1.1 INTRODUCTION

"With every drop of water, you drink, every breath you take, you are connected to the sea. No matter where on Earth you live. Most of the oxygen in the atmosphere is generated by the sea."

- Sylvia Earle

Oceans and major seas constitute approximately 71% of Earth's surface, with a coastline of approximately 1.6 million km. The aquatic environments, including both the oceanic waters and sediments, provide a suitable habitat for a wide variety of plant and animal species. According to Mitra and Zaman (2016), the marine environment is home to a substantial 1,78,000 species that are categorized into 34 phyla, as explained in the Global Biodiversity Assessment, a report published by the United Nations Environment Programme (UNEP).

The Indian Ocean covers approximately 29% of total ocean area ranks 3rd largest ocean (Venkataraman and Raghunathan, 2015). India is a mega biodiversity nation imparts an integral and largest part of the central Indian ocean region along with other countries like Bangladesh, Indonesia, Maldives, Malaysia, Myanmar, Thailand and Sri Lanka (Gopi and Mishra, 2015). India is surrounded by three distinct marine ecosystem zones of the central Indian ocean marine region: the Arabian Sea on West, the Bay of Bengal on East and the Indian Ocean on south of India. In terms of coastal habitat, India has a coastline of approximately 8000 km including Andaman-Nicobar and Lakshadweep Islands (Venkatraman and Raghunathan, 2015).

Coastline area forms unique habitats such as estuaries, lagoons, mangroves, backwaters, salt marshes, rocky coasts, sandy stretches, and coral reefs ecosystems. Among which estuarine zone forms a unique ecosystem and makes a transition zone between the marine and freshwater ecosystem (Sarkar et al., 2012). Coastal and estuarine habitats are recognized for their significant contributions to ecosystem services, such as food provisioning and water filtration (Agardy et al., 2005; Granek et al., 2010). Consequently, these ecosystems have gained recognition as some of the most productive systems globally. Hotspots of environmental variability, biogeochemical transformations, and biological interactions are locations characterized by dynamic exchanges of energy, mass, and nutrients between benthic and pelagic habitats through a variety of mechanisms. Transitional ecosystems located between terrestrial and marine environments are frequently characterized by high population densities and are subject to many human-induced stresses, such as climate change, nutrient enrichment, and fishing activities (Lotze et al., 2006; Halpern et al., 2008; Cloern et al., 2016).

An estuary is a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of sea water with freshwater derived from land drainage (Day, 1981). The word "estuary" originates from the Latin word "aestuarium," which means "tidal inlet of the sea." The estuary system can be divided into three distinct parts, namely the tidal river zone. This particular region is defined by being a fluvial domain, meaning it is influenced by river flow, and is notable for the absence of ocean salt. However, it is still subject to tidal oscillations. The mixing zone, which makes up the actual estuary and is characterized by the mixing of different water masses and the existence of distinct physical, chemical, and biological gradients that stretch from the tidal river zone to the seaward boundary of a river-mouth bar or ebb-tidal delta (Knox, 2001). In estuarine ecosystem diversity of the species may be less but the present populations are highly abundant than adjacent aquatic environments (Chang and Iizuka, 2012).

Estuaries possess a unique combination of features derived from both terrestrial and marine habitats, which is accompanied with distinguishing qualities which are exclusive to these particular ecosystems. Significantly, estuaries were previously favored for human habitation, as evidenced by the presence of various prominent towns globally located near their coastlines. Estuaries possess a range of values, including economic, ecological, and societal characteristics, when seen from a perspective that prioritizes human interests. These values are evident through the presence of essential biological resources, including commercially valuable aquatic organisms such as fish and shellfish (Knox, 2001).

Estuaries have a vital role in facilitating the life cycles of diverse fish and crustacean species, including economically significant ones such as crabs, flatfish, mullet, and prawns. These ecosystems play a crucial role in the migration patterns of important species such as salmon, hilsa, mullets, etc. Additionally, they serve as vital habitats for feeding, nesting, and resting for a wide range of avian species including ducks, geese, swans, and numerous wading birds. In addition to its ecological importance, estuaries play a role in enhancing human well-being through the provision of natural resources like as sand, gravel, and seldom oil (Knox, 2001). In addition, estuaries have inherent advantages as they serve as natural harbors and transportation corridors that enhance commercial activities. These areas function as sites for the establishment of residential and industrial infrastructures, offering recreational prospects for pursuits such as hunting, fishing, boating, swimming, and aesthetic appreciation. Furthermore, it is worth noting that estuaries play a significant role as important platforms for educational purposes and scientific investigations (Allen, 1963). Despite their numerous advantages, estuaries are particularly vulnerable to negative consequences caused by human activities. Estuaries are especially susceptible to the impacts of human interventions due to their intricate ecological equilibrium and diverse range of functions (Knox, 2001).

In India, 14 major and 228 minor estuaries are present beside coastal lagoons and backwaters draining approximately 2000 km^2 hinterland (Venkataraman and Raghunathan, 2015). Estuarine ecosystem is one of the most productive ecosystems of the world consists following properties: abundant number of autotrophs, high oxygen content due to tidal current, influx of inorganic and organic detritus from rivers and coastal wetlands and complex food chain which makes rapid conversion and regeneration of nutrients (Acharya et al., 2019).

