CHAPTER 1

General Introduction

1.1. Background information:

Estuaries are dynamic aquatic habitats, where the mixing of freshwater with seawater creates a transitional zone giving rise to a diverse mosaic of habitats such as mangrove forests, salt marshes, oyster reefs, seagrass meadows and non-vegetated areas (França et al., 2009; Kennish, 2002). Mangroves dominate the estuarine shores in tropical and subtropical regions and are adapted to extreme tides, high salinity, temperature fluctuations, high sedimentation rates and hypoxic to anoxic sediments (Giri et al., 2011). Mangrove ecosystems are complex, biologically rich and among the most productive coastal ecosystems globally (Freitas et al., 2021). These ecosystems offer protection, spawning areas, feeding and nursing grounds for a variety of fish, invertebrates, mammals and birds (Hajializadeh et al., 2022).

Benthic invertebrate assemblages in the mangrove environments are fairly diverse comprising brachyuran crabs, molluscs, hermit crabs, barnacles, sponges, tunicates, polychaetes and sipunculid worms (Nagelkerken et al., 2008). Among them, brachyuran crabs and molluscs dominate in terms of species richness, biomass and abundance (Ngo-Massou et al., 2018; Zvonareva et al., 2015).

Brachyuran crabs and molluscs play a significant ecological role in the structure and function of the mangrove ecosystem (Ashton et al., 2003). They are termed ecosystem engineers for their role in creating, maintaining and modifying their physical environment and in the process influencing the availability of resources for the associated fauna and flora, including microbes (Stiepani et al., 2021). Burrowing, foraging, feeding, and egestion by these macrofauna results in the excavation, mixing and enrichment of sediments leading to alterations in the physical, chemical and biological aspects through a process referred to as bioturbation (Min et al., 2023; Sudharaka et al., 2023). Most mangrove-associated brachyuran crabs construct and maintain burrows in the sediments for refuge to escape extreme environmental conditions and predation, and for food storage (Thongtham & Kristensten, 2003). The burrowing activity significantly increases the surface area of the sediment-air/water interface, facilitating sediment aeration and reducing salinity by removing accumulated salts (Hajializadeh et al., 2022; Ngo-Massou et al., 2018). The aeration and circulation of water enhances porosity which promotes the growth of mangrove seedlings and alters the redox conditions of the surrounding sediment (Khan et al., 2005). The burial of leaf litter in these burrows enhances microbial heterogeneity and activity, thereby accelerating the decomposition of organic matter (Hajializadeh et al., 2020).

Enhanced microbial activity and altered redox conditions influence biogeochemical processes and serve as a driving force for oxidising iron and reducing the toxic sulphide and ammonia concentrations thereby benefiting the productivity of mangroves (Ferreira et al., 2007). In addition to the burrows of brachyuran crabs, the movement of gastropods induces sediment surface rearrangement due to the tracks left by their heavy shells (Cannicci et al., 2008). The maintenance of burrows, especially by sesarmid crabs, creates new ecological niches where small fauna has access to stable environmental conditions, an abundant food source and protection from predators (Kristensen, 2008). Similarly, the empty shells of molluscs and the primary structural habitat created by oysters provide shelter and refuge for smaller organisms (Coen et al., 1999).

Mangrove crabs and gastropods play a crucial role in transporting and processing a large amounts of leaf litter by acting as shredders and consuming microalgae, thus consistently contributing to the retention of mangrove primary production (Fratini et al., 2000). Mangrove leaf litter is a rich source of carbon but is typically low in nitrogen, with a C/N ratio often exceeding 100. Additionally, it contains feeding deterrents such as polyphenolics and tannins, making it an unattractive organic matter source (Lee, 2008). The physical and chemical alterations of leaf litter during the digestion process result in crab faecal material being significantly richer in nitrogen and lower in tannins than unprocessed mangrove litter, thereby making it available to the smaller benthic invertebrates and microorganisms (Kristensen, 2008; Lee, 2008). Seed, seedlings and propagule predation, particularly by brachyuran crabs, is considered an important factor in determining seedling distribution, which in turn governs the structure of mangrove forests (Ngo-Massou et al., 2018), as their feeding activity reduces competition among saplings (Dahdouh-Guebas et al., 2011).

