

1.1 MARINE ECOSYSTEM

The marine ecosystem is the most significant aquatic environment, comprising over 71% of the planet's surface and containing 97% of its water. It is essential to the biogeochemical cycles and global primary production (Sodany and Diab, 2023). These ecosystems, which comprise a variety of habitats such as oceans, seas, salt marshes, estuaries, intertidal zones, coral reefs, lagoons, and mangroves, are distinguished by high concentrations of salt (Ajay, 2016; Biswas *et al.*, 2023). As mentioned in figure no. 1.1, the marine ecosystem is classified into two main categories: the benthic environment, which comprises the supra-littoral, intertidal/littoral, and sublittoral zones and the pelagic environment, which includes the neritic and oceanic zones (Elham, 2023).

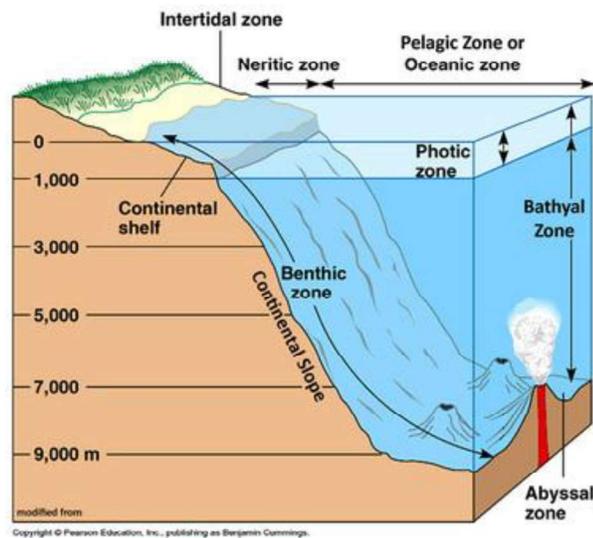


Figure 1.1: Marine environment and classification of zones at rocky shore

Image source: <https://intertidalzones.weebly.com>

Climate, temperature, substratum forms, nutrient load, light availability, and salinity are examples of biological and environmental variables that affect the various types of benthic communities, such as kelp forests, seagrass meadows, and coral reefs. (Agostini, 2020). In addition to providing vital ecosystem services like coastal protection, food provisioning, water filtering, and carbon sequestration, foundation species like seagrass, coral, and mangroves generate habitats that support a broad diversity of related biota (Lester, 2020). A variety of organisms,

such as microalgae, phytoplankton, crustaceans, molluscs, and marine bacteria, produce bioactive substances in marine ecosystems. These compounds have a wide range of medical and therapeutic advantages (Biswas, 2023). The biodiversity of these ecosystems as well as the ecosystem services they offer are threatened by a number of environmental issues, such as marine pollution, overfishing, coastal development, and climate change (Sodany and Diab, 2023). Ocean currents, water temperature, and nutrient availability are three environmental parameters that are directly related to the geographic distribution and life history of marine economic species such as fish and cephalopods. These characteristics are essential for forecasting and managing fisheries (Chen, 2022). More efforts are being taken to restore ecosystems as a result of the degradation of marine habitats. This emphasises the significance of meticulously deciding restoration sites and developing spatial plans to optimise the outcomes of ecosystem services and restoration success (Lester *et al.*, 2020).

Top-down and bottom-up trophic cascades are only one example of the complex interactions that occur within marine ecosystems, highlighting the delicate balance of these habitats and the necessity of comprehensive marine policy and conservation measures to maintain their survival (Cronan, 2023). By improving the knowledge of carbon fluxes and the simulation of biogeochemical indicators, advanced modelling techniques like the incorporation of plankton functional types into marine ecosystem models have contributed to the management and preservation of these essential ecosystems (Ciavatta, 2018).

Marine ecosystems are complex and dynamic in general, necessitating integrated methods for research, management, and preservation of their valuable resources and services.

1.2 INTERTIDAL ZONE

Rocky intertidal zones are dynamic environments that are exposed to both marine and terrestrial conditions because of their position between the highest high tide and the lowest low tide. A clear vertical zonation of flora and fauna is created by the tides, which also act as defining factors for these zones due to their hard surface content. Important factors that shape these communities include the

physical characteristics of the coast, such the kind of substrate and the availability of resources from the surrounding ocean, like food and larvae (Petraitis, 2008; Yulianda, 2013).