Marine biology is a scientific discipline focused on studying the biology of organisms inhabiting marine ecosystems and their interactions with other organisms, as well as with the abiotic components of their environment. This includes studying two broad fields: functional biology and ecology (Levinton, 2001). Functional biology primarily focuses on the investigation of diverse physiological phenomena, such as mating, movement, feeding, and digestion, shown by species inhabiting marine ecosystems. On the contrary, ecology encompasses the examination of the interconnections between organisms and the abiotic components of their surrounding environment. The field of ecology provides valuable insights into the evolutionary patterns and environmental dynamics of marine creatures (Levinton, 2001; Sinha, 2015). The marine ecosystem is the largest ecosystem that may be found on Earth. The ocean covers over 70% of the Earth's surface, rendering the marine environment a highly expansive and diverse natural habitat. The aquatic environment encompasses a diverse array of habitats, including salt-water bodies, estuaries, mangroves, coral reefs, wetlands, and tidal inlets (Levinton, 2001; Gohil and Kundu, 2012).

The beginnings of research in the field of marine biology occurred during a period when distinct scientific disciplines were still emerging. Hence, the initial practitioners in the field of biology were commonly referred to as "natural philosophers" as they endeavored to understand the behavioral patterns and overall anatomical characteristics of aquatic organisms. When Aristotle (384–327 B.C.) and his associates documented the distribution and life cycle of aquatic species, they are credited with starting these kinds of investigations. Because of his significant contributions to the field of marine biology, Aristotle is known as the "Father of Marine Biology." While Aristotle is often recognized as a pioneer in the field of marine biology, it is important to acknowledge the significant contributions made by Linnaeus (1707–1778), who played a crucial role in establishing the modern system of classifying organisms. Edward Forbes (1815–1854) was the pioneering naturalist who formulated the initial marine biological theory positing that life does not extend beyond a depth of 300 fathoms (equivalent to 1800 feet), drawing from his extensive personal observations and experiences.

A famous naturalist, Charles Darwin (1809–1881), collected a vast array of aquatic organisms throughout the course of his five-year circumnavigation on board H.M.S. Beagle (1831–1836). He created other significant contributions based on that collection, such as a book on coral reefs and the first systematic, flawless categorization of barnacles, which is still in use today. A later expedition around the world on the H.M.S. Challenger, headed by renowned naturalists John Murray and C. Wyville Thomson, who gave the world its first comprehensive understanding of the marine richness of the oceans. The magnitude of the collections was such that it necessitated the use of 50 volumes to document the vast quantity of species collected during the voyage (Levinton, 2001). Through the dedicated endeavors and maritime explorations conducted by numerous naturalists and marine biologists, the existing data indicates a projected count of marine species that varies between 2,50,000 (Groombridge and Jenkins, 2000) and 2,74,000 (Reaka-Kudla, 1997). These species encompass a wide spectrum of body structures, spanning from bacteria to baleen whales.

The ocean habitat can be categorized into two primary zones, namely the benthic zone and the pelagic zone. The categorization and characterization of ecosystems can be enhanced by dividing these areas into smaller sections based on their proximity to the shoreline and the water's depth. Compared to the pelagic zone, the benthic zone, which is at the bottom, has a wider range of habitats. These include different types of substrate, levels of immersion (tidal vs. subtidal), temperatures, depths, and access to light (Levinton, 2001).

The pelagic zone, encompassing the whole water column of the ocean, is recognized as a habitat mostly occupied by species that float or swim. Two further sections can be distinguished within this zone: the oceanic region and the neritic region. The neritic zone is situated above the continental shelf, whereas the oceanic region begins at the boundary of the continental shelf and extends to the farthest depths of the ocean. The oceanic zone can be further subdivided based on the degree of light penetration, which has a significant impact on the distribution of many living forms. The different zones within the ocean can be categorized as follows: the epipelagic zone, which spans from the surface of the water to a depth of 200 meters; the mesopelagic zone, which occupies the region between 200 meters and 1000 meters in depth; the bathypelagic zone, which encompasses depths ranging from 1000 meters to 2000 meters; the abyssopelagic zone, which extends to a depth of 6000 meters; and finally, the hadalpelagic zone, which encompasses the seabed and the deepest parts of the oceans (Levinton, 2001) (Fig. 1.1).

The benthic zone is subdivided into distinct zones based on its distance from the surface of the sea. The first zone is known as the intertidal or littoral zone, which is situated between the high tide mark and the low tide mark. The intertidal zone encompasses a depth range of 0 to 60 meters and represents approximately 1% of the benthic zone. The zone in question is of utmost significance and exhibits a remarkable level of diversity, as it sustains a wide array of habitats, including rocky shores, sandy shores, mudflats, coral reefs, estuaries, and mangroves. The second zone is known as the sub-littoral zone, which commences at the low tide level and extends to a depth of 200 meters. This zone encompasses approximately 8% of the benthic area. The third layer is known as the bathyal zone, which is situated at depths ranging from 200 to 2000 meters. This zone encompasses around 16 percent of the benthic species. The abyssal zone is the fourth layer of the ocean and encompasses a substantial section of the marine environment. It is typically located at depths ranging from 2000 to 6000 meters and constitutes around 75 percent of the benthic ecology. The last zone, known as the hadal zone, spans from a depth of 6000 meters to the lowest point on the ocean floor (Levinton, 2001) (Fig. 1.1).