The feeding habits of these macrofaunal groups are varied, occupying all levels of the food web including filter feeders, detritivores, scavengers, herbivores and predators (Cannicci et al., 2008). For instance, sesarmid crabs are primarily leaf litter feeders, while ocypodids are sediment filterers that thrive on microphytobenthos in the sediment (Crane, 1975; Steipani et al., 2021). Similarly, among molluscs, bivalves are efficient filter feeders capable of capturing suspended particles of various origins, whereas gastropods graze on fallen leaves and detritus (Palziat, 1984; Kathiresan & Bingham, 2001). In addition to their roles as consumers in the mangrove ecosystems, these macrofaunal groups produce millions of meroplanktonic larvae, which serve as a potential food source for various planktivorous organisms such as fish (Mohanty et al., 2019). Their juveniles and adults, in turn, are consumed by many birds, snakes, predatory fishes, and even humans (Khan et al., 2005). Consequently, these faunal groups play a crucial role in the mangrove food web and energy flow, linking primary production and detritus at the base of the food web to higher trophic levels (Freitas et al., 2021).

The distribution of brachyuran crabs and molluscs in mangrove environments is influenced by biotic factors such as competition and predation and abiotic factors such as tides, water chemistry, sediment characteristics, and elevation (Hajializadeh et al., 2022; Ma et al., 2020). Mangrove ecosystems are a source of timber, fuel, and traditional medicines for humans mounting to over-exploitation. Besides they also provide potential sites for aquaculture and ecotourism, which further degrades the ecosystem due to unchecked pollution. Coastal development projects (jetties, harbours, bridges etc.) often lead to blockage or divergences of water bodies which leads to increased sedimentation, reduced infiltration capacity, tidal mixing and changes in salinity and temperature (Guimarães et al., 2010). Additionally, nutrient-rich discharge from aquaculture reduces water quality and introduces pathogens, antibiotics, and altered microbial communities (Cabello, 2006; Hashim et al., 2021). Furthermore, growing tourism increases waste and litter (Das, 2023), and frequent boat rides produce hydrological waves that cause erosion on the banks of the water bodies (Akram et al., 2023). Man-made disasters such as oil spills and consequences of global warming such as rising sea levels, changing patterns and magnitude of cyclones, rainfall intensity and shore-line erosion further continue to disrupt the mangrove ecosystems (Chaudhuri et al., 2015). Such disturbances can lead to a loss of biological diversity, and due to a lack of baseline data, the consequences of such an event are often not documented (Zamprogno et al., 2023).

The territorial habits of brachyuran crabs and the sessile nature of most molluscs, combined with their relatively long life cycles and sensitivity to the physico-chemical characteristics of the ambient environment, make them valuable as potential bioindicator species in mangrove ecosystems (Kathiresan & Bingham, 2001; Ashton et al., 2003a; Rittschof & McClellan-Green, 2005). Therefore, ecological studies of these indicator species are essential for understanding the functioning of mangroves as well as their conservation and management.

Goa, located on the west coast of India, lies between 15° 47' 59" to 14° 53' 57" N and 74° 20' 11" to 73° 40' 54" E, with a coastline of around 151 km (Kumar et al., 2006). The state is traversed by nine intertidal rivers harbouring 27 sq. km of mangroves (Forest Survey of India, 2021). A globally renowned tourist destination, Goa attracts a significant number of domestic and international visitors annually, drawn by its beaches, landscapes, festivals, monuments and the hospitality of its people. In 2021, the state received 3.31 million tourists, compared to its population of 1.5 million (Statista, 2023). This rapid growth of tourism has placed enormous pressure on resources and infrastructure, adversely impacting the surrounding environment. The increasing demand for development has led to the fast-paced construction of infrastructure such as jetties, roads, and bridges, resulting in disturbances and the landfilling of mangrove areas. The present scenario highlights the imminent threat to these habitats and therefore need for baseline studies and continuous assessment to document the consequences. Further, considering the importance and role of brachyuran crabs and molluscs in the mangrove habitats, holistically studying them and their environment is essential.

1.2. Literature Review

The Greek philosopher Aristotle (384-322BC) was the first to classify animals into vertebrates and invertebrates which were further classified as insects, crustacea and testacea (molluscs). Carl Linnaeus, a Swedish naturalist, pioneered modern taxonomy with his groundbreaking work "Systema Naturae" (1758). Linnaeus introduced the binomial nomenclature system, assigning a two-part Latin name to each species, which facilitated communication and clarity in scientific discourse. His work formed the cornerstone of modern taxonomy and established the foundation for classifying living organisms based on shared anatomical characteristics (Padate, 2010).

