Studies on brachyuran crabs and molluscs along Chapora and Sal estuaries, Goa, West Coast of India

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By

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DECLARATION

I, Mithila Subhash Bhat hereby declare that this thesis represents work which has been carried out by me and that it has not been submitted, either in part or full, to any other University or Institution for the award of any research degree.

Place: Taleigao Plateau.

Date: 13|01|2025

Ms. Mithila Subhash Bhat

CERTIFICATE

I hereby certify that the above Declaration of the candidate, Mithila Subhash Bhat is true and the work was carried out under my supervision.

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LIST OF ABBREVIATIONS

ANOVA	: Analysis of Variance
BOD	: Biological Oxygen Demand
CCA	: Canonical Correspondence Analysis
Chl-*a*	: Chlorophyll-*a*
CL	: Carapace length
CW	: Carapace width
DCA	: Detrended Correspondence Analysis
Df	: Degrees of freedom
DO	: Dissolved Oxygen
G1	: Male gonopod/ first pleopod
GSPCB	: Goa State Pollution Control Board
H'	: Shannon-Weiner's diversity index
HTL	: High Tide Level
IUCN	: The International Union for Conservation of Nature
IWP	: Indo-West-Pacific
LTL	: Low Tide Level
MS	: Mean squares
MTL	: Mid Tide Level
N	: Total abundance
OC	: Organic Carbon
PSU	: Particle Salinity Units
RDA	: Redundancy Analysis
SD	: Standard Deviation
SL	: Shell length
SPM	: Suspended Particulate Matter
SS	: Sum of Squares
SW	: Shell width
WoRMS	: World Register of Marine Species
ZSI	: Zoological Survey of India

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.

CHAPTER 2

Materials and Methods

2.1. Study area

Goa,located along the central west coast of India, has a coastline of 151 km comprising 44% of sandy beach, 21% rocky coast, and 35% muddy flats (Kumar et al., 2006). Nine intertidal rivers traverse within the state of which two rivers Chapora in the North Goa and Sal in the South Goa are selected for the present study. Both Chapora and Sal estuaries are semi-diurnal micro-tidal estuaries with tidal amplitude of around 0.25 m during neap tide to 2.0 m during the spring tide (Fernandes et al., 2018).

The Chapora river, located in the Bardez taluka with a 32 km stretch of it influenced by salinity fluctuations and harbours around 220 hectares of mangrove forest (Goa State Pollution Control Board [GSPCB], 2019a). The estuary is surrounded by some popular tourist destinations like Vagator beach (South), Morjim beach (North), and Chapora fort (estuarine mouth). Additionally, manual sand extraction activity and aquaculture ponds are common in the estuarine regions. The Sal river in the Salcete taluka is 40 km long with a 14 km stretch of it under the influence of salinity harbouring 11 hectares of mangrove vegetation (Goa State Pollution Control Board [GSPCB], 2019b). The Sal estuary runs along the coastline, featuring shallow shoreline with a narrow mouth, which hinders the transport of domestic wastes into the sea (Fernandes et al., 2018). The Cutbona jetty, located around 2 km from the estuary mouth, is close to popular beaches like Cavellosim, Mobor and Betul, which run parallel to the estuary. Additionally, the collection of bivalves, mussels, and oysters by locals is a common practice along the estuarine banks.

Due to the inflow of population and tourism, anthropogenic activities such as fishing, river cruises, shoreline constructions, sewage disposal, sand mining, extraction of oysters, disposal of fish offal and polythene waste are increasing at an alarming rate. These activities are causing significant alterations to the habitats in these regions.

2.2. Sampling Sites

A total of four mangrove-associated intertidal stations, two each along Chapora (Station C1 and C2) and Sal (Station S1 and S2) estuaries were selected for the present study (Fig. 2.1. Table 2.1). Sites were selected based on habitat diversity, mainly variation in the mangrove vegetation and accessibility. Station C1 is located almost at the mouth of the Chapora estuary (1.5 km) and harbours young and scattered mangrove vegetation (Fig. 2.2). This station is indirectly affected by anthropogenic activities such as the deposition of litter along with the incoming tide and the influence of tourist boat rides. Station C2 is situated 4 km away from

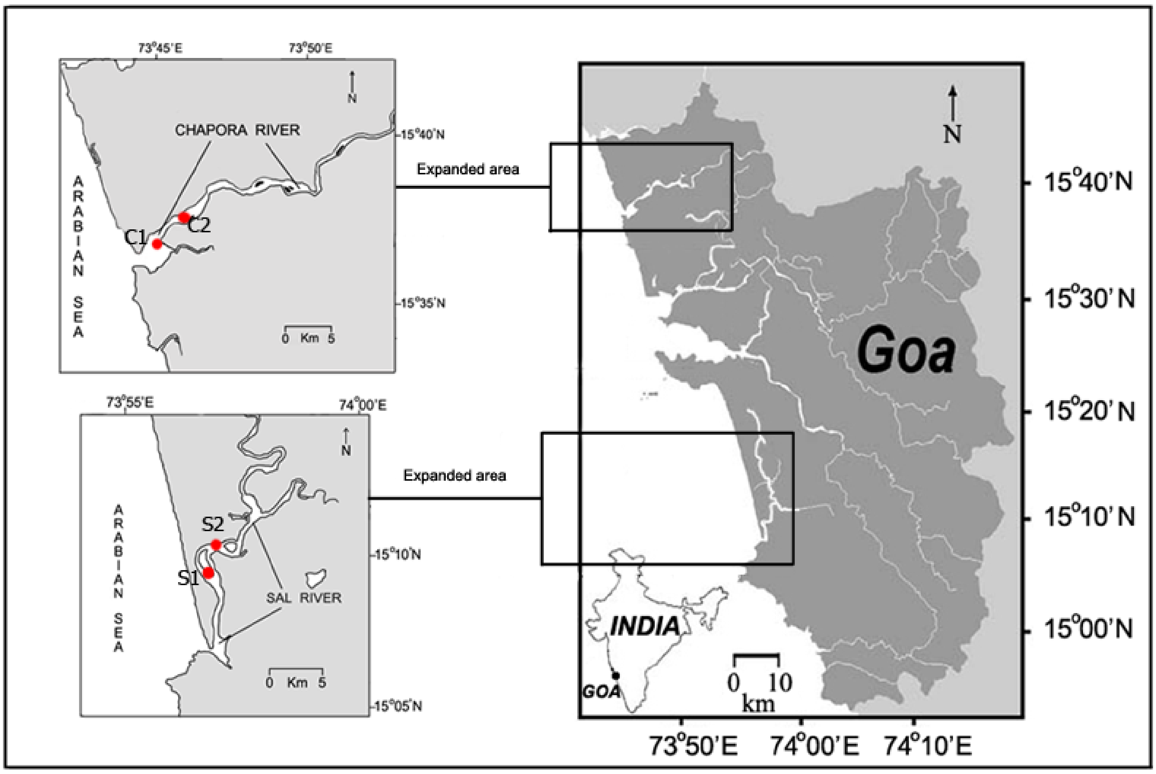

Figure 2.1. Map of the study area indicating the sampling locations.

Table 2.1. Details of sampling stations

Station no.	**Name of Estuary**	**Geographical coordinates**	**Vegetation**
C1	Chapora	15º 37.353'N, 73º 44.758'E	Sandy to muddy substratum with young, scattered *Avicennia marina* mangrove.
C2	Chapora	15º 37.953'N, 73º 45.765'E	Muddy substratum with dense, mixed mangroves (*Avicennia marina, Sonneratia alba* and *Rhizophora mucronata*) and associated shrubs (*Clerodendrum inerme* and *Acanthus ilicifolius*).
S1	Sal	15º 10.095'N, 73º 56.781'E	Muddy substratum with dense, monotypic mangrove *Avicennia marina.*
S2	Sal	15º 09.836'N, 73º 56.952'E	Sand flat lined by *Avicennia marina* mangroves.

the mouth of the estuary. This site is constantly affected by human activities such as the disposal of fish offal and polythene waste, and the movement of fishing canoes of the fisherman. Station S1 is located 3 km away from the mouth of the Sal estuary. The area around the station is surrounded by numerous hotels and resorts, along with shrimp farms. Station S2 is a sand flat located around 4.5 km away from the mouth of the estuary and is relatively pristine.

2.3 Sampling methodology

Intertidal surveys at each station were carried out during low tide at monthly intervals from April 2016 to March 2017 (Table 2.2). The sampling sites were accessed by a motorised canoe. Each survey comprised laying of 1 m^2 quadrant at low, mid and high tide levels to compute epifaunal density and record the types and numbers of brachyuran crabs and molluscs. Species abundance for burrowing fiddler and dotillid crabs was determined directly from the burrow counts; for sympatric crabs (different species occupying the same habitat) was determined with visual counts and photographs in addition to burrow counts and for sesarmids and running crabs with visual counts and photographs. Subsequently, representative subsamples of the biological specimens were picked and stored in pre-labelled containers.

The temperature of water and sediment was recorded on the field using a laboratory thermometer (±0.1°C accuracy). Additionally, samples for estimation of salinity, pH, nutrient concentration, dissolved oxygen, chlorophyll-*a*, suspended particulate matter concentration in seawater and grain size, organic carbon, soil moisture, and chlorophyll-*a* concentration in sediment were collected. For fixing the dissolved oxygen in the water sample, 1 mL Winkler's reagent was added to 125 mL water sample in glass stoppered bottles. For assessing the chlorophyll-*a* pigment concentration, water and sediment sample was collected in amber-coloured polythene bottles. Water samples for recording other environmental parameters were collected separately in plastic bottles. Sediment samples were collected using scoops in pre-labelled polythene bags and stored in ice. Additional details of mangroves and associated vegetation and microhabitats were noted at every tidal level. Sample leaves and flowers were collected from the vegetation for further identification. All the samples were transported in an ice box to the Marine Biology Laboratory at Goa University for further analysis.

Table 2.2. Details of sampling carried out in the study area

Sr. No.	Month and Year of Sampling	Estuary	Date	Time of sampling (h)	Tidal amplitude (m)
1.	April 2016	Chapora	13/04/2016	10.00-12.00	0.3
		Sal	14/04/2016	10.00-12.00	0.4
2.	May 2016	Chapora	13/05/2016	09.30-11.45	0.5
		Sal	14/05/2016	11.00-13.00	0.6
3.	June 2016	Chapora	10/06/2016	8.30-10.45	0.3
		Sal	11/06/2016	9.00-11.00	0.5
4.	July 2016	Chapora	12/07/2016	9.45-12.00	0.7
		Sal	11/07/2016	9.15-11.15	0.8
5.	August 2016	Chapora	10/08/2016	9.15-12.15	0.8
		Sal	09/08/2016	8.15-10.15	0.6
6.	September 2016	Chapora	08/09/2016	9.00-11.00	0.8
		Sal	07/09/2016	9.00-11.00	0.7
7.	October 2016	Chapora	07/10/2016	9.00-11.00	0.8
		Sal	08/10/2016	8.30-10.30	0.8
8.	November 2016	Chapora	20/11/2016	9.30-11.30	0.7
		Sal	21/11/2016	8.30-10.30	0.7
9.	December 2016	Chapora	07/12/2016	9.00-11.00	0.7
		Sal	06/12/2016	9.00-11.00	0.7
10.	January 2017	Chapora	05/01/2017	9.00-11.00	0.5
		Sal	04/01/2017	8.30-10.30	0.6
11.	February 2017	Chapora	04/02/2017	9.45-11.45	0.4
		Sal	03/02/2017	9.00-11.00	0.4
12.	March 2017	Chapora	05/03/2017	9.00-11.00	0.3
		Sal	04/03/2017	9.00-11.00	0.2

2.4. Laboratory procedure

Taxonomic identification and biomass estimation

All the collected specimens were brought to the laboratory and washed under running tap water to remove debris. The larger specimens were photographed using a Sony RX 10II camera, and smaller specimens and body parts were photographed using a DIGITAL SIGHT DS-Fi2 camera attachment for the NIKON SMZ 745T stereomicroscope. Thereafter, standard morphometric characters (Carapace length and width for brachyuran crabs; shell length and width for molluscs) were measured using INSIZE digital vernier calliper, 0-150mm. Subsequently, the specimens were subjected to biomass measurement (wet weight) g per m^2 using electronic weighing balance SHIMADZU ATX124 for weight less than 10 gm and KERN-FCB for weight more than 10 gm weight of the specimens.

The species level identification was carried out using published identification keys, monographs and taxonomic literature. For brachyuran crabs identification, the literature referred included Alcock (1896, 1898, 1899, 1900, 1901); Kemp (1917, 1919); Chhapagar (1957a, 1957b); Banerjee (1960); Serène and Soh (1970); Wee and Ng (1995); Keenan et al. (1998); Ng, (2007); Barnes (2010); Lai et al. (2010, 2013); Padate et al. (2010); Sakai and Holthuis, (2013); Kaullysing et al. (2015); Ng et al. (2017); Shih et al. (2018); Innocenti et al. (2020).

Molluscs specimens were identified following literature such as Gruneberg (1978) Cernohorsky (1984), Reid (1986, 2001); Melvill (1893); Swennen (1997); Tan and Clements (2008); Jagtap et al. (2009); Huber (2010, 2015); Claremont et al. (2013); Ramakrishna and Dey (2010); Reid and Ozawa (2016); Arathi et al. (2018); Nerurkar et al. (2020); Goulding et al. (2021); Ravinesh et al. (2021); Tudu et al. (2021), Hussain et al. (2022).

The species names were updated from the online database World Register of Marine Species (WoRMS) (http://www.marinespecies.org). Further, photographic plates were prepared using Adobe Photoshop (version CC 2019). Abbreviations used in the present study include CW, carapace width; CL, carapace length; G1: male first gonopod for brachyuran crabs and SW, shell width; SL, shell length for molluscs.

Sample preservation

Brachyuran crabs were preserved in 5 % buffered formalin (buffered with hexamethylene tetramine) and molluscs were preserved in 5 % formalin. Samples were stored in plastic bottles and deposited as reference vouchers at the Marine Biology Laboratory, Marine Science programme at the School of Earth Ocean and Atmospheric Sciences, Goa University.

Analysis of physico-chemical parameters of water and sediment

1. *Salinity* (PSU)

The salinity of the water was measured by HANNA HI96822 Seawater Refractometer, calibrated to zero with distilled water with ±0.1 PSU accuracy.

2. *pH*

A portable benchtop pH meter (Model: Thermo Orion Star A211) was used to measure the pH of water samples (Accuracy of ± 0.01). The pH meter was regularly standardised against standard buffer solutions (pH 4.0, 7.0 and 9.2).

3. *Dissolved oxygen* (mg/L)

The dissolved oxygen (D.O.) concentration of the water samples was measured following Winkler's titrimetric method (Grasshoff, 1983). The water samples fixed on field with Winkler's A and B reagents were treated with 50% HCl to dissolve the precipitate and titrated with standard sodium thiosulphate solution, where the endpoint (blue to colourless) was marked using starch as an indicator.

4. *Suspended particulate matter* (mg/L)

Suspended particulate matter (SPM) of water samples was measured by filtering 500 mL of sample through pre-weighed Millipore 0.45 µm membrane filter paper. The filter paper was then oven-dried at 100°C. Once dried, weight was recorded and subtracted from the initial weight to get the SPM value (Grasshoff, 1983). Filter papers were weighed using SHIMADZU ATX124 weighing balance with an accuracy of ±0.001mg.

5. *Nutrients (*µmol/L)

The essential dissolved nutrients (Nitrate-(NO_3-N), Nitrite (NO_2-N), Phosphate (PO_4-P), and Silicate (SiO_4-Si)) were analysed in water samples following the procedure by Grasshoff et. al. (1983). Calibrations were made using aqueous standards and results were expressed in µmol/L. The procedure adopted for analysing each nutrient parameter is provided below briefly:

a) Nitrate and Nitrite

Nitrate and Nitrite in water were measured by colorimetric method, wherein Sulphanilamide (0.5 mL) and N (1-naphthyl)-ethylenediamine dihydrochloride (0.5 mL) were added to a 25 mL sample resulting in the formation of pink coloured azo dye. The optical density of the resultant sample was measured spectrophotometrically after 10 minutes at 543 nm in a 1cm quartz cuvette. For nitrate, the sample (50 mL) was initially passed through the reductor Cadmium column (> 95 % efficiency) where the nitrate is reduced to nitrite.

b) Phosphate

Phosphate in water was estimated by acidifying 25 mL of sample with acid molybdate reagent (0.5 mL) and further addition of ascorbic acid (0.5 mL) giving blue coloured compound, which is measured spectrophotometrically at 880 nm using 1 cm quartz cuvette in 10 minutes.

c) Silicate

Estimation of silicate in water involved acidifying the sample (25 mL) with acid molybdate reagent (1 mL), thereafter treating it with ascorbic acid (0.5 mL) and oxalic acid (1 mL). In 20 minutes, the resultant blue silico-molybdate complex was measured at 810 nm with 1 cm quartz cuvette spectrophotometrically.

6. Chlorophyll-a in water (mg/L) and sediment (mg/m^3)

Estimation of Chlorophyll-*a* in water and sediment was carried out following procedure by Strickland and Parsons (1972). 500 mL of water sample was filtered through 47 mm GF/F filter paper (Millipore, 0.7 µm pore size). The pigments were extracted by immersing the filter papers in 10 mL of 90 % acetone at 4 (±2) °C for 18 h. For sediment samples 1 gm of sediment was weighed and was similarly immersed in 10 mL of 90 % acetone. Following the extraction, filter papers were centrifuged at 1500 rpm for 5 minutes. The clear supernatant liquid was decanted and measured spectrophotometrically at Wavelengths 665 nm, 645 nm and 630 nm.

7. Texture of sediment: (Sand (%); Silt (%); Clay (%))

The grain size distribution i.e. sand (> 63 microns), silt (2.0 to 63 microns) and clay (< 2.0 microns) fractions in sediment samples were estimated by standard pipette method (Folk, 1968). The abundance of each fraction was expressed in terms of percentage of total weight.

10 gm of oven-dried sediment was weighed and 1000 mL of distilled water was added and stirred thoroughly. Upon settlement of the sediment, the supernatant water was decanted and this step was repeated thrice. The fourth time, after decanting the supernatant water, 10 mL of 10 %, sodium hexametaphosphate was added and kept overnight with occasional stirring to break the flocculated clay particles. Further, 5 mL of 30 % Hydrogen peroxide (H_2O_2) was added to oxidize the organic matter. The resultant sample was then passed through a 63-micron sieve to separate the sand fraction. The filtrate after separating the sand fraction was collected in a 1000 mL cylinder, homogenized using a stirrer and left undisturbed to settle at room temperature. At 8 ϕ, 25 mL of filtrate was pipetted out at a depth of 10 cm from the 1000 mL mark following the standard table given by Folk (1968) (Kwankam et al., 2021). Collection for both sand and clay was done in pre-weighed beakers, which were dried at 60°C and weighed again to determine the sand, silt and clay fractions.

8. *Sediment Moisture* (%)

Sediment moisture was estimated using a thermogravimetric method as described by Topp et al. (2008). According to this method, a moist sediment sample is weighed and oven-dried for around 24 hours at 105 °C and reweighed. The weight loss is calculated to determine the moisture content.

9. *Total organic carbon* (%)

To estimate total organic carbon (%), sediment was dried and finely ground using mortar and pestle. 0.2 gm of the sample was weighed and 10 mL of chromic acid was added and kept in a boiling water bath for 15 minutes to oxidise all the organic carbon compounds present in the sample. Once the contents had cooled down, 200 mL of distilled water was added with 1 drop of Ferrous-phenanthroline indicator and titrated with 0.2 N Ferrous ammonium sulphate, until the pink colour persisted (El Wakeel & Riley, 1957) (Rehitha et al., 2017).

2.5. Data Analysis

Species abundance (numbers per m^2) was computed from the burrows, visual counts and photographs of the quadrants. Subsequently, the abundance and biomass of the representative subsamples of each species were extrapolated to the total sample and used to draw inferences on the spatiotemporal variations. Monthly data collected was grouped into seasons as Pre-monsoon (February-May), Monsoon (June-September) and Post-monsoon (October to January) following Sivadas et al. (2011).

Shannon-Weiner diversity index (H') was calculated using PAST version 4.13 statistical software (Hammer et al., 2001). H' measures the overall diversity or heterogeneity of species in a community, taking into account both species richness (the number of different species) and species evenness (relative abundance of each species) (Shannon & Wiener, 1963). Analysis of variance (ANOVA) (two-way, without replication) was carried out to assess the spatial and temporal differences in the diversity, abundance and biomass of brachyuran crabs and molluscs using the MS Excel program.

Redundancy Analysis (RDA) was performed to understand the spatial distribution of brachyuran crabs and molluscs and their relationship with environmental parameters. To know the suitability for the present study Detrended Correspondence Analysis (DCA) was carried out first and from the results obtained the choice of Canonical Correspondence Analysis (CCA) or RDA was made. The criteria for selection is based on the length of the first axis: if the length is > 2.0 CCA is performed, if it is < 2.0 RDA is performed (Pujari et al., 2021). For the present study length was < 2.0, therefore RDA was performed. To perform the above analysis CANOCO 4.5 software was used.

CHAPTER 3

Species composition of brachyuran crabs

3.1. Introduction

The estuarine shores of Goa are marked by mixed habitats comprising mangrove vegetation, rocky and sandy shores harbouring diverse brachyuran crab assemblage (Hegde et al., 2013). Preliminary faunal surveys were carried out by the Zoological Survey of India (ZSI) among these regions reporting fifty-one species (Dev Roy & Nandi, 2005; Dev Roy & Bhadra, 2008; Dev Roy, 2008, 2013). Thereafter, Vijaylaxmi (2020) in work of her doctoral thesis surveyed and provided baseline data for some rocky shore regions of the Mandovi & Zuari estuaries thereby reporting twenty-nine species of brachyura. Additionally, the studies by Padate et al. (2010, 2013, 2015), Joshi et al. (2011), Velip and Rivonker (2014) and Komarpant et al. (2018) reported new species, new records and concentrated on taxonomy and morphometry of some species of brachyuran crabs from the nearshore waters and the sandy coasts. However, the mangrove-associated estuarine regions, especially of the Chapora and Sal estuaries of Goa have largely remained unexplored. Taxonomically accurate baseline data is important not only for systematists but also for researchers from other disciplines and conservationists. Considering these lacunae in the available knowledge, the present study aims to provide baseline data of the brachyuran crab fauna from the mangrove-associated regions of the Chapora and Sal estuaries of Goa.

3.2. Results

The survey along the four study locations in the Chapora (C1, C2) and the Sal (S1, S2) estuaries revealed thirty brachyuran crab species belonging to eleven families and twenty-four genera (Table 3.1). The maximum number of species belonged to the family Sesarmidae (nine species from four genera) followed by Portunidae (four species from four genera) and Ocypodidae (four species from four genera), Macrophthalmidae (three species from one genus), Dotillidae (two species from two genera), Grapsidae and Varunidae (two species from one genus each), Matutidae, Hymenosomatidae, Xanthidae and Pilumnidae (one species each). Three species namely *Metopograpsus cannicci, Nanosesarma tweediei* and *Sarmatium crassum* were recorded for the first time from India, *Episesarma versicolor* was recorded for the first time from the west coast of India, and seven species namely *Macrophthalmus (Macrophthalmus) brevis, Macrophthalmus (Macrophthalmus) parvimanus, Metopograpsus latifrons, Parasesarma bengalense, Portunus reticulatus, Pseudosesarma glabrum*, and *Tubuca alcocki* were recorded for the first time from the state of Goa.

Table 3.1. Checklist of brachyuran crabs reported from the study area

Sr. No.	Family and species list	References/from Goa
	Order **Decapoda** Latreille, 1802	
	Infraorder **Brachyura** Latreille, 1802	
	Section **Eubrachyura** de Saint Laurent, 1980	
A.	Subsection **Heterotremat**a Guinot, 1977	
I.	**Family Matutidae De Haan, 1835**	
1.	*Matuta victor* (Fabricius, 1781)	Alcock, 1896; Dev Roy & Bhadra, 2008
II.	**Family Hymenosomatidae MacLeay, 1838**	
2.	*Neorhynchoplax demeloi* (Kemp, 1917)	Kemp, 1917; Dev Roy & Bhadra, 2008; Vijaylaxmi, 2020
III.	**Family Portunidae Rafinesque, 1815**	
3.	*Charybdis (Charybdis) hellerii* (A. Milne-Edwards, 1867)	Vijaylaxmi, 2020
4.	*Portunus reticulatus* (Herbst, 1799)	Present Study
5.	*Scylla serrata* (Forskål, 1775)	Parulekar et al., 1980; Dev Roy & Bhadra, 2008; Padate et al., 2013
6.	*Thalamita crenata* Rüppell, 1830	Dev Roy & Bhadra, 2008; Dev Roy, 2013
IV.	**Family Xanthidae MacLeay, 1838**	
7.	*Leptodius exaratus* (H. Milne Edwards, 1834)	Dev Roy & Bhadra, 2008; Dev Roy, 2013; Lee et al., 2013
V.	**Family Pilumnidae Samouelle, 1819**	
8.	*Heteropanope glabra* Stimpson, 1858a	Kaullysing et al., 2015
B.	Subsection **Thoracotremata** Guinot, 1977	
VI.	**Family Grapsidae MacLeay, 1838**	
9.	*Metopograpsus cannicci* Innocenti, Schubert & Fratini, 2020	Present study
10.	*Metopograpsus latifrons* (White, 1847)	Present study

VII.	**Family Sesarmidae Dana, 1851**	
11.	*Clistocoeloma merguiense* De Man, 1888	Dev Roy & Bhadra, 2008; Dev Roy, 2013
12.	*Episesarma versicolor* (Tweedie, 1940)	Present study
13.	*Nanosesarma andersoni* (De Man, 1888)	Dev Roy & Bhadra, 2008; Dev Roy, 2013; Vijaylaxmi, 2020
14.	*Nanosesarma minutum* (De Man, 1887)	Vijaylaxmi, 2020
15.	*Nanosesarma tweediei* Serène, 1967	Present study
16.	*Parasesarma bengalense* (Davie, 2003)	Present study
17.	*Parasesarma plicatum* (Latreille, 1803)	Dev Roy & Bhadra, 2008; Dev Roy, 2013
18.	*Pseudosesarma glabrum* Ng, Rani and Bijoy Nandan, 2017	Present Study
19.	*Sarmatium crassum* Dana, 1851	Present Study
VIII.	**Family Varunidae H. Milne Edwards, 1853**	
20.	*Chhapgarus intermedius* (Chhapgar, 1957)	Vijaylaxmi, 2020
21.	*Varuna litterata* (Fabricius, 1798)	Dev Roy & Bhadra, 2008; Dev Roy, 2013
IX.	**Family Dotillidae Stimpson, 1858**	
22.	*Dotilla myctiroides* H. Milne Edwards, 1852	Kemp, 1919a; Dev Roy, 2013; Padate et al., 2015
23.	*Scopimera proxima* Kemp, 1919a	Kemp, 1919a; Dev Roy, 2013
X.	**Family Macrophthalmidae Dana, 1851**	
24.	*Macrophthalmus (Macrophthalmus) brevis* (Herbst, 1804)	Present Study
25.	*Macrophthalmus (Macrophthalmus) parvimanus* Guérin, 1834	Present Study
26.	*Macrophthalmus (Mareotis) pacificus* Dana, 1851	Kemp, 1919b; Dev Roy & Bhadra, 2008; Dev Roy, 2013
XI.	**Family Ocypodidae Rafinesque, 1815**	

27.	*Austruca annulipes* (H. Milne Edwards, 1837)	Vijaylaxmi, 2020
28.	*Gelasimus vocans* (Linnaeus, 1758)	Vijaylaxmi, 2020
29.	*Ocypode ceratophthalmus* (Pallas, 1772)	Dev Roy & Bhadra, 2008; Dev Roy, 2013; Komarpant et al., 2018
30.	*Tubuca alcocki* Shih, Chan & Ng, 2018	Present Study

Systematic accounts of all the recorded brachyuran species including their synonymy, material examined, diagnosis, and notes on their habitat and distribution, supplemented with photographic illustrations of diagnostic morphological characters are provided below.

Systematic Accounts

Order Decapoda Latreille, 1802

Infraorder Brachyura Latreille, 1802

Section Eubrachyura de Saint Laurent, 1980

Subsection Heterotremata Guinot, 1977

Family Matutidae De Haan, 1835

Genus *Matuta* Weber, 1795

***Matuta victor* (Fabricius, 1781)**

(Fig. 3.1)

Cancer lunaris Forskål, 1775: 91 (type locality: Malabar coast, India).

Cancer victor Fabricius, 1781: 502; Fabricius, 1793: 449.

Matuta victor Fabricius, 1798: 369; H. Milne Edwards, 1837: 115, pl. 20 figs. 3-6; Alcock, 1896: 158 (identification key), 160; Gravely, 1927: 142, pl. 22 fig. 28; Galil & Clark 1994: 39, fig. 7a-b, pl. 13a-b; Ng et al., 2002: 357 (identification key), 358, fig. 2G; Ng et al., 2008: 50 (list); Galil & Mendelson 2013: 69, Fig. 1,2; Trivedi et al., 2018: 53 (list).

Matuta peronii Leach, 1817: 13; pl. 127 figs. 1, 2.

Matuta lesueurii Leach, 1817: 14.

Matuta lunaris Kossmann, 1877: 64 (part); Sakai, 1936: 49, pl. 13 fig. 3; Chopra & Das, 1937: 383, fig. la; Barnard, 1950: 358, pl. 67 fig. 1; Sankarankutty, 1962: 153, fig. 2; Holthuis & Sakai, 1970: 118, pl. 10 fig. 2.

Matuta victrix Miers, 1877: 243, pl. 39 fig. 1-3 (type locality: Philippines.

Matuta crebrepunctata Ward, 1941: 1 (type locality: Gulf of Davao, Philippines).

Material examined: CW 15.32–63.00 mm; CL 9.10–39.50 mm (N=12)

Diagnosis: Carapace subcircular, smooth, as long as broad (excluding lateral spine), Front wider than orbit, trilobate, median lobe projecting, anteriorly emarginate. Anterolateral margin arcuate, tuberculate. Posterolateral margin convergent, carinate. Lateral spine massive. Orbits communicating with antennular fossa. Suborbital margin laterally interrupted by curved inhalant canal. On pterygostomial region, stridulating organ comprises rows of elongate tubercles. Chelipeds sub-equal, massive. External surface of palm with two rows of granulate low tubercles, proximal most in lower row largest. Mid-palm with a rounded ridge extending to tip of lower finger proximally with granulate tubercle followed by a prominent spine. At lower proximal angle of palm, a prominent spine. Dactylus in male bearing distinctly milled ridge on outer surface, absent in female. Pereopods natatory, with first propodus bearing triangular tooth on inferior margin; P4 carpus unicarinate; P5 propodus greatly extended. Third pleonal somite transversely carinate. Carapace pale yellow, with numerous small and evenly scattered black spots. Pereopods specially dactylus bright yellow.

Habitat and Distribution: Shallow subtidal, substrate sandy (Naderloo, 2017); Distributed from Red Sea, East coast of Africa and Madagascar through South and Southeast Asia to Japan, Australia and Western Pacific islands; invasive species in the Mediterranean region (Galil & Mendelson, 2013).

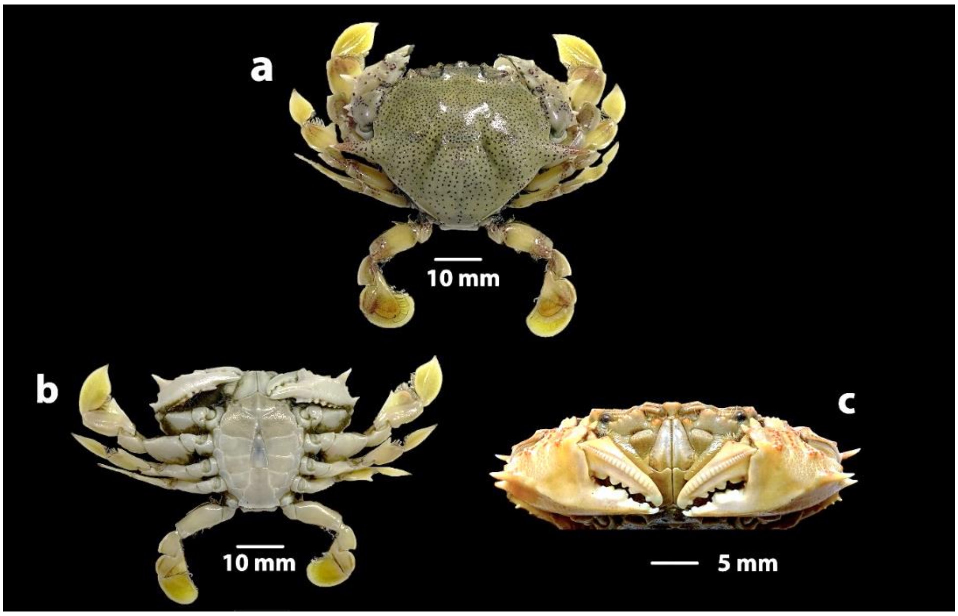

Figure 3.1. *Matuta victor* (Fabricius, 1781); CW 63.00 mm, CL 39.50 mm, male; (a) dorsal view; (b) ventral view; (c) frontal view along with chela.

Family Hymenosomatidae MacLeay, 1838

Genus *Neorhynchoplax* Sakai, 1938

***Neorhynchoplax demeloi* (Kemp, 1917)**

(Fig. 3.2)

Rhynchoplax demeloi Kemp, 1917: 258, figs. 6-9 (type locality: Goa, India).

Neorhynchoplax demeloi Sakai, 1938: 200 (list); Ng et al., 2008: 109 (list); Trivedi et al., 2018: 44 (list); Rahayu et al., 2020: 82 (identification key), 82, figs. 2b, 4a-h.

Material examined: CW 2.70–3.10 mm; CL 2.60–3.00mm (N=2)

Diagnosis: Carapace subcircular, sunken, defined by a marginal rim and the regions delimited by sharply-cut grooves. Rostrum distinctly trilobate, lobes fused, median lobe with rounded distal margin, as long as triangular lateral lobes. External maxillipeds very slender, do not close the buccal cavern. Male chelipeds elongate, subequal, stouter than the walking legs, covered with fine setae; merus long, lower margin with distal strong tooth; carpus subovate; palm slender, surfaces smooth with sparse short setae on upper half; dactylus longer than palm, cutting edge of dactylus and fixed finger with several moderately large teeth. Pereopodal articles broad, lined with bristles; dactylus broad, laterally flattened. Abdominal somites 3–5 of male fused.

Habitat and Distribution: Brackish water environments, plant debris, silty-sand substratum and submerged oyster beds; sluice gate of aquaculture farms (Rayahu et al., 2020). Distributed only along the West coast of India (Kemp, 1917; Haragi et al., 2010; Dineshbabu et al., 2011; Rayahu et al., 2020).

Figure 3.2. *Neorhynchoplax demeloi* (Kemp, 1917); CW 3.10 mm, CL 3.00 mm, male; (a) dorsal view; (b) ventral view; (c) chela dorsal view (d) male abdomen.

Family Portunidae Rafinesque, 1815

Genus *Charybdis* De Haan, 1833

Charybdis (Charybdis) hellerii (A. Milne-Edwards, 1867)

(Fig. 3.3)

Goniosoma hellerii A. Milne-Edwards 1867: 282, 283 (type locality: New Caledonia).

Goniosoma merguiense De Man 1888b: 82, pl. 5, figs. 3, 4 (type locality: Mergui archipelago).

Charybdis (Goniosoma) merguiense Alcock, 1899: 55.

Charybdis (Goniosoma) merguiensis Nobili, 1906a: 196; Chopra 1935: 484, fig. 8.

Charybdis (Charybdis) helleri Leene, 1938: 44, figs. 15, 16a-d, 17a-c, Crosnier, 1962: 77, figs. 133-135, pl. V, fig. 1; Wee & Ng, 1995: 32. Fig. 14A-G; Apel & Spiridonov 1998: 185 (in key), 194, figs. 13-15, 17; Ng et al., 2008: 153 (list); Naderloo 2017: 172 (identification key), 174, figs. 20.3d, 20.5, 20.7; Trivedi et al., 2018: 64 (list).

Charybdis (Charybdis) lucifera Stephensen, 1945: 115 (not *Portunus lucifer* Fabricius, 1798).

Charybdis helleri Guinot 1967: 255 (list); Jones 1986a: 161, pl 47.

Material examined: CW 49.63 mm, CL 32.10 mm (N=1)

Diagnosis: Carapace glabrous, with no ridges present behind epi branchial; six frontal teeth, medians elliptical, laterals acutely triangular, separated from sub medians by deep V-shaped notch; six anterolateral teeth, first and second closer and sub equal in size, last elongate and spiniform, projecting beyond preceding tooth. Basal antennal segment bearing sharp granular ridge. Chelipeds stout and unequal, surface finely pubescent; anterior border of merus with three spines and a spinule at distal end; carpus with strong spine on inner angle and three spinules at outer angle; manus with five spines on upper surface, outer surface three smooth costae, inner surface with median costa, lower surface smooth; fingers stout, deeply grooved. Propodus of natatory leg serrated on posterior border; merus and carpus with spine on posterior border. Penultimate segment of male abdomen with lateral borders parallel then converging distally. G1 distal tip slender and elongate, inner surface with short bristles, ending as tiny spinules at base of G1, outer surface with longer bristles starting from tip and ending at distal third of it.

Habitat and Distribution: Intertidal rocky, cobble, sandy and muddy substrates among mangroves and coral reefs (Stephenson, 1972b). Distributed from South and East Africa through South and Southeast Asia to Australia and New Caledonia; invasive species in the Mediterranean region, the Caribbean coast of Colombia, Atlantic coasts of Florida and Brazil (Apel & Spiridonov, 1998).

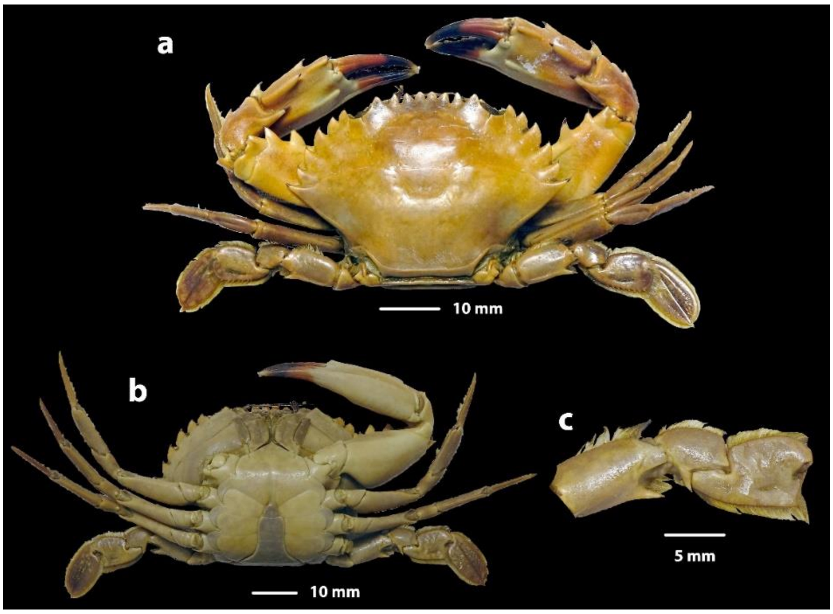

Figure 3.3. *Charybdis (Charybdis) hellerii* (A. Milne-Edwards, 1867); CW 49.63 mm, CL 32.10 mm, male; (a) dorsal view; (b) ventral view; (c) spine on merus and carpus of natatory leg.