The benthic zone is an extremely diverse and crucial component of the marine ecosystem. The benthic zone is characterized by the presence of animals that inhabit the bottom of a body of water or are linked to a specific substrate. The benthic zone exhibits a high concentration of nutrients, which is primarily controlled by the growth of phytoplankton from both terrestrial and aquatic sources (Sinha, 2015). The interaction of benthic-pelagic coupling mechanisms primarily supports crucial ecosystem services, including production and energy transfer in food webs, biogeochemical cycling, and the provision of fish nursery regions (Granek et al., 2010). The usual way of looking at benthic-pelagic coupling has mostly been about how nonliving organic matter settles in benthic habitats (Hargrave, 1973; Smetacek, 1985; Graf, 1992), bio resuspension, and how inorganic nutrients are released from the sediment (Raffaelli et al., 2003). The assessment of seasonal variations and geographical disparities across a variety of habitats has allowed for the quantification of these fluxes (Duineveld et al., 2000; Smith et al., 2006). Numerous scientists have described the various mechanisms that establish connections between benthic and pelagic environments (Marcus and Boero, 1998; Schindler and Scheuerell, 2002; Raffaelli et al., 2003; Baustian et al., 2014). The direct impacts of climate change, nutrient loading, and fishing on the coupling between benthic and pelagic components in coastal and estuarine ecosystems have been extensively studied, revealing significant implications for ecosystem functioning.

Pelagic as well as benthic zones showed variation in habitat characterization and biotic fauna. Organism inhabiting marine ecosystem are classified on bases of the habitat where they live. Organism found in open water are commonly termed as pelagic biota which further classified into planktons and nektons. Planktons are those organisms that drift with the water current and do not exhibit effective locomotion whereas, nektons can swim well in surrounding open water. Organism distributed in benthic zones are commonly known as benthos. Diversity and distribution of organism varies significantly with the different zone of marine ecosystem where maximum diversity observed in the littoral, sub littoral, epipelagic and mesopelagic zone. The abundance of organism in these regions is mainly because of effect of sunlight that drives the physiological activities of various organisms (Levinton, 2001).

The acquisition of knowledge regarding the species composition and habitat preferences of marine invertebrates is an essential prerequisite for comprehending the presence of distinct species within benthic communities. This knowledge also serves as a foundational resource for effectively conserving both the habitat and the benthic fauna. Research on the distribution and diversity of indigenous fauna holds significant importance as it contributes to an extensive understanding of the structure, functionality, and challenges faced by the local animal population (Fransozo et al., 1992). The marine environment has various divisions that provide a range of habitats, with the littoral and sublittoral zones exhibiting the greatest diversity of habitats. The littoral zone provides a diverse range of ecosystems, including mangrove forests, coral reefs, rocky coastlines, mudflats, sandy shores, and estuaries, among others. The sublittoral zone provides a diverse range of marine habitats, including seagrass patches, kelp forests, and deep-sea coral reefs. The maritime environment sustains a significant array of invertebrate species, which serve as the fundamental components of the marine food web. The littoral zone exhibits the highest degree of marine invertebrate biodiversity.

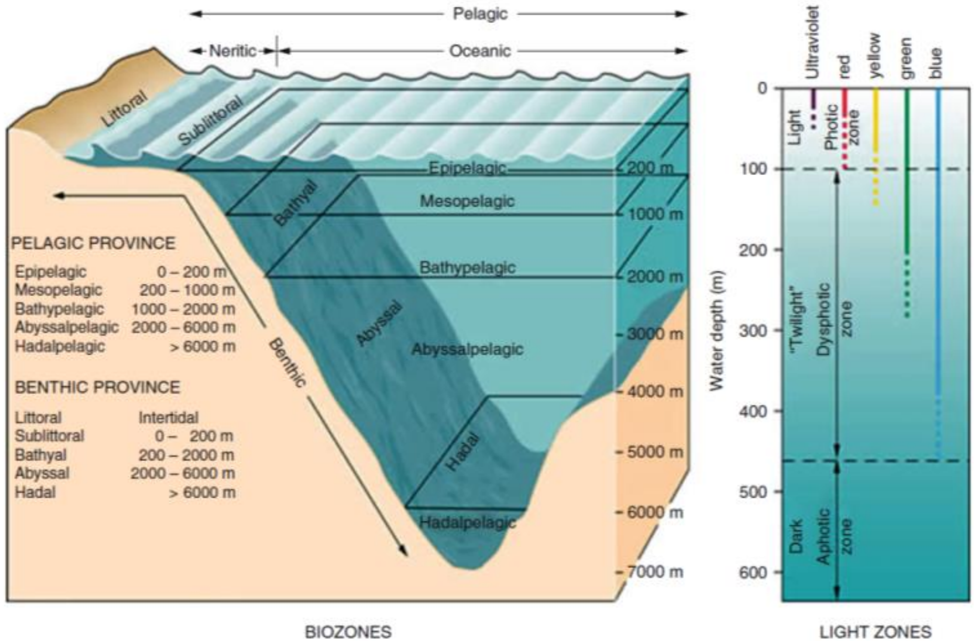

Figure 1.1: Classification of marine environment. (Source: Mitra and Zaman, 2016)

1.1.1 Intertidal area

Intertidal zone is area that lies between high tide mark and low tide mark. Intertidal area receives both marine as well as terrestrial habitat during high tide and low tide respectively and because of that, fluctuation in physical and chemical properties is commonly recorded in intertidal area. During high tide intertidal area is covered with sea water that may increase salinity, pH of surrounding habitat. Seasonal variation might be observed in salinity and other chemical components. In monsoon due to rainfall salinity decreases at some extent while in summer due to water evaporation salinity might be increased. Nutrient quality also varies with season and tidal range (Newell, 1979; Denny, 1988). In intertidal zone, marine organism can be directly encountered during low tide without special kind of equipment.

Out of different types of marine organisms found in the intertidal zone, crustacea is one of the most prominent groups belongs to the largest and dominant phylum Arthropoda (Sinha, 2015). Species inhabiting the intertidal area develops different types of adaptation to get protection from adverse environmental conditions, such as temperature fluctuations, aerial penetration, salinity and hydrodynamic forces (Newell, 1979; Denny, 1988).