The Infraorder Brachyura Laterille, 1802 (true crabs) of the Order Decapoda belonging to Phylum Arthropoda is among the most species-rich groups with seven thousand seven hundred and sixty-eight species worldwide (WoRMS Editorial Board, 2024) distributed across terrestrial and aquatic environments (Davie et al., 2015). In the beginning of the 19th century Latreille (1796- 1831), and H. Milne Edwards (1828-1879) significantly expanded the knowledge of brachyuran crabs species. H. Milne Edwards "*Histoire Naturelle des Crustacés*" (1834-1840), catalogued, described and classified various crustacean species, including brachyuran crabs. Later, work by MacLeay (1838), De Haan (1833-50), Dana (1849-1856), and Miers (1874-1891) classified brachyura into various families and described new taxa worldwide. Moving into the 20th century, Lipke Holthuis's (1946-2006) work on the brachyura of the Siboga and Snellius Expeditions brought attention to Indo-Pacific crab diversity. In the year 2008, Ng et al. presented *Systema Brachyurorum: Part I*, an annotated checklist of extant brachyuran crabs of the world siphoning around six-thousand seven-hundred ninety-three valid species (belonging to thirty-eight superfamilies, ninety-three families, one-thousand two-hundred seventy-one genera) from the ten-thousand five-hundred names which serve as an important document to verify the crab taxa described before the year 2008.

Mangrove forests are typically dominated by sesarmid and fiddler crabs (Kristensen, 2008). Studies by Schubart and Cuesta (1998), Schubart et al. (2000, 2002) and Kitaura et al. (2002) led to the reorganization of the formerly known subfamily Sesarminae into the family Sesarmidae Dana, 1851 which is represented by over two hundred and fifty species (Ng et al., 2008; Davie et al., 2015; Shahdadi & Schubart, 2018). Jocelyn Crane's book 'Fiddler Crabs of the World' first published in 1975, provides a systematic revision of the genus *Uca* based on morphological comparisons, supplemented with data on social behaviour, biogeography, and ecology. Later, Shih et al. (2016) conducted major revisionary work on the genus *Uca* using phylogenetic relationships and reclassified it into thirteen genera which are currently represented by over one hundred and forty species (WoRMS Editorial Board, 2024).

Phylum Mollusca is the second-largest phylum of invertebrates, and occupying terrestrial, freshwater, and marine ecosystems (Edward et al., 2022; Kumar & Ravinesh, 2016). Currently, eighty-six thousand five hundred valid species are recognized globally, including nine thousand eight hundred and forty-two species of bivalves and seventy-three thousand six hundred and sixty-nine species of gastropods (WoRMS Editorial Board, 2024). Early taxonomic studies were conducted by notable researchers such as Lamarck (1744-1829), Gray (1800-1875), and Dall (1845-1927) who described and classified numerous new families, genera, and species. A significant contribution to molluscan taxonomy was made by George Washington Tyon Jr. (1838-1888) whose most notable work, "Manual of Conchology, Structural and Systematic: With Illustrations of the Species" spans forty-five volumes with thirty-nine volumes published posthumously by his assistant, Henry Augustus Pilsbry. Abbott and Dance (1982) presented a collection of the world's marine seashells describing more than four thousand two hundred shells. A textbook on the bivalves of the world by Huber (2010, 2015) gave coloured illustrations of eleven thousand eight hundred species of bivalves from across the globe.

Potamidid and littorinid gastropods are commonly found in association with mangroves in the Indo-West-Pacific (IWP) region. While littorinids are arboreal, potamidids are largely benthic and often occur in extreme abundance (Reid, 1986; Reid & Ozawa, 2016). Taxonomy and systematics of the mangrove-associated gastropods of the families Littorinidae Children, 1834 (Reid, 1986, 2001, 2007; Reid et al., 2010, 2012; Reid & Mak, 1998; Reid & Williams, 2004) and Potamididae H. Adams & A. Adams, 1854 (Reid, 2014; Reid & Claremont, 2014; Reid et al., 2008, 2013; Reid and Ozawa, 2016) have been extensively studied by D. G. Reid simplifying the classification of these groups.

