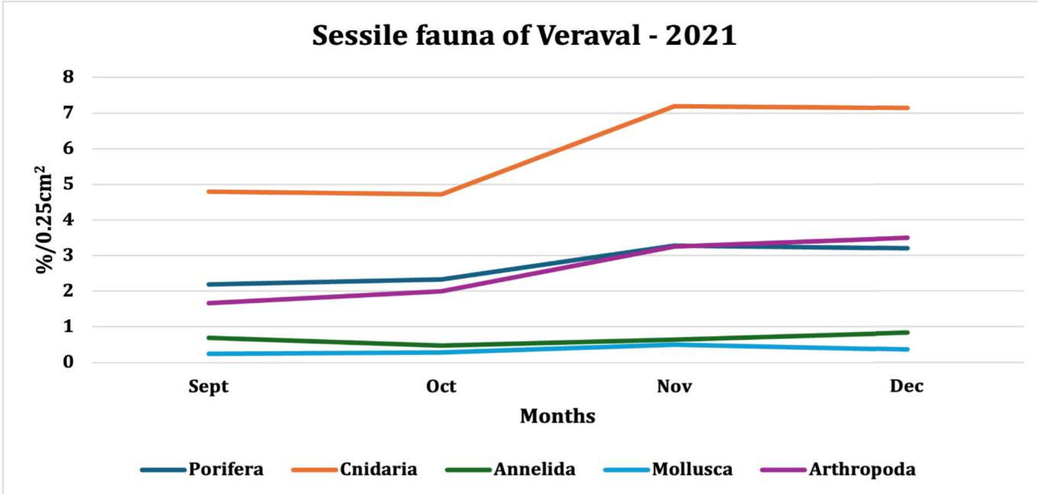
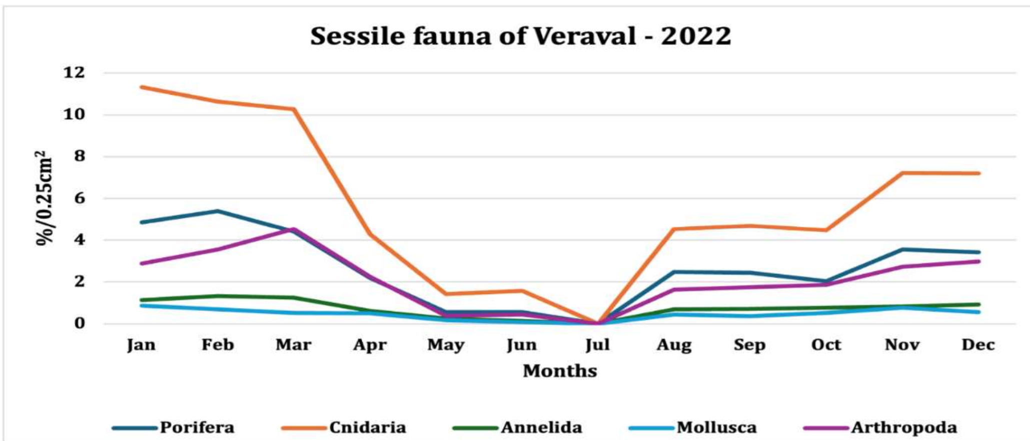


Figure 4.13: Seasonal and Spatial variations in the abundance value of tidepool's motile fauna at Chhara (2021, 2022, 2023).