Genus *Portunus* Weber, 1795

***Portunus reticulatus* (Herbst, 1799)**

(Fig. 3.4)

Cancer pelagicus Fabricius, 1798: 367.

Cancer reticulatus Herbst, 1799: 65, pl. 50 (type locality: East Indies).

Portunus pelagicus Stephenson, 1972a: 15 (identification key); Sethuramalingam & Khan, 1991: 9 (identification key), 27, pl. 18d; Sakai, 1999: 29, pl. 15C.

Neptunus (Neptunus) pelagicus Alcock, 1899: 34; Chopra, 1935: 476, fig. 3; Chhapgar, 1957a: 418, pl. 6a-c, A6.

Neptunus pelagicus De Man, 1888: 328; Henderson, 1893: 367.

Portunus trituberculatus Stephenson & Rees, 1967a: 17

Portunus (Portunus) reticulatus Ng et al., 2008: 152 (list); Lai et al., 2010: 218, 225 (identification key), figs. 6C, 7C, 15, 16, 20C, 21C, 22C, 23C, 23G, 24C.

Portunus reticulatus Trivedi et al., 2018: 67 (list); Ahmed et al., 2021: 3, Fig. 4.

Material examined: CW 10.72–134.78 mm; CL 6.74–60.72 mm (N=48)

Diagnosis: Carapace width 2.2–2.3 times wider than long, surface finely granulated, median frontal teeth spinous, small but conspicuous. Adults with regions relatively poorly indicated. branchial regions not markedly swollen. Cheliped merus relatively short and stout, anterior margin with 3 spines. Natatorial paddle oval but less elongate. Sixth male abdominal somite relatively elongate, tapering. The base of G1 with small but conspicuous rounded basal spur. Males with greenish-blue carapace, large pale green spots with thick reticulations and variable patterns, females with green-brown carapace, tips of chelipeds marked bright red.

Habitat and Distribution: Shallow sandy lagoons (Ameer Hamsa, 1978). Distributed from Southeastern coast of India, eastern coast of Sri Lanka, southwestern Thailand (Lai et al., 2010) and Bangladesh (Ahmed et al., 2021). The present observation is the first record from Goa coast.

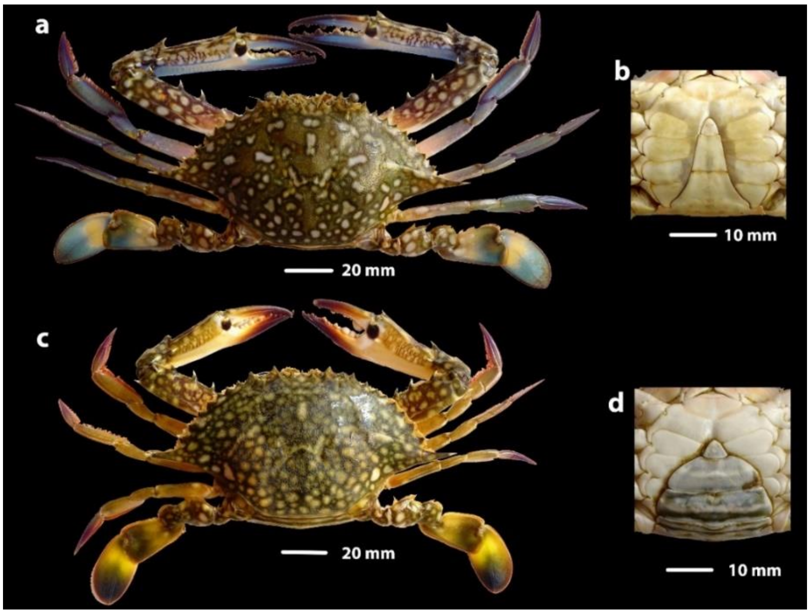

Figure 3.4. *Portunus reticulatus* (Herbst, 1799); CW 130.90 mm, CL 58.81 mm, male; CW 134.78 mm, CL 60.72 mm, female; (a) dorsal view, male; (b) male abdomen; (c) dorsal view, female; (d) female abdomen.

Genus Scylla De Haan, 1833

***Scylla serrata* (Forskål, 1775)**

(Fig. 3.5)

Cancer serratus Forskål, 1775: 90 (type locality: Jeddah, Saudi Arabia).

Portunus serratus Rüppell, 1830: 10, pl. 2.

Achelous crassimanus MacLeay, 1838: 61 (type locality: mouth of Zwartkops River, South Africa); Stebbing, 1910: 308.

Portunus (Scylla) serrata de Haan, 1833: 44.

Scylla tranquebarica var. *oceanica* Dana, 1852a: 270 (type locality: Navigator Islands, Pacific Ocean).

Scylla oceanica (not Dana, 1852) Estampador, 1949: 101, pl. 1 fig. 2.

Scylla serrata A. Milne Edwards, 1861: 349; Barnard, 1950: 160, fig. 31b, c; Crosnier, 1962: 72, figs. 128-129; Guinot, 1966: pl. fig. 1; Apel & Spiridonov, 1998: 312 (identification key), 312; Ng et al., 2008: 153 (list); Padate et al., 2013: 83, figs. 2a, c, 3a, 4a, 5a, 6a-c; Trivedi et al., 2018: 68 (list).

Scylla tranquebarica (not Fabricius, 1798): Joel & Raj, 1980: 39, figs. 1, 3, 5, 7, 9a, b.

Material examined: CW 19.20- 152.70 mm; CL 12.82–99.49 mm (N=11)

Diagnosis: Carapace oval, convex and smooth, 'H' shape groove moderately carved in the center of the carapace; front lobe spines high, bluntly pointed with interspaces rounded. Anterolateral margin with nine narrow equivalent spines. Carpus of cheliped with two obvious spines on distal half of outer margin, palm of cheliped with a pair of distinct spines on dorsal margin behind insertion of the dactyl. Chelipeds and legs all wit polygonal patterning for both sexes and on abdomen of female only.

Habitat and Distribution: Digs large burrows among pneumatophores of mangrove forests inundated with wide range of salinity (Naderloo, 2017). Distributed from South Africa to Australia, Tahiti and Japan (Apel & Spiridonov, 1998).

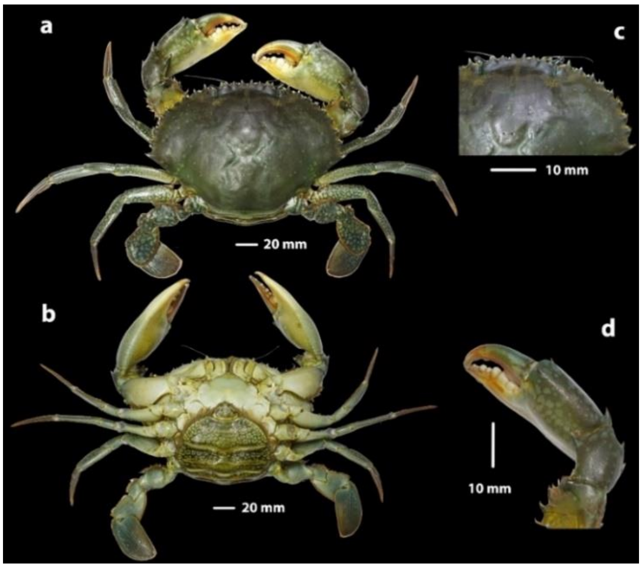

Figure 3.5. *Scylla serrata* (Forskål, 1775); CW 152.70 mm, CL 99.49 mm, female; (a) dorsal view; (b) ventral view; (c) frontal lobes and anterolateral teeth; (d) right chela, showing spines.

Genus *Thalamita* Latreille, 1829

Thalamita crenata Rüppell, 1830

(Fig. 3.6)

Thalamita crenata Rüppell, 1830: 6, pl. 1, fig. 2 (type locality: Southern Red Sea).
Portunus crenatus H. Milne Edwards, 1834: 461.
Thalamita crenata H. Milne Edwards, 1834: 461; Alcock, 1899: 73 (key), 76; Barnard, 1950: 171 (key), 172, 174, figs. 27e, 33a; Crosnier, 1962: 130, figs. 220, 226-227, 232-233; Wee & Ng, 1995: 69, figs. 34A-B, 35A-B, 36A-H; Apel & Spiridonov, 1998: 228 (identification key), 233, figs. 44, 49-50, pl. 8; Ng et al., 2008: 154 (list); Trivedi et al., 2018: 68 (list)
Thalamita prymna var. *crenata* Kossmann, 1877: 49; Laurie, 1906: 418.
Thalamita ceranata [sic] Hashmi, 1963: 17.

Material examined: CW 7.84–52.10 mm; CL 5.82–40.10 mm (N=45)

Diagnosis: Carapace surface glabrous, sparsely pilose. Six frontal lobes, broadly rounded; five anterolateral teeth subequal - decreasing slightly in size from front to rear. Chelipeds unequal; merus bearing three to four spines on anterior border; carpus armed with a strong spine at an inner angle and three spinules at an outer angle; the outer surface of manus smooth, bearing single crest running to the tip of the immovable finger, upper surface bearing five spines including spine at wrist articulation. Propodus of natatory leg with serrulations along distal half of posterior border. Penultimate segment of male abdomen with lateral borders slightly convergent distally. G1 long, gradually tapering, evenly curved along distal portion, single row of bristles line inner border, terminal cluster of bristles on the sternal surface.

Habitat and Distribution: On rocky and muddy intertidal platforms in the vicinity of mangrove-fringe and mangrove swamps (Vezzosi et al., 1995). Distributed from Red Sea, Madagascar, South and east Africa, through South and Southeast Asia to Australia, Japan and Hawaii (Apel & Spiridonov, 1998).

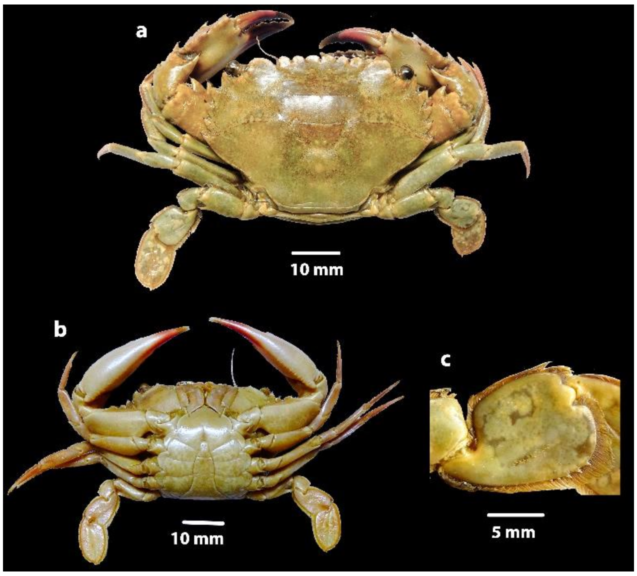

Figure 3.6. *Thalamita crenata* (Latreille, 1829); CW 44.76 mm, CL 30.33 mm, male; (a) dorsal view; (b) ventral view; (c) propodus of the natatory leg with serrulation.

Family Xanthidae MacLeay, 1838

Genus *Leptodius* A. Milne Edwards, 1863

***Leptodius exaratus* (H. Milne Edwards, 1834)**

(Fig. 3.7)

Cancer inaequalis Audouin, 1826: 86 (type locality: Egypt).

Chlorodius exaratus H. Milne Edwards, 1834: 402 (type locality: India).

Leptodius exaratus A. Milne Edwards, 1868: 71; Klunzinger, 1913: 209, pl. 3, fig. 6, pl. 5, fig. 16; Khan, 1977: 181, pl. 1D; Serène, 1984: 184, fig. 106, pl. 26 fig. A; Tirmizi & Ghani, 1996: 48, fig. 18; Ng et al., 2008: 203 (list); Trivedi et al., 2018: 80 (list).

Leptodius exaratus sensu stricto Lee et al., 2013: 190, fig. 2, 4 A-D.

Actaeodes lividus Paul'son, 1875: 35, pl. 5 fig. 2 (type locality: Red Sea).

Chlorodius (Leptodius) exaratus Kossmann, 1877: 32, pl. 2, figs. 1-6.

Xantho exaratus *var. typica* Ortmann, 1893: 445 (in part).

Xantho (Leptodius) exaratus Alcock, 1898: 118 (in part) (identification key); Stephensen, 1945: 149, fig. 37c; Guinot, 1958: 92; Michel, 1964: 32.

Xantho hydrophilus Laurie, 1915: 44, pl. 43, fig. 1 (type locality: Red Sea) (not *Cancer hydrophilus* Herbst, 1790).

Xantho exaratus Monod, 1938: 125, fig. 17b; Vatova, 1943: 19.

Xantho (Leptodius) hydrophilus Barnard, 1950: 223, g. 41c, 42c–e (not *Cancer hydrophilus* Herbst, 1790).

Material examined: CW 4.78–25.28 mm; CL 3.62–17.45 mm (N=47)

Diagnosis: Carapace transversely subovate, 1.5-1.6 times as broad as long, rugose, well defined carapace regions separated by distinct grooves. Anterolateral margin with 4 broad, triangular teeth behind exorbital angle. Chelipeds unequal with long setae on anterior and posterior margin of merus; fine granules on outer surface of carpus; wrinkled external surface, inner angle with blunt tooth; palm inflated, dorsally rugose and ventrally smooth; fingers stout, black coloured, cutting margins irregularly dentate and spoon shaped tips. Male abdomen narrow with fused 3rd and 5th somite. G1 long, slender, with 6–8 stout, curved sub distal spines and 8-10 mushroom-shaped outgrowths. Apical lobe elongate, 0.05–0.07 times total length, slightly angled with rest of gonopod.

Habitat and Distribution: On rocky or cobble substrates in intertidal waters (Naderloo, 2017). Distributed from East and South Africa to the Red Sea and India (Lee et al., 2013).

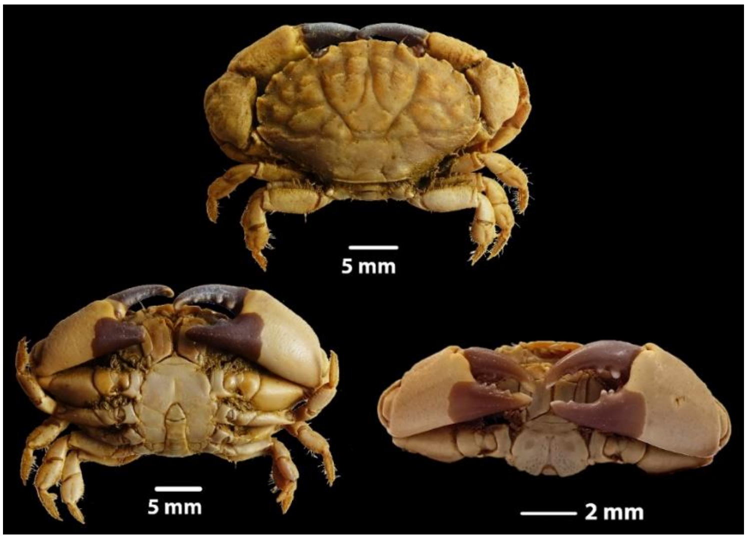

Figure 3.7. *Leptodius exaratus* (H. Milne Edwards, 1834); CW 21.92 mm, CL 14.13 mm, male; (a) dorsal view; (b) ventral view; (c) frontal view of chela.

Family Pilumnidae Samouelle, 1819

Genus *Heteropanope* Stimpson, 1858

***Heteropanope glabra* Stimpson, 1858**

(Fig. 3.8)

Heteropanope glabra Stimpson, 1858a: 35 (type locality: Hong Kong). Stimpson, 1907: 63, pl. 8, fig. 1; Ng et al., 2008: 140 (list); Kaullysing et al., 2015: 1196 (identification key), 1196, figs. 5-7; Trivedi et al., 2018: 59 (list).

Pilumnopeus maculatus A. Milne Edwards, 1867: 227; A. Milne Edwards, 1868: 82, pl. 19, figs. 17-19.
Eurycarcinus maculatus De Man, 1887: 44, pl.2, figs.2-3; Sankarankutty, 1962: 146, fig. 51.
Actumnus nudus (not Milne Edwards, 1867) Grant and McCulloch, 1906: 17.
Not *Heteropanope glabra* Sakai, 1976: 503, fig. 269.
Heteropanape longipedes Davie, 1989.

Material examined: CW 4.62–14.48 mm; CL 3.22–9.75 mm (N=145)

Diagnosis: Carapace smooth, wider than long (1.4 –1.5 times), convex on the mid line, carapace region poorly defined. Front broadly bilobed, each lobe being convex; no lateral lobule distinct from supraorbital angle. Antero-lateral margin cut into four teeth or lobes, which may be pointed but not spinous, first tooth a broad lobe confluent with the outer orbital angle. Chelipeds unequal in size with smooth surface, carpus with strong blunt tooth on the inner side. Walking legs moderate in length; slender in shape; with serrated setae, thicker setae on propodus and dactylus. Male abdomen triangular in shape and seven segmented; first to third segments similar in width; four to seven similar in length; telson bluntly rounded distally and base as broad as wide; G1 slender and elongated; S-shaped with a downward tapering tip.

Habitat and Distribution: Among rock or cobble on muddy substrates in the vicinity of mangroves in intertidal waters (Naderloo, 2017). Distributed from East coast of Africa through South and Southeast Asia to Northern Australia and Solomon Islands (Trivedi et al., 2015).

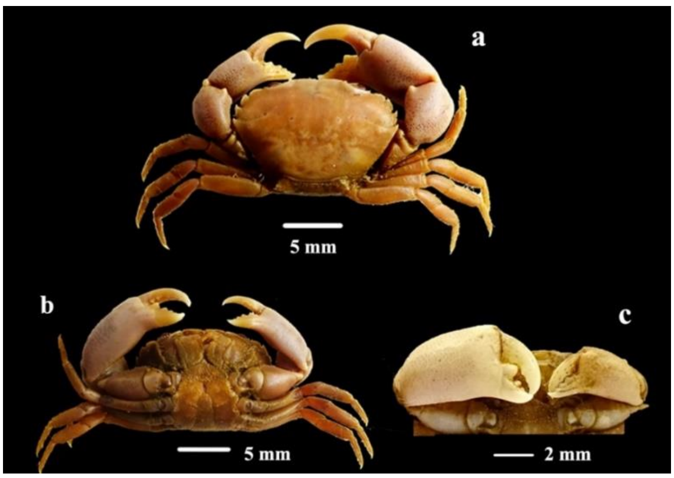

Figure 3.8 *Heteropanope glabra* Stimpson, 1858; CW 12.88 mm, CL 8.33 mm, male; (a) dorsal view; (b) ventral view; (c) frontal view of chela.

Family Grapsidae MacLeay, 1838

Genus *Metopograpsus* H. Milne Edwards, 1853

***Metopograpsus cannicci* Innocenti, Schubart & Fratini, 2020**

(Fig. 3.9)

Metopograpsus thukuhar Crosnier, 1965: 25, Fig. 20-22, 27; Vannini & Valmori, 1981a: 73, Fig. 8B, 9B; Naderloo, 2011: 11, Figs. 4a–g, 5f; Trivedi et al., 2018: 42 (list).

Metopograpsus cannicci Innocenti et al., 2020: 621 Figs. 1A, 2A, 3A, 4A, 5A, 6.

Material examined: CW 3.88–22.00 mm; CL 5.23–28.66 mm (N=156)

Diagnosis: Carapace flat, broader than long and smooth. Lateral margins entire. Regions weakly defined, urogastric region with groove distinct, branchial region having distinct oblique ridges, cardiac and intestinal regions smooth, with no ridge or tubercles. Front broad, deflexed with rugose surface and free margin crenulated, with some concavity, 4 depressed post-frontal lobes along the line of frontal deflexion. Suborbital tooth triangular, suborbital border denticulate. The exposed surface of the base of the antenna densely pubescent. Chelipeds subequal, with no certain handedness, fingers stout with spatulated tip, slight gape visible when closed. The cutting edge of both fingers with series of inconspicuous teeth. Ambulatory legs compressed, merus broad and longest, third and fourth pereiopod longest, first shortest. Male abdomen with 6 distinct segments, basal one as broad as thoracic sternum, somite 6 almost rectangular, telson triangular. Female pleon fringed with long setae, broad, evenly rounded, telson half-moon shaped. In males, G1 slender, with twisted shaft along the longitudinal axis, apical corneous process elongate, bearing long setae at the base.

Habitat and Distribution: On pneumatophores of *Avicennia marina* shrubs, in creeks and fringing mangroves, wooden and concrete vertical surfaces in harbours and vertical jetties (Innocenti et al., 2020). Distributed from East coast of Africa, Madagascar, Mauritius and Iran (Innocenti et al., 2020). The present observation constitutes the first record from India.

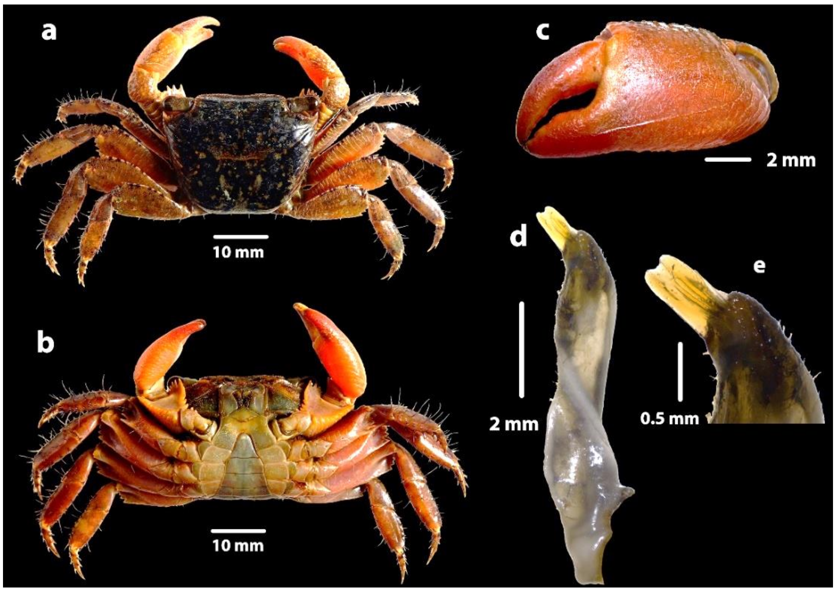

Figure 3.9. *Metopograpsus cannicci* Innocenti, Schubart, and Fratini 2020; CW 25.35 mm, CL 20.61 mm, male; (a) dorsal view; (b) ventral view, (c) left chela showing inconspicuous teeth; (d) left pleopod - G1, dorsal view; (e) G1 apical chitinous process.

Metopograpsus latifrons (White, 1847)

(Figs. 3.10)

Grapsus latifrons White, 1847a: 337, pl. 2 fig. 2 (type locality: Eastern Seas, Singapore).

Metopograpsus maculatus H. Milne Edwards, 1853: 165; 7b: 517, pl. 15.

Metopograpsus latifrons H. Milne Edwards, 1853: 166; Tweedie, 1949: 468, pl. 1; Banerjee, 1960: 12, fig. 4j, 5d, 6a; Ng et al., 2008: 217 (list); Trivedi et al., 2018: 42 (list).

Grapsus (Grapsus) dilatatus Herklots, 1861: 129.

Metopograpsus pictus A. Milne Edwards, 1867: 283.

Grapsus dilatatus De Man, 1879: 68.

Material examined: CW 9.78–23.95 mm, CL 8.04–9.51 mm (N=7)

Diagnosis: Carapace trapezoidal, flat, slightly convex, glabrous, glossy, broader than long. Lateral margin entire, very convergent posteriorly. Front broad, more than half the greatest width of the carapace, sharp, distinct, almost straight, beaded. Post frontal region with 4 distinct lobes separated by furrow, outer lobes broader than the median with tendency to split into two. Orbits are markedly oblique, infraorbital margin slightly serrated, lined with setae. Suborbital tooth obtuse, keeled. Chelipeds sub-equal. Ambulatory legs flattened, long and broad merus. Second pereiopod shortest and fourth longest. Ischium and merus end with a spine, merus, and carpus with distinct squamiform markings. Propodus of every walking leg with unique pattern of setae. Dactylus of all the pereiopod with chitinous spines. The sixth segment of the male abdomen distinctly rectangular in shape, outer border auriculate. G1 slender, coiled, apical chitinous process obliquely T shaped, petal like, the base of the chitinous projection soft with setae. Gonopore on 6th segment, shallow, inverted 'U' shaped.

Habitat and Distribution: on trunks, prop roots and crevices of mangrove trees during low tides, sluice gates of fish ponds (Masagca, 2011). Distributed from southwest coast of India through southeast Asia to the Philippines (Fratini et al., 2018). In India, it is known from Tamil Nadu and Kerala (Kurian & Apreshgi, 2020); the present observation is the first record from the Goa coast.

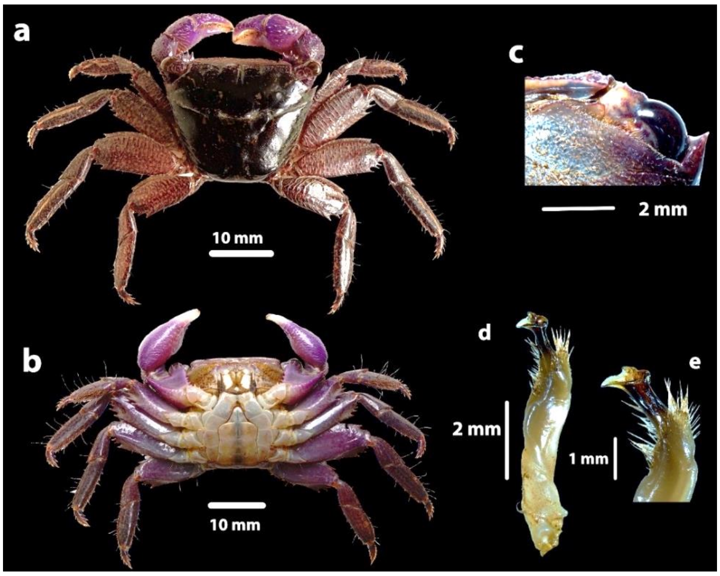

Figure 3.10. *Metopograpsus latifrons* (White, 1847); CW 23.95 mm, CL 19.51 mm, male; (a) dorsal view; (b) ventral view; (c) suborbital tooth and margin; (d) left G1, sternal view; (e) G1 chitinous projection.

Family Sesarmidae Dana, 1851

Genus *Clistocoeloma* A. Milne-Edwards, 1873

***Clistocoeloma merguiense* de Man, 1888 [in de Man, 1887-1888]**

(Figs. 3.11)

Clistocoeloma merguiensis de Man, 1888 (in de Man, 1887-1888): 195, pl. 13, fig. 10 (type locality: Kisseraing Island).

Clistocoeloma merguiense Alcock, 1900: 429; Chopra and Das, 1937: 431, fig. 21; Hsueh and Huang, 1996: 67, Fig. 3C, D; Fig. 4B, D; Ng et al., 2008: 220 (list); Lee et al., 2014: 967, fig. A-F; Trivedi et al., 2018: 71 (list).

Material Examined: CW: 17.71 mm, CL 14.64 mm (N=1)

Diagnosis: Carapace quadrangular, a little more than three-fourths as long as broad; the dorsal surface is convex and the regions well-demarcated, covered with numerous small patches of blackish tomentum. The front slightly sinuate, the epigastric lobes thick. The anterior half of the lateral border cristate and is indistinctly divided into three lobes, the middle lobe shortest; the posterior half of the border depressed and not crested or tomentose. The chelipeds are also fringed with short piles and furnished with small patches of tomentum, the dorsal margin of the dactylus with 15 to 16 granules. The ambulatory legs are compressed and thickly fringed with short, blackish tomentum as in other parts of the body; the merus is rather slender, being about 2.5 times as broad as long, and its dorsal surface marked with several patches of tomentum. G1 short and stumpy with broadly truncate tip which is densely hairy.

Habitat and Distribution: Burrowing in wet mud (Kemp, 1918), and dead and rotten wood (Hutchings & Recher, 1982). Distributed from India through Southeast Asia to Japan (Ghosh, 1995).

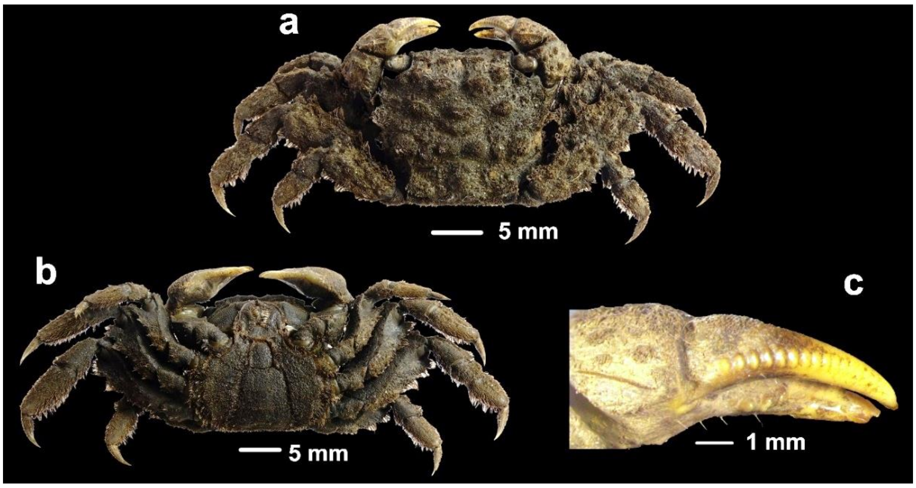

Figure 3.11. *Clistocoeloma merguiense* de Man, 1888; CW 17.71 mm, CL 14.64 mm, male; (a) dorsal view; (b) ventral view; (c) dactylus of the left chela with granules.

Genus *Episesarma* De Man, 1895

Episesarma versicolor (Tweedie, 1940)

(Figs. 3.12)

Sesarma (Sesarma) palawanensis Tweedie, 1936: 54-58, text fig. 1a, pl. 14 (not Sesarma *(Sesarma) palawanense Rathbun, 1914).*

Sesarma versicolor Tweedie, 1940: 98, fig. 7 (type locality: Singapore).

Sesarma (Episesarma) versicolor Soh, 1969: 11 (list), 21 (key), 58, 92 (list), 94, 96, 97, 101 (list), figs. 10, 21, table 13.

Sesarma (Sesarma) versicolor Serène and Soh, 1967: 27, pl. 3, 4.

Neoepisesarma (Neoepisesarma) versicolor Serène & Soh, 1970: 396, 405 (list); Dai et al., 1986: 495, fig. 279 (2), pl. 70 fig. 1.

Episesarma versicolor Ng, 1998: 1140 (key), 1143, figs. 10, 11; Ng et al., 2008: 220 (list).

Material Examined: CW 15.83–29.65 mm; CL 14.46–27.72 mm (N=3)

Diagnosis: Carapace quadrate, slightly wider than long, covered with tufts of setae on the entire carapace, posterior region with inverted 'V' shaped row of setae. Regions well marked, with four distinct frontal lobes. Lateral margin subparallel with one lateral tooth behind the external orbital angle. Adult male cheliped with the dorsal surface of palm sparsely granulated; dorsal margin of the dactylar finger of chela with 46 tubercles increasing in size towards the distal end of dactylus. Single longitudinal pectinated ridge on dorsal margin with 70 fine tubercles. The palm of chela violet with fingers white; juveniles with delicate chela without ridge or dactylar tubercles and with whitish to violet colouration. Ambulatory legs long and slender with violet and black colouration and chitinous dactylus tips. Male abdomen narrow, telson tip oval. Abdomen and sternum white coloured; G1 with a single row of setae on the exterior margin, tip of G1 with dense tufts of setae, single peak with chitinous crest relatively narrow.

Habitat and Distribution: Arboreal species on mangrove vegetation, also digs burrows at mud base of mangrove trees (Sivasothi, 2000). Distributed from India through Southeast Asia to China, Philippines and Australia (Lee et al., 2015; Manikantan et al., 2016). In India, known from Tamil Nadu (Manikantan et al., 2016). The present observation is the first record from the west coast of India.

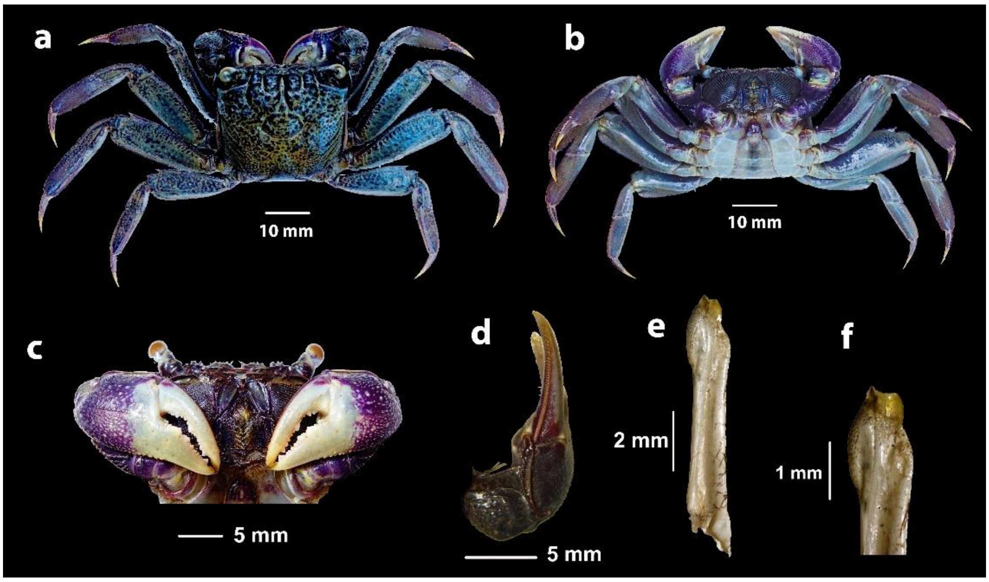

Figure 3.12. *Episesarma versicolor* (Tweedie, 1940); CW 29.65 mm, CL 27.72 mm, male; (a) dorsal view; (b) ventral view; (c) chelae, outer view; (d) upper surface of chela; (e) G1, dorsal view; (f) tip of G1, dorsal view.

Genus *Nanosesarma* Tweedie, 1951

***Nanosesarma andersoni* (de Man 1888)**

(Fig. 3.13)

Sesarma andersoni de Man, 1888a: 172, pl. XII, figs. 1-4; Alcock, 1900: 411 (key), 418.

Sesarma (Parasesarma) andersoni Tesch, 1917: 129.

Nanosesarma andersonii Tweedie, 1950: 312, fig. 1d, e; Ng et al., 2008: 221 (list); Trivedi et al., 2018: 72 (list).

Nanosesarma (Beanium) andersoni Serène & Soh, 1970: 394.

Beanium andersonii Tan & Ng, 1994: 82 (list).

Nanosesarma andersoni Komai et al., 2004: 45, fig. 5A-P; Padate et al., 2022: 2, Figs. 1A, 2, 7A, B)

Material Examined: CW 3.40–8.22 mm, CL 2.54–6.30 mm (N=9)

Diagnosis: Carapace, wider than long, slightly convex, covered with scattered pits, indistinct setal tufts. Exorbital tooth followed by rudimentary epibranchial tooth. Frontal margin wide, bilobed, strongly deflexed, depressed frontal lobes separated by shallow depression. Chelipeds subequal, massive; inner surface of merus with four teeth on lower margin; Manus massive, surfaces rugose, dorsal surface with one oblique pectinated crest and 4–5 oblique granular ridges. Male cheliped dactylus short, with row of 13 -14 small smooth transverse tubercles and proximal granules on dorsal surface; inner surface with proximal granular patch. Ambulatory legs compressed, shorter than chelipeds; P4 merus anterior margin terminates in blunt angle followed by sub-distal spine, postero-distal margin with 3-4 teeth followed by 4 spinules; P5 merus anterior margin with sub-distal prominence, postero-distal margin with progressively increasing 5 teeth followed by alternately arranged 2 teeth and 2 spinules, lower surface smooth; lower posterior margin granulated. G1 long, almost straight, distal tip pectinated, flattened, slightly twisted, medially notched, covered with long, stiff setae, groove at base of tip extends along ventral surface up to G1.

Habitat and Distribution: In cavities made by wood-boring isopods on rotten wood in mangrove swamps (Komai et al., 2004). Distributed from India through Southeast Asia to Japan (Komai et al., 2004; Padate et al., 2022).

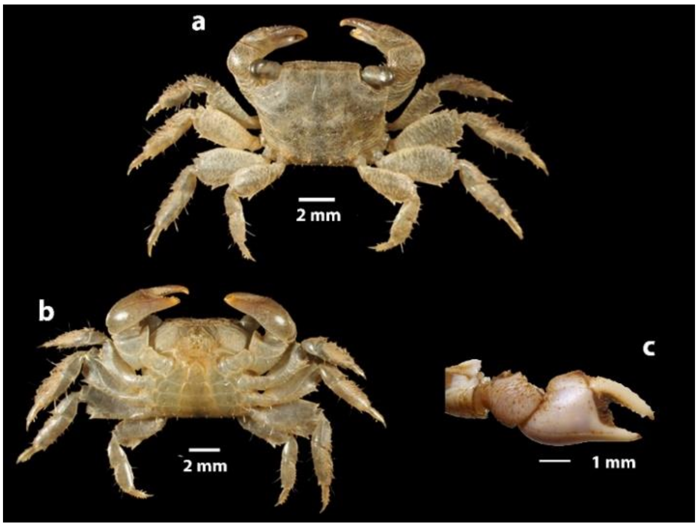

Figure 3.13. *Nanosesarma andersoni* (de Man 1888); CW 6.54 mm, CL 4.90 mm, male; (a) dorsal view; (b) ventral view; (c) outer view of chela.

Nanosesarma minutum (de Man, 1887)

(Figs. 3.14)

Sesarma minuta de Man, 1887: 650 (type locality: Edam Island, Batavia).

Sesarma (Sesarma) minutum Rathbun, 1910a: 327.

Sesarma (Sesarma) minuta Tesch, 1917: 174; Chhapgar, 1957b: 522, pl. 16, figs. k–m.

Nanosesarma minuta Tweedie, 1950: 311.

Nanosesarma cf. *minutum* Crosnier, 1965: 70, text-figs. 89, 109-115, pl. 6, fig. 1.

Nanosesarma minutum Serène & Soh, 1970: 393; Ng et al., 2008: 221 (list); Trivedi et al., 2018: 72 (list); Padate et al., 2022: 8, Figs. 1C, 4, 7E, F).