A review of literature on the spatio-temporal distribution and ecological studies of brachyuran crabs and molluscs revealed a wealth of knowledge available on their diversity and distribution globally. The diverse brachyuran crab and molluscan fauna exhibit spatial segregation in the intertidal zones, however, their distribution in mangrove ecosystems does not conform to a simple vertical zonation (Berry, 1963) as observed in the rocky and sandy shores (Stephenson & Stephenson, 1949). Mangrove habitat forms a three-dimensional community where two main series of zones exist; one, horizontally from the shore towards land and the second vertically from substratum to tree canopy (Berry, 1963; Macnae, 1969). This view was based on classical studies of Berry (1963), Macnae (1968), Sasekumar (1974), and Hartnoll (1975) wherein the zonation of mangrove forests was done based on tidal level, inundation time, floral composition, sediment texture and macrofaunal assemblage typical of each zone in the IWP mangroves. Thereafter, various studies confirmed this distribution pattern and provided significant qualitative or descriptive data (Icely & Jones, 1978; Macintosh, 1988; Dahdouh-Guebas et al., 2002; Lee, 2008). An experimental approach or quantitative data, testing the effect of environmental parameters on the spatial distribution of different species was provided much later (Ashton et al., 2003a, 2003b; Dissanayake & Chandrasekara, 2014; Stiepani et al., 2021; Hajializadeh et al., 2022).

Significant studies on the distribution of brachyuran crabs and molluscs in the mangrove forests of Malaysia and Thailand (Macintosh et al., 2002; Ashton et al., 2003a, 2003b) have provided vital insights into species diversity, community structure and site preferences, including substratum type and mangrove vegetation. Ashton et al. (2003a, b) further compared the community structures in the mangroves under different management schemes, concluding that the brachyuran crab community structure correlated with topographic height, surface water, pH and salinity, while gastropod community structure correlated with the redox potential of water, topographic height, surface water pH and leaf litter. The importance of brachyuran crab community structure was highlighted as an indicator of habitat status, suggesting that the dominance of a single species may signal a stressful environment, whereas high diversity of grapsid and sesarmid crabs may indicate a mature forest (Macintosh et al., 2002). A, study on molluscan diversity at six sites in the Gulf of Thailand by Printrakoon et al. (2008) revealed significant spatial variations in diversity, abundance and biomass, underscoring the necessity of assessing multiple sites within a geographic region before generalizing community structures. Recently, Stiepani et al. (2021) examined the impact of urbanisation on mangrove forests and brachyuran crabs in Penang, Malaysia. Their findings revealed considerable diversity in both large and small interconnected mangrove regions, emphasizing the need for equal protection measures for small and large mangrove forests alike.

In central Vietnam, long-term changes (2005-2013) in species composition, density and biomass of the gastropod assemblages associated with planted mangroves were compared with those of natural mangroves by Zvonareva et al. (2015). The study reported fifty-three gastropods from twenty-one families and revealed that the gastropod assemblages could indicate the state of the mangrove ecosystem. The planted mangrove vegetation was found to be dominated by opportunistic eurybiotic gastropod species, which authors suggested as an indication towards an unbalanced and transition state of a mangrove ecosystem.

Dissanayake and Chandrasekara (2014) described the sediment characteristics and benthic epifauna of the Kadolkele mangrove forests of Sri Lanka and reported distinct patterns in their distribution based on mangrove zonation. Further, on-field observations and feeding experiments of sesarmid crabs by Cannicci et al. (2018) in mangrove regions of southern Sri Lanka revealed the dominance of a single species in a natural habitat as compared to higher density and diversity in a man-made habitat. The authors further inferred that “interference competition”, wherein the consumers interact directly to utilize the food resources, is a key factor in the spatial distribution of mangrove fauna in addition to other biotic and abiotic factors.