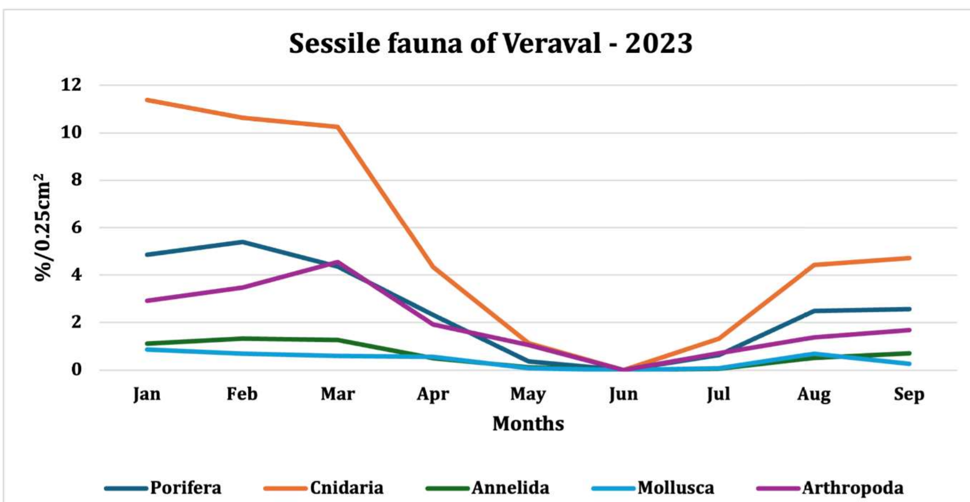
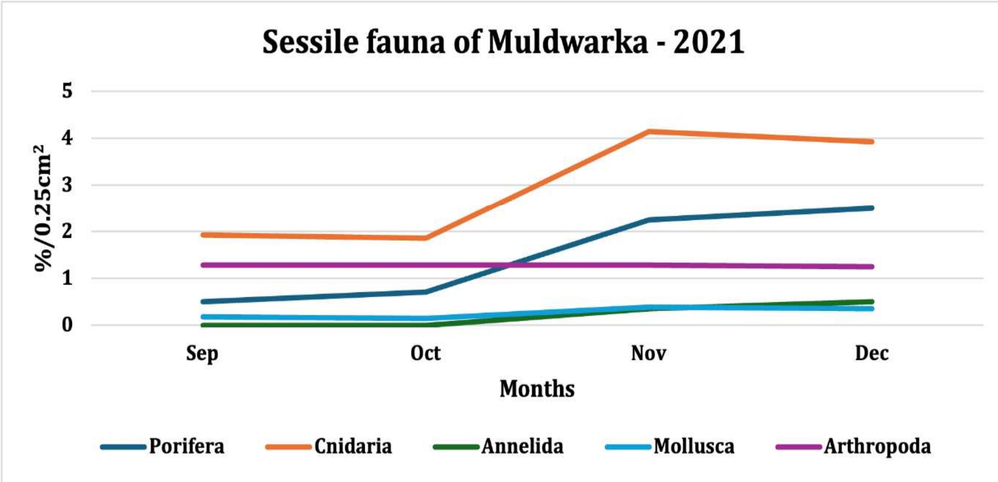
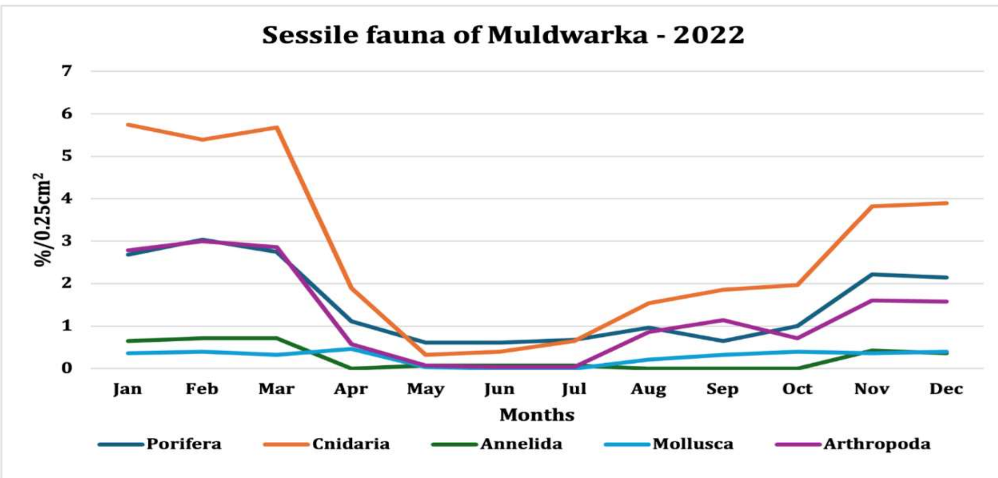