Material Examined: CW 3.08–6.50 mm; CL 2.64–4.40 mm (N=14)

Diagnosis: Carapace quadrangular, wider than long, epibranchial tooth posterior to external orbital angle sharp. Several oblique, low, setose granulated ridges across branchial regions. Third maxilliped ischium length less than 1.5 times merus length. Male chelipeds less than 2.0 times longer than CL, propodus lacking pectinated crest, dactylus with proximal granules on dorsal surface, transverse ridges lacking. Pereiopod merus postero-lateral margin with minute spinules followed by two to three large spinules. G1 distal tip curved, scoop-shaped, flanked by thick bristles, groove at base of tip extends along ventral surface up to G1 base. Gonopore at junction of thoracic sternites 5 and 6, gonopore with long oval operculum on inner side and small semi-circular process on outer side.

Habitat and Distribution: On Rhizophora and Avicennia mangroves, rock crevices and oyster shells (Ravichandran et al., 2007). Distributed from the East coast of Africa and Madagascar to the South China Sea (Padate et al., 2022).

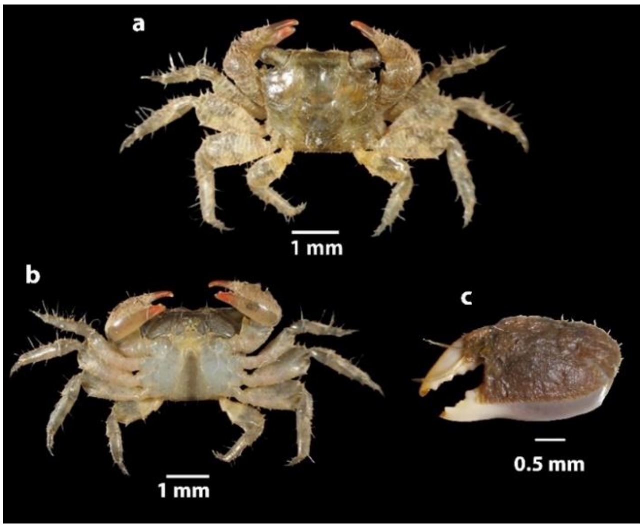

Figure 3.14. *Nanosesarma minutum* (De Man, 1887); CW 5.12 mm, CL 4.10 mm, male; (a) dorsal view; (b) ventral view; (c) densely setose outer surface of palm.

Nanosesarma tweediei Serène, 1967

(Figs. 3.15)

Nanosesarma tweediei Serène, 1967: 818, figs. 1-2, pl. 1A, B; Ng et al., 2008: 221 (list).

Material Examined: CW 3.00–5.48 mm; CL 3.32–5.91 mm (N=26)

Diagnosis: Carapace vase-shaped, longer than wide, thickly setose, epibranchial tooth posterior to external orbital angle rudimentary. No oblique ridges across branchial regions.

Third maxilliped ischium length lesser than 1.5 times merus length. Male chelipeds less than 2.0 times longer than CL, propodus lacking pectinated crest, dactylus with smooth median longitudinal ridge and proximal granules on dorsal surface, outer surface with strong proximal spine. Pereiopod merus postero-lateral margin lacking distinct spinules. Thoracic sternum wide in both sexes, with smooth finely pitted ventral surface. G1 distal tip curved, long scoop-shaped, flanked by thick bristles, groove at base of tip extends along ventral surface up to G1 base. Gonopore on thoracic sternite 6, gonopore with semi-circular operculum on inner side and small semi-circular process on outer side.

Habitat and Distribution: Under and between crevices of dead wooden logs, oyster colonies, rocks and pebbles (present study). Distributed from India to Malaysia, Singapore, Vietnam and the Philippines (Serène, 1967; present study).

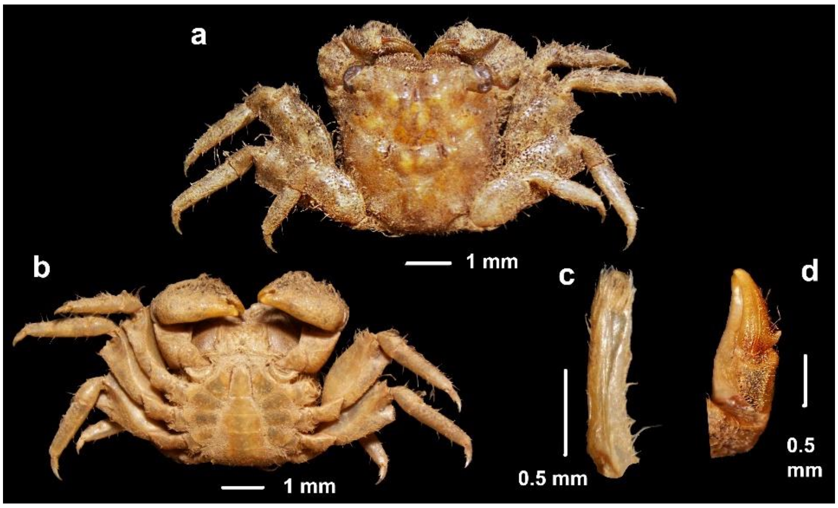

Figure 3.15. *Nanosesarma tweediei* Serène, 1967; CW 5.48 mm, CL 5.91 mm, male; (a) dorsal view; (b) ventral view; (c) right G1 ventral view; (d) right male cheliped dactylus showing smooth longitudinal ridge and proximal spine.

Genus *Parasesarma* De Man, 1895

***Parasesarma bengalense* (Davie, 2003)**

(Fig. 3.16)

Perisesarma bengalense Davie, 2003: 388 (type locality: Colombo, Sri Lanka).

Perisesarma bengalensis Bouillon et al., 2004: 83 (list).

Perisesarma bengalense Ng et al., 2008: 222 (list); Davie, 2010: 197 (list).

Parasesarma bengalense Shahdadi & Schubart, 2018: 525, figs. 3C, 4C, 5C, 6C, 7C, 8C, 9C, 10C; Pati et al., 2019: 3, Fig. 2.

Material Examined: CW 5.32-19.60 mm; CL 4.00–18.95 mm (N=143)

Diagnosis: Carapace sub rectangular, slightly broader than long (CW/CL 1.2–1.5); regions well defined. Postfrontal region with 4 prominent, rounded lobes. Frontal margin sinuous, deflexed downwards. Anterolateral margin with small acutely triangular tooth separated by a distinct notch from large, acutely triangular external orbital tooth. Cheliped subequal, upper surface of palm in males with 2 transverse pectinate crests; 14–18 tall, broad corneous teeth on primary and 13–15 relatively shorter corneous teeth on secondary pectinate crest. Cutting margins of the fingers serrated; strong subdistal tooth along cutting margin of fixed finger. Dactylus displays prominent subdistal tooth and medial tooth along the cutting margin with 16–18 nearly symmetrical tubercles on upper surface and 1–10 closely spaced tubercles proximally. In males, 6th pleonal somite around 2.1 times broader than long. Male G1 gently curved, moderately stout with corneous apical process.

Habitat and Distribution: In the vicinity of intertidal mangroves (Davie, 2003). Distributed in India, Sri Lanka and Thailand (Pati et al., 2019); the present observation is the first record from Goa.

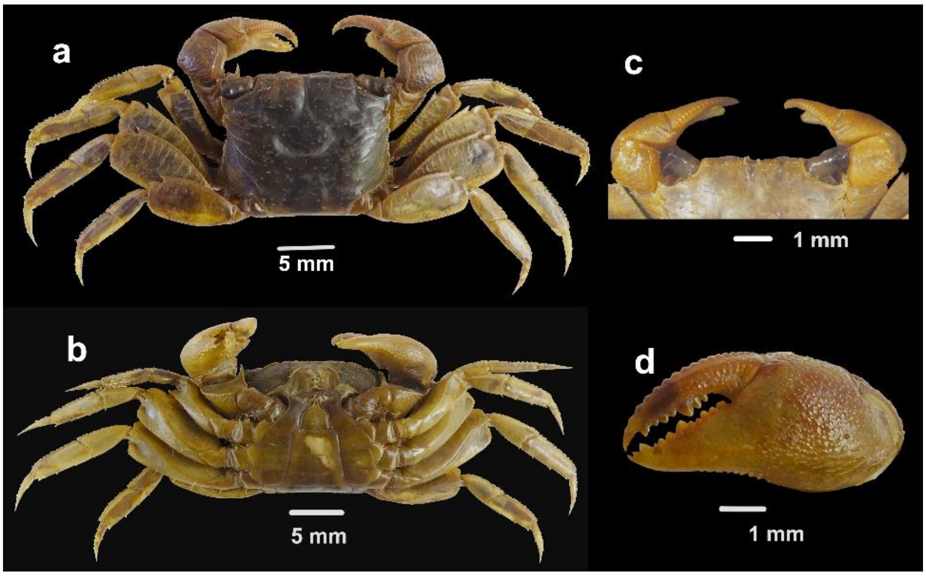

Figure 3.16. *Parasesarma bengalense* (Davie, 2003); CW 14.29 mm, CL 12.15 mm, male; (a) dorsal view; (b) ventral view; (c) front along with chelipeds; (d) chela showing serrations on fingers of cutting margin.

Parasesarma plicatum **(Latreille, 1803)**

(Fig. 3.17)

Cancer quadratus Fabricius, 1798: 341 (type locality: East India); Zimsen, 1964: 650.

Ocypode quadrata Bosc, 1802: 198.

Ocypoda plicata Latreille, 1803: 47.

Sesarma quadrata H. Milne Edwards, 1837: 75.

Sesarma (Parasesarma) plicata Tesch, 1917: 187.

Parasesarma plicatum Naiyanetr, 2007: 114; Ng et al., 2008: 222 (list); Rahayu & Ng, 2010: 2, figs. 1-4; Trivedi et al., 2018: 73 (list).

Sesarma aspera Heller, 1865: 63, pl. 6, fig. 1.

Sesarma quadratum Alcock, 1900: 411 (identification key), 413.

Sesarma aspera Müller, 1887: 476 (not Sesarma aspera Heller, 1865).

Sesarma (Parasesarma) plicatum Serène, 1968: 107.

Material Examined: CW: 3.12–22.10 mm; CL: 2.60–18.80 mm (N=32)

Diagnosis: Carapace 1.35 times broader than long, mesogastric, cardiac regions well defined. Postfrontal margin with 4 distinct, similar lobes, separated by narrow grooves. External orbital tooth triangular, directed upward. Chelipeds subequal, large, robust. The upper surface of the palm with 2 transverse pectinated crests; primary crest composed of 8–12 broad teeth; secondary crest well developed, shorter than the primary, with 5–9 broad teeth. Fixed finger rounded, granular on the outer surface. The dorsal surface of the dactylus with 11–14 tubercles, small proximally, becoming larger distally; tubercles distinct, and subcircular. Walking legs robust, flattened, broad. The male abdomen relatively broad; telson semicircular, evenly rounded. G1 slender, an apical process long, produced, corneous part long, slightly sinuous, tip rounded. Female with chelipeds smaller than in male, pectinated crests on palm replaced by 2 transverse rows of tubercles, dactylar tubercles indistinct.

Habitat and Distribution: In marshy intertidal areas of mangrove habitats (Rahayu & Ng, 2010). Distributed from Thailand and Indonesia (Rahayu & Ng, 2010); India (Trivedi et al., 2018).

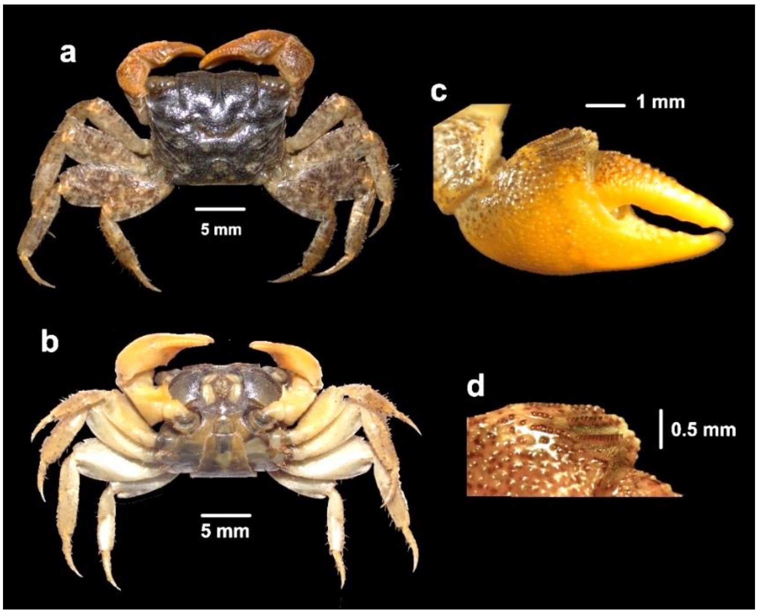

Figure 3.17. *Parasesarma plicatum* (Latreille, 1803); CW 18.21 mm, CL 14.87 mm, male; (a) dorsal view; (b) ventral view; (c) right chela showing pectinated crests and dactylar tubercles; (d) pectinated crests.

Genus *Pseudosesarma* Serène & Soh, 1970

***Pseudosesarma glabrum* Ng, Rani & Bijoy Nandan, 2017**

(Fig. 3.18)

Pseudosesarma edwardsii Shet et al., 2016: 8, 12, fig. 2 (not *Sesarma edwardsii* De Man, 1887).

Pseudosesarma glabrum Ng et al., 2017: 265, fig. 2–5 (type locality: Cochin estuary, India); Trivedi et al., 2018: 73 (list); Pati et al., 2020: 144, fig 2-4.

Material examined: CW 11.34 -15.21mm; CL 9.88-13.68 mm (N=6)

Diagnosis: Carapace 1.1–1.3 times broader than long; frontal margin broad, with relatively shallow median concavity; prominent postfrontal lobes, all at the same level. Anterolateral margin with short external orbital tooth, anteriorly directed with deep, V-shaped cleft separating it from the rest of the margin; one low, distinct, epibranchial tooth, separated by small U-shaped notch from rest of margin. Chelipeds short, stout with almost straight ventral margin of fixed finger and distal half of palm; palm gently convex on the outer surface, with numerous small, rounded granules. Ambulatory legs with relatively short and stout meri. Male thoracic sternites 3 and 4 with distinct groove. Male pleon broad, triangular; 6th somite broad, and distinct convex lateral margins. Male sternopleonal cavity with press-button of pleonal locking mechanism on anterior edge of thoracic sternite 5. G1 long, stout; distal part dilated forming bulbous structure; median part constricted; chitinous tip relatively short, broad, appearing bifurcated. Vulvae large, orbicular, situated on submedian part of thoracic sternite 6 and occupying nearly half of its length.

Habitat and Distribution: Distributed restricted to the west coast of India- Kerala, Karnataka, Maharashtra and Gujarat (Ng et al., 2017; Pati et al., 2020). The present observation is the first record from Goa.

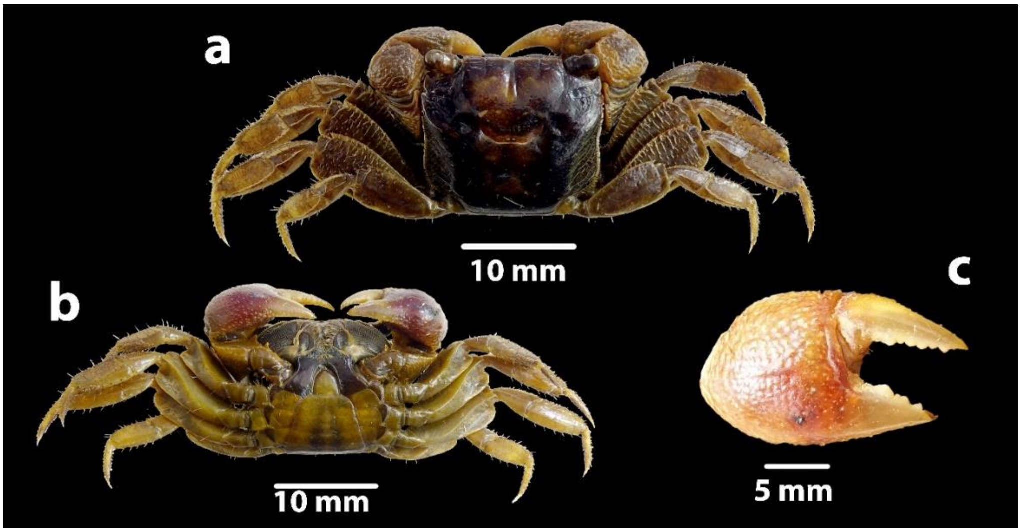

Figure 3.18. *Pseudosesarma glabrum* Ng, Rani and Bijoy Nandan, 2017; CW 15.21 mm, CL 13.68 mm, male; (a) dorsal view; (b) ventral view; (c) major male chela.

Genus *Sarmatium* Dana, 1851

***Sarmatium crassum* Dana, 1851**

(Fig. 3.19)

Sarmatium crassum Dana, 1851: 251 (type locality: Samoa); Barnard, 1955: 28, fig. 9; Crosnier, 1965: 74, figs. 121-124, pl. 5, fig. 1; Davie, 1992: 80 (identification key), 81, figs. 1A, 2A-C; Ng et al., 2008: 223 (list); Trivedi et al., 2018: 73 (list).

?Sarmatium crassum Nobili, 1899: 505 (list); Trivedi et al., 2018: 73 (list).

not *Sarmatium crassum* Serène & Soh, 1970: pl. 4C, D; Serène and Soh, 1971; 237, fig. 2, pl. 2 (= *S. striaticarpus*).

Material Examined: CW 10.6 mm; CL 9.6 mm (N=1)

Diagnosis: Carapace slightly broader than long, glabrous, deeply vaulted, punctate with setae arranged sparsely on branchial lines. Regions moderately defined with mesogastric distinct. Anterolateral margins regularly convex with two blunt teeth behind the exorbital angle. Front bilobed. Branchial ridges prominent forming a series of short broken granular striations. Inner orbital tooth well developed; ocular peduncle swollen basally, cornea constricted and reduced. Chelipeds subequal, large, robust. Merus posterior border with minutely granular striations; distinct subdistal spine; carpus with a small spine at an inner angle. Palm upper surface with a series of transverse grooves separating swollen ridges, distal margin of ridges granular with a row of 8 pectinated comb-like teeth. Dactylus dorsal surface of males bearing 4 large, broad, chitinous tubercles proximally; first proximal tooth placed distally from articulation. Male pleon relatively narrow, third somite widest, telson subequal to the sixth somite in length, longer than wide. G1 moderately stout; slightly curved, dorsal surface of shaft flattened with poorly developed protuberance on the distal end; apical process corneous; strongly produced; straight.

Habitat and Distribution: In mangrove-fringed creeks, river mouths in mudbank at low water (Davie, 1992). Distributed from South Africa, Madagascar and Red Sea to Philippines, Australia Western Pacific Islands (Davie, 1992). According to Davie (1992), the record of *S. crassum* from Nicobar Island (Alcock, 1900) is doubtful, and therefore the present observation is the first confirmed record from India.

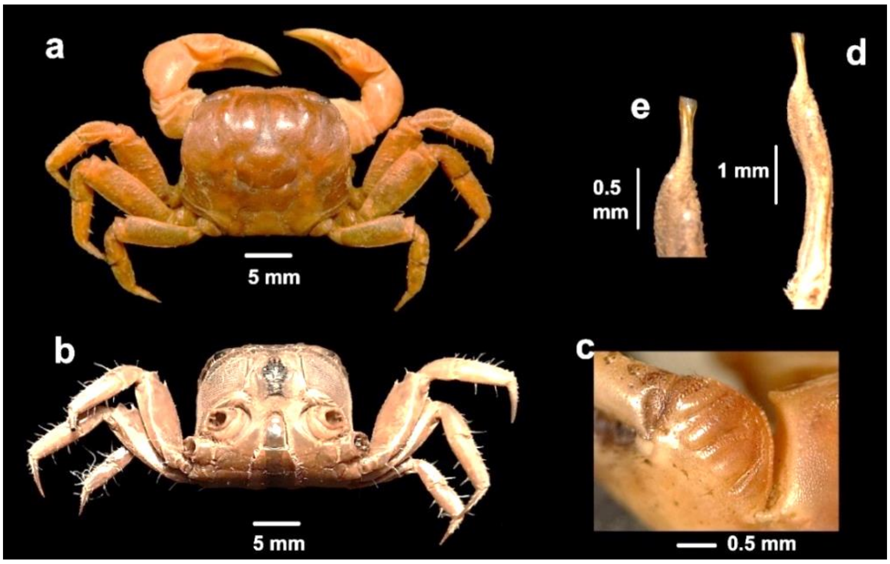

Figure 3.19. *Sarmatium crassum* Dana, 1851; CW 10.6 mm, CL 9.6 mm, male; (a) dorsal view; (b) ventral view; (c) upper surface of palm of left chela; (d) left G1, dorsal view; (e) distal tip of G1, dorsal view.

Family Varunidae H. Milne Edwards, 1853

Genus *Chhapgarus* Ng, Trivedi & Bhat, 2022

***Chhapgarus intermedius* (Chhapgar, 1957)**

(Figs. 3.20)

Pseudograpsus intermedius Chhapgar, 1955: 257 (type locality: Bombay); Tirmizi & Ghani, 1996: 170, fig. 65; Ng et al., 2008: 228 (list); Dineshbabu et al., 2011: 23 (list); Trivedi et al., 2018: 75 (list).

Chhapgarus intermedius Ng et al., 2022: 131, figs. 1-6.

Material Examined: CW 4.60 – 11.82 mm; CL 4.80 – 12.90 mm (N=26)

Diagnosis: Carapace squarish in shape, dorsal surface covered with short brown setae; regions well defined, convex. The frontal margin is slightly convex, and straight. Anterolateral margin sub-cristate with three teeth including the first orbital tooth. Posterolateral margins not sharply demarcated from the anterolateral margin, concave at the branchial region, distinctly subparallel Orbits small, eyes filling orbit. Third maxillipeds are short, and stout. Small, distinct rhomboidal gape when closed, palp short, with short setae. Exopod with the short flagellum. Epistome broad, flat, posterior margin entire. The inner surface of chela with granules; setose. Ambulatory legs with short setae, stout dactyl. Lateral margins of thoracic sternites 4-5 finely granulated; anterior sternal plates without any medial grooves. Male abdomen triangular in shape with seven moveable segments.

Habitat and Distribution: Under dead logs, rock boulders and mud burrows among mid-intertidal mangroves (Ng et al., 2022). Distributed in Pakistan and India (Ng et al., 2022).

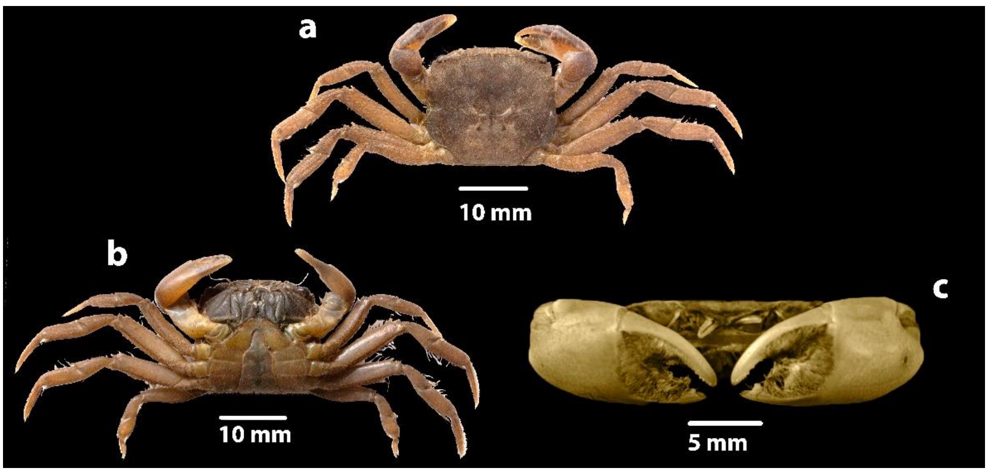

Figure 3.20. *Chhapgarus intermedius* (Chhapgar, 1957); CW 10.1 mm, CL 9.0 mm, male; (a) dorsal view; (b) ventral view; (c) frontal view along with chela.

Genus *Varuna* H. Milne Edwards, 1830

Varuna litterata (Fabricius, 1798)

(Fig. 3.21)

Cancer litteratus Fabricius, 1798: 342 (type locality: east coast of India).

Grapsus litteratus Bosc, 1802: 203.

Varuna litterata H. Milne Edwards, 1830: 511; Barnard, 1950: 122, figs. 22c, 23f, 24d; Chhapgar, 1957b: 518, pl. 15; Crosnier, 1965: 34, figs. 40, 41a-b; 46, pl. 6, fig. 1; Ng et al., 2008: 229 (list); Trivedi et al., 2018: 76 (list).

Trichopus litteratus De Haan, 1835: 33; Dana, 1852: 336, pl. 20, fig. 8.

Varuna tomemtosa Pfeffer, 1889: 30.

Material Examined: CW 30.00 mm, CL 29.20 mm (N=1)

Diagnosis: Carapace quadrangular. Dorsal surface punctate, regions well defined. Front broad, anterior margin almost straight, slightly produced, sloping downwards. Anterolateral margins arched upwards, with three teeth including an orbital tooth. Third maxillipeds closed with a narrow gap. Chelipeds are symmetrical and larger in males. Fingers closed without any gap. Ambulatory legs are long, slender, merus with a small sub-distal spine on the anterior margin, densely setose on anterior, and posterior margins, last ambulatory very flattened. G1 long, stout, distal end with a single lobe, length-to-width ratio 6.9. Female gonopore operculate, with an oval protruding button.

Habitat and Distribution: Slow-moving and stagnant freshwater bodies as well as intertidal areas, on floating clumps of brown algae (Ng, 1998). Distributed from East Africa to New Zealand, Australia and Japan (Chhapgar, 1957b; Ng, 2006).

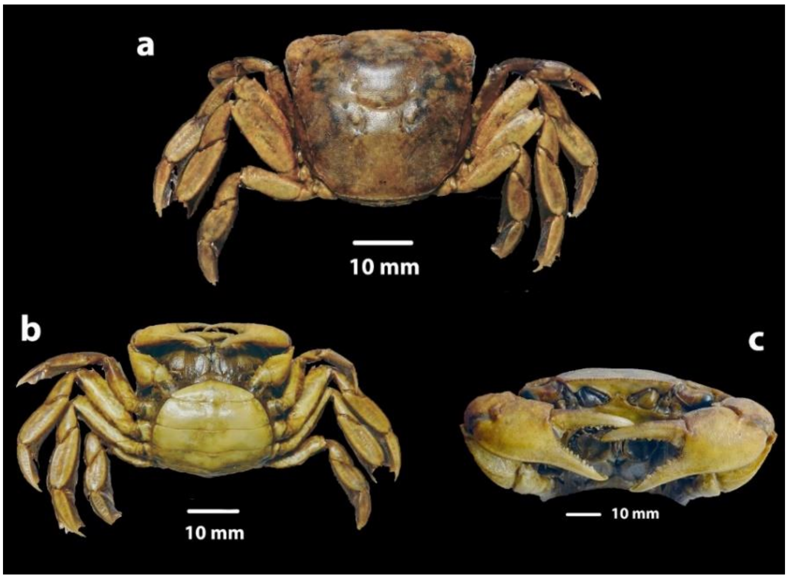

Figure 3.21. *Varuna litterata* (Fabricius, 1798); CW 30.00 mm, CL 29.20 mm, female; (a) dorsal view; (b) ventral view; (c) frontal view along with chela.

Family Dotillidae Stimpson, 1858

Genus *Dotilla* Stimpson, 1858

***Dotilla myctiroides* (H. Milne Edwards, 1852)**

(Figs. 3.22)

Dotilla myctiroides Henderson, 1893: 390; Alcock, 1900: 364 (identification key), 368; Kemp, 1915: 227, fig. 8; Sankarankutty 1961: 102 (list), 114, Figs. 3D-E, 4A; Ng et al., 2008: 235 (list); Padate et al., 2015: 7, Figs. 2-5; Trivedi et al., 2018: 34 (list).

Material Examined: CW 1.75–8.42 mm; CL 1.70–8.40 mm (N=89)

Diagnosis: Carapace oval, as long as broad, with rugose dorsal surface (except cardiac regions). Dorsal surface of the carapace longitudinally and transversely convex, with scattered microscopic granules except for the lateral grooves practically devoid of sculpture. Orbits wide, occupy approximately three-fourths of the anterior carapace margin. Eyes (cornea) elongated, ocular peduncle slightly longer than the cornea. Buccal cavern broader than long, rounded anterolaterally, wider posteriorly. Epistome narrow. Third maxillipeds are large, oval-shaped, and do not leave a gape when closed. Chelipeds are slender, compressed, subequal, and at least three times CL. Ambulatory legs are slender and shorter than chelipeds. Pereiopod meri with characteristic elongated tympana. Margin of tympanic membrane marked with depressed granules. Thoracic sternum with tympana on all segments. Male abdomen narrow comprised of seven distinct, narrow segments the fourth segment overlapping the fifth, with a thick brush of hairs at the distal end. G1 slightly sinuous, distal tip blunt, covered with a tuft of numerous long unbranched setae at the outer margin. Colouration varies from a grey body with pinkish legs to a sand brown colour

Habitat and Distribution: Constructs igloo-shaped and vertical burrows along lower parts of tropical sandy shores (Takeda et al., 1996). Distributed in India, Thailand, Malaysia and Indonesia (Darmarini et al., 2019).

Figure 3.22. *Dotilla myctiroides* H. Milne Edwards, 1852; CW 8.42 mm, CL 8.40 mm, male; (a) dorsal view; (b) ventral view; (c) male abdomen.

Genus *Scopimera* De Haan, 1833

***Scopimera proxima* Kemp, 1919**

(Figs. 3.23)

Scopimera proxima Kemp, 1919a: 317, pl. 12 fig. 3; Silas & Sankarankutty, 1967: 1008; Ng et al., 2008: 235 (list); Trivedi et al., 2018: 35 (list).

Material Examined: CW 3.30–5.00 mm; CL 2.30–3.90 mm (N=15)

Diagnosis: The carapace is smooth, inflated, broader than long, and depth about equal to its length. Lower orbital border sinuous, facet at the inner end sharply defined. Third maxilliped with shallow furrow parallel with the outer border of the merus. Chelipeds are short, and subequal, edges of the merus sharp and serrated. The anterior and posterior borders of the palm are rounded with coarse granules, cutting the edge of the fingers sharp. Male abdomen with deep constriction at the junction of fourth and fifth segments, the fifth segment not channelled, the sixth segment broader than long with straight, slightly divergent sides. The female abdomen is proportionately narrower, with the sides a trifle concave and the seventh segment broader

Habitat and Distribution: Constructs burrows at high-tide level along sandy shores (Silas & Sankarankutty, 1967). Distributed in India (Trivedi et al., 2018) and Thailand (Wada, 2020).

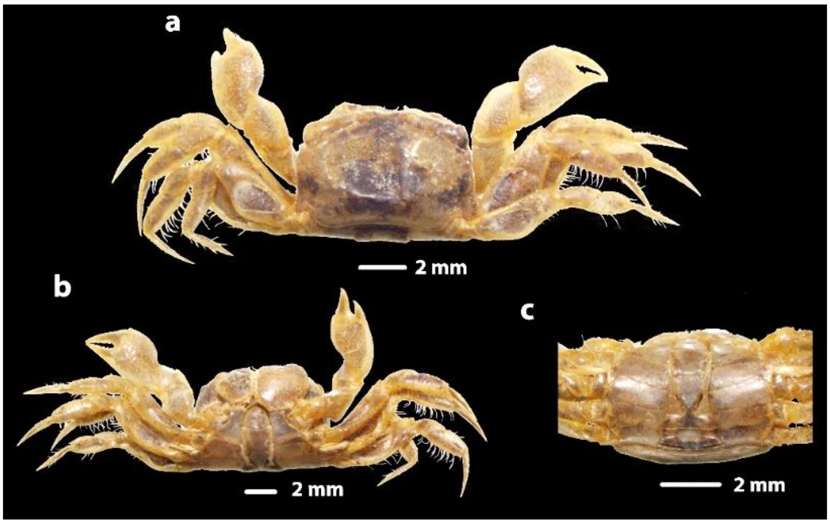

Figure 3.23. *Scopimera proxima* Kemp, 1919; CW 4.06 mm, CL 3.20 mm, male; (a) dorsal view; (b) ventral view; (c) male abdomen.

Family Macrophthalmidae Dana, 1851

Genus *Macrophthalmus* Desmarest, 1823

Subgenus *Macrophthalmus (Macrophthalmus)* Desmarest, 1823

***Macrophthalmus (Macrophthalmus) brevis* (Herbst, 1804)**

(Figs. 3.24)

Cancer brevis Herbst, 1804: 9, pl. 60, fig. 4 (type locality: East India).
Macrophthalmus carinimanus H. Milne Edwards, 1837: 65.
Macrophthalmus dilatatus carens Lanchester, 1900: 759.
Macrophthalmus crassipes Lanchester, 1900: 759 (not H. Milne Edwards, 1852).
Macrophthalmus brevis Tesch, 1915: 169, pl. 6, fig. 5; Barnes, 1977:276 (identification key).
Macrophthalmus simdentatus Shen, 1936: 70, text-figs. 2-3;
Macrophthalmus cf. *crassipes* Tweedie, 1937: 164.
Macrophthalmus tranvancorensis Pillai, 1951: 30, text-fig. 5.

Macrophthalmus (Macrophthalmus) brevis Barnes, 1970: 207; 1971: 4, fig. 1; Dai et al., 1986: 432, pl. 60 fig. 1, fig. 240(2); Komai et al., 1995: 107, fig. 2; Ng et al., 2008: 237 (list); Barnes, 2010: 40, fig. 2; Trivedi et al., 2018: 50 (list).
Not *Macrophthalmus (Macrophthalmus) brevis* Pandya & Vachhrajani, 2013: 243, fig. 3 *(=Macrophthalmus (Macrophthalmus) sulcatus*)
not *Macrophthalmus brevis* Hilgendorf, 1869: 86; Nobili, 1906a: 318 (=*M. grandidieri* A. Milne Edwards, 1867).
not *Macrophthalmus carinimanus* Hilgendorf, 1879: 806 (=*M. grandidieri*); Haswell, 1882: 88 (=*M. crassipes* H. Milne Edwards, 1852); McNeill, 1962: 41, pl. 2, fig. 2 (=*M. crassipes*).

Material Examined: CW 6.00 – 20.82 mm; CL 3.22 – 9.42 mm (N=16)

Diagnosis: Carapace wide, maximum width across 2nd anterolateral teeth, almost 2.0 times as broad as long, covered with granules. Border of the upper orbits strongly granulated (stronger in males in comparison to females). Anterolateral margins with three anterolateral teeth along with narrow, triangular external orbital tooth separated by deep V-shaped incision; 2nd anterolateral tooth triangular, slightly wider than preceding tooth; 3rd anterolateral tooth small but distinct, separated by shallow U-shaped incision from preceding tooth. Male chelipeds with dactylus fairly longer than palm. Outer surface of the proximal half of the palm with central row of granules; the fingers bear small, tuberculate teeth on the proximal half of the cutting edge; Both male and female abdomen very wide. Colour sandy grey.

Habitat and Distribution: Constructs burrows in open mudflats (Komai et al., 1995), intertidal and fine sand dominated areas (Pandya & Vacchrajani, 2013). Distributed from Bay of Bengal through Southeast Asia to Japan (Barnes, 2010).

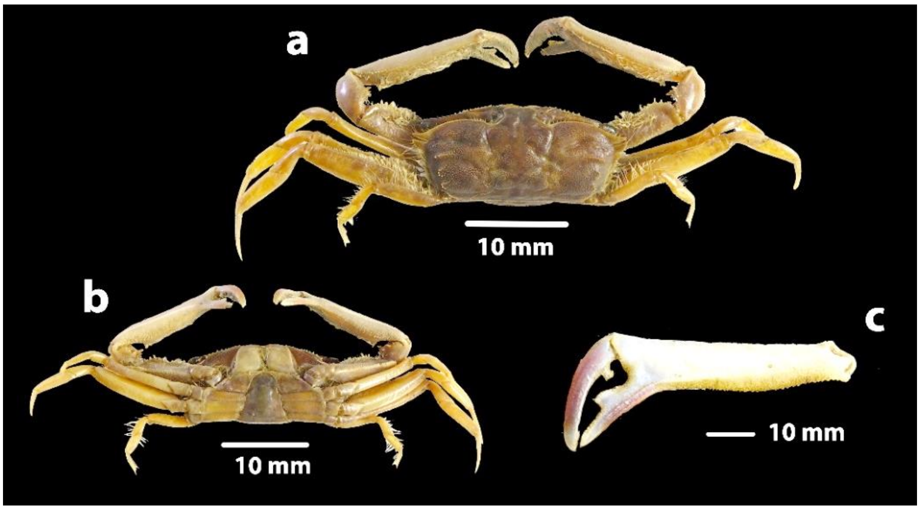

Figure 3.24. *Macrophthalmus (Macrophthalmus) brevis* (Herbst, 1804); CW 13.74 mm, CL 6.32 mm, male; (a) dorsal view; (b) ventral view; (c) outer view of left chela.

Macrophthalmus (Macrophthalmus) parvimanus Guérin, 1834

(Fig. 3.25)

Macrophthalmus parvimanus Guerin-Meneville, 1834: 7, pl. 4, fig. 1 (type locality: Seychelles); Barnes, 1977: 277 (key).

Macrophthalmus convexus Kemp, 1919b: 389, pl. 24, fig. 2 (in part).

Macrophthalmus convexus kempi Gravely, 1927: 150 (type locality: Gulf of Mannar).

?*Macrophthalmus consobrinus* Nobili, 1906c: 265 (type-locality: Rikitea, Tuamotu Archipelago); Crosnier, 1965: 129, figs. 232-234, 237, 238.

Macrophthalmus (Macrophthalmus) parvimanus Barnes, 1970: 211, fig. 2; Vannini & Valmori, 1981b: 216, figs. 9B, 10A; Komai et al, 1995: 119, figs. 7-8; Ng et al., 2008: 237 (list); Trivedi et al., 2018: 50 (list).

Material Examined: CW 15.72–30.22 mm; CL 11.28–21.38 mm (N=2)

Diagnosis: The carapace surface is smooth, naked, lateral areas covered with small granules, 1.74-1.86 times as wide as long with maximum width across external orbital teeth. Border of the upper orbits somewhat oblique and minutely granulate. Anterolateral margins with two or three anterolateral teeth including external orbital tooth. Lateral margin convergent posteriorly from dorsal aspect, armed, with a third tooth, if present, poorly defined. The external orbital tooth narrow, triangular, longer than 2nd anterolateral tooth, separated by V-shaped narrow incision; 2nd anterolateral tooth almost as wide as preceding tooth, triangular from the dorsal aspect. Male chelipeds with dactylus 0.85-0.88 longer than palm. Outer surface of the proximal half of the palm without central row of granules; superior surface with two rows of granules; cutting margin of the fingers with small tuberculate teeth on proximal half. Abdomen, moderately narrow in males. Colour sandy grey.