The countries around the Persian Gulf, where salinity exceeds 43 PSU and may at times reach up to 70-80 PSU (Al-Khayat et al., 2021) also harbour diverse mangrove-associated brachyuran crabs and molluscan assemblages (Naderloo et al., 2013; Hajializadeh et al., 2020, 2022; Al-Khayat & Giraldes, 2020; Al-Khayat et al., 2021). Hajializadeh et al., (2020) analysed the species diversity and functional traits of macrofauna in the beach and creek habitats within the Hara biosphere reserve and reported higher species diversity in creek habitats due to the high water-flow that ensured continuous food supply for both deposit feeders and suspension feeders. Hajializadeh et al., (2022) analysed the spatial and temporal distribution of brachyuran crabs in the vegetated mangroves and unvegetated mudflats in the Hara biosphere reserve and attributed their distribution to variations in sediment grain size and organic matter content, and emphasized their significance in formulating conservation strategies. A comparative study of the coastal wetlands of Qatar by Al-Khayat et al. (2021) revealed higher species diversity of molluscs in natural mangroves as compared to planted mangroves and unvegetated areas. The influence of water temperature and salinity was highlighted and an emphasis was laid on the conservation of mangrove habitats.

Ngo-Massou et al. (2012, 2014, 2016) provided baseline data for benthic macrofaunal groups including brachyuran crabs and molluscs from mangrove regions of Cameroon in the African continent along the east Atlantic Ocean. Considering the immense diversity of brachyuran crabs Ngo-Massou et al. (2018) studied seventeen degraded mangrove areas, further highlighting an urgent need for documentation of brachyuran crabs for assigning IUCN Red List status.

The diversity of brachyuran crabs and molluscs on the Brazilian coast along the west Atlantic Ocean was studied by Freitas et al. (2021) and Zamprogno et al. (2023). The Babitonga Bay mangrove ecosystem on the southern Brazilian coast revealed fourteen brachyuran crab species during the sampling span of eight years. The recorded number of species was substantially low given the time frame of sampling which was attributed to the location of the bay around higher latitudes (26°S). Among the macrobenthos of mangroves in Vitória Bay, the molluscan community was found to be best adapted to the changing environmental factors, especially flooding frequency and variation in organic matter content and standing crop among the other macrofauna species. Further, distinct variations in density and composition of brachyuran crabs and molluscs were observed, which emphasised that modifications even on a small scale in the physical structure of mangroves have a significant impact on these communities and therefore efforts should focus on preventing habitat loss, as well as mitigating changes in the physical structure and on the integrity of the system.

1.2.1. *Studies on brachyuran crabs in India*

The pioneering taxonomic studies of the Indian brachyuran crab fauna were initiated by European naturalists such as Linnaeus (1758), Fabricius (1775, 1787, 1793), Herbst (1782-1804), Henri Milne Edwards (1834-1840) who documented specimens primarily obtained from traders visiting India (Trivedi et al., 2018). Extensive studies during the 19th century, conducted by the British across Indian shelf waters, coasts and islands led to the discovery of hundreds of species (Henderson, 1893; Alcock 1893, 1894, 1899a, c; Alcock & Anderson 1894a, b, 1899; Wood- Mason 1874, 1891; Wood-Mason & Alcock 1891a-h). The extensive compilation of the brachyuran fauna by Alcock (1895a,b, 1896, 1898, 1899a, 1899b, 1900a, b, 1901) published in the *Materials for a carcinological fauna of India* yielded six-hundred and five brachyura with one-hundred and twenty-six new records from India and neighbouring British colonies. Post-independence, substantial work was carried out along Maharashtra (Chhapgar, 1955a, b, 1957 a-c, 1958, 1961, 1969; Chhapgar & Borgaonkar, 1985; Chhapgar & Mundkur 1995; Chhapgar et al. 2004), Gulf of Mannar, Andaman and Nicobar and Lakshadweep islands, east coasts of India (Sankarankutty 1961a, b, 1962a, b, 1966, 1969, 1975; Deb 1985a–c, 1986, 1987, 1989a, b, 1992, 1995a, b, 1998, 1999). Numerous discoveries, species descriptions, and local and regional lists have been published by the Zoological Survey of India (ZSI), various research institutions and Universities. Trivedi et al. (2018) compiled the available literature and presented a checklist on the brachyuran crab fauna of India and estimating that India's brachyuran crab fauna comprises nine-hundred and ten species across sixty-two families.

Studies on the brachyuran crabs associated with the mangrove ecosystems of India started to gain attention in the late 1900s with most of the studies listing the crab fauna of the Sunderbans of West Bengal (Chakraborty & Choudhury,1985, 1992a, b), Andaman and Nicobar Islands (Das, 1985; Das & Roy, 1989; Deb, 1989b;) and Pichavaram of Tamil Nadu (Sethuramlingam & Khan, 1991; Chandrasekaran & Natarajan, 1994).