The dynamic environment of the intertidal zone supports a wide variety of organisms, such as algae, cnidarians, molluscs, crustaceans and echinoderms, all of which have to adjust to the daily cycles of immersion and emersion that cause large variations in body temperature and other environmental factors. Numerous stressors, including desiccation, high temperatures, freezing stress, hypoxia, salinity fluctuations, nitrogenous waste accumulation, Ultraviolet radiation (UV), wave, ice disturbance and Hydrogen Sulphide (H₂S) toxicity, are faced by these organisms. To survive and to adapt to these challenges, intertidal species have evolved a variety of morphological, physiological, behavioral, and biochemical strategies (Leeuwis and Gamperl, 2022). Such organisms are sensitive indicators of environmental change because they are frequently ectotherms with a marine evolutionary origin and must adapt to both aquatic and terrestrial climatic situations (Mieszkowska, 2016). Furthermore, the temperature, salinity and dissolved oxygen levels in intertidal zones vary significantly across large spatiotemporal scales, impacting the dynamics and composition of tidepool populations (Cota-Ortega *et al.*, 2021). These zones require continuing research in order to forecast future changes and support conservation efforts (Cox, 2011).

The rocky littoral zone supports a wide variety of ecosystems formed by both biotic and abiotic influences. It is distinguished by its nearness to the shore and exposure to tide oscillations. These environments, which offer distinct biological niches for different species, include boulder fields, platforms, tidepools and steep, rocky cliffs (Satyam and Thiruchitrambalam, 2018). The distribution of these habitats is greatly influenced by geomorphological features including slope, wave exposure and geological composition in mid littoral zones with factor such as seawater temperature and substrate type are especially important (Cefali *et al.*, 2016).

The physical characteristics of the rocks, such as their porosity and hardness, also influence how marine creatures settle; basaltic and limestone rocks are more porous than granite and sustain distinct ecosystems as a result

(Msangameno, 2016). The organism's adaptations to the extreme environmental factors, such as variations in temperature, salt and moisture, are what cause the vertical zonation observed in these environments (Kon *et al.*, 2020). Water level fluctuations (WLFs) are important because they affect the biota that depends on these habitats for development and reproduction, as well as the availability of littoral resources (Zohary and Gasith, 2014). Understanding habitat dynamics and identifying sub-habitats within the larger mid littoral zone require an understanding of the co-occurrence relationships among species, which are frequently ignored in traditional habitat descriptions (Dedeu *et al.*, 2021). The importance of these ecosystems for sustaining a variety of groups and their susceptibility to human activity and climate change highlight their socio-ecological relevance (Satyam and Thiruchitrambalam, 2018). Coastal marine ecosystems are rich in biodiversity and ecological complexity due to the variety of habitats found in the rocky littoral zone.

1.3 TIDEPOOL

Around rocky coast, where retreating tides leave behind pools of saltwater that support a wide variety of marine life, are dynamic and ecologically vital ecosystems known as tidepools or rockpools (Figure 1.2).



Figure 1.2: Tidepool of intertidal zone

These pools are crucibles of adaptation and change because of their dramatic variations in temperature, salinity, and pH. The rich marine fauna that resides there, which includes a variety of fish species, anemones, sea squirts,

chitons and amphipods, is reflected in the remarkable biodiversity found in these pools, which is higher than that of terrestrial or freshwater habitats (Peter and Hayward, 2022). Tide pool's physical characteristics, like their volume, width and depth, are important in influencing the variety and abundance of species present (Schaefer *et al.*, 2019).

Tidal pools were categorized according to their location in relation to the shore's height, salinity, flora, and water permanence. Multiple studies have demonstrated that species abundance varies along the tidal gradient. The tidepools located higher on the coast are exposed to air temperatures for extended periods of time, which causes the water's characteristics, surrounding temperature, salinity, and pH to increase. The abundance, compositions and overall diversity of the species that live in these tidepools will be estimated to be impacted by these differences in physical and biological characteristics. Geographical location, shore height, and species identification, for example, all influence the effect of tidepool depth on biodiversity. Further evidence that the association between rock pool physical features and diversity appeared to be site dependent resulted from the finding that increased rock pool diameter was linked to higher species richness, albeit not necessarily to taxonomic density. Tidepools are of extreme significance because of how vulnerable they were to climate change. This includes global warming, sea level rise and other anthropogenic activities that pose a significant threat to the biodiversity of these coastal areas. This underscores the need for extensive research and conservation measures in these special habitats.

India has a wide diversity and abundance of rockpools due to its varied geography and heavy monsoon rains, particularly on the southern peninsula.