Habitat and Distribution: On sandy flats at the lowest high tidal level (Komai et al., 1995). Distributed from East coast of Africa to Malaysia and Solomon Islands (Komai et al., 1995).

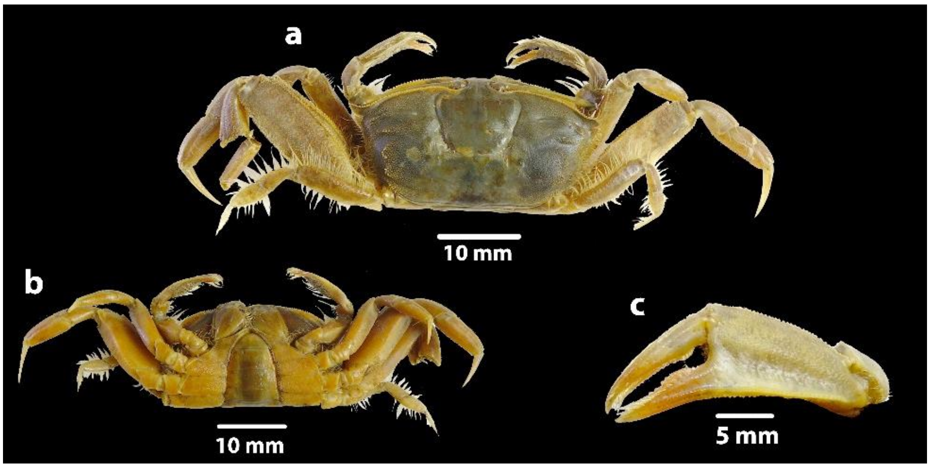

Figure 3.25. *Macrophthalmus (Macrophthalmus) parvimanus* Guérin, 1834; CW 30.22 mm, CL 15.72 mm, male; (a) dorsal view; (b) ventral view; (c) outer view of left chela.

Subgenus *Macrophthalmus (Mareotis)* Barnes, 1967

***Macrophthalmus (Mareotis) pacificus* Dana, 1851**

(Fig. 3.26)

Macrophthalmus pacificus Dana, 1851: 248 (type locality: Samoa); Dana, 1852: 314, pl. 19, fig. 4 a-c; De Man, 1895: 579; Tesch, 1915: 155 (key), 190, pl. 8, fig. 11; Chhapgar 1957b: 514, pl. 15, a-d; Barnes, 1977: 278 (identification key).

Macrophthalmus (Mareotis) pacificus Barnes, 1967: 218, pl. 2b, Fig. 6; Sakai, 1976: 614, text-fig. 337; Dai et al., 1986: 435, pl. 60(5), fig. 242 (3-4); Komai et al., 1995: 128, Fig. 11; Ng et al., 2008: 237 (list); Rahayu & Setyadi 2009: 119, Fig. 1; Barnes, 2010: 37; Davie, 2012: 187, Fig. 27; Trivedi et al., 2018: 51 (list).

? *Macrophthalmus bicarinatus* Heller, 1865: 36, pl. 4, figs. 2, 3 (type-locality: Nicobars).

Macrophthalmus depressus Lanchester, 1900: 259 (not *M. depressus* Rüppell, 1830).

not *Macrophthalmus pacificus* Rathbun, 1910b: 307, pl. 1, fig. 3 (= *M. crinitus* Rathbun, 1913).

Material Examined: CW 2.20–12.00 mm; CL 1.60–8.40 mm (N=16)

Diagnosis: Carapace smooth, shiny with long, slightly oblique rows of granules on branchial regions; 1.30 times as broad as long, maximum width across third anterolateral tooth. Border of the upper orbits nearly transverse, minutely granulate. Anterolateral margins with three anterolateral teeth along with wide, square external orbital tooth separated by deep U-shaped incision, 2nd anterolateral tooth wider than preceding tooth, 3rd anterolateral tooth small but distinct, marked by V-shaped incision. Lateral margins behind third anterolateral teeth fairly convergent posteriorly. Male chelipeds with dactylus equal to that of palm; palm with distinct inferior ridge, extending proximally to level of articulate knob of palm; inferior row of setae absent; superior surface rounded; cutting margin of fingers with small, tuberculate teeth. Abdomen narrow in males and wide in females. Colour sandy grey.

Habitat and Distribution: Muddy substrate along seaward fringe of mangrove forests and river mouths (Rahayu & Nugroho, 2012). Distributed from India through Southeast Asia to Solomon Islands, Papua New Guinea, Japan, and Australia (Komai et al. 1995; Rahayu & Nugroho, 2012).

Figure 3.26. *Macrophthalmus (Mareotis) pacificus* Dana, 1851; CW 6.40 mm, CL 4.32 mm, male; (a) dorsal view; (b) ventral view; (c) outer view of left chela.

Family Ocypodidae Rafinesque, 1815

Genus *Austruca* Bott, 1973

***Austruca annulipes* (H. Milne Edwards, 1837)**

(Fig. 3.27)

Gelasimus annulipes H. Milne Edwards, 1837: 55 (type locality: India).

Gelasimus lacteus Krauss, 1843: 14, 39; Alcock, 1900: 352 (identification key), 355.

Gelasimus annulipes White, 1847b: 36; Tweedie, 1937: 141, fig. 1a; Chhapgar, 1957b: 508, pl. 13, figs. i-o.
Gelasimus annulipes var. lacteus Ortmann, 1894: 759.
Uca annulipes Nobili, 1899: 518; Barnard, 1950: 97, 98, figs. 18g-i, 19e; Crosnier, 1965: 117, figs. 204, 206, 207, 212, 213; Shih et al., 2016b: 77 (identification key).
Uca lactea Pesta, 1911: 22; Tesch, 1918: 39; Maccagno, 1928: 29, fig. 15; Barnard, 1950: 96, 97 (not *Ocypode (Gelasimus) lactea* De Haan, 1835).
Uca lacteus Stebbing, 1917: 16, pl. 4 (not *Ocypode (Gelasimus) lactea* De Haan, 1835).
Austruca annulipes Bott, 1973: 322, fig. 13; Trivedi et al., 2018: 53 (list).
Uca (Celuca) annulipes Dai and Yang, 1991: 467, pl. 3, fig. 362 (2).
Uca (Celuca) lactea annulipes Crane, 1975: 299, 301, 611. figs. 18A-C, 19I-N, 20D-K, 24.
Uca (Paraleptuca) annulipes Ng et al., 2008: 241 (list).
Uca (Austruca) annulipes Naderloo et al., 2010: 3 (identification key), 6, Figs. 2a-h, 3a-e, 4b, 12a-c.

Material Examined: CW 4.60–25.20 mm; CL 3.30–1.81 mm (N=740)

Diagnosis: Carapace smooth, about three-fifths of the greatest breadth. The supraorbital border well arcuate and fairly oblique, the external orbital angles pointed obliquely outward. Anterolateral borders of carapace moderately convergent. Front wide, the width of front, measured between the bases of the eyestalks, is nearly one seventh that of the carapace. The major cheliped unarmed, the outer surface of palm smooth and the lower border marked with a faint ridge, which extends toward the base of the immovable finger, just above which is found a small depressed and rough surface; the inner surface of palm has two salient granular crests, one of which is deeply grooved and nearly vertical and becomes continuous with the dentary edge of the immovable finger; the other, which is very prominent is oblique and runs toward the lower border of the same finger. The fingers widely gaping, the movable finger being curved inward at the tip. Distinct variation in the colouration with a reddish-brown carapace and white stripes with light pink major chela as the most common colouration pattern to the white, blue carapace.

Habitat and Distribution: On intertidal mudflats, sandy habitats in lagoonal beaches (Mokhlesi et al., 2011; Bom et al., 2020). Distributed from Pakistan through Southeast Asia to China (Shih et al., 2022).

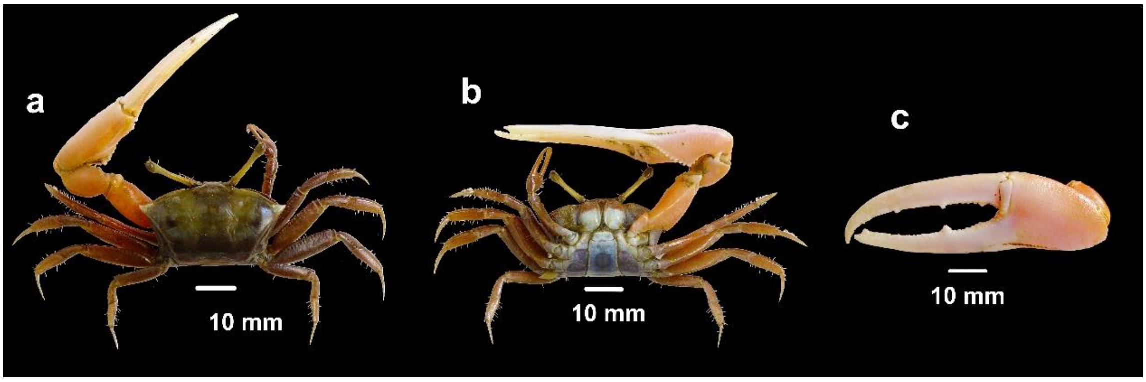

Figure 3.27. *Austruca annulipes* (H. Milne Edwards, 1837); CW 15.61 mm, CL 8.90 mm, male; (a) dorsal view; (b) ventral view; (c) major male chela.

Genus *Gelasimus* Latreille, 1817

***Gelasimus vocans* (Linnaeus, 1758)**

(Fig. 3.28)

Cancer vocans Linnaeus, 1758: 626 (type locality: India).

Ocypode vocans Bosc, 1802: 198.

Gelasimus vocans Desmarest, 1825: 123; Milne Edwards H., 1852: 145, pl. 3, fig. 4a; Trivedi et al., 2018: 54 (list).

Gelasimus marionis Desmarest, 1825: 124; pl. 13, Fig. 1; Alcock, 1900: 353 (identification key), 359; Chhapgar, 1957b: 47, pl. 13p-q, t.

Gelasimus marionis nitidus Alcock, 1900: 353 (identification key), 360; Chhapgar, 1957b: 510, pl. 13.

Uca (Thalassuca) vocans vocans Crane 1975: 92, figs. 38I, L, 56B, 60C-E, 64F, FF, pl. 14E-H; Sakai, 1976: 605, pl. 208(3) (part); Miyake, 1983: 163, pl. 55(2); Dai & Yang 1991: 463, fig. 234, pl. 58 fig. 7.

Uca vocans Lanchester, 1900: 754; Takeda, 1982: 207, 1 unnumbered fig.

Uca borealis Hung, 2000: 140-1, figs. 428–429, 1 unnumbered fig. (part) (not *Uca borealis* Crane, 1975).

Uca vocans vocans Nakasone and Irei, 2003: 269, fig. 31E.

Uca (Gelasimus) vocans Ng et al., 2008: 240 (list); Shih et al, 2016b: 66, fig. 3G, H.

Material Examined: CW 3.20 -23.70 mm, CL 1.80-19.22 mm (N=428)

Diagnosis: Carapace with orbits moderately oblique; front narrow, narrowest between eyestalk bases, frontal groove moderately wide, with sides diverging rapidly posteriorly; anterolateral margins short, sometimes absent, converging, exorbital tooth little produced, acute; suborbital crenellations strong, distinct, no tubercles on the floor of the orbit. Major pollex and dactyl flattened, the dactyl especially notably broad, without furrows except for basal traces sub dorsally; pollex with a deep outer furrow in basal two-thirds; ridge inside palm high, its tubercles strong; tubercles on the outer margin of palm large, particularly near depression at pollex base; major merus with a large, sharp tooth at the distal end of its anterodorsal margin. Gonopods usually with entire tip, or some of its elements, twisted; in subspecies without twisting anterior flange is wider than the posterior. Minor cheliped with gape much longer than manus. Merus of all ambulatories slender. Female gonopore with marginal tubercle or other structures; no pile on postero-lateral part of carapace; dorsolateral margin strongly beaded. Displays distinct variation in the colouration with a greyish brown carapace with yellow major chela being the most common pattern.

Habitat and Distribution: Burrows in muddy and sandy substrates, at the fringe of mangrove vegetation in the lower intertidal zones (Crane, 1975). Distributed from East Africa to Samoa, from the Red Sea to Natal, and from Okinawa to subtropical Australia (Crane, 1975).

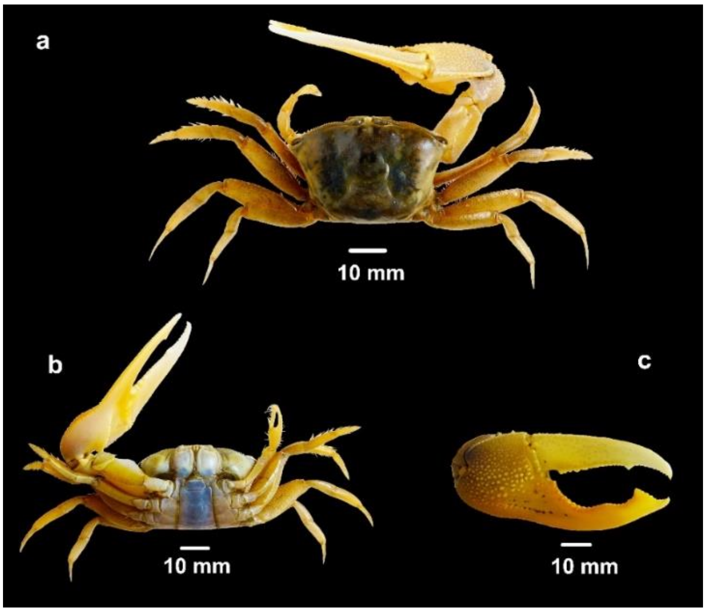

Figure 3.28. *Gelasimus vocans* (Linnaeus, 1758); CW 15.45 mm, CL 12.81 mm, male; (a) dorsal view; (b) ventral view; (c) major male chela.

Genus *Ocypode* Weber, 1795

***Ocypode ceratophthalmus* (Pallas, 1772)**

(Figs. 3.29)

Cancer cursor Linnaeus, 1758: 625 (in part).

Cancer ceratophthalmus Pallas, 1772: 83, pl. 5, fig. 17 (type locality: unknown).

Ocypode (Ocypode) ceratophthalmus de Haan, 1835: pl. C.

Cancer caninus Herbst, 1782: 78.

Ocypode ceratophthalma Weber, 1795: 92; Fabricius, 1798: 347.

Ocypode rhombea Weber, 1795: 92 (nomen nudum).

Ocypode rhombea Fabricius, 1798: 348.

Ocypode cursor Olivier, 1811: 416 (not *Cancer cursor* Linnaeus 1758).

Ocypode ceratophthalma Barnard, 1950: 86, fig. 17c-d; Crosnier, 1965: 93, figs 152, 160, 167–168, pl. 8, fig. 1, pl. 10, fig. 3; Dai & Yang, 1991: 458, text-fig. 231, pl. 58 (4); Ng et al., 2008: 240 (list); Sakai &Türkay, 2013: 685, figs. 1D-I, 10, 32; Komarpant et al., 2018: 73, Fig. 2-4; Trivedi et al., 2018: 55 (list).

Ocypode Urvillei Guérin-Méneville, 1829: pl. 1, fig. 1

Ocypoda (Ocypode) ceratophthalma Voigt, in Cuvier, 1836: 119.

Ocypoda ceratophthalma Milne Edwards H., 1837: 48; Alcock, 1900: 345 (identification key), 345; Chopra and Das, 1937: 418, fig. 17a-a'; Sakai, 1939: 614, fig. 91a, pl. 104, fig. 5; Chhapgar, 1957b: 4, pl. B, fig. 1, pl. 13 a-c.

Ceratophthalma cursor MacLeay, 1838: 64.

Ocypode urvillei Stebbing, 1917: 11.

Ocypoda urvillei Bouvier, 1915: 122.

Ocypode cursor White, 1847b: 35 (in part).

Ocypoda pallidula Dana, 1852: 324, pl. 20, fig. 1.

Ocypoda Urvillii Dana, 1852: 328.

Ocypoda brevicornis var. longicornuta Dana, 1852: 327.

Ocypoda brevicornis Dana, 1852: 326.

Ocypode cordimanus Jacquinot & Lucas, 1853: 64; Heller, 1865: 42.

Ocypoda Macleayana Hess, 1865: 143, pl. 4, fig. 8; Haswell, 1882: 95.

Ocypode Fabricii Hilgendorf, 1869: 82.

Ocypode aegyptiaca Hoffmann, 1874: 13.

Parocypoda ceratophthalma Neumann, 1878: 26.

Ocypoda cordimanus Kingsley, 1880: 185 (in part).

Ocypoda fabricii Kingsley, 1880: 182.

Ocypoda macleayana De Man, 1887: 696.

Ocypoda Kuhlii Pfeffer, 1889: 30.

? Ocypoda ceratophthalma: Matsuura, 1894: 55;

Ocypoda Urvillei Nobili, 1907: 407.

Ocypode gaudichaudii Estampador, 1937: 542.

Cancer francisci Curtiss, 1938: 175.

? Ocypode longicornuta Ng et al., 2008: 240 (list).

Material Examined: CW 4.62 -28.78 mm, CL 3.10-24.34 mm (N=24).

Diagnosis: The carapace is squarish, broader than long, external orbital angles are broadly triangular, front narrow, deflexed; eyestalks are large, elongated, and prolonged beyond the cornea, Chelipeds stout, unequal, fingers with truncate ends, Stridulating ridge of male cheliped with 7 interspaced round tubercles, 12 thick striae and 25-27 closely spaced striae; in females, it consists of 4 interspaced round tubercles, 8-12 thick striae and 29 closely spaced striae. P2–P3 propodi with setae. G1 slender, bears sub-distal palp. Gonopore surrounded by sunken sternite.

Habitat and Distribution: Burrowing in intertidal sandy shores in tropical and temperate regions (Lucrezi & Schlacher, 2014). Distributed from East coast of Africa (except Red Sea) to Japan, Micronesia, and eastwards to Polynesia and Clipperton Island (Sakai &Türkay, 2013).

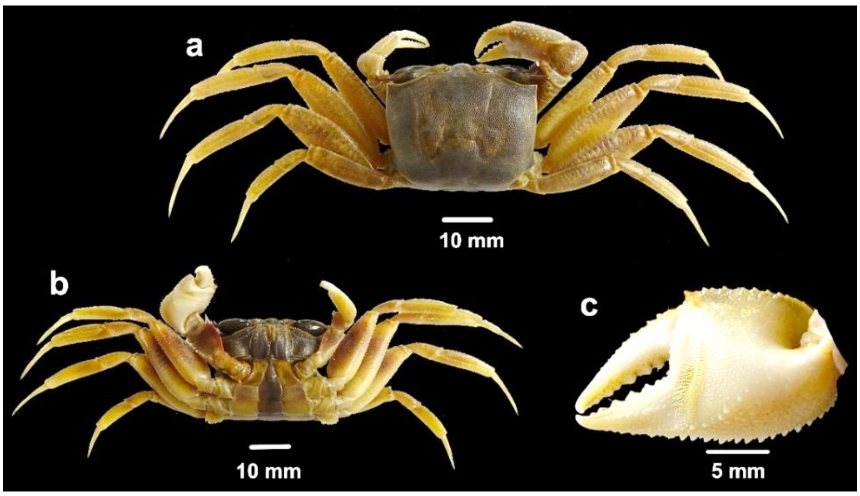

Figure 3.29. *Ocypode ceratophthalmus* (Pallas, 1772); CW 28.78 mm, CL 24.34 mm, male; (a) dorsal view; (b) ventral view; (c) major male chela.

Genus *Tubuca* Bott, 1973

Tubuca alcocki (Shih, Chan, and Ng 2018)

(Figs. 3.30)

Gelasimus dussumieri H. Milne Edwards, 1852: 148, pl. 4(12) (type locality: Malabar, India); Chandy 1973: 402.

Gelasimus acutus Alcock, 1900: 360 (not G. acutus Stimpson, 1858).

Gelasimus urvillei Alcock, 1900: 362 (not G. urvillei H. Milne Edwards, 1852).

Uca angustifrons Lundoer, 1974 (type locality: Phuket, Thailand): 8;

Uca (Deltuca) [coarctata] urvillei Crane, 1975: 35, 58-61, figs. 8B, 9E, pl. 9C, D.

Uca urvillei Tirmizi & Ghani, 1996: 103, fig. 39; Odhano et al., 2015: 170, figs. 1-2.

Uca (Deltuca) urvillei Hogarth 1986: 222; Krishnan, 1992: 471.

Uca (Deltuca) dussumieri Krishnan, 1992: 471.

Uca (Tubuca) urvillei Beinlich & von Hagen, 2006: 10, 14, 25, fig. 7f, k

Uca (Tubuca) acuta Trivedi et al., 2015: 27.

Tubuca urvillei Shih et al., 2016: 159, 174 (part), fig. 12A.

Tubuca alcocki Shih et al., 2018: 49, figs. 3, 4A, C, 5A–D, 6, 7A, C, E, G (type locality: Ranong, Thailand); Trivedi et al., 2018: 55 (list).

Material Examined: CW 5.74–25.72 mm, 3.16–15.38 mm (N=59)

Diagnosis: Diagnosis: Carapace smooth, trapezoidal. Front narrow, with narrow median groove. The floor of the orbit with a row of 5–11 tubercles, sometimes with a blunt ridge in males and with a row of 17–19 tubercles in females. Anterolateral angle acutely triangular, directed obliquely anteriorly; anterolateral margin short to moderately long. Major cheliped with dactylus longer than palm; One long groove on the outer surface of dactylus and pollex each proximally extending beyond midlength. Fingers of minor cheliped without conspicuous tooth in males and with conspicuous tooth on occlusal margin in females. Male G1 with slender distal tube, straight to slightly curved, width of proximal and distal parts subequal; moderate length thumb, extending beyond the base of the distal tube.

Habitat and Distribution: In muddy banks of mangroves (Shih et al., 2018). Distributed from Red Sea to India and Western Thailand (Shih et al., 2018).

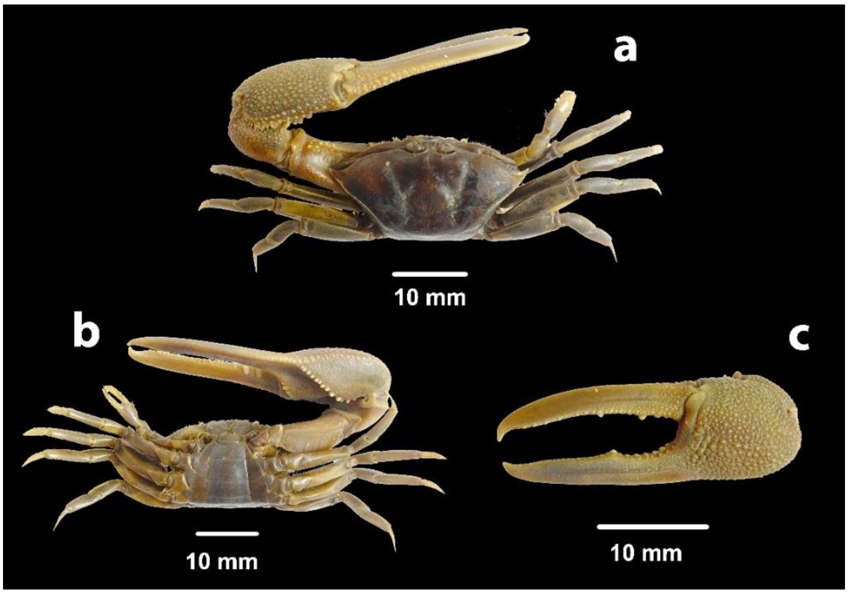

Figure 3.30. *Tubuca alcocki* (Shih, Chan, & Ng, 2018); CW 22.72 mm, CL 14.22 mm, male; (a) dorsal view; (b) ventral view; (c) major male chela.

3.3. Discussion

The present study is the first systematic attempt to document the occurrence of brachyuran crabs from the mangrove-associated regions of Chapora and Sal rivers of Goa. A review of the mangrove-associated crabs of the Indian wetlands revealed the lowest number of brachyuran crab species from Goa (sixteen species) and Karnataka (fourteen species) in comparison to the other coastal states (Chennuri et al., 2023). In view of this, the current study documents thirty species of brachyuran crabs from eleven families and twenty-two genera and thus helps to fill the existing lacunae in species distribution data of the mangrove-associated regions.

Out of the eleven families recorded during this study, the maximum number of species belonged to the family Sesarmidae (nine species from four genera) followed by Portunidae (four species from four genera) and Ocypodidae (four species from four genera). Family Sesarmidae belongs to the superfamily Grapsoidea, which along with the superfamily Ocypodoidea, is known to dominate mangroves all over the world (Hogarth, 2015; Hajializadeh et al., 2022). Most of the sesarmids are herbivorous in nature and therefore show a preference for the mangrove-associated regions (Colpo & Fransozo, 2011; Ferreira et al., 2019) whereas ocypodids are deposit feeders and are known to show their preference for the mangrove-associated regions (Colpo & Fransozo, 2011; Ferreira et al., 2019).

Metopograpsus cannicci is reported for the first time from India indicating its eastward extension. The taxonomy of the genus *Metopograpsus* is difficult owing to the subtle differences in the morphological features between species (Fratini et al., 2018; Innocenti et al., 2020). Recently Innocenti et al. (2020) examined specimens identified as *M. thukuhar* and on the basis of their morphological and genetic investigations described a new species, *M. cannicci*, referring to it as a pseudo-cryptic taxon. Fratini et al. (2018), through molecular phylogenetic investigation, found that the hitherto widely distributed *M. thukuhar* comprised two species with different distributions. *M. thukuhar* is confined to Southeast Asia and Pacific islands, while populations from the East African coast, Red Sea and Seychelles were described as distinct species, *M. cannicci* by Innocenti et al. (2020).

A sesarmid crab *Sarmatium crassum* recorded in the present study has so far been recorded from Eritrea (Red Sea) to Tanzania, South Africa, Madagascar, Philippines, eastern Australia, New Caledonia, Tahiti and Samoa. The taxonomy of the genus *Sarmatium* Dana, 1851, has a very confused history and has been revised on several occasions (Tesch, 1917; Serène and Soh, 1970; 1971; Davie, 1992) and is currently represented by five species which are distributed in the Indo-Pacific region (Davie, 1992): Alcock (1900) recorded *S. crassum* from India on the basis of a single female specimen from Nicobar Island. Davie (1992) commented that this record from India by Alcock (1900) is doubtful, as the diagnostic characters of *S. crassum* are present on male individuals only; the identification of a female specimen may not be precise. Since the specimen was not traceable in the crustacean collection of the Zoological Survey of India, Kolkata, the identity of the *S. crassum* female specimen collected by Alcock (1900) could not be confirmed. The present study confirms the occurrence of the sesarmid crab *Sarmatium crassum* in India.

The genus *Nanosesarma* Tweedie, 1950 comprises ten valid species of intertidal crabs (Ng et al. 2008) inhabiting mixed intertidal habitats across the Indo-Pacific region (Serène & Soh, 1970). *Nanosesarma tweediei* is recorded for the first time from the Indian coasts, indicating a westward extension of geographical range i.e. Malaysia, Singapore, Vietnam and Philippines (Serène, 1967).

The sesarmid genus *Episesarma* (De Man, 1895) contains some of the largest sesarmid crabs. Currently, *Episesarma* is represented by seven species out of which three species *E. chentongense, E. mederi* and *E. versicolor* are reported from India (Manikantan et al., 2016; Trivedi et al., 2018). *E. versicolor* (Tweedie, 1940) also known as violet vinegar crab is a widely distributed species in south-east Asian countries. However, its presence in India is restricted, with just one record from Pichavaram and Vellar mangroves of Tamil Nadu state located on the east coast of India. The present study records the occurrence of *E. versicolor* for the first on the west coast of India.

Large-scale baseline studies of the brachyuran crabs of the estuaries and coasts of Goa by the Zoological Survey of India (Dev Roy and Bhadra, 2008) revealed fifty-one species, out of which thirty species were reported from various estuaries in the region. Subsequently, Vijaylaxmi (2020) reported twenty-nine species from the Mandovi and Zuari estuaries. It is noteworthy, that despite the earlier attempts to document the brachyuran crab communities of the estuarine regions, the present study yielded the first records of *M. latifrons, P. bengalense*; *P. glabrum*, *M. brevis*, *M. parvimanus* and *T. alcocki* from Goa.

It is apparent from the present study and comparison with published literature that the brachyuran crab assemblages of this region are substantially diverse, and long-term systematic studies encompassing all the estuaries of the state would yield several records of rare and possibly new species.

CHAPTER 4

Species composition of molluscs

4.1. Introduction

Mollusca, the second largest phylum of invertebrates occupying the terrestrial, freshwater and marine ecosystems (Edward et al., 2022). The marine and brackish water molluscan fauna of Goa was explored by Parulekar et al. (1980) as part of the macrobenthic fauna of the Mandovi-Zuari estuarine complex and reported thirty-five molluscan species of which ten were gastropods and twenty-five were bivalves. The coastal intertidal shores both sandy and rocky were surveyed by Sonak (2017) from the conchological viewpoint point and reported one hundred and three gastropods. Later, Arathi (2018) studied the bivalves specifically from the four sandy shores of Panjim, Anjuna and Vagator and reported sixty-three species. Hussain et al. (2022) carried out extensive surveys from 2016–2018 on the benthic floor by SCUBA diving and trawls along the rocky shore coastline, Grand Island and Zuari estuarine regions investigating the Heterobranch gastropods providing a novel record to India and the west coast region. Occasional new records of gastropods from Goa were provided by Jagtap et al. (2009) and Kumbhar and Rivonker (2012). However, the mangrove-associated estuarine regions, especially the Chapora and Sal estuaries of Goa have largely remained unexplored. Considering this lacuna in the available knowledge, the present study aims to provide baseline data of the molluscan fauna from the mangrove-associated regions of the Chapora and Sal estuaries of Goa.

4.2. Results

The survey along the four study locations in the Chapora (C1, C2) and the Sal (S1, S2) estuaries revealed thirty-five species belonging to thirty genera from two classes (Gastropoda and Bivalvia), thirteen orders and twenty-three families of molluscs (Table 4.1).

Class Gastropoda comprised nineteen species belonging to six orders, fourteen families and sixteen genera. The highest number of species belonged to the families Littorinidae, Muricidae, Nassariidae, Neritidae, Potamididae (two species each) followed by Aplysiidae, Assimineidae, Cerithiidae, Ellobiidae, Naticidae, Plakobranchidae, Planaxidae, Onchidiidae and Turritellidae (one species each). Seven species namely *Littoraria carinifera*, *Littoraria pallescens*, *Nassarius fuscus*, *Nassarius jacksonianus*, *Optediceros breviculum*, *Cassidula nucleus* and *Platevindex* cf *martensi* were reported first time from Goa.

Class Bivalvia comprised sixteen species belonging to seven orders, nine families and fourteen genera. Family Veneridae (five species) was the most speciose group, followed by

Mytilidae, Ostreidae, Tellinidae (two species each), Arcidae, Cyrenidae, Isognomonidae, Placunidae and Psammobiidae (one species each). Six species namely *Brachidontes pharaonis, Isognomon isognomum, Quadrans gargadia, Hiatula diphos*, *Meretrix aurora* and *Pelecyora katiawarensis* were recorded for the first time from Goa.

Table 4.1. Checklist of molluscs reported from the study area

Sr. No.	Name of the Family/ Species	References from Goa
A. Class **Gastropoda Cuvier, 1795**		
I.	**Family Neritidae Rafinesque, 1815**	
1.	*Clithon oualaniense* (Lesson, 1831)	Apte, 2014
2.	*Neripteron violaceum* (Gmelin, 1791)	Rajagopal & Mookherjee, 1978; Rao, 1989
II.	**Family Cerithiidae J. Fleming, 1822**	
3.	*Clypeomorus batillariaeformis* Habe & Kosuge, 1966	Sonak, 2017
III.	**Family Potamididae H. Adams & A. Adams, 1854**	
4.	*Pirenella cingulata* (Gmelin, 1791)	Patil, 2008; Sonak, 2017.
5.	*Telescopium telescopium* (Linnaeus, 1758)	Patil, 2008; Reid et al, 2008; Sonak, 2017.
IV.	**Family Turritellidae Lovén, 1847**	
6.	*Turritella attenuata* Reeve, 1849	Parulekar et al. 1980; Ansari et al. 1986
V.	**Family Planaxidae Gray, 1850**	
7.	*Planaxis sulcatus* (Born, 1778)	Sonak, 2017
VI.	**Family: Littorinidae Children, 1834**	
8.	*Littoraria pallescens* (R. A. Philippi, 1846)	Present study
9.	*Littoraria carinifera* (Menke, 1830)	Present study
VII.	**Family: Naticidae Guilding, 1834**	
10.	*Paratectonatica tigrina* (Röding, 1798)	Parulekar et al., 1980
VIII.	**Family: Assimineidae H. Adams & A. Adams, 1856**	
11.	*Optediceros breviculum* (L. Pfeiffer, 1855)	Present study
IX.	**Family: Muricidae Rafinesque, 1815**	
12.	*Indothais blanfordi* (Melvill, 1893)	Rao & Rao, 1993

13.	*Indothais lacera* (Born, 1778)	Rao & Rao, 1993
X.	**Family: Nassariidae Iredale, 1916 (1835)**	
14.	*Nassarius fuscus* (Hombron & Jacquinot, 1848)	Present study
15.	*Nassarius jacksonianus* (Quoy & Gaimard, 1833)	Present study
XI.	**Family: Plakobranchidae Gray, 1840**	
16.	*Elysia bangtawaensis* Swennen, 1998	Jagtap et al., 2009
XII.	**Family: Aplysiidae Lamarck, 1809**	
17.	*Bursatella leachii* Blainville, 1817	Hussain et al., 2022
XIII.	**Family: Ellobiidae L. Pfeiffer, 1854 (1822)**	
18.	*Cassidula nucleus* (Gmelin, 1791)	Present study
XIV.	**Family: Onchidiidae Rafinesque, 1815**	
19.	*Platevindex* cf *martensi* (Plate, 1893)	Present study
B.	Class: **Bivalvia Linnaeus, 1758**	
XV.	**Family- Mytilidae Rafinesque, 1815**	
20.	*Brachidontes pharaonis* (P. Fischer, 1870)	Present study
21.	*Perna viridis* (Linnaeus, 1758)	Sonak, 2017; Arathi, 2018
XVI.	**Family Arcidae Lamarck, 1809**	
22.	*Tegillarca rhombea* (Dunker, 1868)	Huber, 2015
XVII.	**Family Ostreidae Rafinesque, 1815**	
23.	*Saccostrea cucullata* (Born, 1778)	Sonak, 2017; Arathi, 2018
24.	*Magallana bilineata* (Röding, 1798)	Arathi, 2018
XVIII.	**Family Isognomonidae Woodring, 1925 (1828)**	
25.	*Isognomon isognomum* (Linnaeus, 1758)	Present study
XIX.	**Family Placunidae Rafinesque, 1815**	
26.	*Placuna placenta* (Linnaeus, 1758)	Sonak, 2017; Arathi, 2018
XX.	**Family- Tellinidae Blainville, 1814**	
27.	*Alaona ala* (Hanley, 1845)	Dey, 2006
28.	*Quadrans gargadia* (Linnaeus, 1758)	Present study
XXI.	**Family- Psammobiidae J. Fleming, 1828**	
29.	*Hiatula diphos* (Linnaeus, 1771)	Present study

XXII.	**Family- Veneridae Rafinesque, 1815**	
30.	*Pelecyora katiawarensis* (Fischer-Piette & Métivier, 1971)	Present study
31.	*Meretrix aurora* Hornell, 1917	Present study
32.	*Meretrix casta* (Gmelin, 1791)	Sonak, 2017
33.	*Marcia opima* (Gmelin, 1791)	Arathi, 2018
34.	*Marcia recens* (Holten, 1802)	Present study
XXIII.	**Family- Cyrenidae Gray, 1840**	
35.	*Geloina bengalensis* (Lamarck, 1818)	Huber, 2015

Systematic accounts of all the recorded gastropod and bivalve species including their synonymy, material examined, diagnosis, and notes on their habitat and distribution, supplemented with photographs of the shells are provided below.

Systematic Accounts

Class Gastropoda Cuvier, 1795

Order Cycloneritida

Family Neritidae Rafinesque, 1815

Genus *Clithon* Montfort, 1810

***Clithon oualaniense* (Lesson, 1831)**

(Fig. 4.1)

Neritina oualaniensis Lesson, 1831: 379

Clithon oualaniense Meinhardt, 2003: 143, figs. 9.1, 9.2.

Clithon (Pictoneritina) oualaniensis Okutani, 2000: 108, pl. 54, fig. 37.

Clithon oualaniensis [sic] Tan & Yeo, 2010: 293 (list).

Nerita (Neritina) ceylanensis Récluz, 1851: 202.

Nerita guttata Récluz, 1841: 316.

Nerita nebulata Récluz, 1843: 71.

Neritina (Clithon) cincta Récluz, 1850a: 158.

Neritina (Vitta) pulchella Mörch, 1872: 27.

Neritina baconi Reeve, 1856: pl. 10, species no. 37.

Neritina coluber Hanley & Theobald, 1876: 64, pl. 157 fig. 10.

Neritina conferta E. von Martens, 1878: 193.

Neritina deficiens Mabille, 1887: 18.

Neritina delicatula Mousson, 1870: page no. unknown.

Neritina frondicincta E. von Martens, 1878: 193.

Neritina gaimardi Souleyet, 1842: 269.

Neritina garretti Mousson, 1870: 223.

Neritina guttata Récluz, 1841: 316.

Neritina multipicta Mousson, 1870, von Martens, 1878: 193.

Neritina nigrobifasciata E. von Martens, 1878: 193.

Neritina nubila Philippi 1845, 30, pl. 1, fig. 13.

Neritina ornatella Mousson, 1870, von Martens, 1878: 193.

Neritina parcepicta E. von Martens, 1878: 193.

Theodoxus oualaniense Meinhardt, 2003: 143.

Material examined: SW 1.70–5.50 mm: SL 7.12–17.89 mm (N=21)

Diagnosis: Shell small, smooth, glossy with a globose to slightly elongate shape. Spire low and often eroded, depending upon the habitat conditions. Aperture and parietal shelf are white, grey, yellow, or occasionally orange with deeper interior of the aperture transitioning to bluish white or grey. Parietal shelf flat to slightly swollen with occasionally fine wrinkles or transverse grooves. Operculum grey, greenish grey, or black, with lighter grey or yellow staining around the perimeter and in the area of the nucleus. Colour bright and extremely variable, usually shades of yellow or green, with darker, sometimes black, bands or axial streaks, often with a network pattern of triangular marks.

Habitat and Distribution: The species was found on sandy substrates in the low-tide to mid-tide region in the present study. Distributed throughout the Indian and Western Pacific Oceans (Eichhorst, 2016).