Khan et al. (2005) compared the diversity of brachyuran crabs in natural (thirty-eight species) and planted (eight species) mangroves of the Vellar estuary. They highlighted the role of the longevity of the mangrove stand in sustaining the diversity of these crabs. Subsequent studies on the distribution of brachyuran crabs in the Pichavaram mangroves by Ravichandran et al. (2001) identified five distinct zones: *Cardisoma, Sesarma, Ocypoda, Uca*, and a mixed zone, based on the dominant species of brachyuran crabs in each zone.

Kumar and Khan (2013) conducted spatio-temporal studies and evaluated the effect of environmental parameters. Their findings concluded that salinity, dissolved oxygen levels, organic matter content, and sulphide concentrations were the most significant factors influencing the distribution of brachyuran crabs.

Sen et al. (2014) studied long-term temporal changes in the brachyuran crab community of natural and newly planted mangrove stands in the Sunderban mangroves. Their study revealed the dominance of the ocypodid crab *U. rosea* at both study sites. CCA analysis suggested total acidity, total alkalinity, pH of water, Total dissolved solids, inorganic phosphate content of water, soil specific gravity, soil density and the physical structures of the habitat play a crucial role in moderating the crab community structure. Further, the study revealed that brachyuran crab diversity can be used as a potential indicator of the alterations of mangrove habitats.

Devi et al., (2021) studied the habitat ecology, habitat preference and distribution of mangrove crabs and its habitat preference in the Kochi backwaters. Their findings revealed that the distribution of brachyuran crabs was significantly influenced by the presence of a muddy substratum, high organic carbon and moisture content, and the presence of mangrove vegetation.

Mohanty et al. (2019) delineated habitat-based assemblages of mangrove-associated brachyuran crabs in the Devi estuary, Odisha, based on water salinity, sediment texture, and organic matter. They also reported that the availability of detritus and leaf litter, brought in by tidal surges from the surrounding mangrove environment, supported the crabs.

An extensive review of the mangrove-associated brachyuran crab diversity of the Indian coastline by Chennuri et al. (2023) presented a checklist of one hundred and eighty-four species and revealed a positive correlation between crab diversity, species richness and mangrove cover.

1.2.2. *Studies on molluscs in India*

Molluscan taxonomic research in India began with the establishment of the Asiatic Society of Bengal (1784) and the Indian Museum, Kolkata (1814) (Biju Kumar & Ravinesh, 2015). Early studies were conducted around the Arabian Sea, Bay of Bengal, and the Andaman, Nicobar, and Lakshadweep Islands, with significant contributions from researchers such as

Melvill (1893, 1898, 1909; Melvill & Abercrombie, 1893; Melvill & Standen, 1898, 1907), Smith (1878, 1894, 1895, 1896, 1899, 1904, 1906a, b), and Winckworth (1927a, b, 1928, 1929, 1936, 1940). In the 20th century, general surveys on molluscan taxonomy covering coastal regions, coral reefs, freshwater, and mangrove ecosystems were conducted by the Zoological Survey of India (ZSI). A series of publications, titled Contributions to the Knowledge of Indian Marine Molluscs, by Dr. N. V. Rao and his team from the ZSI, provided family-wise accounts of molluscan fauna from various regions and habitats of India (Rao, 1970, 1977, 1980, 1989, 1991, 2003; Rao & Dey, 1984, 1986; Rao & Rao, 1981, 1991, 1993). The taxonomy of Opisthobranchs, a group of colorful slugs, has recently gained attention, with detailed descriptions and records published by researchers such as Apte (2009), Apte and Bhave (2014), Apte et al. (2012), Bhave and Apte (2011), Carmona et al. (2014), Raghunathan & Sivaperuman (2010), Ramakrishna et al. (2010), and Sreeraj et al. (2012). Further, the available literature pertaining to the gastropod family Nassaridae was reviewed by Nerurkar et al. (2020) revealing a total of one thousand and sixty species from India. Thereafter, an urgent need for comprehensive taxonomic studies was emphasised by the authors as most of the studies from India are local inventories with erroneous names and misidentifications (Nerurkar et al., 2020). The latest study by Edward et al. (2022) on the molluscan fauna of the Gulf of Mannar and adjacent waters provided pictorial illustrations of one thousand and forty-one species of molluscs. The total diversity of molluscs from India is over five thousand species representing almost 7% of the global molluscan diversity (Rao, 1998; Nerurkar et al., 2020). However, there is no consensus among various authors on the total number of marine molluscs from India with numbers varying from two thousand three hundred (Tripathy & Mukhopadhyay, 2015) to three thousand three hundred and seventy (Venkatraman & Wafar, 2005) and three thousand four hundred (Rao, 1991, 1998).