1.3.1 Origin and formation of tidepool

The majority of tidepool forms originate when rain or water moving through space and time dissolution of the soft, xenolithic of feldspar parts occurs on the surface or in rocks and boulders. Tidepools may on a variety of shapes, sizes and types depending on the water's force, composition and duration of action. Physical, chemical and biological processes work in tandem with wind,

temperature and other forces to cause dissolution and erosion. The dissolving of limestone and other soft rocks occurs along small cracks and can create channels that range in size from tiny holes less than an inch wide to massive caverns that can hold considerable amounts of water.

Large boulders sometimes have their "faults" totally dissolved, forming a broad, long, and deep crevice along the direction of foliation. Alternatively, two enormous boulders may frequently be separated by a narrow crevice, or large boulders may become closer to one another as a result of crustal movements, forming a crevice in between. These cracks often fill with water to produce cleft-style tidepools, which are typically deep and have an elongated or crescent shape. According to Parker (1980), openings in rock that were present during its formation are referred to as primary openings, while those that developed as a result of external physical and chemical processes are referred to as secondary openings. Older rocks frequently have secondary openings. Although they are quite uncommon, tidepools created by volcanic or glacial activity are also known to exist.

1.3.2 Classification of tidepool

Plains tidepools and hill tidepools are the two main types of tidepools, identified by the position of the rocky surface with the water-filled holes. The existence of a completely catchment region, which is typical for endorheic (internal flow) hill tidepools, appears to be the primary element contributing to the difference between plains and hill rockpools. The plains tidepools are exoreic because water is constantly entering and leaving them.

In the lower regions of rugged terrain, humans have cut and removed granite rocks for construction, forming profound canyons. These massive, rocky-bottomed depressions, sometimes known as quarries, fill with water and create artificial, man-made tidepools. These quarry tidepools are distinct from plains tidepools and hill tidepools even though they are often found at ground level. Shallow quarry tidepools, for instance, have high water temperatures, a thin layer of organic silt present, a distinct population of

conchostracans, and no aquatic macrophytes. These quarry tidepools are ecosystems into themselves.

Hill tidepools are holes or depressions in boulders and rocks found at higher elevations in hilly terrain. These tidepools have a rocky floor, rocky walls, and occasionally a rocky top. There is a catchment area, although it is not well defined. These enclosed areas are endorheic pools. Because they are endorheic, they retain the materials that are gathered from the catchment area and rain, turning them into "Nutrient Sinks". Ephemeral tidepools might disappear within a few days, whereas semipermanent and permanent tidepools remain for longer.

1.3.3 Structure of tidepool

The structure of the high altitude tidepools varies depending on how and where they are located. They might be open tidepools or depressions on smooth rocky surfaces that are exposed to the elements. A portion of the depressions could have an overhanging rocky hood, creating partially covered tidepools, because they are situated on top of rocks or other large rock. They may resemble a mouth-like entrance going into a hole of varying sizes, or they can resemble a depression in the vertical rock. As a result, the rocky basin is covered by a rocky roof. These are cavern tidepools that are completely covered. The cave may occasionally be enormous, producing a stone domed hall. After that, it is referred to as large cave tidepool.

There might be a large hole in the cave that opens into a small cave with an arched roof. This is an arched cave tidepool. Sometimes, huge rocks can form a chamber like cave with two or more openings. We refer to these as chamber cave tidepools. In certain slopes, boulders may form a long, tunnel-like cave with a limited location, known as a tunnel cave tidepool.

1.3.4 Shape of tidepool

The form of the actual pool of water, whether it is covered or open, is determined by the edge of the depression or pool. Circular, oval, elliptical, elongated, triangular, square, rectangular, polygonal, irregular, slipper, sickle, crescent, and turtle forms are among them. This might be shaped geometrically or asymmetrically, as shown below and shown graphically in figure 1.3.