Figure 4.1. *Clithon oualaniense* (Lesson, 1831); SW 9.70 mm, SL 11.00 mm; (a) dorsal view; (b) ventral view.

Genus *Neripteron* Lesson, 1831

***Neripteron violaceum* (Gmelin, 1791)**

(Fig. 4.2)

Nerita violacea Gmelin, 1791: 3686 (type locality: not stated).

Dostia crepidularia: Govindan & Natarajan, 1972: 225.

Neripteron violaceum: Mustapha et al., 2021: 52, figs. 3E–F, 4I.

Neripteron (Dostia) violaceum: Eichhorst, 2016: 392, pl. 102.

Neritina (Dostia) crepidularia: Blanford, 1867: 60, pl. 1, figs. 20-22.

Neritina (Dostia) depressa: Blanford, 1867: 60, pl. 1, figs. 17-19.

Neritina (Dostia) schlaeflii: Prashad, 1921: 216.

Neritina (Dostia) violacea: Rajagopal and Mukherjee, 1978: 6 (list), 44.

Neritina (Mitrula) schlaeflii Mousson, 1874: 49.

Neritina crepidularia Lamarck, 1822b: 186 (type locality: not stated).

Neritina depressa W.H. Benson, 1836: 748 (type locality: Hugli, India).

Neritina exaltata Récluz, 1850b: 65, pl. 3, fig. 3.

Neritina gracilenta G. B. Sowerby I, 1825: 45 (list).

Neritina mitrula Menke, 1830: 48 (type locality: not stated).

Neritina montrouzieri Gassies, 1875: 228 (type locality: Ouagap, New Caledonia).

Neritina plumata Menke, 1830: 48 (type locality: not stated).

Neritina schlaeflii: Prashad, 1921: 216.

Neritina touranensis Souleyet, 1842: 269 (type locality: Tourane, Cochinchine).

Neritina violacea: Wang et al., 2019: 2942.

Material examined: SW 4.0–16.78 mm; SL 4.61–17.72 mm (N=55)

Diagnosis: Shell small, solid, ovate shape. The final whorl greatly expanded and flared into an oval base with a sharp lip that can extend completely 360° around the base. No spiral ridges, aperture orange solid band around the outer lip and on the parietal shelf. Beyond the orange band, inside the aperture, the colour fades to cream. Two interior palatal hinge teeth within the aperture; the lower one most developed while the upper tooth is small and indistinct and often completely absent. The parietal shelf smooth and flat with a small concave or depressed area; central portion along the columella. Columella central indentation with numerous small teeth (10 to 12) across the indented area, or the columella may be smooth and completely without teeth. Operculum a with dark grey irregular spiral bands and evident growth striae. Colour cream, grey, pale orange or brown, sometimes with darker axial streaks, aperture and columellar deck orange, shiny; periostracum yellowish brown.

Habitat and Distribution: The species was found on muddy substrates, often covered with mud at high tide levels under the mangrove trees. Distributed from India through Southeast Asia to Japan, Australia and the western Pacific (New Caledonia, Samoa, Fiji) (Eichhorst, 2016).

Figure 4.2. *Neripteron violaceum* (Gmelin, 1791); SW 16.28 mm, SL 11.42 mm; (a) dorsal view; (b) ventral view.

Order Caenogastropoda L. R. Cox, 1960

Family Cerithiidae J. Fleming, 1822

Genus *Clypeomorus* Jousseaume, 1888

***Clypeomorus batillariaeformis* Habe & Kosuge, 1966**

(Fig. 4.3)

Cerithium baccatum Hombron & Jacquinot, 1848: pl. 24, figs. 11-12.

Cerithium moniliferum Kiener, 1841: 49, pl. 16, fig. 3 (type locality: Indian Ocean).

Cerithium obscurum Hombron & Jacquinot, 1848: pl. 24, figs. 5-6.

Cerithium wainingoli Ladd, 1972: 40, pl. 10, figs. 6-7.

Clypeomorus batillariaeformis Habe & Kosuge, 1966: 314, pl. 29, fig. 13 (type locality: Arafura Sea, Indonesia); Houbrick, 1985: 51, figs. 23-27.

Clypeomorus moniliferus: Cernohorsky, 1972: 70 [in part, pl. 16: figs. 3, 4].

Material examined*:* SW 10.00 mm; SL 17.00 mm (N=1)

Diagnosis: Shell small, thick, finely tuberculate; and solid, tele conch comprising seven somewhat inflated whorls and well-defined sutures. Anterior canal very short. Penultimate whorl sculptured with three dominant, similarly spaced, spiral, beaded cords. Middle cord solid and with largest beads. Anterior cord smaller and with less distinct beads than other two cords. Beads smooth, rounded, somewhat drawn out, usually not axially aligned. Fine spiral lirae between dominant spiral cords are occasionally sculptured with tiny beads. Body whorl with prominent, hump-like, dorsal varix. Aperture ovate, 1/3 length. Columella hollow with slight callus. Outer lip thick, rounded, smooth, sometimes softly crenulate. Periostracum thin, tan, frequently worn or lacking. Colour dark brown to buff, blackish with darker tubercules.

Habitat and Distribution: A single specimen was found in the present study around the oyster colonies. Distributed from the east coast of Africa to Japan, Australia and eastern Polynesia in the Pacific Ocean (Houbrick, 1985).

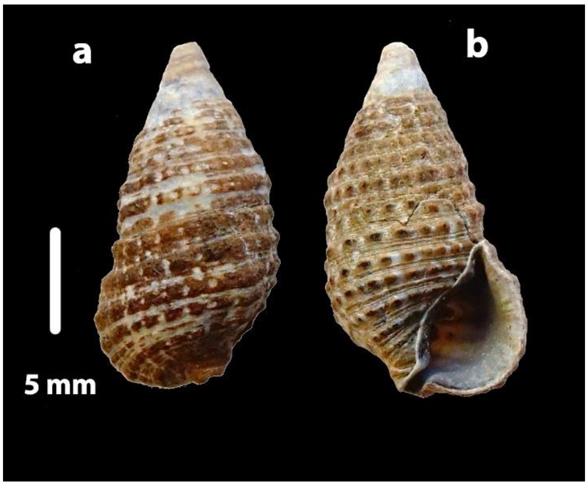

Figure 4.3. *Clypeomorus batillariaeformis* Habe & Kosuge, 1966; SW 10.00 mm, SL 17.00 mm; (a) dorsal view; (b) ventral view.

Family Potamididae H. Adams & A. Adams, 1854

Genus *Pirenella* Gray, 1847

***Pirenella cingulata* (Gmelin, 1791)**

(Fig. 4.4)

Murex cingulatus Gmelin, 1791: 3561 (type locality: Tranquebar, India).

Cerithidea (Cerithideopsilla) cingulata: Rajagopal & Mookherjee, 1982: 3 (list), 27; Rao & Dey, 2000: 52.

Cerithidea cingulata: Tan & Yeo, 2010: 293 (list).

Cerithidea fluviatilis: Gravely, 1942, 80, pl. 5, figs. 7a-b.

Cerithideopsilla cingulata: Shafique et al., 2015: 1518.

Cerithium fluviatile Potiez & Michaud, 1838: 363, pl. 31, fig. 19-20 (type locality: Malabar).
Pirenella cingulata: Reid & Ozawa, 2016: 41, figs. 1, 2L–N, 4A, 14, 15A.
Potamides cingulatus: Panikkar & Aiyar, 1939: 357.
Potamides fluviatilis: Annandale, 1918: 160 (list), 164.
Pyradus cinculatus: Morozov, 1952: page no. unknown.
Pyrazus cingulatus: Hedley, 1916: 190.
Strombus picta Röding, 1798: 97 (refers to Chemnitz, 1780: vol. 4, p. 328, pl.157, fig. 1492).
Tympanotonos fluviatilis: Adams & Adams, 1854: 291.

Material examined: SW 6.62–18.20 mm; SL 7.18–26.86 mm (N= 49)

Diagnosis: Shell small; elongate conical to somewhat fusiform; moderately solid; nine to eleven whorls; spire shape straight to slightly convex, spire whorls even. Aperture moderately oblique, margin almost smooth; adult lip slightly wide, slightly to moderately thickened; posterior canal; strong projection of lip together to deep anterior canal. Sculpture on spire of three strap-like spiral cords, ventrolateral varix swollen, usually angled at base; grooves two and occasionally three obsolete after ventrolateral varix, axial ribs remain strongly only on cord one. Base through seven to nine cords. Aperture whitish through purplish brown lines, thickened margin pale grey.

Habitat and Distribution: On open sand and mud flats in areas of sparse mangrove cover or small aquatic plants from mean low water to high water of spring tides (Reid & Ozawa, 2016). Distributed from Pakistan to Malaysia and Vietnam (Reid & Ozawa, 2016).

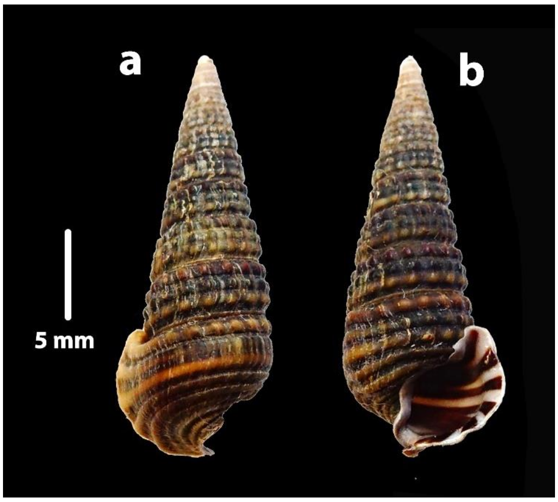

Figure 4.4. *Pirenella cingulata* (Gmelin, 1791); SW 8.22, SL 40.00; (a) dorsal view; (b) ventral view.

Genus *Telescopium* Montfort, 1810

***Telescopium telescopium* (Linnaeus, 1758)**

(Fig. 4.5)

Trochus telescopium Linnaeus, 1758: 760 (type locality: not stated).

Cerithium montisselae K. Martin, 1879: 66 (type locality: Java).

Cerithium telescopium Kiener, 1842: 88, pl. 28, fig. 1.

Potamides telescopium von Martens, 1897: 180.

Telescopium indicator Montfort, 1810: 439 (type locality: East India).

Telescopium mauritsi Butot, 1954: 7, pl.1, figs. 3, 4, pl. 2, figs. 2, 3 (type locality: Sunda Strait).

Telescopium telescopium Rajagopal & Mookherjee, 1982: 30; Rao & Dey, 2000: 53.

Material examined: SW 24.00–30.90 mm; SL 56.18–65.86 mm (N=6)

Diagnosis: Shell medium to large, elongate, multi whorled, with strong spiral and axial sculpture; extremely thick, heavy, pointed, with level whorls that very gradually widen and between which it is almost impossible to find the suture. Skewed, oval aperture. Twisted columella; regular spirals and more distinct growth lines. Dark brown, spirals often somewhat lighter. Aperture dark brown. Colour, Dark brown to buff, often greyish with black or brown beads which may be drawn out to form transverse lines.

Habitat and Distribution: On soft, muddy substrates in shady places of mangrove forests and around runoff gulleys (Houbrick, 1991). Distributed from Mauritius, Gulf of Oman, Persian Gulf through Southeast Asia to Japan and Australia (Houbrick, 1991).

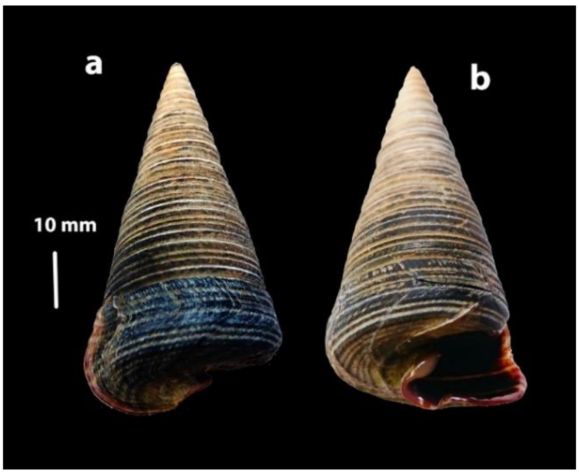

Figure 4.5. *Telescopium telescopium* (Linnaeus, 1758); SW 29.22, SL 64.20; (a) dorsal view; (b) ventral view.

Family Turritellidae Lovén, 1847

Genus *Turritella* Lamarck, 1799

***Turritella attenuata* Reeve, 1849**

(Fig. 4.6)

Turritella attenuata Reeve, 1849: pl. 1, sp. 4; Tripathy et al. 2013: 126 (identification key).

Material examined: SW 21.75–22.95 mm, SL 68.25–73.17 mm (N= 3).

Diagnosis: Shell medium to large; slender, elongated; teleoconch wormlike pointed apex; high spired, turreted; with many whorls, apical whorls with two spiral cords on upper whorls and three spiral cords on lower whorls; teleoconch whorls twisted and separate; three thick spiral cords crossed by axial ribs; sculpted with fine spiral ridges, aperture subquadrate. Colour dull grey to yellowish-tan; shape of apex conic and pointed.

Habitat and Distribution: On sandy and muddy-sand substrates in coastal intertidal and subtidal waters (Tripathy et al., 2013). Distributed along the peninsular coasts of India and the Eastern Seas (Tripathy et al., 2013).

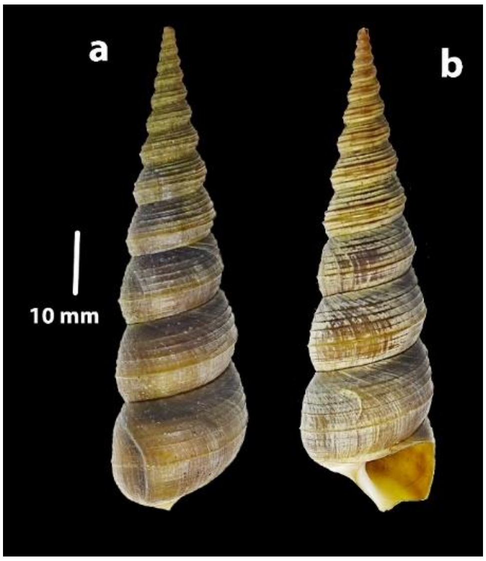

Figure 4.6. *Turritella attenuata* Reeve, 1849; SW 22.95, SL 68.25; (a) dorsal view; (b) ventral view.

Family Planaxidae Gray, 1850

Genus *Planaxis* Lamarck, 1822

***Planaxis sulcatus* (Born, 1778)**

(Fig. 4.7)

Buccinum sulcatum Born, 1778: 251 (type locality: not stated).

Buccinum pyramidale Gmelin, 1791: 3488 (type locality: Tranquebar, India).
Planaxis brevis Quoy & Gaimard, 1833: 488, pl. 33 figs 30-32 (type locality: Guam and New Guinea).
Planaxis buccinoides Deshayes, 1828: 13 (type locality: not stated).
Planaxis menkeanus Dunker, 1861: 41 (type locality: Red Sea).
Planaxis obscura A. Adams, 1853: 271 (type locality: not stated).
Planaxis sulcatus Rao & Dey, 2000: 45.
Planaxis (Planaxis) sulcatus: Rajagopal & Mookherjee, 1982: 3 (list), 24.
Planaxis undulata Lamarck, 1822a: 51 (type locality: Eastern Indian Ocean).

Material examined: SW 13.60 mm, SL 18.20 mm (N=1)

Diagnosis: Shell small to medium; thick, solid, conical; spire raised, apex blunt; body whorl slightly angular, constricted at base; surface sculptured with spiral grooves; outer lip spirally ridged within; columella narrow, aperture ovate, callous anteriorly thick, posteriorly thin at the base; anterior canal prominent, deeply concave 'V' shaped; distinct white spiral ridge runs inwards from posterior columellar border; just below this a spiral groove on the dorsal side extends into aperture; posterior canal shallow. Colour purplish brown to greyish black with irregular white transpirable bands; margin of outer lip and columella brownish.

Habitat and Distribution: On intertidal rocky shores and seawalls, at mid to low tidal zones during low tides (Houbrick, 1987). Distributed from the Gulf of Suez and the eastern coast of Africa through Southeast Asia to the Philippines, Australia and Hawaii (Rajagopal & Mookherjee, 1982).

Figure 4.7. *Planaxis sulcatus* (Born, 1778); SW 13.60 mm, SL 18.20 mm; (a) dorsal view; (b) ventral view.

Order Littorinimorpha Golikov & Starobogatov, 1975

Family Littorinidae Children, 1834

Genus *Littoraria* Gray, 1833

***Littoraria carinifera* (Menke, 1830)**

(Fig. 4.8)

Phasianella carinifera Menke, 1830: 141 (type locality: not stated).

Littoraria (Palustorina) carinifera Reid, 1986: 186, figs 80, 82–85 (full synonymy).

Littoraria carinifera Lozouet & Plaziat, 2008: 116–117, pl. 22, figs. 14–15.

Littorina (Littorinopsis) carinifera Rajagopal & Mookherjee, 1982: 2 (list).

Littorina rubropicta E. von Martens, 1887: 170, pl. 16, figs. 2a-f (type locality: King Island Bay).

Littorinopsis carinifera Brandt, 1974: 55.

Material examined: SW 10.28–16.09 mm, SL 12.11–18.03 mm; (N=5)

Diagnosis: Shell small to medium, thick; solid; spire whorls almost flat; keel strong. Spire outline slightly convex; whorls almost flat, sometimes slightly turreted; sutures indistinct. Peripheral keel strong, carinate. Columella wide, shallowly excavated; primary grooves 7-9; secondary sculpture weak; 15-30 ribs on last whorl, peripheral rib carinate; grooves narrow. Lip not flared; varices absent; pillar straight or with a slight convex flexure at base; micro sculpture of spiral striae on ribs, axial striae in grooves. Colour bluish grey, whitish or pale yellow, palest near suture and on carinae. Pattern of rusty orange or dark brown vertical, oblique or zigzag axial stripes. Aperture with blacks or dark purple brown; columella pale pink, purple brown, grey or white.

Habitat and Distribution: On trunks, deadwood and leaves of mangroves at upper intertidal levels as well as in marsh grass (Reid, 1986); also on rocks, seawalls, house and pier poles and muddy sand (Sanpanich et al., 2004). Distributed from India to Philippines (Reid et al., 2010).

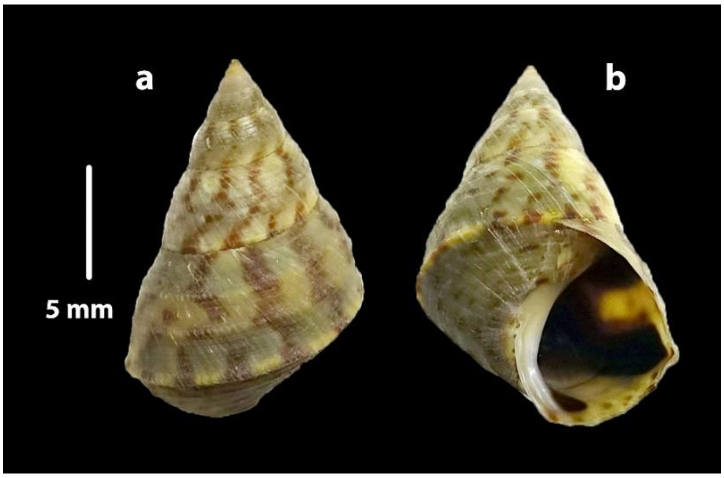

Figure 4.8. *Littoraria carinifera* (Menke, 1830), SW 18.03 mm, SL 16.09 mm; (a) dorsal view; (b) ventral view.

***Littoraria pallescens* (R. A. Philippi, 1846)**

(Fig. 4.9)

Litorina pallescens R.A. Philippi, 1846: 142 (type locality: Insula Mindanao, Philippines).

Littoraria pallescens: Sanpanich et al., 2004: fig. 1g.

Littorina arboricola Reeve, 1857: 10, pl. 5, fig. 27a-b (type locality: Singapore).

Littorina pallescens R.A. Philippi, 1846: Reid, 1986: 109 (synonymy).

Littorina sieboldii R.A. Philippi, 1846: 142 (type locality: Japan).

Material examined: SW 5.53–15.33 mm, SL 7.53–24.68 mm (N=20)

Diagnosis: Shell small to medium; thick, solid. Spire outline gently convex; whorls rounded; sutures impressed. Protoconch normal and teleoconch smooth. Outer lip thickened, a little flared; varices unusual. Columella wide, excavated, inner lip of aperture rough and rounded; primary grooves 9-10; secondary sculpture absent; ribs rounded or flattened, grooves wide or narrow; micro sculpture faint. Micro sculpture of axial development striae cover surface, stronger in grooves; even spiral striae visible wide grooves. Colour highly polymorphic; various shades of brown, white, yellow and sometimes pink, often striped or banded. External pattern and colour visible inside aperture, concerned by whitish callus. Columella purple, pillar and inner lip of aperture whitish; entire columella white in shells absence dark pigment.

Habitat and Distribution: On leaf edges, trunks, roots of mangroves and rocks from the sea shore to the upper regions of estuaries at 1-4.5 m above the ground (Reid, 1986). Distributed from East coast of Africa to Japan, Marshall Islands and Samoa (Reid, 1986).

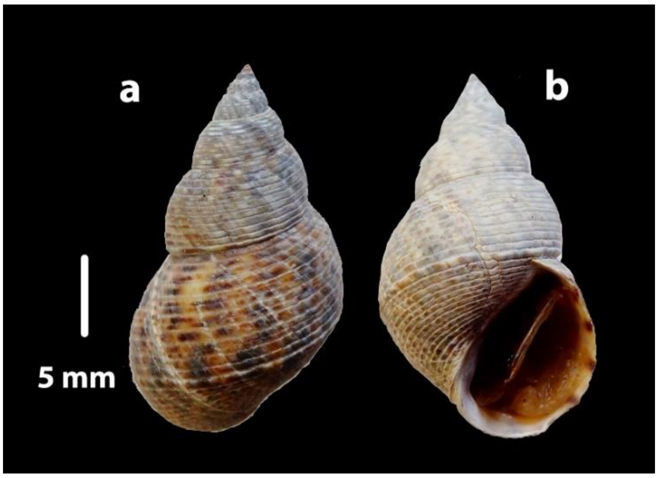

Figure 4.9. *Littoraria pallescens* (R. A. Philippi, 1846); SW 18.03 mm, SL 16.09 mm; (a) dorsal view; (b) ventral view.

Family Naticidae Guilding, 1834

Genus *Paratectonatica* Azuma, 1961

***Paratectonatica tigrina* (Röding, 1798)**

(Fig. 4.10)

Cochlis tigrina Röding, 1798: 147 (type locality: not stated).

Natica javanica Lamarck, 1822b: 204 (type locality: Java).

Natica maculata Perry, 1811: pl. 48, Natica no. 3 (type locality: South Seas).

Natica maculosa Lamarck, 1822b: 202 (type locality: Seas of India).

Natica pellistigrina Deshayes, 1838: 642 (type locality: not stated).

Natica tigrina Mookherjee, 1985: 42 (identification key), 44, pl. 6, fig. 28.

Notocochlis tigrina Kabat, 2000: 348 (list), 364 (identification key).

Paratectonatica tigrina Torigoe & Inaba, 2011: 101, pl. 3, fig. 30.

Material examined: SW 11.91–21.83 mm; SL 12.88–24.98 mm (N=12)

Diagnosis: Shell small to medium; globosely pear shaped, body whorl highly inflated; longer than wide; low spire, raised; aperture wide; columella heavily calloused; umbilicus anteriorly placed; funicle and open posteriorly. Colour white to cream, dotted all over with closest purple-brown spots dull brownish white speckled with round, dark purplish brown squarish spots; umbilical region whitish yellow; aperture white.

Habitat and Distribution: On sandy substrates in sublittoral and shallow subtidal waters to a depth of about 30 m (Poutiers, 1998). Distributed from Mascarene Islands and Pakistan through Southeast Asia to Australia and Japan (Mookherjee, 1985; Poutiers, 1998).

Figure 4.10. *Paratectonatica tigrina* (Röding, 1798); SW 16.66 mm, SL 19.98 mm; (a) dorsal view; (b) ventral view.

Family Assimineidae H. Adams & A. Adams, 1856

Genus *Optediceros* Leith, 1853

***Optediceros breviculum* (L. Pfeiffer, 1855)**

(Fig. 4.11)

Hydrocena brevicula L. Pfeiffer, 1855: 306 (type locality: Singapore).

Assiminea (Metassiminea) australis Thiele, 1927: 131.

Assiminea (Sphaerassiminea) brevicula: Sri-aroon et al., 2005: tables 1-3, 5-6.

Assiminea brevicula Rao & Dey, 2000: 43.

Assiminea brevicula miniata E. von Martens, 1866: 204 (type locality: Singapore).

Assiminea brevicula var. *bibalteata* G. Nevill, 1881: 159.

Assiminea brevicula var. *bicolor* G. Nevill, 1881: 159.

Assiminea miniata E. von Martens, 1866: 204 (type locality: Singapore).

Assiminea pinguis E. von Martens, 1866: 203 (type locality: Macao).

Assiminea rubella Blanford, 1867a: 384, fig. 6 (type locality: Dalhousie, Irawaddy Delta).

Assiminia rubella Blanford, 1867b: 55, pl. 13 fig. 11-12.

Hydrocena marginata Morelet, 1865: 226 (type locality: Thailand).

Ovassiminea brevicula Suzuki et al., 2002: 265

Optediceros breviculum Chan & Lau, 2021: 1, fig. 1.

Material examined: SW 5.23–10.72 mm; SL 4.32–6.72 mm (N=18)

Diagnosis: Shell small, globose, thick, 6-7 whorls, sutures sharp, smooth columellar pillar yellowish tan; operculum corneous, thin, elongate with nucleus far off to one side. Colour bright brick red or yellowish tan.

Habitat and Distribution: On muddy and sandy flats in intertidal mangrove forests (Suzuki et al., 2002). Distributed from India to Philippines (Rao & Dey, 2000).

Figure 4.11. *Optediceros breviculum* (L. Pfeiffer, 1855); SW 4.46 mm, SL 5.28mm; (a) dorsal view; (b) ventral view.

Family Muricidae Rafinesque, 1815

Genus *Indothais* Claremont, Vermeij, S. T. Williams & D. Reid, 2013

***Indothais blanfordi* (Melvill, 1893)**

(Fig. 4.12)

Purpura (Stramonita) blanfordi Melvill, 1893: 53-54, pl. 1, fig. 3 (type locality: Bombay).
Purpura pura E.A. Smith, 1903: 376, pl. 15, fig. 21 (type locality: Umkomaas, South Africa).
Thais blanfordi Rao, 2003: 242, pl. 59, fig. 2; Rao & Dey, 2000: 112.
Thais (Thaisella) blanfordi Kilburn, 1972: 410, figs. 7b, 9b.
Indothais blanfordi Houart & Delemarre, 2013: 13.

Material examined: SW 8.56–20.25 mm; SL 12.45–31.14 mm (N=10).

Diagnosis: Shell small to medium; thick; outline ovate; fusiform; spire raised; acute; whorls angulate; body whorl large, shoulder obviously angulate; axial sculpture low, less prominent tubercles; aperture ovate; outer lip strongly crenulate; interior of aperture strongly lirate, inner lip smooth, slightly twisted towards anterior part; anal canal short, wide, open. Colour light brown; interior aperture white; columella bearing dark blotches.

Habitat and Distribution: On rocky shores in the midlittoral zone (Tan & Sigurdsson, 1996). Distributed from southern and eastern coasts of Africa to India (Tan & Sigurdsson, 1996).

Figure 4.12. *Indothais blanfordi* (Melvill, 1893); SW 14.41 mm, SL 22.61; (a) dorsal view; (b) ventral view.

***Indothais lacera* (Born, 1778)**

(Fig. 4.13)

Murex lacerus Born, 1778: 307 (type locality: not stated).

Cymia carinifera: Rao & Mookherjee, 1975: 170.

Cymia lacera: Rao et al., 1987: 153 (list), pl. 6, fig. 6.

Mancinella mutabilis Link, 1807: 115 (type locality: not stated).

Purpura carinata Schubert & J.A. Wagner, 1829: 141, pl. 232 fig. 4078, pl. 233 fig. 409I-4092, pl. 232 fig. 4078, pl. 233 Figs. 4091-4092.

Purpura carinifera Lamarck, 1822a: 241 (type locality: South Atlantic Ocean).

Purpura umbilicata H.M. Jenkins, 1864: 53, pl. fig. 5a-b (type locality: Java).

Purpura undataeformis K. Martin, 1884: 110 (type locality: Java).

Thais (Thaisella) mutabilis Kilburn, 1972: 412.

Thais carinifera Preston, 1916: 29.

Thais lacera Rao & Dey, 2000: 113.

Thaisella lacera Crocetta, 2012: 1359 (list).

Indothais lacera Pedro et al., 2023: 7, fig. 2A-D.

Material examined: SW 32.21 mm; SL 42.57 mm (N=1)

Diagnosis: Shell medium to large; thick, conical, solid and heavy; biconical; spire raised, sharply pointed; whorls four, body whorl angulates; surface sculptured with irregular smooth or transverse striations; spiral ridge of each whorl bearing spiny tubercles; prominent spiral ridge on body whorl. Aperture wide and large, widely ovate, aperture detached posteriorly from body whorl; outer lip crenulated, interior of aperture lirate; smooth columella, straight, polished; closed umbilicus.

Habitat and Distribution: On rocky substrates in the intertidal regions near the river mouths and backwaters (Nolf, 2009). South Africa and the Persian Gulf through south and southeast Asia to Taiwan; Invasive species in the Mediterranean Sea (Nolf, 2009) and western Atlantic regions (Pedro et al., 2023).

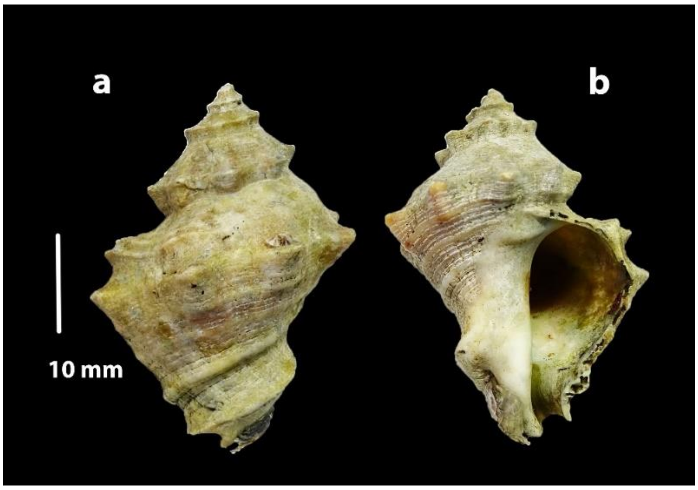

Figure 4.13. *Indothais lacera* (Born, 1778), SW 14.41 mm, SL 22.61; (a) dorsal view; (b) ventral view.

Order Neogastropoda Wenz, 1938

Family Nassariidae Iredale, 1916 (1835)

Genus *Nassarius* Duméril, 1805

***Nassarius fuscus* (Hombron & Jacquinot, 1848)**

(Fig. 4.14)

Nassa fusca Hombron & Jacquinot, 1848: pl. 21 figs. 7-8 (type locality: Solomon Islands).
Nassa (Alectrion) mitralis Adams, 1852: 108.
Nassa melanioides Reeve, 1853: pl. 22 fig. 150a, b (type locality: Moreton Bay, Australia).
Nassa mitralis Adams, 1852: 608, pl. 19 fig. 128 (type locality: Negros Islands, Philippines).
Nassa taenia var. *mitralis* A. Adams, 1852: Mari, 1934: 43.

Nassarius fuscus (Hombron & Jacquinot, 1848): Nerurkar et al., 2020: 4, fig. 2A-L.
Nassarius (Zeuxis) fuscus (Hombron & Jacquinot, 1848): Tsuchiya, 2017: p. 716.
Nassarius melanioides (Reeve, 1853) Wilson, 1994: p. 88, pl. 14: fig. 20a, b.
Nassarius (Zeuxis) mitralis Adams & Adams, 1853: p. 119.
Tarazeuxis mitralis: Habe & Kosuge, 1966: 62, pl. 22, fig. 29.
Zeuxis mitralis (A. Adams, 1852) Okutani, 2000: 445, pl. 221: fig. 33.

Material examined: SW 4.56 mm; SL 18.59 mm (N=1)

Diagnosis: Shell small; heavy, solid, conical; moderately high spire. Teleoconch of 4.25 whorls; first 2 axially ribbed; remaining whorls sculptured through numerous equidistant growth lines and several transverse striae, resulting square to rectangular interstices. Aperture oval; outer lip prominently thickened; edge somewhat turned backwards middle, crenulated. Columella callus plicate. Siphonal canal short, wide and marked with spiral grooves; anal canal deep and narrow. Parietal denticle prominent. Colour dark brown to yellowish brown; aperture whitish cream to brown.

Habitat and Distribution: On soft mud substrates covered with dead and decaying mangrove leaves in intertidal regions (Nerurkar et al., 2020). Distributed from India through Southeast Asia to Japan, Australia and Solomon Islands (Nerurkar et al., 2020).

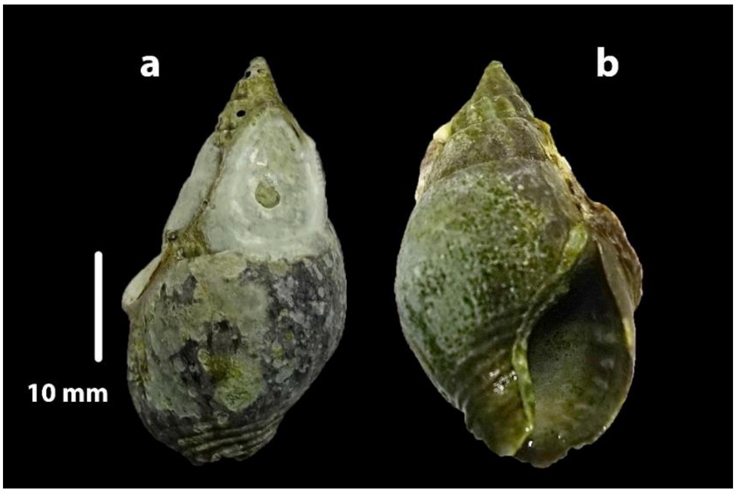

Figure 4.14. *Nassarius fuscus* (Hombron & Jacquinot, 1848), SW 4.56 mm; SL 18.59 mm; (a) dorsal view; (b) ventral view.

***Nassarius jacksonianus* (Quoy & Gaimard, 1833)**

(Fig. 4.15)

Buccinum jacksonianum Quoy & Gaimard, 1833: 452, pl. 32, figs. 28, 29 (type locality: Singapore).

Buccinum polygonatum sensu A. Adams, 1852: 94 (not Lamarck, 1822).

Nassa (Phrontis) siva Preston, 1904: 76, pl. 6, figs. 3-4 (type locality: Ceylon).

Nassa jacksoniana Natarajan, 1957: 205, figs. 109-113.

Nassarius jacksonianus Tan & Yeo, 2010: 293 (list).

Nassarius (Alectrion) jacksonianus Melvill, 1928: 106

Nassarius (Niotha) jacksonianus Cernohorsky, 1984: 96, p. 13, figs. 1-4; Rao, 2003: 268, pl. 64, fig. 2.

Material examined: SW 6.00- 8.70 mm; SL 10.00 -14.71 mm (N=24)

Diagnosis: Shell small; elongate to ovate and solid, teleoconch 5-6 whorls, sutures depressed; pre- and post-embryonic whorls sculptured with coarse, axial ribs thick which are encircled with 3-4 sharp spiral threads. Axial ribs obsolete, Aperture moderately narrow, outer lip thickened and strong, columellar callus narrow, broad varix and 5-8 denticles within, laminated and glazed above parietal wall, columella with small, strong denticles, parietal denticle distinct.

Habitat and Distribution: In shallow tidal pools on muddy substrates (Cernohorsky, 1984). Distributed from Persian Gulf through Southeast Asia to Philippines, Australia and Hawaii (Gili, 2015).

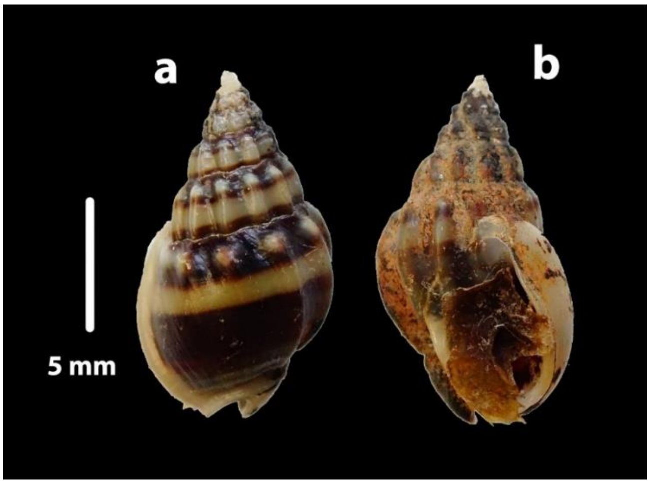

Figure 4.15. *Nassarius jacksonianus* (Quoy & Gaimard, 1833), SW 7.56 mm; SL 14.50 mm; (a) dorsal view; (b) ventral view.

Superorder Sacoglossa

Family Plakobranchidae Gray, 1840

Genus *Elysia* Risso, 1818

***Elysia bangtawaensis* Swennen, 1998**

(Fig. 4.16)

Elysia bangtawaensis Swennen, 1998: 33, fig. 1A-O (type locality: Bang Tawa, Thailand); Jagtap et al., 2009: 30, fig. 2a-d; Swennen, 2011: 32, figs. 1-7.

Material examined: SW 10.00–15.00 mm; SL 20.00–31.00 mm (N=4)

Diagnosis: Animal small; Prominent reddish to orange, glandular warts along parapodial borders. White spots different sizes and fine reddish specks dispersed on dorsal and ventral sides, including foot sole. Green ductules of digestive gland cover renal part; not reaching tips of rhinophores. Tips pale or coloured by white and orange spots. Digestive gland appears yellowish in hue.

Habitat and Distribution: On muddy substrates in shallow, water-filled depressions in mangrove forests (Swennen, 2011). Distributed in India, Thailand, Malaysia and Australia (Swennen, 2011).