Animals inhibiting intertidal zone develops various kind of adaptation to remain protected from harsh environmental condition. Several crustaceans simply move from exposed area to wet holes, cracks, burrows or gastropod shells to minimize water loss. Nature of the intertidal system and the distribution of sediments are depended on tidal wave action. Due to this the intertidal population is a key target during harsh environmental condition (Ribeiro et al., 2005). Intertidal area supports different kind of habitat like rocky, mangrove forest, mudflats, coral reefs, sandy shores, estuaries etc. (Levinton, 2001; Gohil and Kundu, 2012). The intertidal zone, instead of being a harsh environment for survival, exhibits a notable abundance of organisms due to the substantial influx of nutrients from land and the even penetration of sunlight into the shallow waters. This favorable condition enables various organisms, such as plants, seaweeds, and corals, to thrive at the bottom of the intertidal zone. These organisms additionally serve as habitats and sources of nourishment for other living organisms. Moreover, the periodic influx of tides delivers a replenishing influx of oxygen, plankton, and additional nutrients to the intertidal zone (Nugroho et al., 2020).

1.1.2 Different zones of Intertidal area

Organisms inhabiting the intertidal region exhibit a particular spatial distribution, forming bands characterized by their vertical position within the intertidal zone. Certain species are found predominantly in the upper intertidal region, while others are concentrated closer to the lower intertidal mark. Zonation patterns of this nature are evident across all coastal communities. However, it should be noted that the species composition of subzones within these patterns may exhibit variations based on factors such as geographical location, tidal range, aerial exposure, wave action patterns, and other similar influences. The investigation of zonation has involved the examination of the upper and lower boundaries of the predominant flora and fauna. This has been accomplished through the implementation of surveying techniques, which have been used to establish a correlation between these boundaries and both tidal constants and a standardized land measure (Johnson and York, 1915; Johnson and Skutch, 1928). The above method is valuable for determining the duration of an organism's submersion in water or exposure to atmospheric conditions. Based on this zonation method, the intertidal region was separated into three distinct zones: the Littorina zone (also known as the supralittoral fringe), the balanoid zone (or midlittoral fringe), and the sublittoral fringe (or infralittoral fringe). Zonation is a highly responsive phenomenon that exhibits instantaneous reactions to even the subtlest alterations in the quantity, composition, and intensity of wave activity that rocky surfaces may encounter. According to Stephenson and Stephenson (1949), several elements, such as subtle variations in shade or sunlight exposure, differences in slope, and other similar alterations, can influence zonation in distinct manners. Nevertheless, the complexity of this zonation scheme arises from the significant variability in tidal range, tidal behavior, and wave action across different coastal regions worldwide. Hence, it is unreasonable to anticipate that these zones would exist in their uncomplicated state, such that they would be readily apparent upon initial examination of the coastline (Cranwell and Cranwell, 1938; Stephenson and Stephenson, 1949).

It is often believed that zonation is a result of wave action, but that is not always true. Zonation can even occur in static water bodies like lakes and ponds where there is no tidal action. The chief cause of zonation is the presence of an interface between air and water. Light penetrates in a gradient fashion below the surface of water, which can be further affected by other gradients like changes in sedimentation with increasing depth. Above the water level, zonation is controlled by the degree to which surrounding rock surfaces are exposed to certain parameters like water spray, moisture formed by evaporation, etc. Therefore, it can be believed that tides are not the sole reason for zonation, but they can strengthen the pattern of zonation, making it more marked (Stephenson and Stephenson, 1949). Although factors like temperature, wind, rain, and waves might have some effect on zonation, only tidal variation has profound effects on biological zonation. Zonation does vary with time and topography, and therefore the listing of zones as above is only for convenience in order to understand the complex biological circumstances that are not outlined by exact boundaries. For survival in different regions of the intertidal zone, organisms develop special types of adaptations. For the majority of intertidal species, there is a general correlation between physical tolerance and shore position (Palumbi et al., 2019).

The intertidal zone, which is defined by its exposure to tidal changes, is sometimes divided into separate parts for the purpose of facilitating investigation. The aforementioned portions encompass the upper intertidal, mid-intertidal, low intertidal, and subtidal zones. The upper intertidal zone is characterized by infrequent water exposure, leading to prolonged periods of dryness, whereas the subtidal zone is consistently submerged. The spray or splash zone situation above the upper intertidal zone (Mitra and Zaman, 2016),

The spray zone, or upper intertidal region, where organisms are exposed to water alone during the highest high tide, encounters desiccation as the primary constraining factor. The dynamic nature of these environmental factors has a significant impact on desiccation, a process that depends on temperature, wind, and humidity. Consequently, several animals inhabiting this particular zone, such as barnacles and bivalves, exhibit the behavior of firmly closing their shells in order to preserve moisture. Similarly, several organisms that move by crawling or walking seek refuge in fissures and cracks as a means of shielding themselves from excessive heat exposure (Newell, 1979). As one progresses towards the lower coasts, competition emerges as a significant constraint. In the lower intertidal zone, competition arises due to limited resources such as space, food, light, and shelter. The acquisition of a suitable microhabitat presents difficulties due to the dense population of organisms, resulting in competition among individuals of the same species as well as between different species for enough resources (Wethey, 1983). Moreover, there is an observed elevation in predation rate inside the lower intertidal region as compared to both the spray zone and the higher intertidal region. Ecologists have historically been deeply concerned with variations in community structure across different geographical areas. While the variances in species diversity have garnered significant attention and are considered the most prominent variations, it is important to note that other elements of community structure, such as patterns of space utilization, species composition, trophic structure, and body size structure, can also exhibit variability.