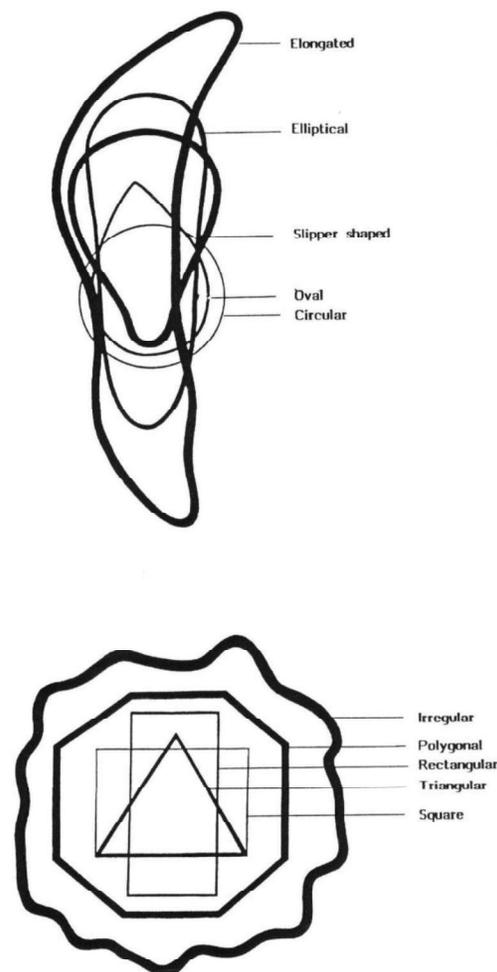


Figure 1.3: The various forms of tidepools

1.3.5 Depth of tidepool

These tidepools can range in depth from a few millimetres to many meters. This suggests that the forms of rockpools might be shallow, deep or very deep.

1.3.6 Basin type of tidepool

Depending on their depth, symmetry and interior shape, the depressions in these tidepools may form a variety of basin forms. The majority of the time, these basins have regular, symmetrical forms, much like glassware. They might occasionally be erratic. The many forms of tidepool basins include the Watch glass, Bowl, Beaker, Pot, Funnel, Canyon, and Irregular types (Figure 1.4).

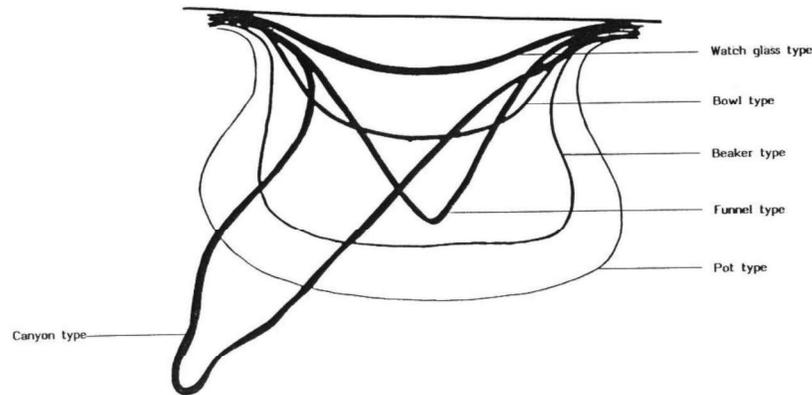


Figure 1.4: Various form of tidepools based on basin type

1.3.7 Life span of tidepool

Some of the tidepools that rain forms in little depressions on rocky surfaces could only exist for a few days or hours. These are tidepools that are temporary, short-term and static. Deeper tidepools may not dry up as quickly and may remain wet for more parts of the year. These are considered as seasonal/semipermanent tidepools. Durable, and extremely deep tidepools, such as those found in canyons, may be connected to groundwater. These are the perennial and permanent tidepools.

1.4 COMMUNITY STRUCTURE OF TIDEPOOL

The southern peninsula of India, with its varied terrain and heavy monsoonal precipitation, is especially rich in tidepools, which act as mesocosms for marine life.

Tidepool communities are characterized by a range of ecological, biological, and environmental traits that underscore the complicated structure and uniqueness of these micro-ecosystems. The extreme environmental conditions of tidepools, which are found in the intertidal zone, include large fluctuations in water temperature, light intensity, and conductivity. As a result, resident organisms must develop specialized adaptations to survive in these environments (Pribadi and Kanza, 2017). Both permanent and migratory species use these pools as vital habitats; although some species visit them sporadically, others, such as

certain fish and macroinvertebrates, create more permanent populations (Barreiros, 2004; Castellanos-Galindo *et al.*, 2005).

A tidepool's community usually consists of primary producers, which are mostly algae that carried out photosynthesis. These include macroalgae, such as kelp, and microalgae, or phytoplankton. Primary consumers: The algae is grazed by herbivores such sea urchins, limpets, and some varieties of snails. Secondary consumers: Species that feed on main consumers and are either carnivorous or omnivorous include sea stars, crabs, and several types of fish. Tertiary consumers: Larger fish and birds that feed on the secondary consumers are examples of apex predators in a tidepool (Figure 1.5).