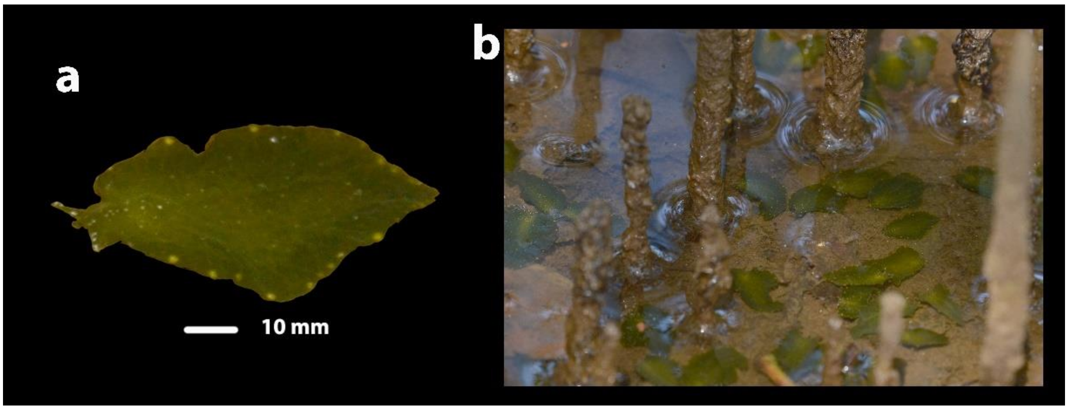

Figure 4.16. *Elysia bangtawaensis* Swennen, 1998; SW 3.58 mm; SL 31.00 mm; (a) dorsal view; (b) colonies of *E. bangtawaensis* in nature.

Order Aplysiida

Family Aplysiidae Lamarck, 1809

Genus *Bursatella* Blainville, 1817

***Bursatella leachii* Blainville, 1817**

(Fig. 4.17)

Bursatella leachii Blainville, 1817: 138 (type locality: not stated).

Aclesia africana Engel, 1926: 180, figs. 11–14 (type locality: South Africa).

Aclesia freeri L. E. Griffin, 1912: 65, figs. 1-5, pls. 1-6.

Aclesia glauca Cheeseman, 1878: 277, pl. 15 fig. 4 (type locality: Auckland, New Zealand).

Aclesia rosea Engel, 1926: 184, figs. 15–16 (type locality: Western Sahara).

Aplysia bursatella Eales & Engel, 1935: 297.

Aplysia cirrhifera Quoy & Gaimard, 1832: 311, pl. 24 fig. 8 (type locality: Mauritius).

Aplysia pleii Rang, 1828: 70, pl. 21 figs. 2-4 (type locality: Sea of Antilles).

Barnardaclesia cirrhifera: Bebbington, 1974: 95, 96 (identification key).

Bursatella lacinulata Gould, 1852: 223, figs. pl. 16, figs 269-269a (type locality: Rio de Janeiro).

Bursatella leachi [sic]: Olita, 2006: 115.

Bursatella leachii africana: Eales & Engel, 1935: 302.

Bursatella leachii guineensis Bebbington, 1969: 340, figs. 1-15 (type locality: Tema Harbour, Guinea).

Bursatella leachii hirasei Eales & Engel, 1935: 298 (type locality: Japan).

Bursatella leachii lacinulata Eales & Engel, 1935: 302.

Bursatella leachii leachii Eales & Engel, 1935: 302.

Bursatella leachii pleii Eales & Engel, 1935: 302.

Bursatella leachii rosea Eales & Engel, 1935: 302.

Bursatella leachii savigniana Eales & Engel, 1935: 302.

Bursatella savigniana Audouin, 1826: 17, pl. 2, fig 2.1, 2.13 (type locality: Egypt (Red Sea).

Notarchus (Bursatella) leachii Lin &Tchang, 1965: page no. unknown.

Notarchus brevipes Hägg, 1904: 1, pl. 1 figs 1–3 (type locality: Tor, Red Sea).

Notarchus cirrhifera Barnard, 1974: 729 (list).

Notarchus cirrosus W. Stimpson, 1855: 378 (type locality: China).

Notarchus intrapictus Cockerell, 1893: 219 (type locality: Jamaica).

Notarchus laciniatus Rüppell & Leuckart, 1830: 24-25, Plate 7, Fig. 2 a-c (type locality: Red Sea coast of Egypt).

Notarchus leachii cirrosus: Guo et al., 1999: 21 (list).

Notarchus pleii: Morch, 1863: 25.

Notarchus savignyanus [sic]: Vine, 1986: page no. unknown.

Notarchus villosus O'Donoghue, 1929: 25, pl. 3 figs. 27–32 (type locality: South Africa).

Ramosaclesia rex Allan, 1932: 317, pl. 35 figs. 1–6 (type locality: Queenscliff, Australia).

Material examined: SW 50.00–60.00 mm; SL 90.86–100 mm (N=2)

Diagnosis: Animal large; head short and broad, with numerous branched median villi. Oral tentacles broad; projecting laterally. Foot broad, with a short or small acute tail. Parapodia short. Rhinophores rolled and large having villi on the edges. In rhinophores, two large compound villi are present; larger villi are dendritically branched at the tip. Colour dull brown or greenish brown, with reticulated markings, blue and black spots scattered on the notum and clear on brighter green areas, Inner edges and parapodia, mantle cavity sole paler.

Habitat and Distribution: On sand or muddy substrates of estuaries, intertidal and subtidal waters, in tropical subtropical seagrass and mangrove communities (Lowe & Turner, 1976; Clarke, 2006. Distributed across the Indo-Pacific regions (except Hawaiian Islands and Eastern Pacific); Mediterranean Sea and Western Atlantic region (Delgado et al., 2022).

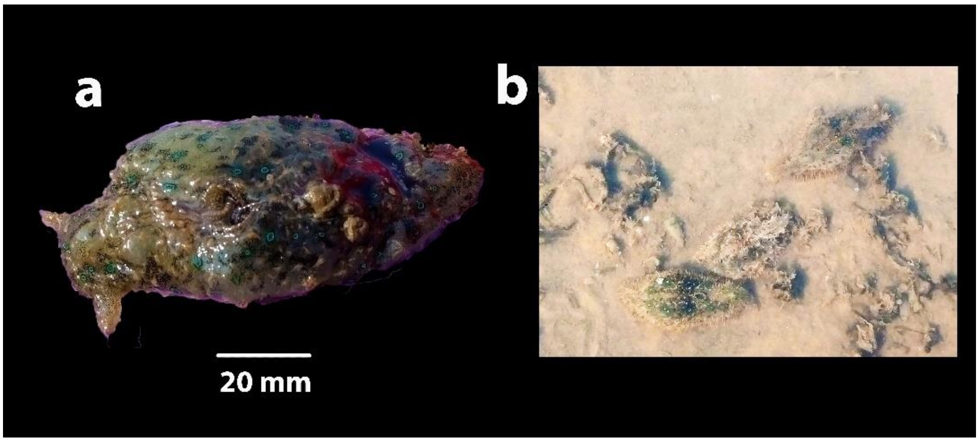

Figure 4.17. *Bursatella leachii* Blainville, 1817; SW 60.00 mm; SL100.00 mm; (a) dorsal view; (b) colonies of *B. leachii* in nature.

Order Ellobiida

Family Ellobiidae L. Pfeiffer, 1854 (1822)

Genus *Cassidula* A. Férussac, 1821

***Cassidula nucleus* (Gmelin, 1791)**

(Fig. 4.18)

Helix nucleus Gmelin, 1791: 3651 (type locality: Tahiti).

Auricula (Cassidula) crassiuscula var. *vitiensis* Mousson, 1870: 131.

Auricula mustelina Deshayes, 1830: 92 (type locality: not stated).

Auricula rhodostoma Hombron & Jacquinot, 1848: pl. 9 figs 1-3 (type locality: New Guinea).

Cassidula nucleus Rao & Dey, 2000: 188; Raven & Vermuelen 2007: 43, 50, pl. 4, figs 35–36.

Cassidula (Cassidula) nucleus Smith, 1992: page no. unknown.

Cassidula mustelina Adams & Adams, 1855: 31.

Sidula mustelina: de Morgan, 1885: 394.

Material examined: SW 7.48–14.35 mm; SL 11.20–21.89 mm (N=15)

Diagnosis: Shell small to medium, solid, opaque. Outline inverted ovoid, short spire made up of rather flat whorls. Body whorl large; covered fine spiral grooves. Aperture columellar fold, two parietales and a thick lip at palatal side; shallow incisions part below tooth. Colour dark brown with a single or double paler band just above the periphery or with alternating dark brown- and cream-coloured bands. Aperture usually cream, but some specimens bright pink

Habitat and Distribution: Attached to Mangrove tree trunks and seedlings above tide level and on muddy tidal flats (Lozouet & Plaziat, 2008). Distributed from India through Southeast Asia to Japan (Lozouet & Plaziat, 2008).

Figure 4.18. *Cassidula nucleus* (Gmelin, 1791); SW 13.78 mm; SL 21.30 mm; (a) dorsal view; (b) ventral view.

Order Systellommatophora Pilsbry, 1948

Family Onchidiidae Rafinesque, 1815

Genus *Platevindex* H. B. Baker, 1938

***Platevindex* cf. *martensi* (Plate, 1893)**

(Fig. 4.19)

Oncis martensi Plate, 1893: 196, pl. 7, figs 7, 23a, pl. 10, fig. 50 (type locality: Gulf of Siam).

Oncis inspectabilis Plate, 1893: 198.

Platevindex inspectabilis: Goulding et al., 2021: 102-103.

Platevindex martensi: Goulding et al., 2021: 96, figs. 54-58.

Material examined: SW 3.83–5.22 mm; SL 7.36–22.17 mm; (N=14)

Diagnosis: Animal small to medium; dorsal notum brown to dark brown or black, often mottled with two colours. notum small, elongated (longitudinal) ridges. Ventral colour varied; hyponotum yellow, beige or yellow-orange, with distinct darker spots of variable size (small to large) and colour (faintly tan to black). When those spots are large and dark enough, the hyponotum appears nearly black.

Habitat and Distribution: In the vicinity of mangroves, on tree roots and trunks as well as dead logs at high tide level (Goulding et al., 2021). Distributed from India through Southeast Asia to Australia (Goulding et al., 2021).

Figure 4.19. *Platevindex* cf. *martensi* (Plate, 1893); SW 15.22 mm; SL 22.17 mm; (a) dorsal view; (b) ventral view.

Class Bivalvia Linnaeus, 1758

Order Mytilida Férussac, 1822

Family Mytilidae Rafinesque, 1815

Genus *Brachidontes* Swainson, 1840

***Brachidontes pharaonis* (P. Fischer, 1870)**

(Fig. 4.20)

Mytilus pharaonis P. Fischer, 1870: 178, pl. 11, fig. 5 (type locality: Suez, Egypt).
Brachyodontes (Hormomya) karachiensis Melvill & Standen, 1907: 800, pl. 54, fig. 8 (type locality: Karachi).
Brachyodontes karachiensis Wagh & Bal, 1970: 353.
Modiola (Brachydontes) compressula E. von Martens & Thiele, 1908: 287, pl. 6, fig. 22.
Brachidontes pharaonis Costello et al., 2001: 206 (list).

Material examined: SW 6.20–14.02 mm; SL 13.00–26.53 mm (N=5)

Diagnosis: Shell small, almost triangular in outline, equivalve and inequilateral; elongated, asymmetrical, with dysodont hinge between the valves; sculpture of the valve comprises numerous fine radial bifurcating ribs, which become coarser posteriorly and finely scalloped towards the edge. Umbo almost terminal, and the umbonal region somewhat raised. Outline mytiliform with terminal umbo, shape very variable, highly expanded posteriorly, irregularly curved. Anterior end bluntly rounded, while the posterior end comparatively expanded and rounded. Shell dark brownish black, and shell interior purplish-black.

Habitat and Distribution: In midlittoral and infralittoral rocky habitats (Doğan et al., 2007). Distributed from the Red Sea through the Indian Ocean to the western Pacific Ocean; Lessepsian invasive species in the Mediterranean Sea (Sarà et al., 2008).

Figure 4.20. *Brachidontes pharaonis* (P. Fischer, 1870); SW 12.52 mm; SL 22.18 mm (a) right valve dorsal; (b) left valve dorsal; (c) right valve ventral; (d) left valve ventral.

Subfamily Mytilinae Rafinesque, 1815

Genus *Perna* Philipsson, 1788

***Perna viridis* (Linnaeus, 1758)**

(Fig. 4.21)

Mytilus viridis Linnaeus, 1758: 706 (type locality: O. Meridionali)

Perna viridis: Rao & Dey, 2000: 207; Ramakrishna & Dey, 2010: 75.

Mytilus opalus Lamarck, 1819: 124 (type locality: Southern Sea).

Mytilus smaragdinus Gmelin, 1791: 3359 (type locality: Tranquebar, India).

Material examined: SW 61.60 mm; SL 33.61 mm (N=1)

Diagnosis: Shell small to very large, thick, elongated, triangular, Anterior adductor scar lacking, but posterior adductor scars separated into two. Equivalve and inequilateral with sharply tapering umbonal area and broadly rounded posterior end. Hinge plate well developed and bears two small teeth below the umbo in the left valve and one large tooth in the right valve. Dorsal margin curved in the ligamental area and arcuate in the middle, and the ventral margin concave. Ligament long and strong. Shell surface with strong, irregularly spaced decussate striae and growth lines. Periostracum iridescent greenish black with brightly greenish margins. Shell interior shining with deeply impressed muscle scars.

Habitat and Distribution: In rocky littoral and shallow sublittoral ecosystem, polluted harbours and submarine pipelines of coastal power stations (Rajagopal et al., 2006). Distributed from Persian Gulf, to New Guinea, South Pacific islands and Japan; invasive species in the tropical regions of the Western Atlantic Ocean (Rajagopal et al., 2006).

Figure 4.21. *Perna viridis* (Linnaeus, 1758), SL 33.61 mm; SW 61.60 mm; (a) left valve dorsal; (b) right valve dorsal; (c) left valve ventral; (d) right valve ventral.

Order Arcida Stoliczka, 1871

Family Arcidae Lamarck, 1809

Genus *Tegillarca* Iredale, 1939

***Tegillarca rhombea* (Born, 1778)**

(Fig. 4.22)

Arca rhombea Born, 1778: 76 (type locality: Eastern India).
Anadara rhombea: Ramakrishna & Dey, 2010: 64.
Anadara (Tegillarca) rhombea: Narasimhan, 1988: 203.
Arca bronnii R.A. Philippi, 1851: 49 (type locality: Java, Indonesia)
Scapharca rhombea: Comber, 1906: 214 (list).
Tegillarca rhombea: Tudu et al., 2019: 45, 46 (identification key), fig. 5g-h.

Material examined: SW 34.72–52.55 mm; SL 35.82–50.69 mm (N=6)

Diagnosis: Shell medium, fairly thick, heart-shaped, equivalve and distinctly inequilateral, ovate, inflated, and solid. Ligament area rhomboidal and broad with brownish blam chevron markings. Umbo narrow, umbones widely separated and prosogyrate. Ventral, anterior and posterior margins of valves with strong crenulations. Outside of shell white in colour under periostracum, inner side white often tinged light yellow towards the umbonal cavity.

Habitat and Distribution: On muddy substrates in intertidal and shallow subtidal waters in protected bays, estuaries, and mangrove swamps (Poutiers, 1998). Distributed from the East coast of Africa through northern Indian Ocean and Southeast Asia to the South China Sea (Ramakrishna & Dey, 2010).

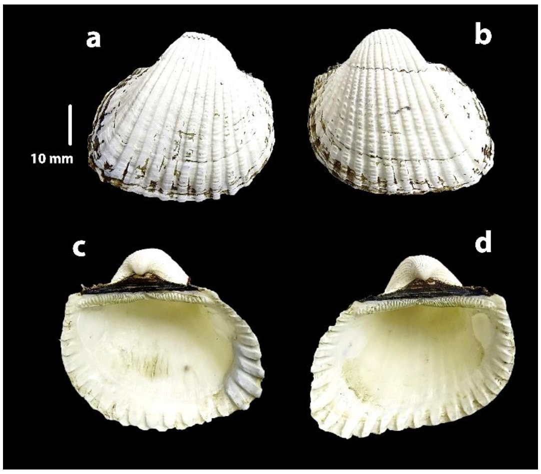

Figure 4.22. *Tegillarca rhombea* (Born, 1778); SW 47.90 mm, SL 40.90 mm; (a) left valve dorsal; (b) right valve dorsal; (c) left valve ventral; (d) right valve ventral.

Family Ostreidae Rafinesque, 1815

***Magallana* Salvi & Mariottini, 2016**

***Magallana bilineata* (Röding, 1798)**

(Fig. 4.23)

Ostrea bilineata Röding, 1798: 169 (type locality: not stated).

Crassostrea (Magallana) bilineata: Sigwart et al., 2021: 82 (list), fig. 5.

Crassostrea bilineata: Guo et al., 2018: 760 (list).

Crassostrea graphoides var. *cuttackensis* Newton & Smith, 1912: 13, pls. 7-8.

Crassostrea iredalei: Guo et al., 2018: 760 (list).

Crassostrea lugubris: Lam & Morton, 2004: 14, fig. 3A-C.

Crassostrea madrasensis: Tikader et al., 1986: 99.

Ostraea angulata sensu G.B. Sowerby II, 1871: pl. 8, species no. 12.

Ostraea lugubris G.B. Sowerby II, 1871: pl. 26, species no. 63 (type locality: North America).

Ostrea bilineata Röding, 1798: 170 (type locality: not stated).

Ostrea iredalei Faustino, 1932: 546, Pl. 1 (type locality: Philippines).

Ostrea madrasensis Preston, 1916: 33, figs. 11, 11a (type locality: Ennur backwaters, Madras).
Ostrea orientalis Dillwyn, 1817: 274 (type locality: East Indian Seas).
Magallana bilineata Chan &Lau, 2022: 1.
Magallana cuttackensis Ramakrishna &Dey, 2010: 101.

Material examined: SW 11.00–51.38 mm; SL 12.00–74.15 mm (N=10)

Diagnosis: Shell medium to large, solid, elongated, variable in shape in accordance with environments. Left valve is more strongly convex than the right, generally with a wide attachment area. Adductor muscle scar reniform, placed near the posteroventral margin from the centre of the valve. Commonly, chalky deposit fills hollow chambers in the shell. Shell surface chalky white to purplish brown, irregularly folded. Externally, the shell may be purple, white, brown or a combination of these shades. Inner margins are pure white and nacreous with purple colour on its inner border.

Habitat and Distribution: Attached to hard objects or growing in bunches, on soft substrates in intertidal and shallow subtidal waters (Poutiers, 1998). Distributed from Pakistan through Southeast Asia to Japan and Australia (Willan et al., 2021).

Figure 4.23. *Magallana bilineata* (Röding, 1798), SW 47.90 mm, SL 40.90 mm; (a) left valve dorsal; (b) right valve dorsal; (c) left valve ventral; (d) right valve ventral.

Subfamily Saccostreinae Salvi & Mariottini, 2016

Genus *Saccostrea* Dollfus & Dautzenberg, 1920

***Saccostrea cucullata* (Born, 1778)**

(Fig. 4.24)

Ostrea cucullata Born, 1778: 100 (type locality: not stated).
Crassostrea cucullata Hassanine, 2006: 1211, fig. 3.

Crassostrea cucullata Durve, 1975: 422.

Crassostrea forskahlii Everett et al., 2008: 87.

Dendostrea turbinata Bernard et al., 1993: 45.

Dioeciostrea subtropica Orton, 1928: 321.

Gryphaea cucullate Granier, 1970: 209, fig. 2.

Ostrea cornucopiae Gmelin, 1791: 3336 (type locality: Indian Ocean).

Ostrea forskahlii Gmelin, 1791: 3336 (type locality: Red Sea).

Ostrea forskali [sic]: Mohammed, 1992: 181.

Ostrea gibbosa Lamarck, 1819: 209 (type locality: not stated).

Ostrea stellata Gmelin, 1791: 3337 (type locality: Guinea).

Ostrea turbinata Lamarck, 1819: 212 (type locality: Indian Ocean).

Saccostrea cuccullata (Born, 1778): Thanormjit et al., 2020: 1.

Saccostrea cucullata [sic] Rao &Dey, 2000: 231; Ramakrishna &Dey, 2010: 104.

Saccostrea forskahlii Nel et al., 2012: 511.

Material examined: SW 9.6–32.48 mm; SL 17.20– 24.82 (N=15)

Diagnosis: Shell solid, medium to large, inequivalve, inequilateral; circular to oval. Variable in shape, depending on substratum; outline irregular, smooth sculpture. Lower valve with relatively large area of attachment, upturned margin with numerous plications, ligament area may be very elongated; upper valve flat with marginal lobes fitting plications of lower valve. Muscle scar kidney shaped. Nodular chomata usually present around all margins. Cemented valve with a small ligament area, upper valve flat more or less smooth. Colouration internally white with a broad purple-black border, muscle scar may be darker than surrounding shell area. Outer colouration purple-black often with pale or white radial streaks.

Habitat and Distribution*:* On intertidal and subtidal rocks in marine, estuarine and mangrove areas to a depth of 5 m (Poutiers, 1998). Distributed throughout the Indo-Western Pacific regions (Hamaguchi et al., 2014); invasive species in the Western Pacific islands (Ardura et al., 2021).

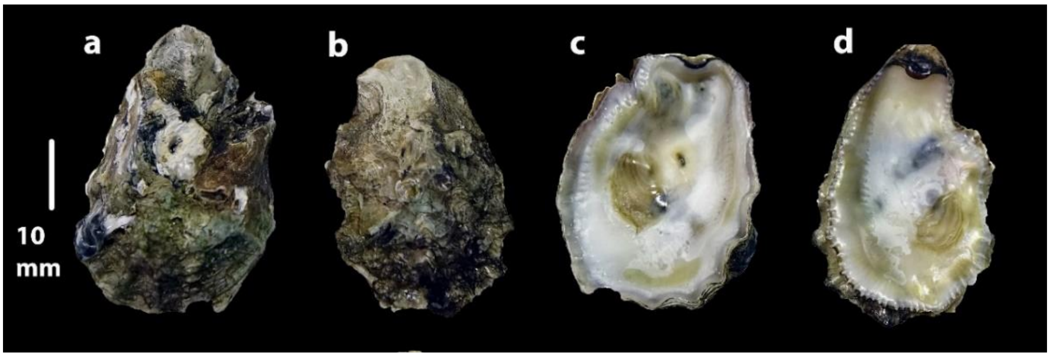

Figure 4.24. *Saccostrea cuccullata* (Born, 1778), SW 20.72 mm, SL 32.48 mm; (a) left valve dorsal; (b) right valve dorsal; (c) left valve ventral; (d) right valve ventral.

Family Isognomonidae Woodring, 1925 (1828)

Genus *Isognomon* [Lightfoot], 1786

***Isognomon isognomum* (Linnaeus, 1758)**

(Fig. 4.25)

Ostrea isognomum Linnaeus, 1758: 699 (type locality: not stated).

Isognomon attenuata Sanpanich 2011: 198.

Isognomon aviculare Dautzenberg, 1929: 359.

Isognomon brevirostre Link, 1807: 155 (type locality: not stated).

Isognomon isognomon Rao &Dey, 2000: 216; Ramakrishna &Dey, 2010: 93.

Isognomon rude Dautzenberg, 1929: 567.

Isogonum gnomon Röding, 1798: 168 (type locality: not stated).

Isogonum norma Röding, 1798: 168 (type locality: not stated).

Isognomon perna Dautzenberg, 1929: 567.

Ostrea isogonum Linnaeus, 1767: 1149 (type locality: India).

Perna attenuata Reeve, 1858: pl. 6, fig. 25 (type locality: Red Sea).

Perna avicularis Lamarck, 1819: 140 (type locality: not stated).

Perna canina Lamarck, 1819: 141 (type locality: Australia).

Perna femoralis Lamarck, 1819: 140 (type locality: Indian Ocean).

Perna fimbriata Reeve, 1858: pl. 5, fig. 23 (type locality: Moluccas, Indonesia).

Perna isognomon var. *brachyptera* E. von Martens, 1894: 94.

Perna isognomon var. *obliqua* E. von Martens, 1894: 94.

Perna isogona Bosc, 1801: 283 (type locality: Indian and American Seas).

Perna novohollandiae Clessin, 1890: Huber, 2010: page no. unknown (type locality: not stated).

Perna patibulum Reeve, 1858: pl. 4, fig. 19 (type locality: not stated).
Perna rudis Reeve, 1858: pl. 5, fig. 20 (type locality: not stated).
Perna tranquebarensis Leach, 1815: 142, pl. 114 (type locality: Tranquebar, India).
Perna vespertilio Reeve, 1858: pl. 6, fig. 26 (type locality: Bay of Manila).
Perna vulsella Lamarck, 1819, *sensu* Reeve, 1858: pl. 5, fig. 21 (type locality: not stated).

Material examined: SW 91.31 mm–97.63; SL 74.03 mm–100.64 mm (N=4)

Diagnosis: shell large, with flat valves of variable shape; Outline elongate tending to be regular with parallel lateral margins; hinge line as long or slightly longer than width of main body. Surface of shell scaly, radial markings absent or very faint. Nacreous· area of shell large, non-nacreous border usually narrower. Adductor scar crescent shaped, subcentral slightly towards posterior margin. Colour: external purple-black to purple-brown, internal nacreous area lustrous, tinged blue.

Habitat and Distribution: Attached to mangrove prop roots or large stones in gravelly clay covered with silt substratum and coastal reefs (Printrakoon & Tëmkin, 2008). Distributed from the East coast of Africa through South and Southeast Asia to Japan, Australia and islands in the Western Pacific Ocean (Poutiers, 1998; Huber 2010).

Figure 4.25. *Isognomon isognomum* (Linnaeus, 1758), SW 94.92 mm, SL 100.64 mm; (a) right valve dorsal; (b) left valve dorsal; (c) right valve ventral; (d) left valve ventral.

Order Pectinida Gray, 1854

Family Placunidae Rafinesque, 1815

Genus *Placuna* [Lightfoot], 1786

***Placuna placenta* (Linnaeus, 1758)**

(Fig. 4.26)

Anomia placenta Linnaeus, 1758: 703 (type locality: Pelago).

Ephippium transparens Röding, 1798: 166.

Placenta (Placenta) orbicularis Gray, 1849: 115.

Placenta auriculata Mörch, 1853: 63.

Placenta communis Megerle von Mühlfeld, 1811: 59.

Placuna placenta Rao & Dey, 2000: 230; Ramakrishna & Dey, 2010: 127.

Material examined: SW 92.39 mm; SL 94.88 mm; (N=1)

Diagnosis: Shell large; slightly inequivalve, left valve a little convex, right valve little concave, very compressed. Outline subcircular. Hinge line straight but short, with two ventrally diverging crurae supporting ligament material. Sculpture concentric of very thin appressed lamellae which are overall radially vermiculate. Adductor scar circular in a central position.

Habitat and Distribution: On and under a thin layer of mud and debris, soft muddy and sandy-mud substrates in coastal lagoons, protected bays, mangrove areas and estuaries, from low tide levels to a depth of about 100 m, prominently from 4 to 20 m deep (Poutiers, 1998). Distributed from Gulf of Aden to Indonesia, Taiwan and Australia (Poutiers, 1998, Huber 2010).

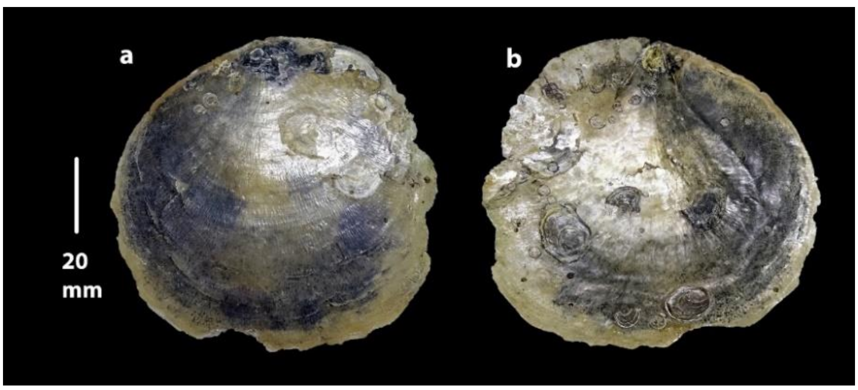

Figure 4.26. *Placuna placenta* (Linnaeus, 1758) (length 94.88 mm, breadth 92.39 mm SW 92.39 mm, SL 94.88 mm; (a) left valve dorsal; (b) left valve ventral.

Family Tellinidae Blainville, 1814

Subfamily Tellininae Blainville, 1814

Genus *Alaona* M. Huber, Langleit & Kreipl, 2015

***Alaona ala* (Hanley, 1845)**

(Fig. 4.27)

Tellina ala Hanley, 1845: 165 (type locality: Ceylon).

Arcopagia ala Hylleberg & Killburn, 2002: 68 (list).

Macoma (Psammotreta) ala Dey, 2006: 17 (list), 69, pl. 32 fig. 1, pl. 35 fig 6.

Tellina callosa Deshayes, 1855: 361.

Alaona ala Huber et al., 2015: page no. unknown.

Material examined*:* SW 1.51–21.24 mm; SL 8.00–15.45 mm (N=9)

Diagnosis: Shell small to medium; solid, trigonal-ovate, subequal, superficially smooth, sub trigonal and compressed, pointed umbo, raised and almost in the middle. Anterior end rounded, posterior end subrostrate. Ligament partly embedded and sunken. Lunule obscure or absent. Adductor scars moderate in size and unequal, anterior narrow and elongate, posterior subquadrate. Externally shell white with a shade of yellow.

Habitat and Distribution: On loose muddy substrates at mid-tide level (Dey, 2006). Distributed from the Persian Gulf to Philippines and Japan (Dey, 2006).

Figure 4.27. *Alaona ala* (Hanley, 1845); SW 17.42 mm, SL 13.34 mm; (a) right valve dorsal; (b) left valve dorsal; (c) right valve ventral; (d) left valve ventral.

Genus *Quadrans* Bertin, 1878

***Quadrans gargadia* (Linnaeus, 1758)**

(Fig. 4.28)

Tellina gargadia Linnaeus, 1758: 674 (type locality: East Asia).

Tellina (Quidnipagus) gargadia: Rao &Dey, 2000: 258.

Tellina inaequalis Hanley, 1844: 71 (type locality: Ceylon).

Quodrans gargadia: Spry, 1964: 151.

Quadrans gargadia: Huber et al., 2015: page no. unknown.

Material examined: SW 14.55 mm; SL 10.21 mm; (N=1)

Diagnosis: Subequivalve, left valve a little flatter, posterior flexure not apparent. Strongly inequivalve, beaks well to the posterior. Outline subovate-truncate: anterior margin narrowly rounded; anterior dorsal margin long straight or slightly concave; posterior margin straight almost vertical; posterior dorsal margin short steeply sloping; ventral margin not sinuous. Posterior area well demarcated but not strongly angulate, small narrow lunule present. Sculpture scissulate except on posterior area on both valves, posterior area wrinkled or irregularly nodulose, posterior dorsal margin with blunt spines. Hinge with 2 cardinal teeth in each valve, right valve with strong elongate laterals, left valve with marginal extensions fitting in RV sockets. Pallial sinus very deep nearly touching the anterior adductor scar; dorsal line greatly curved not arcuate; ventral line free from the pallial line for about 1/3 of its length. Colour white.

Habitat and Distribution: On sandy substrates (Taylor, 1968). Distributed from South Africa to Philippines to Japan and Australia (Dey, 2006).

Figure 4.28. *Quadrans gargadia* (Linnaeus, 1758), SW 14.55 mm, SL 10.21 mm; (a) left valve dorsal; (b) right valve dorsal; (c) left valve ventral; (d) right valve ventral.

Order Cardiida A. Férussac, 1822

Family Psammobiidae J. Fleming, 1828

Genus *Hiatula* Modeer, 1793

***Hiatula diphos* (Linnaeus, 1771)**

(Fig. 4.29)

Solen diphos Linnaeus, 1771: 544 (type locality: India).

Sanguinolaria (Soletellina) diphos: Ramakrishna &Dey, 2010: 219.

Sanguinolaria acuminata: Higo et al., 1999: B1065 (list)

Sanguinolaria diphos: Poutiers, 1998: 310.

Solen rostratus [Lightfoot, 1786]: 160

Soletellina acuminata Reeve, 1857: 80, pl. 3, fig. 12

Soletellina diphos: Poutiers, 1998: 310.

Soletellina radiata Blainville, 1824: 350.

Hiatula diphos: Rajendra & Raghunathan, 2022: 205, fig. 2a, b.

Material examined: SW 86.11-89.32 mm SL 39.36-42.93 mm, (N=2)

Diagnosis: Shell moderate, compressed, equivalve; shell surface purple coloured with paler concentric zones and two whitish radial rays and concentric growth lines covered by strong dark periostracum; muscle scars well developed at anterior end whereas posterior end acuminates with obtuse; angle gap on posterior end broad; posterior end narrower than anterior

Habitat and Distribution: On muddy substrates from low tide levels to a depth of about 30 m (Poutiers, 1998). Distributed from the Persian Gulf through Southeast Asia to Japan (Ramakrishna & Dey, 2010).

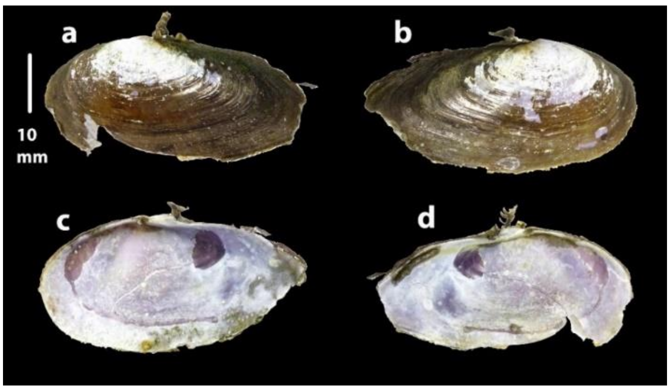

Figure 4.29. *Hiatula diphos* (Linnaeus, 1771; SW 89.32 mm, SL 42.93 mm; (a) right valve dorsal; (b) left valve dorsal; (c) right valve ventral; (d) left valve ventral.

Family Veneridae Rafinesque, 1815

Subfamily Tapetinae Gray, 1851

Genus *Marcia* H. Adams & A. Adams, 1857

***Marcia opima* (Gmelin, 1791)**

(Fig. 4.30)

Venus opima Gmelin, 1791: 3279 (type locality: India).

Katelysia opima Rao, 1951: 94.

Marcia opima Arathi et al*.,* 2018: 5, fig. 3.

Tapes ceylonensis G. B. Sowerby II, 1852: 683, pl. 146, figs. 24-25 (type locality: Ceylon)

Venus gravida Röding, 1798: 181.

Venus nebulosa Gmelin, 1791: 3279 (type locality: Tranquebar, India).

Venus pinguis Chemnitz, 1782: 355, pl. 34, figs. 355-357 (type locality: East Indian Seas).

Venus triradiata Gmelin, 1791: 3279 (type locality: Tranquebar, India).

Material examined: SW 23.46–33.72 mm; SL 19.44–28.09 mm (N=11)

Diagnosis: Shell small to medium; equivalve, relatively thin; tumid, outline ovate subcordate, lunule large distinct and broad, escutcheon broad. Umbos prominent, twisting away from the ligament side of the shell, produced and elongated. Pallial sinus broad, deep and oval with a bluntly angular apex. Sculpture smooth with weak incremental lines. Pallial sinus almost horizontal, rounded. Adductor muscles scar equal. Pallial sinus vertically aligned, broadly rounded, extending to midline of shell. Colour pale-cream to greyish with bold beige to brown blotches over the umbonal and posterior areas.

Habitat and Distribution: Buried at shallow depth in predominantly muddy substrates in estuaries, backwaters and creeks (Lagade et al., 2013). Distributed from the East coast of Africa through the northern Indian Ocean to Malaysia (Huber, 2010).

Figure 4.30. *Marcia opima* (Gmelin, 1791) SW 33.72 mm, SL 28.09 mm; (a) right valve dorsal; (b) left valve dorsal; (c) right valve ventral; (d) left valve ventral.

***Marcia recens* (Holten, 1802)**
(Fig. 4.31)

Venus recens Holten, 1802: page no. unknown (originally described by Chemnitz, 1795; type locality: Tuticorin, India).

Chione ustulata Deshayes, 1853: 152 (type locality: Australia).

Hemitapes dohrni Römer, 1870: 10 (type locality: Philippines).

Katelysia marmorata: Subrahmanyam et al., 1949: 56.

Marcia marmorata: Arathi et al., 2019: fig. 2G-I.

Marcia recens: Ramakrishna & Dey, 2010: 255; Arathi et al., 2018: 7, figs. 4-9.

Paphia marmorata: Gravely, 1941: 52.

Tapes bicolorata Reeve, 1864: pl. 9, fig. 42 (type locality: not stated).

Tapes ferruginea Reeve, 1864: pl. 10, fig. 51 (type locality: Philippines).

Tapes laterisulca Sowerby II, 1852: 686, pl. 148, figs. 67-76 (type locality: Philippines).

Tapes occidentalis Reeve, 1864: pl. 8, fig. 35 (type locality: Guadeloupe, West Indies).

Tapes orientalis Reeve, 1864: pl. 8, fig. 34a, b (type locality: Bombay, India).

Tapes sinensis Reeve, 1864: pl. 5, fig. 24 (type locality: China).

Venus marmorata Lamarck, 1818: 600 (type locality: seas of Southern Europe).

Venus variabilis Philippi, 1844: 178, pl. 3, figs. 8-9 (type locality: Bombay).

Material examined: SW 26.64–36.82 mm; SL 18.71–26.83 mm (N=7)

Diagnosis: Shell small to medium, moderately thick, inequilateral, moderately inflated; outline elongated, subovate. Lunule flattened, not well defined. Hinge plate with each valve containing three cardinal teeth. Escutcheon surface slightly glossy; weakly defined. Shell external sculpture with weak lines and growth stops sometimes with defined ridges. Adductor muscle scars weakly heteromyarian, posterior adductor scar large. Pallial sinus wide, horizontal, broadly rounded extending to one third of shell length. Shell colour and pattern vastly variable with cream, red, white and brown shades patterned with 3–4 black radiating rays or darker trigonal blotches. Internal shell with pale yellow, white colouration, sometimes with pinkish umbonal cavity.

Habitat and Distribution: Buried at shallow depths in estuarine and backwater habitats (Arathi et al., 2018). Distributed from India through Southeast Asia to southern China (Huber, 2010).

Figure 4.31. *Marcia recens* (Holten, 1802); SW 26.64 mm, SL 18.71 mm; (a) left valve dorsal; (b) right valve dorsal; (c) left valve ventral; (d) right valve ventral.

Subfamily Meretricinae Gray, 1847

Genus *Meretrix* Lamarck, 1799

***Meretrix aurora* Hornell, 1917**

(Fig. 4.32)

Meretrix meretrix var. *aurora* Hornell, 1917: 162, pl. 4, figs. 9-11 (type locality: Tellicherry, Malabar, India); Ramakrishna et al., 2004: 41.
Meretrix aurora Joshi et al., 2018: 19, 71 (list).