Figure 4.14: Seasonal and Spatial variations in the percentage value of tidepool's sessile fauna at Veraval (2021, 2022, 2023)





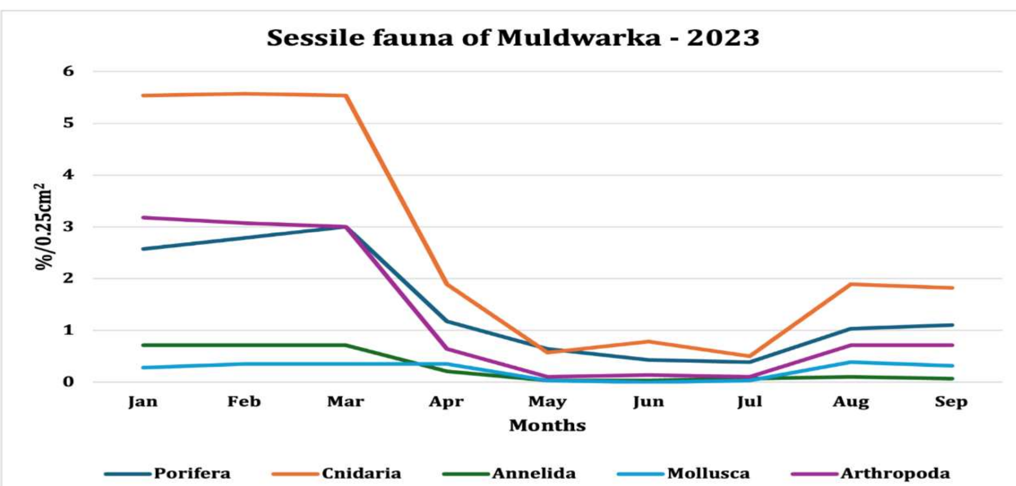


Figure 4.15: Seasonal and Spatial variations in the percentage value of tidepool's sessile fauna at Mul Dwarka (2021, 2022, 2023)