The physical environment controlled by tidal cycles, which ensures that organisms stay submerged and extends their upper distribution limits compared to emergent substrata, is one of the factors that affect the community structure within tidepools. This leads to less prominent vertical zonation and a distinct assemblage of species that may aggregate in or avoid tidepools depending on their particular needs. While the effects of predation are less well-documented, herbivory and interspecific competition particularly among algae species have a substantial influence on the dynamics of communities. (Metaxas and Scheibling, 1993).

Furthermore, each tidepool is unique due to its physical characteristics, which include depth, volume, orientation, shading and flushing rate. These characteristics contribute to the significant geographic variation in community structure, making each study's replication of the pool extremely important (Metaxas and Scheibling, 1993). Additionally, tidepools offer an adaptable and stable habitat across short temporal scales; in tropical places, seasonal variations are minimal, but community structure remains largely consistent (Castellanos-Galindo *et al.*, 2005). Furthermore, because of their manageable size and well-defined limits, tidepools may be used as experimental mesocosms to test broad ecological ideas regarding community structure (Metaxas and Scheibling, 1993).

The principle of cooperative ecology, as shown by Steinbeck in his literary works, may also be applied to tidepool communities, since species cooperate and

can strengthen and harmonize the environment (McNeilly, 2018). In such unpredictable and sometimes harsh conditions, the cooperative dynamic is vital to the survival and well-being of species. In summary, the introduction to tidepool communities highlights the significance of these habitats in marine ecology and the larger knowledge of ecological principles by presenting an intricate web of interactions and adaptations.

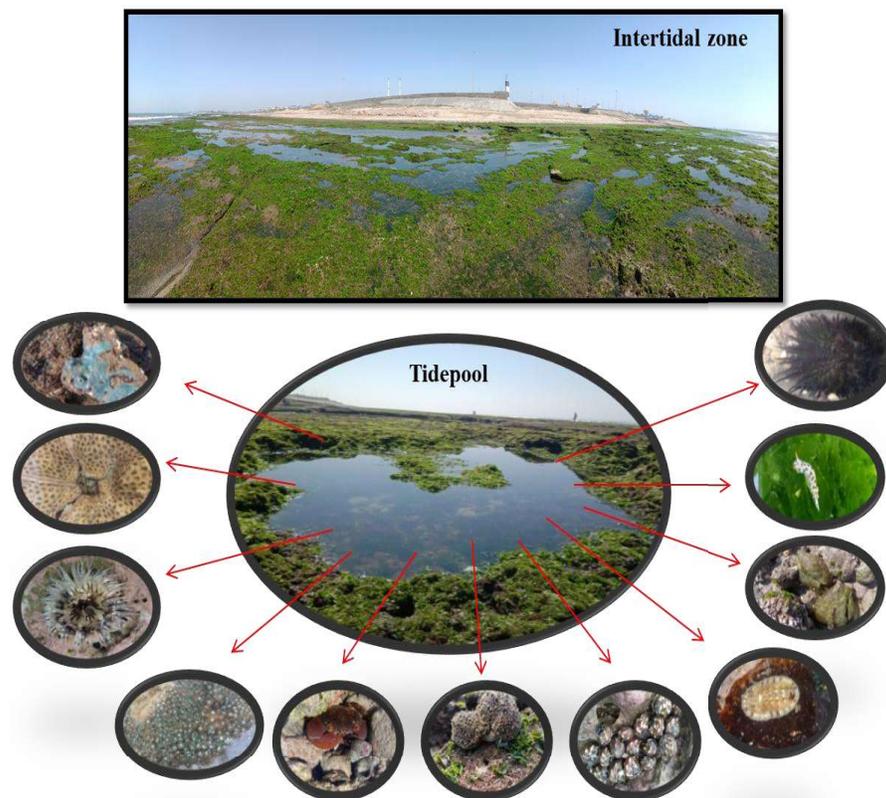


Figure 1.5: Community structure of tidepool

It is known that tidepools are home to a wide variety of species and taxa, including as sponges, hydroids, bryozoans, ascidians and fish that are rarely observed on emergent rock surfaces. According to research (Evans, 2016), which has been linked to tidepool physical features, are crucial in determining the

species composition of these microenvironments. However, tidepools' ability to maintain a wide range of biodiversity depends on their ability to mitigate natural stresses, which are determined by factors like size and shoreline position.