Material examined: SW 2.65–49.37 mm; SL 2.34–44.11 mm (N=24)

Diagnosis: Shells small to medium, solid, triangular ovate, inequivalve, ventral margin rounded, dorsal edge straight. Umbones elevated, above the hinge line; posterior margin longer than anterior margin. Shell exterior smooth, with fine growth lines grooves are absent on the surface. Pallial sinuses shallow to deep, reaching end of cardinal tooth. Pallial line almost reaches middle of posterior adductor scar. Shells are highly variable colour pattern roughly divided into yellowish white, reddish brown, dark brown streakings. Shell interior thin and glossy, Yellowish white colour, posterior sections of deep purple.

Habitat and Distribution: In shallow estuarine waters (Hornell, 1917). This is endemic to South India and Sri Lanka (Huber, 2010; Ravinesh et al., 2021; Edward et al., 2022).

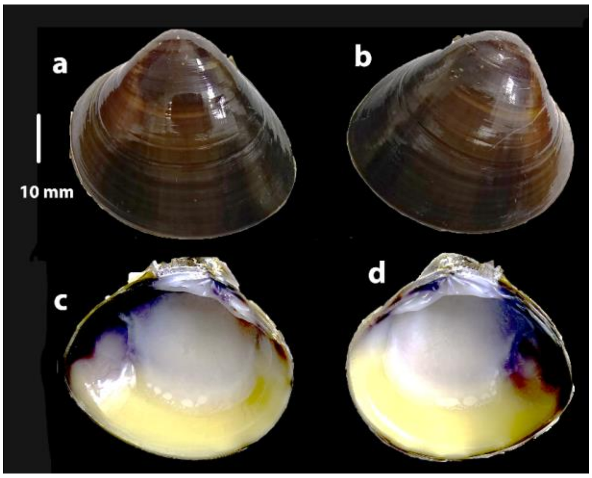

Figure 4.32. *Meretrix aurora* Hornell, 1917, SW 46.19 mm, SL 40.28 mm; (a) left valve dorsal; (b) right valve dorsal; (c) left valve ventral; (d) right valve ventral.

Meretrix casta (Gmelin, 1791)

(Fig. 4.33)

Venus casta Gmelin, 1791: 3278 (type locality: India).

Corbicula (Velorita) satparaensis Preston, 1914: 306, figs. 22, 22a (type locality: Satpara, Orissa).

Corbicula satparaensis Preston, 1914: Huber, 2010: page no. unknown.

Cytherea crassa Gray, 1825: 137 (type locality: Madras, India).

Cytherea impudica Lamarck, 1818: 561 (type locality: Indian Ocean).

Cytherea ovum Hanley, 1845: 21 (type locality: not stated).

Meretrix exilis Römer, 1865: 35, pl. 10, fig. 3.

Meretrix casta: Rao & Dey, 2000: 276; Ramakrishna & Dey, 2010: 244.

Venus (Cytherea) creplini Dunker, 1852: 61.

Material examined: SW 41.60 mm; SL 36.61 mm; (N=1)

Diagnosis: Shell moderately large, thick, subtrigonal, trigonal ovate; postero-dorsal margin more straight, umbo slightly anterior. Anterior adductor scar elongately oval; posterior adductor scar subcircular and larger than the posterior one. Hinge thick and with three cardinal teeth. External surface smooth and pale yellowish brown. A dark greyish band present at the posterior margin. Outer shell surface colour white; periostracum brown or dirty grey and horny; inner shell surface white with a posterior dark purple ray; hinge plates and teeth robust; umbones highly inflated. Pallial sinus very shallow.

Habitat and Distribution: On sandy substrates as well as mud banks (Nayar & Mahadevan, 1974) in backwaters and estuarine channels (Hornell, 1917). Distributed along the coasts of the northern Indian Ocean (Qasim, 1998).

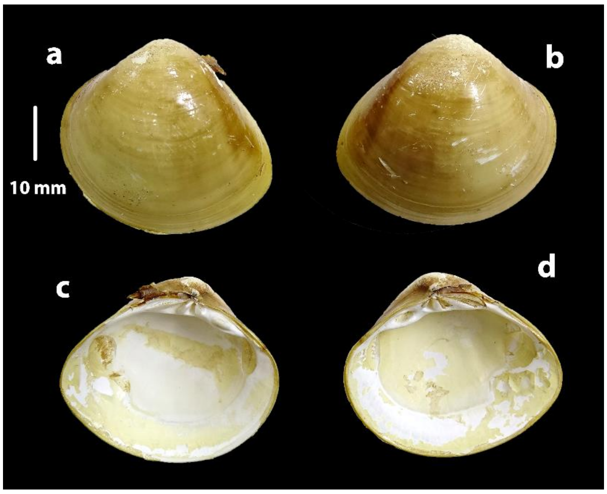

Figure 4.33. *Meretrix casta* (Gmelin, 1791), SW 41.60 mm, SL 36.61 mm; (a) left valve dorsal; (b) right valve dorsal; (c) left valve ventral; (d) right valve ventral.

Subfamily Callocardiinae Dall, 1895

Genus *Pelecyora* Dall, 1902

***Pelecyora katiawarensis* (Fischer-Piette & Métivier, 1971)**

(Fig. 4.34)

Dosinia (Sinodia) katiawarensis Fischer-Piette & Métivier, 1971: 1282, fig. 1 (type locality: Katiawar); Fischer-Piette, 1976: 244, pl. 1, Fig. 1; Ramakrishna et al., 2004: 29.

Dosinia katiawarensis Ramakrishna & Dey, 2010: 263.

Pelecyora katiawarensis Rao, 2017: 313; Tudu et al., 2021: 402, fig. 1a-d.

Material examined: SW 16.94-20.86 mm; SL 15.94-20.57 mm (N=3)

Diagnosis: Lenticular, becoming trigonal, higher than long; ligament margin long, steeply sloping; posterior margin curving confluent with ventral margin. Escutcheon long, bevelled, smooth. Lunule sunken never domed. Sculpture of smooth fine dense concentric: ridges forming small but distinctly raised lamellae along the escutcheon margins. Pallial sinus very deep extending very close to anterior adductor scar. Pallial line indented. Umbo prominent and obliquely curved pointing anteriorly. Posterior end pointed. Surface bears concentric ribs, strong. Umbo almost smooth. Interior of shell smooth. Colour white.

Habitat and Distribution: Buried in shallow marine and brackish waters (Tudu et al., 2021). Distribution restricted only to Kerala, Gujarat and Odisha (Tudu et al., 2021).

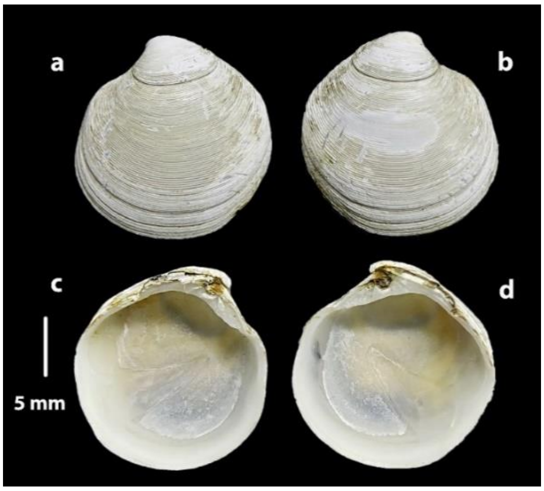

Figure 4.34. *Pelecyora katiawarensis* (Fischer-Piette & Métivier, 1971), SW 20.86 mm, SL 20.57 mm; (a) left valve dorsal; (b) right valve dorsal; (c) left valve ventral; (d) right valve ventral.

Order Venerida Gray, 1854

Family Cyrenidae Gray, 1840

Genus *Geloina* Gray, 1842

***Geloina bengalensis* (Lamarck, 1818)**

(Fig. 4.35)

Cyrena bengalensis Lamarck, 1818: 554

Cyrena eximia Dunker, 1852: 9: 51

Cyrena siamica Prime, 1867: 8, 86, fig. 35.

Polymesoda (Geloina) bengalensis Morton, 1984: 78 pl I, II.

Polymesoda bengalensis Dey, 2006: 74

Geloina bengalensis Prashad, 1932: 175; Rao, 1989: 210, Fig. 593, 594

Material Examined: SW 35.40–70.19 mm; SL 33.26–65.14 mm (N=9)

Diagnosis: Shell medium to large, solid, inequilateral, subtriangular to almost ovate, inflated, umbones prominent, almost central and incurved, cardinal teeth three in each valve, lateral teeth smooth and short, two in left valve and four in right valve, pallial tine entire pronounced inequilateral, solid dentition, no posterodorsal grove, lunule absent. Dorsal margin very small with a long slope, truncated at the end, anterior margin very short, posterior margin very long, high, markedly convex, umbones anterior. Immature materials colour brownish green or yellow and matured specimen dark brownish to black and coarsely striate or finely ridged periostracum.

Habitat and Distribution*:* On soft muddy substrates in brackish to almost fresh-water areas of mangrove swamps (Poutiers, 1998). Distributed from India to Vietnam and Vanuatu (Poutiers, 1998).

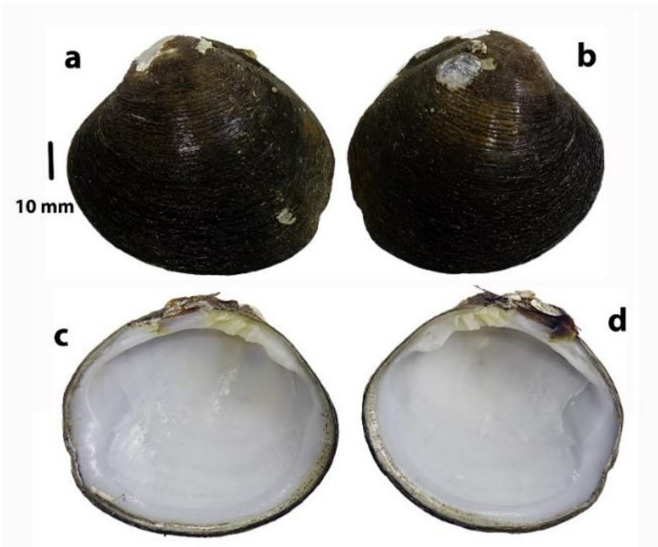

Figure 4.35. *Geloina bengalensis* (Lamarck, 1818) SW 20.86 mm, SL 20.57 mm; (a) left valve dorsal; (b) right valve dorsal; (c) left valve ventral; (d) right valve ventral.

4.3. Discussion

The present study is the first systematic attempt to document the occurrence of molluscs from the mangrove-associated regions of Chapora and Sal rivers of Goa. A review of the mangrove-associated gastropods and bivalves of India by Yadav et al (2019) revealed the least number of species from Goa (three gastropods and five bivalves) as compared to other coastal states. In view of this, the current study helps to fill the existing lacunae in species distribution data, and documented thirty-five species belonging to thirty genera from two classes (Gastropoda and Bivalvia), thirteen orders and twenty-three families.

The family Veneridae was the most dominant among the bivalves, represented by five species, followed by families such as Ellobidae, Littorinidae, Potamididae, and Neritidae, each represented by two species. Families like Ellobidae, Littorinidae, Potamididae, and Neritidae are commonly found to dominate mangrove ecosystems (Kantharajan et al., 2017). While Veneridae is not always one of the most dominant families in all mangrove environments, it still contributes significantly to the overall molluscan diversity, as seen in Khánh Hòa Province, Vietnam, where it is one of the richest families of bivalves (Zvonareva et al., 2019). Although Teredinidae, a family of bivalves known as shipworms or wood borers, is typically associated with mangrove ecosystems, it was not represented in the present study. Santhakumaran (1983) reported ten species of Teredinidae from the Mandovi-Zuari estuarine system, where they infected *Avicennia officinalis* and *Rhizophora mucronata* mangrove species. However, *A. officinalis* was absent, and *R. mucronata* was present in very low numbers in the study area. These species of mangroves may be the specific requirement of these Terenids and therefore probably the reason for their absence in the present study. Nonetheless, a more focused survey in various locations around the Chapora and Sal estuaries might help trace their presence.

Studies on the molluscan diversity of Goa have been fragmented, largely focusing on data compilation of macrobenthic fauna (Parulekar et al., 1980), regional compilations of family-wise data from the Indian coast (Rajagopal & Mookherjee, 1978, 1982; Rao & Rao, 1993), or reports on specific species (Kumbhar & Rivonker, 2012; Jagtap et al., 2016; Hussain et al., 2022) and ecological studies (Clemente & Ingole, 2011). Extensive surveys in the mangrove regions of Goa have been lacking, which highlights the significance of the first report of thirteen species from the state. This further underscores the need for comprehensive, long-term systematic surveys across all the estuaries of Goa to strengthen the molluscan database.

CHAPTER 5

Spatial and temporal variation of brachyuran crabs and molluscs with respect to their diversity, abundance and biomass

5.1. Introduction

Brachyuran crabs and molluscs are known to be the major groups among the mangrove fauna and play an important role in the structuring and functioning of mangrove ecosystems (Cannicci et al., 2008). Knowledge of community structure and their temporal variability is vital in understanding changes caused by human interference and natural elements (Ansari et al., 1986). Given the importance of brachyuran crabs and molluscs in mangrove environments it is essential to explore their spatio-temporal variation. Additionally, certain species are referred to as indicators of pollution and stress in several studies (Ashton et al., 2003a; Satheeshkumar & Khan, 2012; Dissanayake & Chandrasekara, 2014; Kantharajan et al., 2017; Stiepani et al., 2021).

Spatial and temporal variations in benthic estuarine macrofauna of Mandovi and Zuari estuaries of Goa were studied by Parulekar et al. (1980) and Ansari et al. (1986). Vijaylaxmi (2020) evaluated the spatio-temporal trends of brachyuran crab species along five rocky intertidal shores of Mandovi and Zuari estuaries. However, studies on the spatio-temporal trends of brachyuran crabs and molluscs in the mangrove-associated regions have not been attempted. Therefore, present study aims at elucidating the diversity, abundance and biomass of the brachyuran crabs and molluscan fauna in less explored mangrove regions of Chapora estuary in the North Goa and Sal estuary in South Goa.

5.2. Results:

5.2.1. Spatial and temporal variation with respect to diversity:

i. Brachyuran crabs

The survey across the four sampling stations spanning two estuaries recorded altogether thirty species belonging to twenty-four genera from eleven families of brachyuran crabs. The highest number of species was recorded from station C2 (twenty) followed by C1 (nineteen), S1 (eighteen) and S2 (fourteen). The total number of species recorded at Chapora and Sal estuaries were twenty-eight and twenty-one, respectively (Table 5.1).

An analysis of species-wise spatial distribution indicated the presence of seven species (*Thalamita crenata, Heteropanope glabra, Metopograpsus cannicci, Nanosesarma minutum, Macrophthalmus pacificus, Austruca annulipes* and *Gelasimus vocans*) at all the four stations, followed by six species (*Matuta victor, Portunus reticulatus, Metopograpsus latifrons, Nanosesarma andersoni, Dotilla myctiroides* and *M. brevis*) at three stations, eight species (*Scylla serrata, Leptodius exaratus, Nanosesarma tweediei, Parasesarma bengalense, Parasesarma plicatum, Chhapgarus intermedius, Ocypode ceratophthalmus* and *Tubuca alcocki*) at two stations, and nine species (*Neorhynchoplax demeloi, Charybdis hellerii, Clistocoeloma merguiense, Episesarma versicolor, Pseudosesarma glabrum, Sarmatium crassum, Varuna litterata, Scopimera proxima* and *Macrophthalmus parvimanus*) at one station only (Table 5.1).

Table 5.1. List of brachyuran crabs reported across the four stations of Chapora and Sal estuaries. (+ Present, - Absent)

Family	**Species**	**C1**	**C2**	**S1**	**S2**
Matutidae	*Matuta victor*	+	-	+	+
Hymenosomatidae	*Neorhynchoplax demeloi*	-	+	-	-
Portunidae	*Charybdis hellerii*	-	-	-	+
	Portunus reticulatus	+	-	+	+
	Scylla serrata	+	-	+	-
	Thalamita crenata	+	+	+	+
Xanthidae	*Leptodius exaratus*	+	+	-	-
Pilumnidae	*Heteropanope glabra*	+	+	+	+
Grapsidae	*Metopograpsus cannicci*	+	+	+	+
	Metopograpsus latifrons	+	+	+	-
Sesarmidae	*Clistocoeloma merguiense*	+	-	-	-
	Episesarma versicolor	-	+	-	-
	Nanosesarma andersoni	+	+	-	+
	Nanosesarma minutum	+	+	+	+
	Nanosesarma tweediei	-	+	+	-
	Parasesarma bengalense	-	+	+	-
	Parasesarma plicatum	-	+	+	-
	Pseudosesarma glabrum	+	-	-	-
	Sarmatium crassum	-	+	-	-
Varunidae	*Chhapgarus intermedius*	-	+	+	-
	Varuna litterata	-	+	-	-
Dotillidae	*Dotilla myctiroides*	+	-	+	+

	Scopimera proxima	+	-	-	-
Macrophthalmidae	*Macrophthalmus (Macrophthalmus) brevis*	+	-	+	+
	Macrophthalmus (Macrophthalmus) parvimanus	-	-	-	+
	Macrophthalmus (Mareotis) pacificus	+	+	+	+
Ocypodidae	*Austruca annulipes*	+	+	+	+
	Gelasimus vocans	+	+	+	+
	Ocypode ceratophthalmus	+	+	-	-
	Tubuca alcocki	-	+	+	-
	Total	**19**	**20**	**18**	**14**

Computation of the Shannon-Wiener's diversity index (H') revealed the highest mean diversity value at station C2 (1.82 ± 0.15), followed by S1 (1.65 ± 0.43), C1 (1.55 ± 0.19) and S2 (0.93 ± 0.29) (Figure 5.1). Two-way Analysis of Variance (ANOVA) of the station-wise H' index revealed significant variations between the stations ($p < 0.001$) (Table 5.2).

An analysis of the seasonal trends in the H' indicated that Station C1 recorded slightly higher mean value during the pre-monsoon season (pre-monsoon: 1.71 ± 0.07) as compared to the post-monsoon (1.59 ± 0.08) and monsoon seasons (1.33 ± 0.16). Station C2 and S2 recorded marginally higher mean value during the post-monsoon season (1.89 ± 0.09; 1.09 ± 0.37 respectively) as compared to the monsoon (1.84 ± 0.20; 0.90 ± 0.23 respectively) and pre-monsoon seasons (1.72 ± 0.12; 0.81 ± 0.23 respectively). Station S1 recorded notably higher mean values during the monsoon season (2.00 ± 0.17) as compared to pre-monsoon (1.65 ± 0.14) and post-monsoon seasons (1.31 ± 0.56). (Fig. 5.2). Two-way ANOVA did not reveal significant variations between the seasons ($p > 0.05$) (Table 5.3).

ii. Molluscs

A total of thirty-five species belonging to two classes (Gastropoda and Bivalvia), twenty-three families and thirty genera of molluscs were recorded during the present study. The highest number of species was recorded at station S2 (twenty-two), followed by C1 (twenty-one), S1 (nineteen), and C2 (fifteen). The total number of species recorded at the Sal and

Chapora estuaries were twenty-eight and twenty-five, respectively (Table 5.2). The highest number of gastropod species were recorded at station C1 (thirteen) followed by S1 (twelve), C2 (eleven) and S2 (seven); the highest number of bivalves were recorded at station S2 (fifteen), followed by C1 (eight), S1 (seven) and C2 (four).

Table 5.2. List of molluscs reported across the stations of Chapora and Sal estuaries. (+ Present, - Absent).

Family	**Species**	**C1**	**C2**	**S1**	**S2**
	Class: Gastropoda				
Neritidae	*Clithon oualaniense*	+	+	+	+
	Neripteron violaceum	+	+	+	+
Cerithiidae	*Clypeomorus batillariaeformis*	+	-	-	-
Potamididae	*Pirenella cingulata*	+	+	+	+
	Telescopium telescopium	+	+	+	+
Turritellidae	*Turritella attenuata*	+	+	-	-
Planaxidae	*Planaxis sulcatus*	+	-	-	-
Littorinidae	*Littoraria pallescens*	+	+	+	-
	Littoraria carinifera	-	-	+	-
Naticidae	*Paratectonatica tigrina*	+	-	+	+
Assimineidae	*Optediceros breviculum*	-	+	+	-
Muricidae	*Indothais blanfordi*	+	-	-	-
	Indothais lacera	-	-	-	+
Nassariidae	*Nassarius fuscus*	+	-	-	-
	Nassarius jacksonianus	+	+	+	+
Plakobranchidae	*Elysia bangtawaensis*	-	+	-	-
Aplysiidae	*Bursatella leachii*	-	-	+	-
Ellobiidae	*Cassidula nucleus*	+	+	+	-
Onchidiidae	*Platevindex* cf *martensi*	-	+	+	-
	Class: Bivalvia				
Mytilidae	*Brachidontes pharaonis*	+	+	+	+

	Perna viridis	+	-	-	-
Arcidae	*Tegillarca rhombea*	+	-	+	+
Ostreidae	*Magallana bilineata*	+	+	+	+
	Saccostrea cucullata	+	+	+	+
Isognomonidae	*Isognomon isognomum*	-	-	-	+
Placunidae	*Placuna placenta*	-	-	-	+
Tellinidae	*Alaona ala*	+	-	-	+
	Quadrans gargadia	-	-	-	+
Psammobiidae	*Hiatula diphos*	-	-	-	+
Veneridae	*Pelecyora katiawarensis*	-	-	-	+
	Meretrix aurora	+	-	+	+
	Meretrix casta	-	-	-	+
	Marcia opima	+	-	+	+
	Marcia recens	-	-	+	+
Cyrenidae	*Geloina bengalensis*	-	+	-	+
	Gastropods	**13**	**11**	**12**	**7**
	Bivalves	**8**	**4**	**7**	**15**
	Total species	**21**	**15**	**19**	**22**

An analysis of species-wise spatial distribution revealed that eight species (*Brachidontes pharaonis, Saccostrea cucullata, Magallana bilineata, Telescopium telescopium, Pirenella cingulata, Nassarius jacksonianus, Clithon oualaniense* and *Neripteron violaceum*) occurred at all the four stations, followed by six species (*Meretrix aurora, Marcia opima, Tegillarca rhombea, Littoraria pallescens, Paratectonatica tigrina* and *Cassidula nucleus*) at three stations, six species (*Alaona ala, Geloina bengalensis, M. recens, Turritella attenuata, Optediceros breviculum* and *Platevindex martensi*) at two stations, and fourteen at one station only (*Perna viridis, Pelecyora katiawarensis, Meretrix casta, Isognomon isognomum, Placuna placenta, Hiatula diphos, Quadrans gargadia, Clypeomorus batillariaeformis, Planaxis sulcatus, Littoraria carinifera, Nassarius fuscus, Indothais blanfordi, I. lacera, Bursatella leachii* and *Elysia bangtawaensis*) (Table 5.2).

Computation of the H' indicated the highest mean diversity value at station S2 (2.13 ± 0.23), followed by C1 (1.44 ± 0.43), C2 (1.31 ± 0.28) and S1 (0.78 ± 0.29) (Figure 5.3). Two-way ANOVA of the station-wise H' index displayed significant variations between the stations ($p < 0.001$) (Table 5.4).

An analysis of the seasonal variations in the H' did not show a distinct seasonal trend except at the station where moderately lower diversity was observed during the monsoon season (1.12 ± 0.44) in comparison to pre-monsoon (1.70 ± 0.28) and post-monsoon (1.52 ± 0.42) seasons. (Fig. 5.4). Two-way ANOVA did not reveal significant variations between the seasons ($p > 0.05$) (Table 5.4).

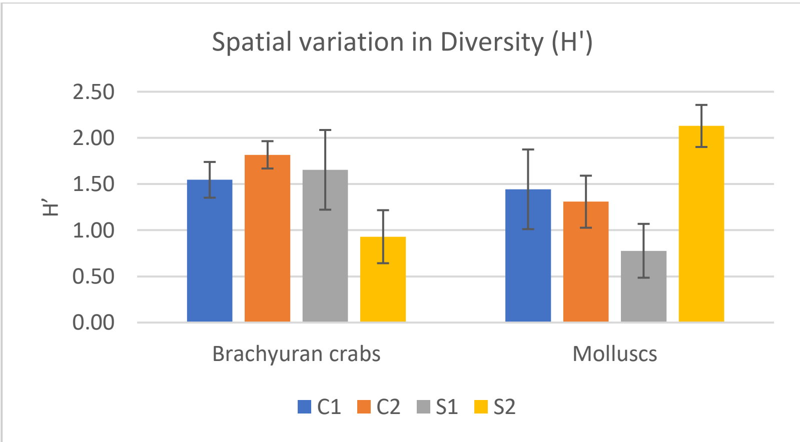

Figure 5.1. Spatial variation in diversity of brachyuran crabs and molluscs

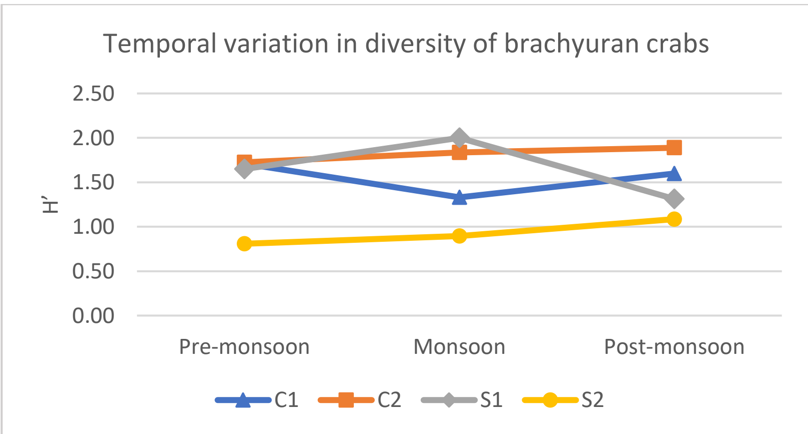

Figure 5.2. Temporal variation in diversity of brachyuran crabs across

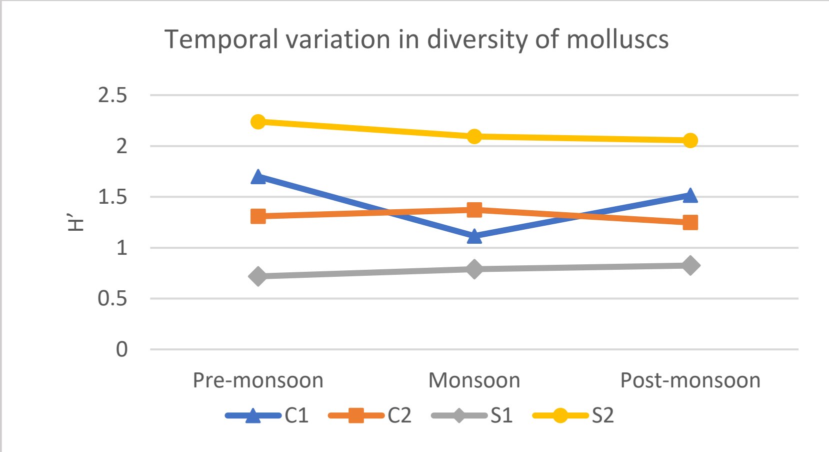

Figure 5.3. Temporal variation in diversity of molluscs

Table 5.3. Spatial and temporal variation in diversity of brachyuran crab using two-way ANOVA

Source of Variation	Sum of Squares (SS)	Degrees of freedom (df)	Mean squares (MS)	F-value	P-value	F critical
Months	0.269182	11	0.024471	0.241849	0.9920413	2.093254
Stations	5.40483	3	1.80161	17.80538	0.0000005	2.891564
Error	3.339055	33	0.101183			
Total	9.013067	47				

Table 5.4. Spatial and temporal variation in diversity of molluscs using two-way ANOVA

Source of Variation	Sum of Squares (SS)	Degrees of freedom (df)	Mean squares (MS)	F-value	P-value	F critical
Months	1.209935	11	0.109994	1.127762	0.372173	2.093254
Stations	11.14929	3	3.716431	38.10431	0.000000	2.891564
Error	3.218592	33	0.097533			
Total	15.57782	47				

5.2.2. Spatial and temporal variation with respect to abundance:

i. Brachyuran crabs

An analysis of the mean annual abundance data of brachyuran crabs indicated higher value at station C1 (50 ± 13 no/m^2) followed by S2 (38 ± 23 no/m^2), C2 (33 ± 13 no/m^2) and S1 (26 ± 12 no/m^2). Higher abundance at station C1 was primarily due to the higher density of

A. annulipes and *S. proxima* (42% and 31% of the total abundance, respectively), and at S2 due to *D. myctiroides* (71% of the total abundance). Stations C2 and S1 were characterized by relatively even distribution of species (C2 – *A. annulipes*, 40% of the total abundance followed by *G. vocans* (19%), *P. bengalense* and *T. alcocki* (10% each); S1 – *G. vocans*, 26% of the total abundance followed by *P. bengalense* (24%), *A. annulipes* (15%) and *M. cannicci* (14 %)). Two-way ANOVA revealed significant variations between stations with $p < 0.01$ (Table 5.5)

Temporal variations in the mean abundance suggested a slightly higher mean value during the monsoon season (51 ± 11 no/m^2) as compared to post-monsoon (50 ± 19 no/m^2) and pre-monsoon seasons (47 ± 11 no/m^2) at Station C1. Station C2 recorded marginally higher mean value during the post-monsoon season (34 ± 21 no/m^2) as compared to monsoon (31 ± 10 no/m^2) and pre-monsoon seasons (29 ± 9 no/m^2) (Fig. 5.6). At stations S1 and S2, mean values were higher during the pre-monsoon season (34 ± 17 no/m^2 and 65 ± 17 no/m^2, respectively) as compared to the monsoon (22 ± 3 no/m^2 and 24 ± 5 no/m^2, respectively) and post-monsoon seasons (19 ± 7 no/m^2 and 21 ± 8 no/m^2, respectively) (Fig. 5.6). Two-way ANOVA of the seasonal data did not reveal significant variations between the seasons ($p > 0.05$) (Table 5.5).

ii. Molluscs

An analysis of spatial variation across four stations indicated highest mean abundance at station S1 (49 ± 32 no/m^2), followed by C1 (32 ± 14 no/m^2), S2 (30 ± 11 no/m^2) and C2 (29 ± 15 no/m^2) (Fig. 5.4). Higher abundance with wide fluctuations at station S1 corresponded to the overwhelming dominance of *P. cingulata* (86% of the total abundance) with high monthly fluctuations. *P. cingulata* was a dominant species at also at stations C1 and C2 forming 69% and 66% of the total abundance. Stations S2 was characterized by a relatively even distribution of species *P. cingulata* (27.8%) *N. jacksonianus* (21.1%), *M. bilineata* (11.3%), *I. isognomum* (10.1%) and *C. oualaniense* (8.5%). Two-way Analysis of Variance (ANOVA) revealed significant variations between stations with $p < 0.05$ (Table 5.5, Fig. 5.5).

An analysis of the temporal variations in the mean abundance revealed substantially lower values during the monsoon season in comparison to pre-monsoon and post-monsoon seasons except at station C1 where higher values were observed during the monsoon season (Fig.

5.5). At stations S1 and S2, mean values for the pre-monsoon season were (78 ± 34 no/m^2) and (38 ± 14 no/m^2) respectively, in post-monsoon season were (38 ± 27 no/m^2) and (30 ± 3 no/m^2), respectively and in monsoon seasons (32 ± 11 no/m^2) and (21 ± 5 no/m^2), respectively. Station C2 recorded marginally higher mean value during the post-monsoon season (38 ± 17 no/m^2) as compared to pre-monsoon (31 ± 2 no/m^2) and monsoon seasons (17 ± 16 no/m^2). Station C1 recorded a slightly higher mean value during monsoon season (38 ± 24 no/m^2) as compared to pre-monsoon (29 ± 3 no/m^2) and post-monsoon seasons (27 ± 6 no/m^2). Two-way ANOVA revealed significant variations between the seasons ($p < 0.05$) (Table 5.5).

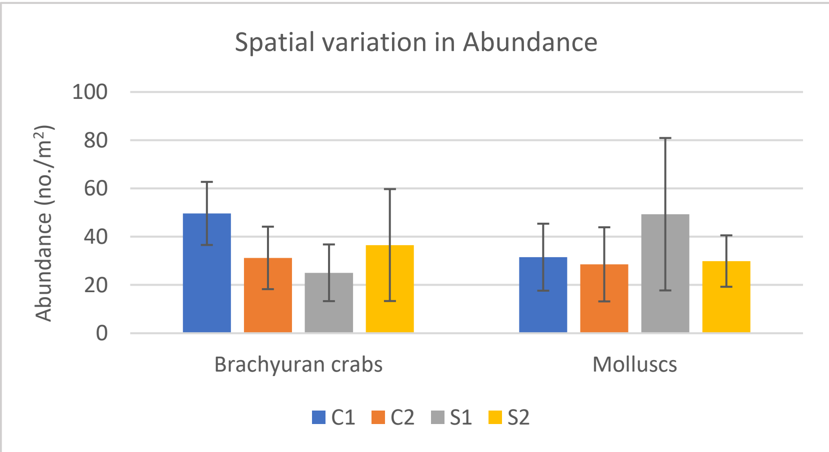

Figure 5.4. Spatial variation in abundance of brachyuran crabs and molluscs

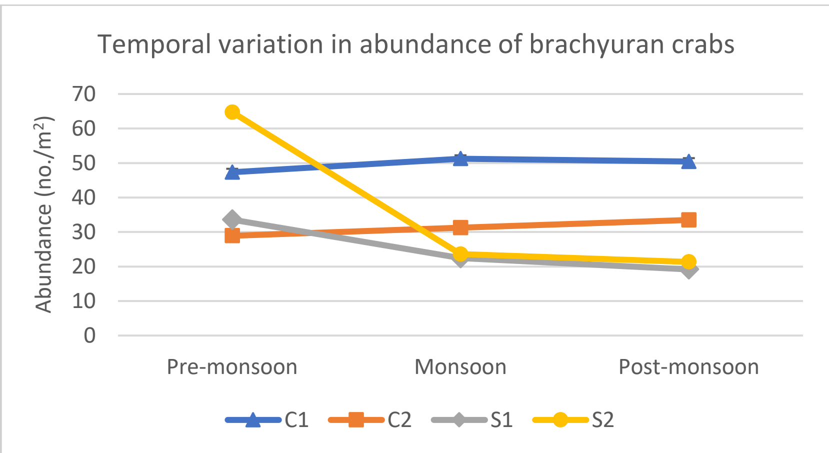

Figure 5.5. Temporal variation in abundance of brachyuran crabs

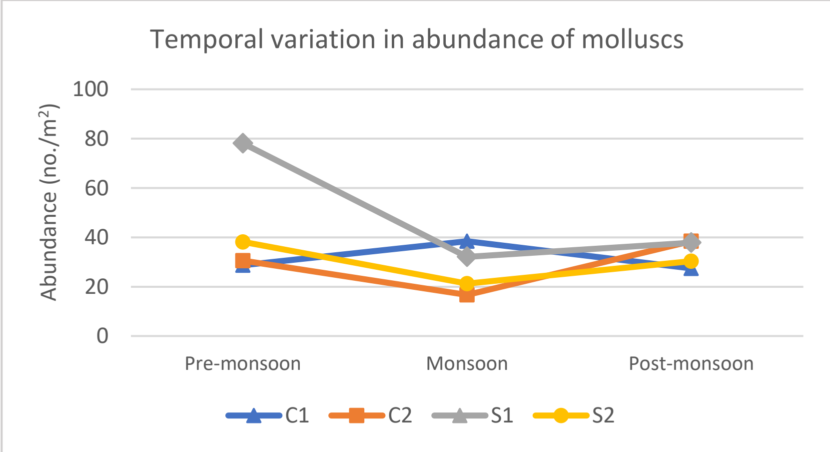

Figure 5.6. Temporal variation in abundance of molluscs

Table 5.5. Spatial and temporal variation in abundance of brachyuran crab using two-way ANOVA

Source of Variation	Sum of Squares (SS)	Degrees of freedom (df)	Mean squares (MS)	F-value	P-value	F critical
Months	4194.612	11	381.3283	1.804991	0.093417	2.093254
Stations	3949.583	3	1316.528	6.231692	0.001795	2.891564
Error	6971.688	33	211.2633			
Total	15115.88	47				

Table 5.6. Spatial and temporal variation in abundance of molluscs using two-way ANOVA

Source of Variation	Sum of Squares (SS)	Degrees of freedom (df)	Mean squares (MS)	F-value	P-value	F critical
Months	7159.889	11	650.899	2.195167	0.040055	2.093254
Stations	3417.13	3	1139.043	3.841441	0.018325	2.891564
Error	9784.981	33	296.5146			
Total	20362	47				

5.2.3. Spatial and temporal variation with respect to biomass:

i. Brachyuran crabs

Highest mean biomass was recorded at station C1 (97.63 ± 39.53 g/m^2), followed by C2 (85.17 ± 26.94 g/m^2), S2 (83.37 ± 63.50 g/m^2) and S1 (54.85 ± 32.01 g/m^2) (Fig. 5.7). High biomass recorded at station C1 corresponded with the perennial presence of fiddler crab species *A. annulipes* (39%) and *G. vocans* (15%), coupled with swimming crabs such as *M.*

victor, *P. reticulatus, S. serrata* and *T. crenata* which together contributed to 23% of the total biomass. Similarly, at station C2, 76% of the total biomass was due to the perennial presence of fiddler crabs (*A. annulipes, G. vocans* and *T. alcocki*) with sesarmid (*P. bengalense*) and grapsid (*M. cannicci*) contributing to 9 and 6% of the total biomass. High densities of dotillid crab *D. myctroides* (37%) and fiddler crab *G. vocans* (20%) along the presence of few individuals of swimming crabs *M. victor, P. reticulatus, C. hellerii* and *T. crenata* (together 37%) contributed significantly to the total biomass at station S2. At station S1, fiddler crabs (*A. annulipes, G. vocans* and *T. alcocki*) contributed with 47%, sesarmid (*P. bengalense*) and grapsid (*M. cannicci*) contributed 17% and 18 % each, whereas swimming crabs (*M. victor*, *P. reticulatus, S. serrata* and *T. crenata*) contributed to 14% of the total biomass. Two-way ANOVA revealed significant variations between stations with $p < 0.01$ (Table 5.7).