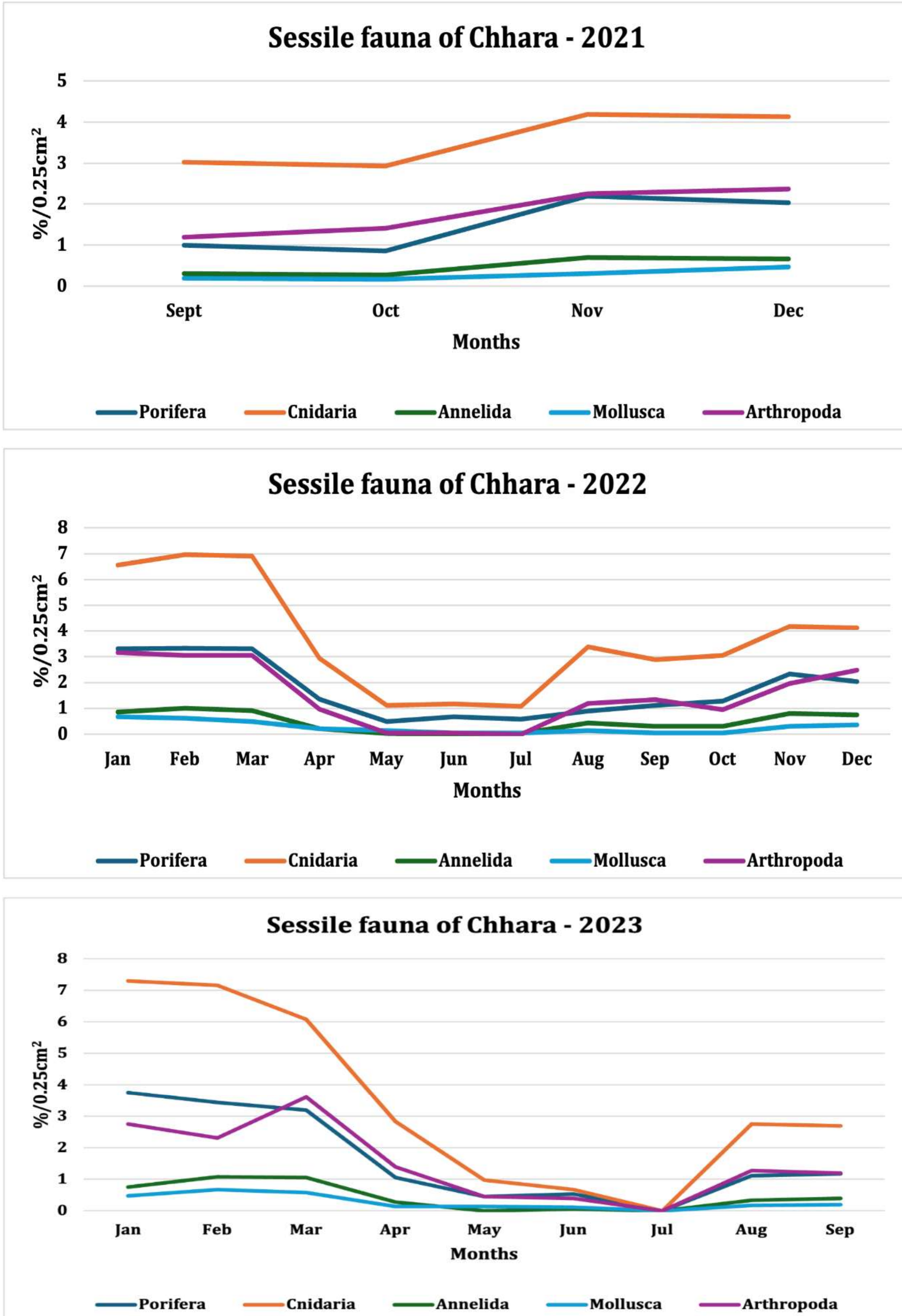


Figure 4.16: Seasonal and Spatial variations in the percentage value of tidepool's sessile fauna at Chhara (2021, 2022, 2023)

4.4 COMMUNITY INTERACTIONS IN TIDEPOOLS

In an ecosystem, species interact with one another in many different ways that are referred to as community interactions. Macrobenthic communities have highly complex and diverse interactions between species through several types of associations, including mutualism, amensalism, competition, and predation. macrobenthic communities' distribution, composition, and overall health are greatly impacted by these interactions (Flach and Tamaki, 2001). Many interactions between species have been observed in the tidepools during the study.

4.4.1 Competition

When species compete for the same limited resources such as food, space, light, or territory competition results (Begon *et al*., 1996). Different species compete for the limited resources in a tidepool, resulting in complex interactions that influence the community structure. One important aspect of competition is intraspecific competition, which arises when members of the same species compete over resources like food, territory, and mates. The distribution and abundance of species inside the tidepool can be significantly impacted by this type of competition. Competition between species, known as interspecific competition, is another important factor in developing tidepool ecosystems. Herbivory, predation, and interspecific competition all have an impact on tidepool communities, and the particular physical characteristics of tidepools cause geographic heterogeneity in community structure (Metaxas and Scheibling, 1993).

INTERSPECIFIC COMPETITION

Interspecific competition have been observed in several algae species, including *Ulva lactuca*, *Padina* spp., *Sargassum* spp., and *Scinaia carnosa*. In tidepools, interspecific competition has been repeatedly shown to be important, especially among algae species, which are often the dominating space occupants (Metaxas et. al., 1993).

This particular type of competition, which involves complex interactions for limited resources like space, light, and nutrition, has also been reported between *Halichondria panicea* and *Zoanthus sansibaricus*.