1.5 COMMUNITY INTERACTIONS IN TIDEPOOL

The goal of community ecology is to describe patterns of distribution and abundance of species' assemblages and to understand the processes that give rise to these patterns (Begon *et al.*, 1986, Diamond & Case 1986). These processes include biological interactions, such as herbivory, predation and competition, as well as the effect of the physical environment.

Early ecological theory included both positive and negative interactions among species as important driving forces in the structure and organization of natural communities (Abrams, 1993; Allee *et al.*, 1949) More recently, the role of competition in natural communities has received considerable attention (Boucher *et al.*, 1982; Clements *et al.*, 1926), while positive interactions have received little attention and are largely ignored in current models of community organization (Connell, 1983; Connell & Slatyer, 1977)

Predator-prey interactions have played a substantial role in shaping the diversity of life, leading to many adaptations and counter-adaptations for attack and defence (Cott, 1940; Ruxton *et al.*, 2004; Wallace, 1889). Perhaps the most widespread defence is camouflage, preventing an object from being detected or recognised by an observer (Stevens & Merilaita, 2009).

Whereas the ecology and evolutionary biology of mutualisms has attracted recent attention (DeAngelis *et al.*, 1983), the role that they play in the structure and organization of natural communities has not. The lack of recent attention paid to the role of positive interactions in communities is at least partly due to their uncritical acceptance by early ecologists and the preoccupation of contemporary community ecologists with competition (Dethier & Duggins, 1984).

In addition, much of the early development of ecology which highlighted positive interactions pre-dated the common use of field experiments in ecology and thus received little critical testing. Moreover, fascination with competition has focused attention on communities where competition is conspicuous, potentially

distracting ecologists from even recognizing positive interactions. Consequently, while facilitative and/or positive interactions are part of most working ecologists' conventional wisdom, and while anecdotal examples can be shown in most communities, the general importance of positive interactions to community diversity, structure and productivity is rarely acknowledged (Bertness & Callaway, 1994).

Prey such as fish and crabs, as well as sea stars, eat gastropods like limpets and snails. While they are predominantly primary producers, certain herbivores, like sea urchins, graze on algae. They have developed a variety of defence mechanisms against predators, including powerful adhesive foot structures and the capacity to retreat inside their shells and algae (e.g., kelp, sea lettuce), while primarily primary producers, other species that depend on algae for habitat and food may be impacted by sea urchin overgrazing, which can cause major changes in the algal population.

The foraging behaviour of predators includes Active predators are those that constantly search for prey as part of their foraging activity. Sea stars, for instance, actively search for bivalves or other prey by moving across the substrate of the tidepool. Sit-and-Wait Predators are another; these include a more stationary approach may be taken by certain predators, such as certain crabs, as they wait for prey to approach them. Various predators in tidepools use chemical signals for finding their prey. Some fish, for example, use olfactory signals to find tiny crustaceans.

The Impact of predation on prey populations, including regulating prey numbers: predators support in maintaining population balance in their prey, preventing any one species from assuming an excessively dominating role. Sea stars, for example, may prevent mussel beds from controlling space and resources in tidepools by feeding on the mussels. Though less frequent, mutualistic interactions where both species benefit from the relationship can also be observed in tidepools. Among which are Cleaner Host Species and Fish Certain cleaner fish in tidepools help the host fish (which get cleaned) and the cleaner fish (which acquire

a food supply) by removing parasites from bigger fish. Algae and Invertebrates: Some algae offer food and home to tiny invertebrates, which can support the algal community's health and aid in nutrient recycling. (Wilde,1991).

Organisms found in tidepools have to adapt to many environmental stresses, including temperature variations, desiccation, and changes in salinity. Behavioural adaptations are one type of adaptive strategy. Many organisms have evolved defence mechanisms against harsh environments, including burrowing or hiding. Physiological Adaptations: certain creatures possess physiological systems that enable them to endure significant changes in their surroundings. For example, they may close their shells strongly to avoid desiccation.

Ecological succession and disturbances can affect tidepool communities; succession is a tidepool's species composition may change over time as a result of factors like competition and predation. For instance, following a disturbance, pioneer species may settle in the region, which is followed by a more stable community when disturbance is Physical disruptions like storms and human activity can change the distribution and interactions of species, which in turn can change the structure of the community.

Due to aspects including accessibility, scale, visibility, funding, and complexity, the study of community structures and diversity in rocky tidepools is not as widespread as it is in other marine habitats. Rocky tidepools are less visible to the general public and have less scientific visibility, whereas coral reefs and other habitats receive more support and media attention. Gathering and analysing data of tidepools may also be made more difficult by their tiny size and adaptable environments.