1.1.3 Biotic component distributed within intertidal zone

Arthropoda, the most diverse phylum, comprises about 1.2 million species in terrestrial and marine environments. These organisms are well-adapted to all ecosystems and play a crucial role in the food chain and food web (Bouchet, 2006; Sanchez-Contreras and Vlisidou, 2008). Crustacea, a subphylum of Arthropoda, is a highly diverse group of marine organisms (Martin and Davis, 2001) with around 67,000 species (Ahyong et al., 2011). Crustaceans, including crabs, lobsters, crayfish, shrimp, prawns, krill, woodlice, and barnacles, originated 500 million years ago and have undergone dynamic species radiation (Zhang et al., 2007). They are found in various habitats, including marine, limnic, and terrestrial regions. Adult forms range in size from one-tenth of a millimeter to four meters, with maximum ages ranging from a few days to over 70 years (Vogt, 2012).

Crustaceans serve an essential role in sustaining aquatic habitats. Planktonic organisms, such as certain copepods and krill species, engage in the consumption of microscopic marine plankton. Plankton, as microorganisms within aquatic ecosystems, serve as an essential supply of nutrition for larger organisms such as fish, seabirds, and whales, hence contributing to the overall stability and functionality of the food web. Crustaceans of the order Decapoda, often known as crabs, fulfill a significant ecological function as predatory organisms. The ongoing interplay between crabs and their prey species engenders a dynamic process that drives the development and acquisition of novel adaptations. The elaborate shells of marine gastropods are believed to serve as a defense mechanism against predation by crabs, leading to the development of larger and stronger pincers in the latter. In addition to this, it is worth noting that crustaceans exhibit parasitic behavior, whereby they engage in parasitism with many aquatic organisms, including sea anemones, whales, and even larger crustaceans (Boxshall and Hayes, 2019).

Decapoda Latreille, 1802, represents an order within the superorder Eucarida Calman, 1904, belonging to the subclass Eumalacostraca of the class Malacostraca Latreille, 1802 within the subphylum Crustacea Brünnich, 1772 (Poore, 2004). These organisms are commonly referred to as marine arthropods. Insects have a significant level of diversity and are widely distributed in terrestrial environments. Conversely, decapods demonstrate a comparable level of diversity and prevalence within marine habitats. According to Abele (1974), this particular group of crustaceans is characterized by its high species richness, diversity, visibility, popularity, and economic significance. According to a recent study by De Grave et al. (2009), the estimated decapod diversity in the current ecosystem is around 14,756 species spread across 2,725 genera. Additionally, the fossil record indicates the existence of approximately 3,300 decapod species. The category encompasses various well-known creatures, including shrimps, lobsters, freshwater crayfish, hermit crabs, and "true" crabs. These organisms play a significant role in supporting the seafood and marine sectors, which contribute billions of dollars annually to the global economy (Shen et al., 2013).

"True crabs" are the members of the Subphylum crustacea, Order Decapoda, and Infraorder Brachyura Latreille, 1802. The brachyuran species exhibit a wide distribution, spanning from a depth of 6,000 meters in the deep ocean to 2,000 meters above sea level in mountainous regions (Ng et al., 2008). They occupy many aquatic habitats, with the exception of the Antarctic Sea and the Southern Ocean, which can be attributed to the unfavorable low temperatures in these regions (Lee, 2015). The majority of brachyuran species primarily inhabit marine environments, although a significant number have successfully adapted to freshwater and terrestrial habitats, notably in tropical regions. Numerous aquatic brachyurans have evolved to survive in environments that can be a hazard to life, like cold seeps or hydrothermal vents (Lessard-Pilon et al., 2010; Lee, 2015). According to Ng et al. (2008), numerous Brachyurans that inhabit arid regions have the ability to endure extended periods of drought, lasting up to six years, by engaging in a state of dormancy known as aestivation. During this period, these organisms retreat inside burrows that are sealed with clay.

The Indo-West Pacific region is known for harboring the greatest species variety, particularly on coral reefs, with Brachyurans being prominently associated with this phenomenon. The Indo-Malayan region within the Indo-West Pacific has the highest number of species (Schram and Castro, 2015). According to Schram and Castro (2015), there is a notable abundance of brachyurans found in mangroves and adjacent muddy intertidal substrates in tropical locations, resulting in a significant diversity of species. The Brachyurans of the Andaman and Nicobar Islands, as members of the Indo-Malayan area, exhibit a notable level of species richness. Based on the checklist compiled by Trivedi et al. (2018a), the Indian seas include an enormous diversity of Brachyuran species, encompassing a total of 910 species belonging to 361 genera and 62 families.

1.2 REVIEW OF LITERATURE

"What do researchers know? What do they not know? What has been researched and what has not been researched? Is the research reliable and trustworthy? Where are the gaps in the knowledge? When you compile all that together, you have yourself a literature review."

— Jim Ollhoff, How to Write a Literature Review

The marine ecosystem is the largest ecosystem, comprising 34 animal phyla, of which 13 are unique to the marine ecosystem. Whereas the terrestrial ecosystem comprises 11 phyla, of which only one is endemic. The marine ecosystem supports diverse habitats and related species diversity. Approximately 1.7 million species have been recorded to date, including approximately 2,50,000 from the marine habitat (McAllister, 1995). The marine ecosystem is further divided into various zones depending on the distance from the sea surface and the depth of the sea floor. Among these, the intertidal zone is the most highly diverse and important zone because it supports various kinds of habitats and thus harbours huge faunal diversity. The intertidal zone lies between the high tide mark and the low tide mark, and their physicochemical conditions may vary due to habitat fluctuation that may affect the biotic communities of the intertidal zone (Stillman and Somero, 2000). In the intertidal zone, microhabitat conditions are observed due to sediment deposition (Johannesson et al*.,* 2000).