Cinachyrella spp. and *Palythoa heliodiscus* compete for space. For attachment, both require hard substrates. Due of the limited availability of sufficient attachment sites in tidepools, direct competition being developed. *Cinachyrella* spp. may be physically displaced by *Palythoa heliodiscus* colonies, which would negatively affect the sponge's capacity to take in nourishment and reproduce. Zoanthids, such as Palythoa spp., are known to interact with the organisms around them. They are considered to compete with other intertidal organisms (Pandya et al., 2012).

Additionally, competition for limited resources including light, space, and nutrients has been seen between *Ulva* spp., *Palythoa mutuki*, *Anthopleura elegantissima*, and *Zoanthus sansibaricus*.

This type of competition has also been reported in *Isaurus tuberculatus*, *Ulva lactuca*, *Caulerpa racemosa*, *Zoanthus sansibaricus*, and *Zoanthus vietnamensis*.

On rocks, barnacles and mussels (*Mytilus* spp.) frequently compete for the same attachment sites. A number of variables, including predation pressure, wave exposure, and desiccation tolerance, may affect how this competition turns out.

INTRASPECIFIC COMPETITION

Actiniarian species such as *Exaiptasia diaphana* and *Anthopleura* spp. have also been seen involved in this type of competition. They fight for territory in tidepools, where they may adhere themselves to the substrate (rocky surfaces) and get food supplies carried in by the tides. Because of their protective environment from predators and nutrient-rich surroundings, tidepools offer a rare and valuable habitat.

Cinachyrella spp. and *Halichondria panicea* compete for space in tidepools. *Halichondria panicea* has an advantage over other organisms in terms of space occupancy due to its rapid growth rate and ability to colonize new environments quickly.

Zoanthus vietnamensis and *Zoanthus sansibaricus* were seen competing. The primary competitors for resources are light for their symbiotic algae (zooxanthellae), space on the substrate, and water-borne nutrients. For their symbiotic zooxanthellae to carry out photosynthesis, both species depend on sunlight. They fight for positions that let in the lightest.

Because of the uniqueness of system biology, aggregating behavior has been seen in *Anthopleura elegantissima*. *Anthopleura elegantissima* is a species of anemone that is prominent for its aggression (Shah *et al*., 2017).

These organisms have nerve nets in their tentacles to receive signals Specialized nerve cells in the tentacles of *A. elegantissima* are capable of detecting light, chemicals, and touch. The anemone uses these cells to help it react to changes in its surroundings, including predators and prey. The nerve net of an anemone enables coordinated reactions, such as the closure or stretching of tentacles to grab prey, when a tentacle perceives a stimulus. Polyp aggregation can give some defence against predators as well as prevention from desiccation at low tides.

Competing for food and space on a rock face might hinder the capacity of barnacles (*Amphibalanus* spp., & Acorn barnacle) to grow and multiply. The larvae of barnacles compete in intense competition for both spaces to cling and grow upon an occupied rock and for access to suspended food particles in the water. The population as a whole may be impacted by this competition, which might restrict individual growth rates and reproductive success. Due to their ability to compete and adaptability to the environment, various species or individuals within the same species may settle in different places, resulting in zonation patterns.

4.4.2 Prey – Predation

Interactions of this type have been observed between *Pilumnus* spp. and *Charybdis* spp. *Charybdis*, a swimming crab known for its agility and effectiveness as a predator, here prey was *Pilumnus*.

Additionally, also found in *Pilumnus* spp. and *Aplysia oculifera*. Here, the prey is *Aplysia oculifera*, a type of sea hare that moves slowly, rendering it vulnerable to predation, and the predator is *Pilumnus*, a crab species. When threatened, Aplysia oculifera produces purple ink from its ink gland. This ink has several defensive applications. The ink includes chemicals that can irritate or repel predators, impairing their sensory perception and decreasing their ability to hunt efficiently. In a few studies it has been suggested that predation limits species abundance in tidepools (Metaxas *et al*., 1993).