One of the first studies focusing on the molluscs from the mangrove regions of India was in the mid-1900s when the wood-boring bivalves of the family Teredinidae particularly caught the attention of early researchers from Sunderbans (Roonwal, 1954 a,b) and Godavari estuary (Ganapati & Rao, 1959). Later, surveys of mangrove-associated molluscs were conducted in Krishna and Godavari estuary (Radhakrishna & Janakiram, 1975) and Mahanadi estuary (Rao & Mookherji, 1975). Murty and Rao (1977) studied the ecology of molluscs from Machilipatnam mangroves in Tamil Nadu. The study divided the molluscan fauna into arboreal (attached to stems and leaves of mangrove plants) and benthic (subjected to tidal action). The results obtained were compared with the molluscan fauna of Malaysia and South Africa which revealed a greater similarity between molluscan fauna of South India and Malaysia.

The mangroves from Andhra Pradesh have been widely explored by a lot of researchers accounting for a total of sixty-two species including forty-five gastropods and twenty-four bivalves – Machilipatnam (Murty & Rao, 1977), Nizapatnam (Rambabu et al., 1987), Coringa (Rajendar, 2016; Ramadevi et al., 2017; Satyanarayan & Krishna, 2017), Bhavanapadu (Ranjan & Babu, 2014), Karangad (Venkatesan et al., 2010).

Kantharajan et al., (2017) carried out extensive surveys in eight mangrove areas of Mumbai, Maharashtra and recorded sixty-one species of molluscs including forty-six gastropods, fourteen bivalves and one polyplacophora which together with previous studies in Uran (Pawar, 2012); Raigarh (Khade & Mane, 2012) and Ratnagiri (Kulkarni & Mukadam, 2015) accounted to eighty-four mangrove-associated molluscan species of the state.

A recent study by Ravinesh et al. (2021) of the molluscan fauna of the Ashtamudi estuary, Kerala, recorded seventy-two species from mangroves of which three were novel records to India and twenty-one were new records to Kerala. The study highlighted the importance of mangroves as hotspots of biodiversity and recommended the need for extensive surveys on a larger time scale.

A review of mangrove-associated gastropods and bivalves of India by Yadav et al., (2019) reported that the gastropods were represented by one hundred and eighty-two species belonging to fifty families and bivalves were represented by ninety-two species belonging to twenty-seven families. Gastropod families Nertidae, Muricidae, Nassaridae and Ellobiidae; and bivalve families Teredinidae and Veneridae, were dominant families in India.

The role of environmental parameters in the distribution of molluscs has received far less attention. Assessment of the distribution of molluscs across seasons at four mangrove stations in Pondicherry revealed physico-chemical parameters such as organic matter of sediment, sulphide concentrations, dissolved oxygen content and salinity influenced the distribution of the molluscan fauna (Satheeshkumar & Khan, 2012).