The terms intertidal zone and littoral zone are interchangeable and refer to the coastal zone, which experiences periodic exposure at low tide (falling tides) and submersion during high tide (rising tides) (Lalli and Parsons, 1997). The intertidal regions serve as the boundary between terrestrial and marine environments. Despite their relatively tiny proportion of the global ocean, these areas sustain a wide array of marine flora, avian species, nearshore fish, and invertebrates (Lalli and Parsons, 1997). The region under consideration is characterized by a complex biotic system that undergoes large fluctuations in physico-chemical conditions and periodic changes in habitat. These variations have a profound impact on the biotic communities existing in the region (Stillman and Somero, 2000). Water is consistently accessible through tidal patterns, while its salinity levels fluctuate depending on rainfall and the drying process that occurs between tidal inundations. Furthermore, the impact of wave activity has the potential to displace inhabitants residing inside the littoral zone. The intertidal zone experiences significant solar exposure, resulting in a wide temperature range that spans from high temperatures under direct sunlight to near-freezing conditions in colder climes. Organisms inhabiting intertidal zones have developed adaptations that enable them to thrive in an environment characterized by frequent and drastic fluctuations in physical conditions. The organisms inhabiting the littoral zone have developed adaptations to effectively utilize the abundant nutrients regularly supplied by the sea. These nutrients are actively transported to the zone through tidal movements (Rebach, 1974; Taylor, 1981; Barnes, 2002; Turra and Denadai, 2003).

Species living in intertidal areas modified themselves to get protection from the harsh environmental conditions of the intertidal zone. Due to the tidal fluctuation, the environmental condition of the intertidal area may vary, like changes in temperature, salinity, and pH (Moser et al*.,* 2005). Such changes in turn affect the distribution pattern and diversity of resident fauna. Thus, the intertidal community is a key target to be affected by harsh environmental conditions. Animals living in marine habitats show different kinds of adaptation, especially those that inhabit intertidal zones. Some of them remain associated with hard substratum, some are found within gastropod shells, and several brachyuran crabs inhibiting mudflat habitat were found to construct burrows to get protection from outer environmental conditions.

Extensive research has been conducted on Brachyuran crabs in the fields of taxonomy and systematics. Numerous researchers have compiled lists of Brachyuran crab species from around the world at various points in time. The taxonomy of Brachyuran crabs is known to be confusing, with multiple synonyms existing for different species. Consequently, the compilation of valid species has been of utmost importance. Ng et al. (2008) conducted a comprehensive survey of the literature on Brachyuran crab diversity from various global regions. They identified a total of 6,793 valid species, which were classified into 1,271 genera and subgenera, 93 families, and 38 subfamilies. Brachyuran crabs inhabit diverse marine habitats, with the highest species diversity being reported in the Western

Pacific region, where approximately 2,000 species were documented. The Indo-Malaya region followed closely, with around 1,000 reported species (Ng et al., 2008).

Marine sediments, primarily sand or mud, are diverse in both median particle size and distribution, which affects ecosystem processes. The spectrum of particle sizes, from fine-grained silts and clays to coarser sands, influences the density and types of fauna in the sediment, impacting species interactions and ecosystem functions. The composition of particle sizes also influences animal burrow construction, sediment transport susceptibility, and solute exchange. Nuanced variations in benthic diversity and ecosystem function often correlate with grain size, but these relationships can vary depending on the specific range of grain sizes studied (Pratt et al., 2013; Douglas et al., 2018). Transitional zones across the sediment-water interface highlight the dynamic interplay between sediment characteristics and marine ecosystem dynamics (Thrush, et al., 2021).

Habitat type influences the variety of brachyuran crabs. Brachyuran crabs are a significant taxonomic group in terms of species diversity and abundance within the mangrove forest ecosystem. The crabs exhibit a preference for particular substrata when selecting their settlement locations, thereby demonstrating a significant correlation between sediment type and distribution (Bolam, 2003). According to Shih et al. (2005), the construction of burrows by crabs has a crucial role in enhancing oxygenation at greater depths and promoting the upwelling of sediment, resulting in a higher abundance of organisms in the upper sediment layer. The hydrodynamic conditions, resulting beach profile, sediment sorting, and variations in sediment characteristics contribute to gradients and patchy habitat structure, which can be seen as the primary factors influencing broad-scale community patterns over space and time (Attrill and Rundle, 2002).

Several brachyuran crabs of the intertidal zone construct burrows on sandy and muddy shores and remain inside the burrow during high tide. Such a biogenic structure helps them survive in the harsh environmental conditions of their surroundings. Such kinds of biogenic structures and their maintenance generate complexity in habitat. Some brachyuran crabs construct burrows for various purposes, like protection from predators, facilitating larval settlement, mating, and reproduction (Wolfrath, 1992). Chan et al. (2006) studied burrowing behaviour in the ghost crab *Ocypode ceratophthalma* (Pallas, 1772). They mentioned that ghost crabs construct burrows to get rid of physical stresses and to refuse predators such as shore birds. Several species live in their burrows to avoid high-tide wave action. They come out of the burrow during the low tide (Weinstein, 1995) and perform various physiological functions such as feeding, mating, mud balling, etc. During high tide, a large amount of water enters the burrow, which is useful for different purposes like gaseous exchange, nutrient distribution, environmental relaxation, and the removal of metabolic waste. The burrow is constructed in such a way that its structure must be advantageous to the crab, especially for quick evacuation when followed or threatened by a predator. Burrows play an important role in growth and survival, and they also provide protection from aerial as well as terrestrial predators (Chan et al., 2006).