4.4.3 Camouflage

Rock gobies that live in tidepools use camouflage to blend into their environment and make it more difficult for predators to notice them and for prey to detect them. *Bathygobius cocosensis*, for example, was the most frequently seen species in pools. Individuals of this species may alter their colour from creamy white to dark brown with scattered black and light blotches, allowing them to camouflage in with a variety of environments such as pebbles, rock ledges, coralline algae, or sandy substrates (White *et al*., 2015).

4.4.4 Food & Feeding

Pilumnus spp. are omnivorous and active feeders that graze on *Cladophoropsis*. To add the algae to their diet, they pierce and grab bits of *Cladophoropsis* using their claws. This feeding behavior regulates the development of algae in tidepools and helps in the cycling of nutrients.

Rock sediments constitute the food source for *Ophiuroidea* spp. Brittle stars, or *Ophiuroidea* spp., are detritivores and suspension feeders. Their long, flexible arms are used for both sifting through sediments and grabbing organic material from the water column. In the tidal pool ecology, they also contribute to the decomposition and recycling of organic materials by feeding on *Ulva* spp.

Hypselodoris maritima, a species of nudibranch (sea slug), feeds on *Ulva lactuca* by grazing on its surface. To remove algae from surfaces, nudibranchs employ their unique radulae, or toothed tongues. By controlling algal populations, their feeding helps maintain the ecosystem's dynamic equilibrium in tidepools.

Amphiroa anceps are the food source for the flatworm species *Pseudoceros susanae*. The influence that flatworms have over populations of calcareous algae and their contribution to the structural complexity of tidepools are highlighted by this feeding interaction.

Species of Nereididae feed on *Ulva*, The Nereididae family of polychaete worms is well-known for its omnivorous feeding patterns. They grab and feed algae like *Ulva* using their jaw-equipped eversible proboscis. Their consumption aids in the recycling of nutrients and the breakdown of algal biomass.

Using its radula, the sea hare *Aplysia oculifera* grazes on the *Caulerpa racemosa*. As herbivores, sea hares help regulate the growth of algae.

Samla bicolor feeds on *Palythoa mutuki*, which contains toxins such palytoxin that can repel some predators. Their physical characteristics and chemical defences make them difficult prey. Despite *Palythoa mutuki's* chemical defences, *Samla bicolor* has evolved methods to consume poisonous zoanthids. The nudibranch may have detoxifying processes that allow it to absorb poisonous tissues without damage, or it may engage in selective feeding, focusing on specific parts of the *Palythoa mutuki* colonies that are more accessible or less protected. *Samla bicolor* ability to feed on poisonous zoanthids demonstrates how nudibranchs have evolved to overcome prey defences. These adaptations include behavioral, physiological, and biochemical systems for detoxifying and using poisonous prey.

As a way to recycle nutrients, maintain the populations of their food sources, and conserve the diversity and ecological balance of these dynamic marine habitats, each species is essential. Gaining an understanding of these interactions might help researchers comprehend more thoroughly how tidepool communities' function and adapt.

Plate 4.12: Different types of community interactions in tidepools at study sites

4.4.5 Food Web in tidepool

The interactions that occur within a tidepool ecosystem can be characterized by trophic level, such as primary producers to primary consumers. Photosynthesis, the process by which algae convert sunlight into energy, serves as the foundation for the food chain/web. Herbivores graze on algae, transferring energy from producers to the primary consumers. Secondary consumers, such sea stars and predatory snails, ate herbivores. Predation affects herbivore population dynamics and dispersion. Apex predators, such as larger fish or birds, consume secondary consumers, which helps to regulate their populations and maintain ecological balance.