1.2.3. *Studies on brachyuran crabs and molluscs from Goa*

The initial studies on brachyuran crabs of Goa were carried out by Kemp (1917, 1919a, 1919b), who reported seven species belonging to three families from the Mandovi-Zuari estuarine regions. The ZSI carried out preliminary faunal surveys in the early 2000s, resulting in the reporting of fifty-one species belonging to thirty-seven genera from the Mandovi-Zuari estuaries and intertidal shores (sandy and rocky) along the coastline (Dev Roy & Nandi, 2005; Dev Roy & Bhadra, 2008; Dev Roy, 2008, 2013). Guinot (1985) and Galil (2009), in their revisionary work on the genus *Parapanope* De Man, 1985 and *Philyra* Leach, 1817, respectively, also contributed one species each to the brachyuran fauna of the state. Padate et al. (2010) and Velip and Rivonker (2014) described two new species to science, whereas Joshi et al. (2011) and Padate et al. (2013) reported new records to the nearshore waters off Goa. Padate et al. (2015) and Komarpant et al. (2018) assessed the morphometric characters of two brachyuran crab species *Dotilla myctiroides* and *Ocypode ceratophthalmus* from three anthropogenically impacted sandy beaches of North Goa. Kaullysing et al. (2015) and Vijaylaxmi et al. (2016) explored the intertidal rocky shore areas with two new records from Goa and one new record of *Carupella banlaensis* from India. Additionally, Vijaylaxmi et al. (2020) studied the population biology of four dominant species of brachyuran crabs of rocky shore regions around Mandovi-Zuari estuaries, and reported their biological parameters, seasonal abundances, along with the predominance of gravid females during both pre-monsoon and post-monsoon seasons.

The pioneering study on the molluscs of Goa was by Rao and Kumary (1973) describing a new species of nudibranch from offshore waters off Dona Paula. Thereafter, scientists from ZSI in their preliminary surveys across India reported thirty-one species belonging to seventeen genera from Goa (Rajagopal & Mookherjee 1978, 1982; Rao & Dey, 1984; Rao, 1989; Rao & Rao, 1993). Santhakumaran (1983) reported thirteen species of wood-boring bivalves from the mangrove regions of Mandovi estuary. Parulekar et al. (1984) assessed the environmental characteristics, growth rate, total production and technically feasible methods for the mass cultivation of *Meretrix casta, Paphia malabarica, Villorita cyprinoides, Donax incarnatus, Perna viridis, Modiolus metcalfei* and *Crassostrea gryphoides.* Ingole et al. (1994) provided the first record of the mud clam *Polymesoda erosa* from the Chorao mangroves in the Mandovi estuary and studied its post-larval settlement and survival pattern (Clemente & Ingole, 2011) and found high densities of juveniles at low tide and mid tide levels with maximum settlement pattern during the month of September. Kumbhar and

Rivonker (2012), Jagtap et al. (2009) and Hussain et al. (2022) provided new of bivalves and gastropods from the mangroves of Mandovi and nearshore regions off Goa. Sonak (2017) identified and provided photographs of one hundred and three gastropods and bivalves from the intertidal sandy and rocky shores along the coastline of Goa. However, the study lacked a scientific approach in general and did not include the collection and deposition of specimens in any scientific institution. Arathi (2018) in her doctoral thesis titled 'Taxonomy and diversity of bivalves molluscs of Lakshadweep and west coast of India' from the University of Kerala, reported a total of sixty-three species from regions around Panjim, Anjuna and Vagator.

Spatio-temporal variations in the estuarine benthic macrofauna of the Mandovi-Zuari estuarine complex were studied by Parulekar et. al. (1980) from 1971-73 which revealed sixty-nine macrobenthic species of which ten were brachyuran crabs and thirty-five were molluscs (gastropods: ten; bivalves: twenty-five). Ansari et al. (1986) resurveyed the same stations after a gap of ten years and noticed a 40% reduction in macrobenthic population which was attributed to the disturbances caused by mining refuge, sand excavation and extraction in both the estuaries. Hegde et al. (2013) and Rivonker et al. (2018) presented an inventory of macrobenthic invertebrates from the nearshore waters off Goa and reported six new records of brachyuran crabs and five new records of molluscs in the study area.

It is apparent from the above review of literature that although studies on the taxonomy and biology of the brachyuran crab fauna of Goa are available, the studies on the molluscan fauna are scanty. Moreover, the majority of the available studies are from the Mandovi-Zuari estuaries, intertidal shores (sandy and rocky) and nearshore waters. Further, the mangrove-associated brachyuran crab and molluscan fauna largely remain unexplored. Hence, the present study has attempted to provide taxonomic accounts and draw inferences about the distribution of epifaunal brachyuran crabs and molluscs in the mangrove areas of Chapora (North Goa) and Sal (South Goa) estuaries of Goa.

1.3. Objectives

In view of the above, the present study addresses the following objectives

1. To assess species composition of brachyuran crabs and molluscs in the study area.
2. Spatial and temporal variation of brachyuran crabs and molluscs with respect to their diversity, abundance and biomass.
3. To assess the role of habitat in species distribution.