Previous research has indicated that different brachyuran faunal communities can be identified by analysing the composition of the sediment (Bolam, 2003). The small-scale textural features of the grain population can affect the longevity of sediment patches and the spatial patchiness of crabs (Peter et al., 2001). Brachyuran crabs are closely linked to the substratum, making the examination of the animal-sediment interaction an essential focus of research. Various species of crabs demonstrate their presence through cryptic behavioural patterns, such as the construction of burrows, the deposition of burrowing, feeding, or excretory pellets, or the creation of trail traces (Chakrabarti et al., 2006). The bioturbation activities described above contribute to the alteration of sediment characteristics, including micro-habitat variations, changes in micro-topography, modifications to sediment chemistry, alterations in sediment transport, and adjustments to drainage patterns. The activities of feeding and burrowing result in disturbances to sediment, which in turn have consequences for other organisms. The dominant species typically exerts influence on several ecological factors, such as recruitment patterns, site selection, survival and death rates of settling larvae, control of food availability, predation, and other related aspects that ultimately contribute to the regulation of the community.

Brachyuran crabs are commonly observed as the predominant macrofauna engaged in bioturbator activities within intertidal ecosystems. Furthermore, the study of brachyuran burrow shape and substratum preference can yield valuable insights into various aspects such as tidal cycles, high water reaches (Xin et al., 2009), behavioral responses, and the paleo-sub environment of the beach (Seike and Nara, 2008), among others. The majority of studies have observed a correlation between brachyuran forms and ecological characteristics such as sediment and water conditions. However, without a comprehensive understanding of the interactions between these animals and their habitat, it is challenging to fully comprehend their ecological importance. Shorebirds, who are significant vertebrate predators in intertidal areas, use habitats according to factors like sediment penetrability, prey density, and prey availability (Botto et al., 1998). The coastal sediment landscape undergoes continuous changes as a result of the diverse activities of intertidal creatures, with the rate of disturbance being influenced by the abundance and activity levels of these animals.

India possesses huge coastal area as well as land area and harbor four hotspot region out of 25 hotspots rich and highly endangered eco-regions of the world. Indian coastline is around 8000 km long with an exclusive economic zone of 2.2 million km^2. Indian coastline is extremely diverse and having rich fauna of crustaceans published in several faunistic reports over the past hundred years (Chakrabarti, 1981; Trivedi, 2015). In India Gujarat state possess longest coastline that is extended around 1650 km and contributes 21% of Indian coastal region (Trivedi et al., 2015a). Gujarat coastline supports various kinds of habitats like mangroves, coral reefs, rocky shores, mudflats, sandy shores and estuaries which support rich marine biodiversity. Many researchers Dixit et al. (2010), Venkataraman et al. (2004), Singh et al. (2004) have carried out different ecological studies related to the marine biodiversity of the Gujarat state. Trivedi et al. (2015a) prepared a review article on crustacean fauna of Gujarat. They have listed total 157 species of crustaceans belonging to 87 genera and 41 families which were reported from various coastal areas of Gujarat state. Recently Trivedi et al. (2018a) compiled the checklist of marine brachyuran crabs of India and recorded 910 species inhabiting different marine habitats along the Indian coastline. According to them, 147 species of brachyuran crab belonging to 84 genera and 29 families were recorded from Gujarat.

In crustacea, crabs are divided into anomurans crab and brachyuran crab commonly known as hermit crab and true crab respectively. Both groups of crabs show numerous behavioral, morphological and physiological specializations permitting terrestrial life (Sinha, 2015).

Tremendous work has been done on brachyuran crab taxonomy but lesser information is available on the ecological aspects of brachyuran crabs. Ecological studies on brachyuran crabs inhabiting coastal areas of India are quite less. Silas and Sankarankutty (1965) studied ecology of *Scopimera proxima* Kemp, 1909 and correlated the effect of environmental factors on distribution of the species in muddy intertidal zone. Pandya and Vachhrajani (2010) have checked the effect of sediment texture and abiotic factors on burrow distribution pattern of *Macrophthalmus depresses* (now identified as *Ilyoplax sayajiraoi* Trivedi, Soni, Trivedi & Vachhrajani, 2015. Chakrabarti (1981) has studied the burrow morphology of *O. ceratophthalma* in West Bengal. He has commented that the burrow architecture of the species varies with change in the size and age of an individual, habitat type and seasons. Dubey et al. (2013) studied burrow architecture of red ghost crab *Ocypode macrocera* H. Milne Edwards, 1837 in Indian Sundarbans. They concluded that smaller crabs located near sea while larger individuals are distributed far from sea and also mentioned that biogenic structure like burrows provide refuge from predation and facilitate larval settlement. They have also checked the variation in air temperature and burrows temperature and recorded significant correlation between them.

1.2.1 Gulf of Khambhat (GoKh)

According to the International Union for Conservation of Nature (IUCN, 1976), critical habitats are defined as regions that are essential for the survival of a species at different times of its life cycle, or that play a fundamental role in maintaining the well-being of a community due to the biological processes that take place within them. According to the Technical Report of GoG (2002), critical habitats refer to areas that serve as nesting, breeding, and rearing grounds for estuarine and marine animals. These habitats are also distinguished by remarkable species diversity, high productivity, or unique scientific relevance. The Gulf of Khambhat is considered to be one of the significant habitats in the region.