- Primary producer- Sea weeds, phytoplankton, zooplankton
- Primary consumer- Periwinkle, Common Limpet, Acorn Barnacle, Common Prawn
- Secondary consumer- Common whelk, crab, worm, fish
- Top consumer- Gull

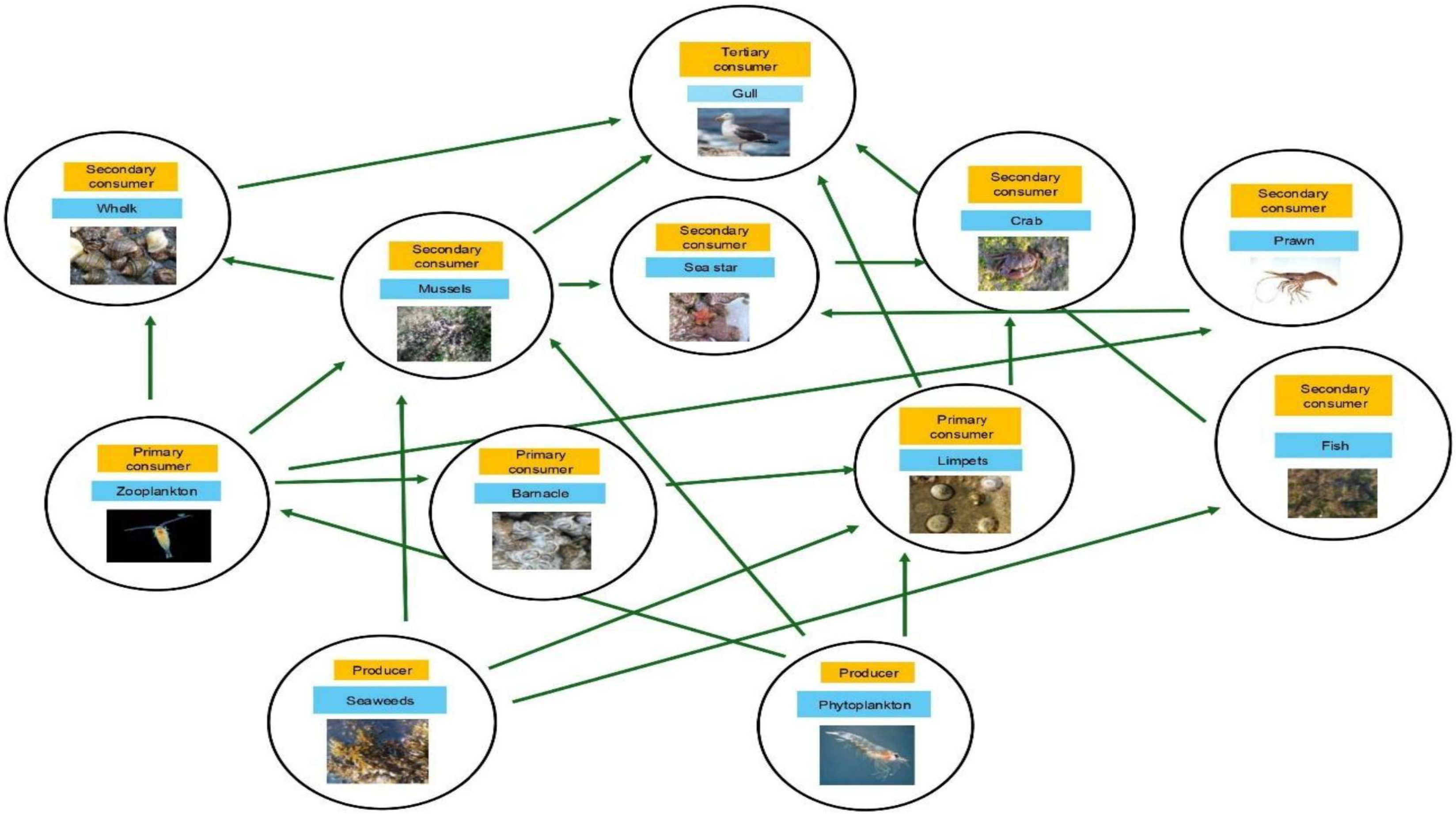


Figure 4.17: Diagram showing an example of interactions in form of a food web in tidepool ecosystem