Along India's western coast, between the Saurashtra peninsula and Gujarat's mainland, lies the Gulf of Khambhat, extending from the southern to the northern Arabian Sea. The geographical coordinates of the location are approximately situated between 20°30´ and 22°20´ N in latitude and 71°45´ and 72°53´ E in longitude. The Gulf widens to a maximum width of just 20 km at its northern end, which is between the mouths of the Sabarmati and Mahi rivers. From there, it funnels southward to its greatest width, which is located south of Gopnath point. The Gulf is estimated to have a length of around 115 kilometers in the north-south direction, including an area of roughly 3,120 square kilometers. It is predominantly characterized by mudflats, with some intertidal parts consisting of stony sandstone. The entire volume of the Gulf is estimated to be around 62,400 million cubic meters.

The Gulf of Khambhat is characterized by a substantial intertidal region covering 3,268 square kilometres, making it the most expansive intertidal area along the Indian coastline. The expansive intertidal area is a consequence of the substantial amplitude of the tides. The northern region of the Gulf is characterized by its conical morphology, which encompasses mudflats that span a distance of around 5 kilometers. In contrast, the southern region of the Gulf predominantly exhibits mudflats along its eastern shoreline. According to a technical report by GoG (2002), the mudflats in the Gulf have an approximate area of 2,588 square kilometers. The habitats found in the Gulf region, which include mangroves, estuaries, streams, and huge intertidal mud flats, are widely recognized for their high levels of biodiversity. These ecosystems support a wide range of plant and animal species that are unique to the region (Nayak and Sahai, 1985, Technical Report, GoG 2002).

The Gulf of Khambhat's surrounding coastal region has become increasingly important because of the following: the proposed ferry service between Dahej and Gogha; the existence of related chemical industries and fertilizer near Bharuch and Hajira; the thermal power station at Dhuvaran; the planned landfall points for an oil pipeline near Ubharat; and the recently proposed tidal power station in the Gulf of Khambhat. Additionally, as one proceeds further towards the northern direction, substantial shoals become discernible at periods of low tide. In the vicinity of the Gulf's entrance, a sequence of shallow banks is present, arranged in a linear manner, hence posing navigational difficulties, particularly for smaller watercraft. The coastal stretch between Bhavnagar and Gopnath exhibits a confluence of geological phenomena, namely tectonic and eustatic influences, which have contributed to the accumulation of land between Bhavnagar and Mahuva. According to a technical report published in 2002 by GoG, the Gulf's coastline has experienced significant environmental degradation and a reduction in biodiversity due to its rapid development and heavy industrialization.

The GoKh exhibits a width of 80 kilometers near its mouth, gradually narrowing to 25 kilometers during a longitudinal stretch covering 140 kilometers. The Gulf exhibits a rather shallow nature, as evidenced by a maximum water level of approximately 30 meters. Moreover, the northern section of the Gulf is distinguished by a water depth of less than 10 meters, accompanied by expansive tidal flats (Shetye, 1999). The tidal patterns seen in GoKh have a semi-diurnal nature, characterized by significant diurnal inequality and variable amplitudes. These amplitudes progressively grow in magnitude from the southern to the northern regions of GoKh. In the northern region of the Indian Ocean, the highest amplitude of tides is observed in the Gulf of Khambhat (GoKh), specifically at Bhavnagar, with an average tidal range of 10 meters (Shetye, 1999).

According to recent measurements conducted in GoKh, it has been seen that the maximum current speed recorded is 3.3 m/s. Additionally, it has been noted that during flood tide, the current flows in a north-northwest direction, and during ebb tide, the current flows in a south-southeast direction (Kumar and Kumar, 2010). The primary rivers that contribute to the GoKh are the Narmada, Tapi, Mahi, and Sabarmati. These rivers carry a significant quantity of suspended sediment, exceeding 1000 mg/L/d. Consequently, the Gulf experiences increased turbidity as the sediment levels fluctuate within the region until they are eventually flushed out to the open sea. The rivers in question contribute a significant amount of freshwater discharge into the gulf, particularly in the monsoon season. The Narmada River, as the primary river, exhibits a flow variation of 10,000 to 60,000 m^3/s during periods of monsoonal floods.

1.3 ORIGIN OF THE STUDY

The Gulf of Khambhat has immense tidal variations which ranges up to 6-8 m along the inner most part of the gulf (near Khambhat/ Kamboi) with the highest velocity of the flow more than 3 m/sec. These special conditions make the habitat very specific and highly vulnerable with reference to sedimentation and siltation. The open mudflat has hard mud, soft mud and soup mud habitats in relatively smaller spread along the intertidal area. The diversity, distribution and ecological studies on some of the selected species have been carried out in other areas of Gujarat and India but the intertidal conditions are very different in the present study area. Therefore, the open mudflats of upper north eastern margin of Gulf of Khambhat was selected for present study.

"Research is seeing what everybody else has seen and thinking what nobody else has thought."

- Albert Szent-Györgyi, Nobel laureate - Hungarian pharmacologist

1.4 OBJECTIVES

1. To study the diversity and distribution pattern of brachyuran crabs.
2. To study the burrowing behavior of the dominant brachyuran crabs (*Austruca sindensis* (Alcock, 1900), *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015 and *Dotilla blanfordi* Alcock 1900).
    a) To study the burrow architecture*
    b) To study the effect of lunar phases on burrowing activity.
3. To study the foraging behavior and bioturbation activity* of three dominant species.

(* *D. blanfordi* not done since the burrows are shallow and distributed along loose mud)