An analysis of the temporal variations in the mean biomass revealed markedly higher value during pre-monsoon season (C1: 129.28 ± 44.01 g/m^2 ; S1: 88.41 ± 35.74 g/m^2; S2: 160.03 ± 28.84 g/m^2) as compared to post-monsoon (C1: 97.13 ± 33.11 g/m^2; S1: 39.02 ± 6.12 g/m^2; S2: 62.30 ± 33.53 g/m^2) and monsoon seasons (C1: 66.49 ± 8.16 g/m^2; S1: 37.11 ± 13.68 g/m^2; S2: 27.79 ± 16.78 g/m^2) except at station C2 where marginally higher mean value was observed during the monsoon season (91.57 ± 26.87 g/m^2) as compared to pre-monsoon (82.25 ± 27.82 g/m^2) and post-monsoon seasons (81.70 ± 32.91 g/m^2) (Fig. 5.8). Two-way ANOVA of the seasonal data revealed significant variations between the seasons ($p < 0.05$) (Table 5.7).

ii. Molluscs

Station-wise, S2 recorded the distinctly high mean biomass (1101.67 ± 126.76 g/m^2), followed by C1 (264.79 ± 49.37 g/m^2), S1 (199.53 ± 117.57 g/m^2) and C2 (146.48 ± 60.82 g/m^2). High biomass recorded at station S2 is attributed to the perennial presence of large clumps of oysters (*I. isognomum, M. bilineata* and *S. cuccullata*) and venerid bivalves (*G. bengalensis* and *M. aurora*) with a combined 92% of the total biomass. Moderately high biomass at station C1 is attributed to the presence of oyster clumps (*M. bilineata* and *S. cuccullata*) and the potamidid gastropod *P. cingulata* with a combined biomass of 82.5%. Moderately low biomass at station S1 is attributed to the presence of *S. cuccullata* and *P. cingulata* only. Lowest biomass at station C2 is attributed to the perennial presence of *P. cingulata* and *S. cuccullata,* and seasonal occurrences of *G. bengalensis* and the potamidid

T. telescopium (Table 5.7, Fig. 5.8). Two-way ANOVA) revealed significant variations between stations with $p < 0.001$ (Table 5.5, Fig. 5.5).

An analysis of the seasonal variations in the mean biomass revealed that station C1 recorded a slightly higher mean value during the monsoon season (277.99 ± 86.22 g/m^2) as compared to pre-monsoon (268.05 ± 29.19 g/m^2) and post-monsoon seasons (248.35 ± 6.60 g/m^2). Station C2 recorded a markedly higher mean value during monsoon season (191.57 ± 80.66 g/m^2) as compared to post-monsoon (130.52 ± 44.74 g/m^2) and pre-monsoon seasons (117.35 ± 29.56 g/m^2) (Fig. 5.6). At stations S1 and S2, markedly higher mean values during the pre-monsoon season (320.89 ± 117.62 g/m^2 and 1171.09 ± 193.71 g/m^2, respectively) as compared to the post-monsoon (144.86 ± 71.22 g/m^2 and 1107.47 ± 73.41 g/m^2, respectively) and monsoon seasons (132.85 ± 47.19 g/m^2 and 1026.44 ± 44.60 g/m^2, respectively) roughly corresponded with their abundances at these stations (Fig. 5.6). Two-way ANOVA of the seasonal data did not reveal significant variations between the seasons ($p > 0.05$) (Table 5.5).

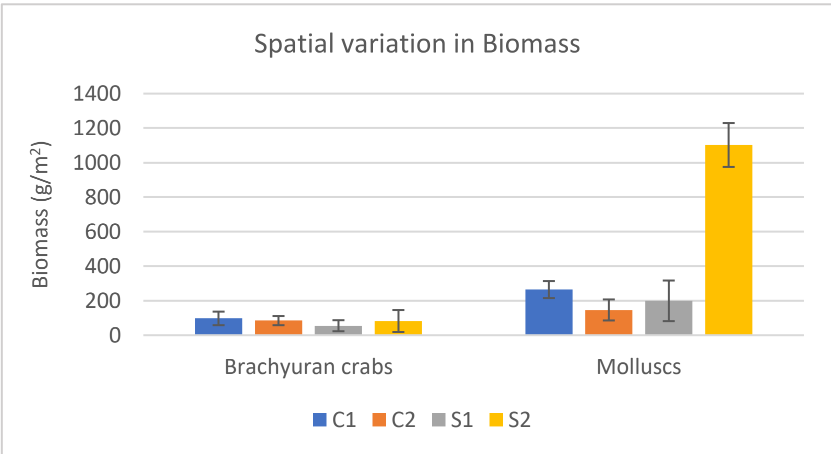

Figure 5.7. Spatial variation in biomass of brachyuran crabs and molluscs

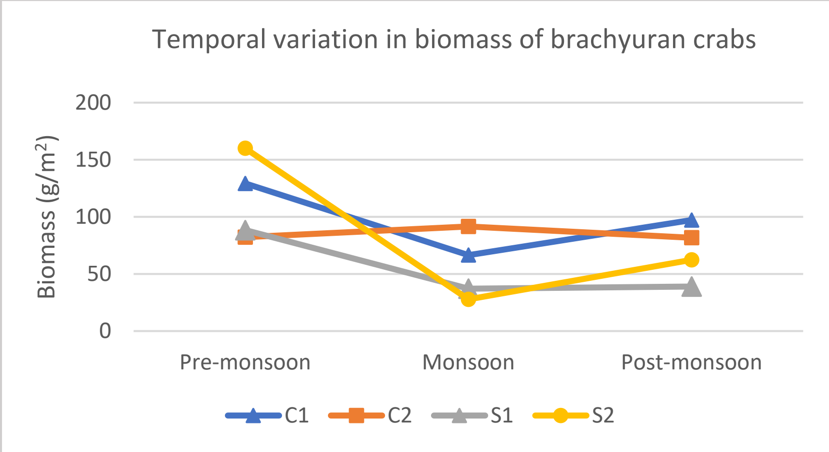

Figure 5.8. Temporal variation in biomass of brachyuran crabs

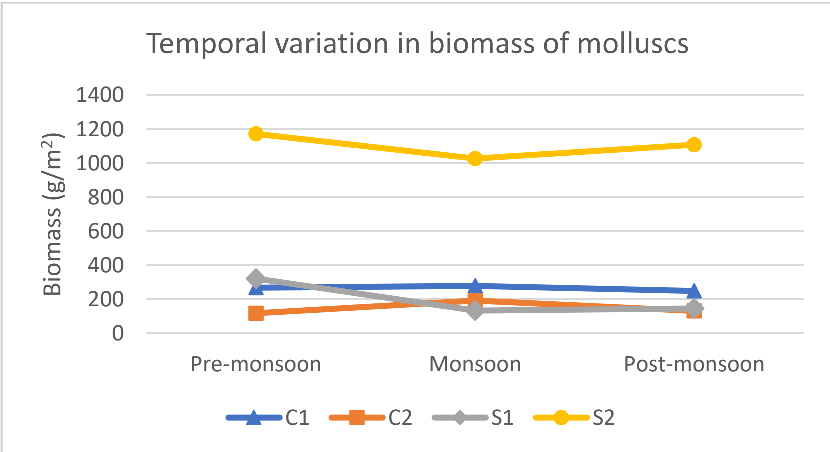

Figure 5.9. Temporal variation in biomass of molluscs

Table 5.7. Spatial and temporal variation in biomass of brachyuran crab using two-way ANOVA

Source of Variation	**Sum of Squares *(SS)***	**Degrees of freedom *(df)***	**Mean squares *(MS)***	**F-value**	***P*-value**	**F-critical**
Months	40344.92	11	3667.72	2.992257	0.00725	2.093254
Stations	11777.04	3	3925.681	3.20271	0.035812	2.891564
Error	40449.32	33	1225.737			
Total	92571.28	47				

Table 5.8. Spatial and temporal variation in biomass of molluscs using two-way ANOVA

Source of Variation	Sum of Squares (SS)	Degrees of freedom (df)	Mean squares (MS)	F-value	P-value	F-critical
Months	150838.1	11	13712.55	1.843455	0.085979	2.093254
Stations	7342938	3	2447646	329.0507	1.19E-24	2.891564
Error	245470.7	33	7438.507			
Total	7739247	47				

5.3. Discussion

5.3.1. Spatial and temporal variation with respect to diversity:

Spatial variation in diversity of brachyuran crabs revealed maximum diversity at station C2 followed by station S1, C1 and S2. The role of mangrove vegetation in influencing the distribution of brachyuran crabs has been extensively studied, and it is widely accepted that denser and more diverse mangrove cover supports higher brachyuran crab diversity (Ashton et al., 2003, Ngo-Massou et al., 2014, Sharifian et al., 2020, Chennuri et al., 2023 In the present study, a similar trend was observed, with Station C2, characterized by dense mixed mangrove vegetation, showing the highest diversity. This was followed by Station S1 (monotypic mangrove vegetation), Station C1 (young and scattered mangrove vegetation), and Station S2 (a sand flat with a fringe of mangroves).

Temporal variation in the diversity of brachyuran crabs was not statistically significant in the present study. However, moderately lower diversity was observed during the monsoon season at station C1, in contrast to station S1 where moderately higher diversity was observed during the same period. Stations C2 and S2 exhibited marginally higher diversity during the post-monsoon season. This pattern of higher diversity during the monsoon and post-monsoon seasons aligns with the findings of Apreshgi and Kurian (2019) in the Kochi estuary mangroves, which suggested that brackish water-dependent species tend to disappear during periods of higher salinity. Although statistically significant changes in diversity were not observed in the current study, certain species exhibited seasonal preferences: *C. merguiense, E. versicolor, P. glabrum*, and *S. crassum* were found only during the monsoon season; *V. litterata* occurred only during the post-monsoon season; *N. demeloi, C. helleri*, and *M. parvimanus* were present only during the pre-monsoon period;

and *M. victor* and *P. reticulatus* were observed in non-monsoon seasons. These observations indicate that some species have distinct seasonal preferences.

In contrast to the brachyuran crabs, the sand flat mangrove habitat (S2) and young mangrove habitat (C1) reported higher mollusc species than the dense mangrove habitats (C2 and S1). Among the molluscs, maximum diversity of bivalves was recorded in the sand-flat mangrove habitat, while the mangrove-dominated stations (C2 and S1) showed greater diversity of gastropods. Bivalves are generally better adapted to lower tidal levels due to their feeding and larval settlement requirements (Kantharajan et al., 2017). Additionally, bivalves prefer firmer substratum for burrowing which is absent in the mangrove-dominated habitats which are mostly soft mud and often anoxic due to poor exchange of water (Kabir et al., 2014). On the other hand, gastropods are better adapted to, and showed greater tolerance for, the harsher conditions found in mangrove-dominated regions, such as anoxic sediments and extended dry spells (Kabir et al., 2014; Kantharajan et al., 2017). This explains the higher diversity of bivalves in sand-flat mangrove environments and the comparatively higher diversity of gastropods in mangrove-dominated environments.

Temporal variation in the diversity of molluscs like brachyuran crabs was not statistically significant in the present study. However, lower diversity was observed at station C1 during the monsoon season. Similar observation was reported by Satheeshkumar and Khan (2012) in the Pondicherry mangroves, where environmental factors such as dissolved oxygen and higher salinity were observed to be stable during the pre-monsoon season and were attributed to these variations. Nine species of molluscs which occurred rarely in the present study were found only during pre-monsoon season *C. batillariaeformis, P. sulcatus, N. fuscus, B. leachii, Q. gargadia, P. katiawarensis, M. casta, P. placenta* and *H. diphos* showing higher affinity of the molluscs towards the pre-monsoon season.

5.3.2. Spatial and temporal variation with respect to abundance:

Spatial variation in abundance of brachyuran crabs indicated maximum abundance at station C1 followed by station S2, C2 and S1. The higher abundance at station C1 was due to the higher density of two species *A. annulipes* and *S. proxima*. *A. annulipes*, a common fiddler crab found at all four study locations, achieved specifically higher density at station C1. *A. annulipes* prefers lower zones in the protected shores with scarce vegetation (Zolkhiflee et al., 2021), quite similar to the habitat prevailing at station C1 that displays young and scattered mangrove vegetation, thus probably a reason for their higher densities. On the other hand, *S. proxima,* a tiny crab with a size of less than 0.5 cm, prefers area near the HTL of sandy substratum, with a slightly elevated slope (Silas & Sankarankutty, 1967) which was likewise observed in the present study. Similarly, at station S2, high abundance was due to high of density of *D. myctiroides*. *D. myctiroides*, is known to achieve high density under favourable conditions as documented by Hails and Yaziz (1982) in Malaysia where it reached densities as high as 579 no/m^2. In the present study, the highest density of 130 no/m^2 was achieved in the month of May at station S2, Sal estuary. The recorded density is distinctly higher than previous studies by Padate et al. (2015) from Miramar beach, Goa (24 no/m^2) and by Ali and Chakraborty (2015) at the Aksa beach, Mumbai (38-40 no/m^2). Contrary to stations C1 and S2, stations C2 and S1 showed a more even distribution in abundance of species *A. annulipes, G. vocans, T. alcocki, P. bengalense* and *M. cannicci*. Competition between the species for resources and predation might be a reason for the even distribution of abundance (Mohanty et al., 2019).

Temporal variation in abundance of brachyuran crabs did not exhibit a distinct seasonal variation except at station S2 where markedly high abundance was found during the pre-monsoon season. Insignificant variation in brachyuran crab abundance in the mangrove regions of Persian Gulf was attributed to unchanged grain size and organic matter in varying location (Hajializadeh et al., 2022). However, marginally high abundance was observed during the pre-monsoon season at stations S2 due to the migration of swimming crabs such as *P. reticulatus, M. victor* and *C. helleri.* These crabs are usually found in marine environments and travel the estuarine regions when salinity is at its peak in the pre-monsoon season as observed by Devi et al. (2022) in Kochi estuary. Influence of these swimming crab species on the total abundance was also seen at station S1 recording marginally high abundance during the pre-monsoon season.

The spatial variation in abundance of molluscs was observed to be higher at Station S1 followed by C1, C2 and S2. A potamidid gastropod *P. cingulata* was dominant at all four studied sites in varying abundance; however, an overwhelming density (maximum 102 no./m^2) at station S1 contributed significantly to the high abundance at this station. Dominance of *P. cingulata* was previously observed in mangroves of Pondicherry, India (Satheeshkumar & Khan, 2012), Karachi, Pakistan (Ullah et al., 2015), central Vietnam (Zvonareva et al., 2015).

Temporal variation indicated distinctly lower abundance during the monsoon season mainly owing to the influx of freshwater. Bivalves being filter feeders are dependent on the water column and a drop in salinity during monsoon leads to a lowering of their population. This lowered salinity initiates migration of *P. cingulata* species to areas less affected by salinity such as high tide levels and in absence of such areas eventually leads to their death (Rao & Sukumar, 1982; Solanki et al*.,* 2017). The higher abundance during the monsoon season at station C1 is mainly owing to the higher number of *P. cingulata* which migrated from lower tidal levels to higher tidal levels at this station.

5.3.3. Spatial and temporal variation with respect to biomass:

Spatial variation in biomass of brachyuran crabs indicated comparatively higher biomass at station C1 followed by station S2, C2 and S1. The cumulative biomass varying at every station was due to combination of two factors - size and abundance. The dominant crabs (fiddlers and dotillids) found in the present study were medium-sized (< 3cm) and their contribution to biomass was attributed by their high abundance. However, few individuals of swimming crabs such as *P. reticulatus, T. crenata, M. victor*, *S. serrata* and *C. hellerii* with size > 3 cm contributed significantly to the overall biomass. As mentioned earlier species such as *P. reticulatus, M. victor* and *C. helleri* are marine migrants and travel the estuarine regions when salinity is at its peak in the pre-monsoon season (Devi et al., 2022). In addition, although these species spawn throughout the year, their peak breeding activity is during the non-monsoon seasons (Mohanty et al., 2019). Thus, the spawning season and migration of brachyuran crab species mainly of bigger-sized swimming crabs during the pre-monsoon season led to the higher biomass during this season. However, at station C2 where the swimming crabs were not encountered the slightly higher biomass was observed during the monsoon season due to the increase in abundance of sesarmid crabs corresponding to the abundant food source in the mangroves during the monsoon season.

Spatial variation in biomass of molluscs indicated distinctly higher biomass at station S2 due to the presence of oyster colonies of *I. isognomon, M. bilineata* and *S.cucullata*. Among them *I. isognomon* is irregularly shaped, flat and thin-shelled reaching a size up to 100 mm in the present study which is biggest of any other mollusc species found in the study area. The species forms clusters bound together by their byssal threads, which along with their bigger size contributed significantly to the higher biomass (Printrakoon & Temkin, 2008). Further, *G. bengalensis* another bigger sized bivalve known to be present exclusively in the mangrove regions of the Indo-Pacific region contributed significantly to higher biomass at two stations C2 and S2.

Temporal variation in biomass was not pronounced in the present study as the major contributors to the biomass were sedentary oyster colonies. Marginally lower values during the monsoon season at stations S1 and S2 corresponded with the lower abundance of bivalves at these stations during the monsoon season.

5.3.4. Brachyuran crabs and molluscs as an indicator of the health of an ecosystem

The Shannon-Wiener Diversity Index (H') is commonly used as an indicator of pollution (Wilhm & Dorris, 1966; Satheeshkumar & Khan, 2014) with values < 1.0 indicating heavy pollution; 1.0 - 3.0 moderate pollution and > 3.0 non-polluted areas. The H' values in the present study (Fig. 5.1) suggest a moderate level of pollution in the Chapora and a heavy to moderate level of pollution in the Sal estuary. These findings attest to the findings of the Goa State Pollution Control Board (GSPCB, 2019a, b), which classified river Sal as the most polluted river (Priority III) of Goa and Chapora as moderately polluted (Priority V) based on Biological Oxygen Demand (BOD) values and faecal coliform counts. Additionally, the high abundance of ocypodid crabs, which are associated with disturbed or young mangrove forests (Ashton et al., 2003), further supports these findings. Two gastropod species, N. violaceum and C. nucleus, known indicators of pollution, were encountered in both estuarine stations, indicating that the mangroves of Chapora and Sal estuaries are under stress (Dissanayake & Chandrasekara, 2014; Kantharajan et al., 2017; Satheeshkumar & Khan, 2012; Yadav et al., 2019). Moreover, high biomass observed in these regions suggests the potential for supporting crab, clam and oyster fisheries provided the health of these estuaries is preserved. Therefore, long-term monitoring of the brachyuran crab and mollusc communities in these mangrove ecosystems can serve as a tool to gain insight into its ecological health (Stiepani et al., 2021). In conclusion, this study provides baseline data on the distribution, abundance, and biomass of brachyuran crabs and molluscs in the mangrove-associated ecosystems of the Chapora and Sal estuaries in Goa.

CHAPTER 6

Role of habitat in species distribution

6.1. Introduction

Mangrove habitats are complex ecosystems that provide different kinds of shelter and food resources for organisms, thus facilitating high biodiversity, functional-diversity and stability in ecosystems (Hajializadeh et al., 2020). Habitat complexity in vegetated areas is a key factor influencing the abundance and distribution patterns of macrofauna living in these systems (Heck & Orth, 1980). Unlike rocky and sandy shores, the distribution of fauna in mangrove habitats cannot be described in terms of simple two-dimensional vertical zonation. A mangrove is a three-dimensional community where two main series of zones are demarcated. One, horizontally from the land towards the sea; second, vertically from the tree tops down to the soil (Berry, 1963). Mangrove zonation pertains to distinct regions within a mangrove ecosystem where a particular family, genus, or species tends to dominate. (Baloloy et al., 2021).

Considering this habitat complexity, the aim of the present study is to elucidate the distribution and zonation pattern of brachyuran crabs and molluscs at three tidal levels of four mangrove-associated stations. Further, the role of physicochemical parameters of water and sediment is assessed in determining the distribution of these faunal groups.

6.2. Results

6.2.1. Physico-chemical parameters of water

The average and range of water quality parameters obtained are presented in Table 6.1.

Temperature did not exhibit distinct station-wise variations; however, seasonal variations were recorded with maximum temperatures in the pre-monsoon season (31 ± 2°C) and lowest in the post-monsoon season (28 ± 1°C). Similarly, pH did not exhibit distinct station-wise variations, however, displayed seasonal variations with lower pH during the monsoon season (7.4 ± 0.3) in comparison to pre-monsoon (7.7 ± 0.4) and post-monsoon (7.9 ± 0.2). During the monsoon season, the land runoff contributes a large amount of organic material which upon degradation releases organic acids resulting in a decrease in pH (Shenai-Tirodkar et al., 2016; Patra et al., 2021)

Salinity showed station-wise variation, with maximum salinity at station S1 whereas lowest at station C2 (Table 6.1). The monsoon season leads to an influx of freshwater which dilutes the saline water resulting in lower salinity of up to 1 PSU at stations C2, S1 and S2 and 2 PSU at station C1 during the month of July.

Table 6.1. Average (±SD) and Range of physico-chemical parameters of water at four stations

Parameters	**Chapora**		**Sal**	
	C1	**C2**	**S1**	**S2**
Temperature (°C)	29 ± 2 27 – 32	30 ± 2 28 – 33	29 ± 2 27 – 34	30 ± 2 27 – 34
pH	7.8 ± 0.4 6.7 – 8.1	7.7 ± 0.3 6.8 – 8.0	7.6 ± 0.5 6.7 – 8.2	7.5 ± 0.4 6.6 – 8.0
Salinity (PSU)	18 ± 8 2 – 27	14 ± 8 1 – 22	23 ± 13 1 – 34	20 ± 13 1 – 33
Dissolved Oxygen (mg/L)	7.19 ± 0.98 5.05 – 8.59	7.38 ± 0.88 6.08 – 9.08	6.15 ± 0.92 5.21 – 8.62	6.25 ± 0.97 4.53 – 8.62
Nitrite (µmol/L)	0.50 ± 0.60 0.09 – 2.26	0.64 ± 0.72 0.22 – 2.86	0.54 ± 0.29 0.17 – 1.11	0.62 ± 0.43 0.28 – 1.69
Nitrate (µmol/L)	2.31 ± 2.29 0.12 – 6.61	3.01 ± 2.61 0.16 – 7.03	5.06 ± 5.97 0.21 – 18.21	5.46 ± 5.46 0.25 – 17.07
Phosphate (µmol/L)	0.96 ± 0.45 0.41 – 2.14	1.27 ± 0.78 0.55 – 2.95	1.38 ± 0.77 0.73 – 3.59	1.21 ± 0.50 0.36 – 2.05
Silicate (µmol/L)	64.28 ± 29.01 25.60 – 133.80	80.45 ± 27.36 37.10 – 147.70	41.29 ± 30.81 14.45 – 106.60	46.56 ± 25.16 23.95 – 96.40
SPM (mg/L)	33.46 ± 18.16 6.00 – 70.00	33.36 ± 11.85 18.80 – 60.00	29.60 ± 13.11 6.40 – 53.00	36.64 ± 27.19 8.40 – 114.00
Chlorophyll *a* (mg/m^3)	4.95 ± 2.97 1.47 – 10.99	5.52 ± 3.21 1.94 – 11.84	5.64 ± 3.92 1.77 – 14.82	7.78 ± 6.57 1.29 – 23.76

Dissolved Oxygen (DO) and nutrients (nitrite, nitrate, silicate) showed spatial and seasonal variations. Higher DO was noted in both the stations of Chapora estuary in comparison to the stations of Sal. On the other hand, nitrate was high at both the stations of the Sal estuary in comparison to Chapora. Further, silicate was found to be higher in both the stations of the Chapora estuary. DO, nitrate and silicate achieved maximum values during the monsoon season. Heavy rainfall, freshwater flow and higher wind velocity cumulatively lead to higher dissolved oxygen during the monsoon season (Satheeshkumar & Khan, 2012). Higher agricultural runoff coupled with anthropogenic activities and sand mining in the region led to higher values during the monsoon season (Prabhudessai et al., 2019). Phosphate did not exhibit distinct station-wise and seasonal trends however higher values were observed during the pre-monsoon season at stations C2 and S1 owing to the upwelling from the sediment as explained by Naik et al. (2017).

SPM and Chlorophyll-*a* (an indicator of phytoplankton biomass) showed maximum values at station S2. SPM did not reveal a general seasonal trend but showed higher values in the monsoon season at station C1 (closest to the mouth of the estuary) and lower values during monsoon at stations of the Sal estuary. Chlorophyll-*a* did not display any seasonal variation in stations of Chapora estuary, however, higher values were observed during the monsoon season and lowest during the post-monsoon season.

The values observed in the present study are similar to the study by Prabhudessai and Rivonker (2020); Shenai-Tirodkar et al. (2016) and Patra et al. (2021).

6.2.2. Physico-chemical parameters of sediment

The average and range values of physicochemical parameters of sediment at three tidal levels are presented in Table 6.2.

Temperature did not reveal distinct station-wise variation but tidal level-wise variation was observed at every station. A decrease in temperature was observed from LTL to HTL. The presence of vegetation at HTL might have led to this decrease. Seasonal trend was observed as that of water temperature with maximum temperature noted during the pre-monsoon (32 ± 2°C) and lowest during the post-monsoon season (28 ± 2°C).

Sediment texture showed significant station-wise and tidal level-wise variation. In general decrease in sand fraction coupled with an increase in silt and clay fraction from LTL to HTL was observed, except at station C1 where a reverse trend was recorded (Table 6.2). The highest sand fraction was recorded at Station S2 (LTL) and the maximum silt and clay fraction was recorded at station C2 (HTL).

Sediment moisture, Organic carbon (represents organic matter in the sediment) and Chlorophyll-*a* (represents the primary productivity-mainly measure of microphytobenthos) displayed significant station-wise and tidal level-wise variation. Greater moisture content was observed at MTL and HTL in comparison to LTL at stations C2, S1 and S2. However, at station C1, LTL and HTL displayed comparable moisture content and MTL recorded the least moisture content. Organic Carbon (OC) content increased from LTL to HTL in general with the highest OC content reported at station C2. Chlorophyll-*a* (Chl-*a*) increased from LTL to HTL, except

Table 6.2. Average (±SD) and Range of physico-chemical parameters of sediment at four stations

Station	Tidal Level	Temperature (°C)	Sand (%)	Silt (%)	Clay (%)	Sediment Type	Organic Carbon (%)	Moisture (%)	Chlorophyll (mg/m^3)
C1	**LTL**	29 ± 3 24 – 34	76.83 ± 10.95 59.66 – 92.41	10.83 ± 5.57 1.34 – 18.85	12.34 ± 8.43 1.37 – 29.25	Sandy loam	0.62 ± 0.35 0.19 – 1.30	21.64 ±6.59 15.36 – 40.06	7.24 ± 5.32 1.05 – 21.56
	MTL	28 ± 3 23 – 34	83.31± 6.96 64.16 – 90.99	9.39 ± 8.34 1.07 – 29.89	7.28 ± 5.79 0.93 – 18.97	Loamy sand	0.42 ± 0.25 0.07 – 0.97	14.29 ± 5.14 8.34 – 22.90	9.56 ± 5.60 3.50 – 23.93
	HTL	28 ± 3 22 – 33	85.59 ± 3.67 77.63 – 90.33	5.09 ± 2.85 1.15 – 10.61	9.32 ± 5.40 2.20 – 19.45	Loamy sand	0.50 ± 0.22 0.29 – 0.97	20.05 ± 6.04 11.70 – 28.81	13.86 ± 11.89 5.16 – 50.08
C2	**LTL**	32 ± 2 29 – 36	67.44 ± 10.08 46.89 – 81.76	15.76 ± 10.43 1.32 – 31.95	16.80 ± 12.58 1.77 – 47.62	Sandy loam	1.08 ± 0.48 0.56 – 1.97	28.07 ± 10.20 11.25 – 55.11	26.67 ± 17.93 10.30 – 65.67
	MTL	30 ± 2 28 – 35	54.30 ± 8.97 37.12 - 74.06	26.33 ± 6.82 14.49 – 41.78	19.37 ± 6.77 10.47 – 31.45	Sandy loam	2.62 ± 2.07 0.28 – 7.04	40.46 ± 14.92 16.01 – 67.52	35.63 ± 18.58 12.49 – 74.93
	HTL	27 ± 2 25 – 30	39. 82 ± 15.00 10.66 – 68.27	28.50 ± 9.44 14.45 – 48.89	31.69 ± 8.31 17.28 – 43.12	Clay loam	3.11 ± 1.27 1.04 – 6.42	40.89 ± 12.98 20.08 – 56.26	27.87 ± 3.58 21.21 – 33.52
S1	**LTL**	30 ± 3 25 – 34	75.84 ± 19.16 17.28 – 88.33	8.64 ± 8.44 1.12 – 28.54	15.52 ± 13.45 3.48 – 54.80	Sandy loam	0.70 ± 0.27 0.22 – 1.23	27.96 ± 10.20 16.82 – 54.45	32.06 ± 17.88 8.26 – 69.20
	MTL	29 ± 3 25 – 35	73.46 ± 12.89 47.44 – 87.47	10.64 ± 5.31 3.06 – 17.88	15.89 ± 9.65 4.87 – 34.64	Sandy loam	1.19 ± 0.72 0.38 – 3.04	27.17 ± 5.65 21.22 – 37.54	36.36 ± 13.16 17.64 – 58.61
	HTL	27 ± 2 24 – 31	58.10 ± 6.11 44.75 – 68.72	18.51 ± 4.83 13.17 – 31.86	23.39 ± 6.45 13.55 – 35.77	Sandy clay loam	1.67 ± 0.51 0.35 – 2.45	39.43 ± 8.67 25.20- 53.12	42.75 ± 23.24 18.26 – 105.29
S2	**LTL**	32 ± 3 28 – 36	91.81 ± 1.49 89.49 – 94.39	3.31 ± 2.83 0.24 – 9.78	4.88 ± 2.37 0.53 – 7.62	Sand	0.48 ± 0.25 0.17 – 0.91	17.70 ± 4.73 9.60 – 28.04	13.84 9.29 2.47 – 33.25
	MTL	32 ± 3 28 – 36	83.70 ± 3.34 79.51 – 89.97	5.85 ± 4.58 1.05 – 13.44	10.45 ± 5.07 2.00 – 17.50	Loamy sand	0.50 ± 0.12 0.32 – 0.67	23.65 ± 7.13 14.86 – 35.59	22.33 ± 19.09 3.25 – 65.23
	HTL	31 ± 3 27 – 35	77.34 ± 9.23 51.37 – 90.11	10.04 ± 7.38 0.24 – 30.96	12.62 ± 2.46 9.65 – 17.67	Sandy loam	0.74 ± 0.25 0.29 – 1.09	23.79 ± 3.97 16.39 – 30.10	26.13 ± 8.40 9.86 – 38.51

at station C2, where the highest values were recorded at MTL. The maximum Chl-*a* concentration was observed at station S1 followed by stations C2, S2 and C1. Although monthly variations were noted in all the parameters, no consistent seasonal trend was evident in any of them.

6.2.3. Distribution of brachyuran crabs

The survey across the four sampling stations spanning two estuaries recorded altogether thirty species belonging to twenty-four genera from eleven families of brachyuran crabs. The highest number of species was recorded from station C2 (twenty) followed by C1 (nineteen), S1 (eighteen) and S2 (fourteen). Tidal level distribution indicated maximum abundance at MTL, except at station C2 where the higher abundance of species was recorded at LTL (Fig. 6.1).

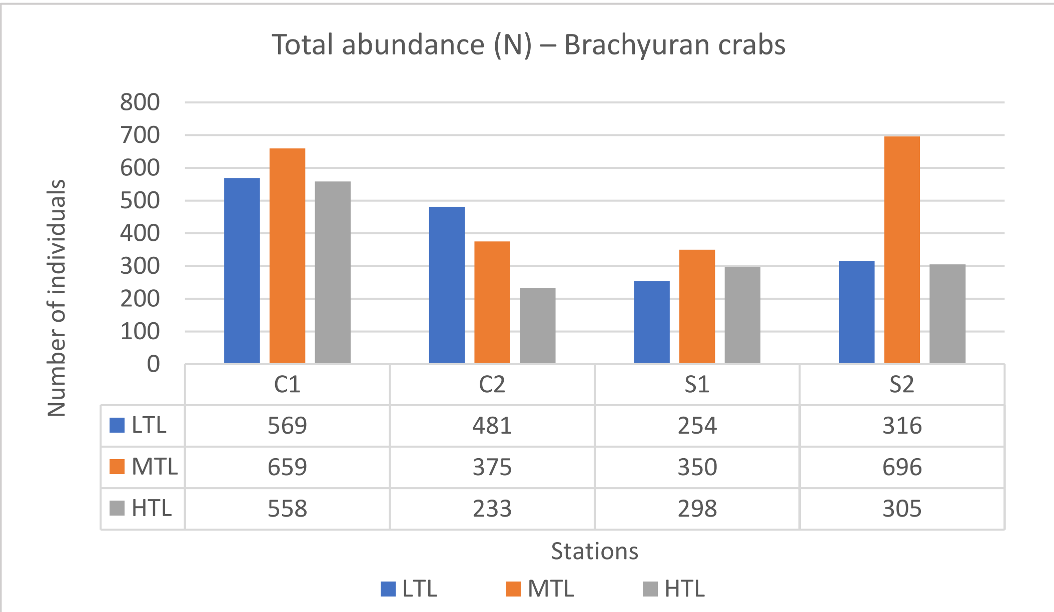

Figure 6.1. Total abundance (N) of brachyuran crabs across four stations at LTL, MTL and HTL

Fiddler crabs–*A. annulipes*, *G.vocans* (family Ocypodidae) dominated the LTL at stations C1, C2 and S1, whereas, station S2 was dominated by dotillid crab *D. myctiroides*. MTL was dominated by another dotillid crab *S. proxima* at station C1; fiddler crabs – *A. annulipes*, *G.vocans* and *T. alcocki* at stations C2 and S1; and *D. myctiroides* at station S2. The HTL at station C1 was dominated by *A.annulipes* with the frequent presence of a grapsid crab *M. cannicci;* stations C2 and S1 were collectively occupied by species of family Sesarmidae mainly *P. bengalense* and *P. plicatum* and a grapsid crab *M. cannicci*; lastly, station S2 was dominated by fiddler crab *G.vocans*.

Redundancy analysis (RDA) bi-plot of brachyuran crabs and substratum characteristics at LTL indicated a strong correlation between the dominant species *A. annulipes* and *G. vocans* with silt fraction, moisture and organic carbon content and *D. myctiroides* showing high correlation with the sand fraction (Fig. 6.2). Further, sand fraction was found to be statistically significant in the distribution of brachyuran crab species ($p < 0.01$) at the LTL. RDA at MTL indicated a positive correlation between the dominant species *D. myctiroides* and *S. proxima* with sand fraction; whereas, the fiddler crab species *A. annulipes, G. vocans* and *T. alcocki* showed a strong positive correlation with Chl-*a.* moisture content and clay fraction (Fig. 6.3). Sand fraction ($p < 0.01$), temperature ($p < 0.01$) and Chl-*a* ($p < 0.05$) were found to be statistically significant in the distribution of brachyuran crab species. At HTL, the sesarmid crabs (*P. bengalense, P. plicatum, N. tweediei* etc.) showed a strong correlation with moisture, organic carbon, clay and silt fraction and *A. annulipes* displayed higher co-relation with sand fraction. *G. vocans* exhibited a strong positive correlation with temperature, conversely, *M. cannicci* showed a strong negative correlation with temperature (Fig. 6.4). Like at MTL, sand fraction ($p < 0.01$), temperature ($p < 0.01$) and Chl-*a* ($p < 0.05$) were found to be statistically significant in the distribution of brachyuran crab species at HTL.

Table 6.3. Habitat preference and feeding habits of brachyuran crabs found at the four study stations. (LTL – Low Tide Level; MTL- Mid Tide Level; HTL- High Tide Level).

Name of the species	**Habitat preference**	**Feeding habit**
M. victor	LTL, shallow waters around the shores	Omnivore, scavenger (Innocenti et al., 2017)
N. demeloi	LTL, under oyster colonies	Surface deposit feeder (Jayachandran et al., 2019)
C. hellerii	LTL, shallow waters around the shores	Omnivore (Sant'Anna et al., 2015)
P. reticulatus	LTL, shallow waters around the shores	Carnivore, scavenger (Karam et al., 2023)
S. serrata	LTL, shallow waters around the shores	Carnivore (Hill, 1979)
T. crenata	LTL, under oyster colonies, tide puddles	Carnivore (Cannicci et al., 1996)
L. exaratus	LTL, under rocks and oyster colonies and crevices	Omnivore (Al-Wazzan et al., 2019)
H. glabra	LTL to HTL associated with crevices of oyster colonies	Scavenger, detritus feeder
M. cannicci	LTL to HTL, from tree trunks to the floor	Generalist feeder (Innocenti et al., 2020)
M. latifrons	LTL, on the tree trunks	Generalist feeder (Innocenti et al., 2020)
C. merguiense	LTL, under rocks	Herbivore (mangrove leaves and microalgae), detritus feeder (based on family Sesarmidae) (Ashton, 2002)
E. versicolor	HTL, mangrove trunks and crevices	Herbivore (mangrove leaves and microalgae), detritus feeder (based on family Sesarmidae) (Ashton, 2002)
N. andersoni	LTL to HTL, dominant at HTL under the mangrove canopy	Herbivore (mangrove leaves and microalgae), detritus feeder (based on family Sesarmidae) (Ashton, 2002)
N. minutum	LTL to HTL, dominant at HTL under the mangrove canopy	Herbivore (mangrove leaves and microalgae), detritus feeder (based on family Sesarmidae) (Ashton, 2002)
N. tweediei	HTL, on dead wood, rocks	Herbivore (mangrove leaves and microalgae), detritus feeder (based

		on family Sesarmidae) (Ashton, 2002)
P. bengalense	HTL under the mangrove canopy, sometimes wonder to MTL	Herbivore (mangrove leaves and microalgae), detritus feeder (based on family Sesarmidae) (Ashton, 2002)
P. plicatum	HTL under the mangrove canopy, sometimes wonder to MTL	Herbivore (mangrove leaves and microalgae), detritus feeder (based on family Sesarmidae) (Ashton, 2002)
P. glabrum	HTL, drier regions between *Portulaca sp.* vegetation	Herbivore (mangrove leaves and microalgae), detritus feeder (based on family Sesarmidae) (Ashton, 2002)
S. crassum	HTL, under the mangrove canopy	Herbivore (mangrove leaves and microalgae), detritus feeder (based on family Sesarmidae) (Ashton, 2002)
C. intermedius	MTL, on dead wood, rocks	Omnivore (based on Family Varunidae) (Devi et al., 2021)
V. litterata	LTL, shallow waters around the shore	Omnivore (Devi et al., 2021)
D. myctiroides	LTL to MTL, sandy substratum	Deposit feeder (Luschi et al., 1997)
S. proxima	MTL, sandy substratum	Deposit feeder (Luschi et al., 1997)
M. brevis	LTL to MTL, sandy tide puddles	Deposit feeder (Schuwerack et al., 2006)
M. parvimanus	LTL to MTL, sandy tide puddles	Deposit feeder (Schuwerack et al., 2006)
M. pacificus	LTL to MTL, sandy tide puddles	Deposit feeder (Schuwerack et al., 2006)
A. annulipes	LTL (preferably) to HTL, lower abundance at HTL, mix substratum	Herbivores (microalgae), deposit feeder (Zolkhiflee et al., 2021)
G. vocans	LTL to HTL, lower abundance at HTL mix substratum	Herbivores (microalgae), deposit feeder (Zolkhiflee et al., 2021)
O. ceratophthalmus	LTL, sandy substratum	Generalist feeder (Hughes, 1966)
T. alcocki	MTL of mangrove-dominated regions	Herbivores (microalgae), deposit feeder (Zolkhiflee et al., 2021)

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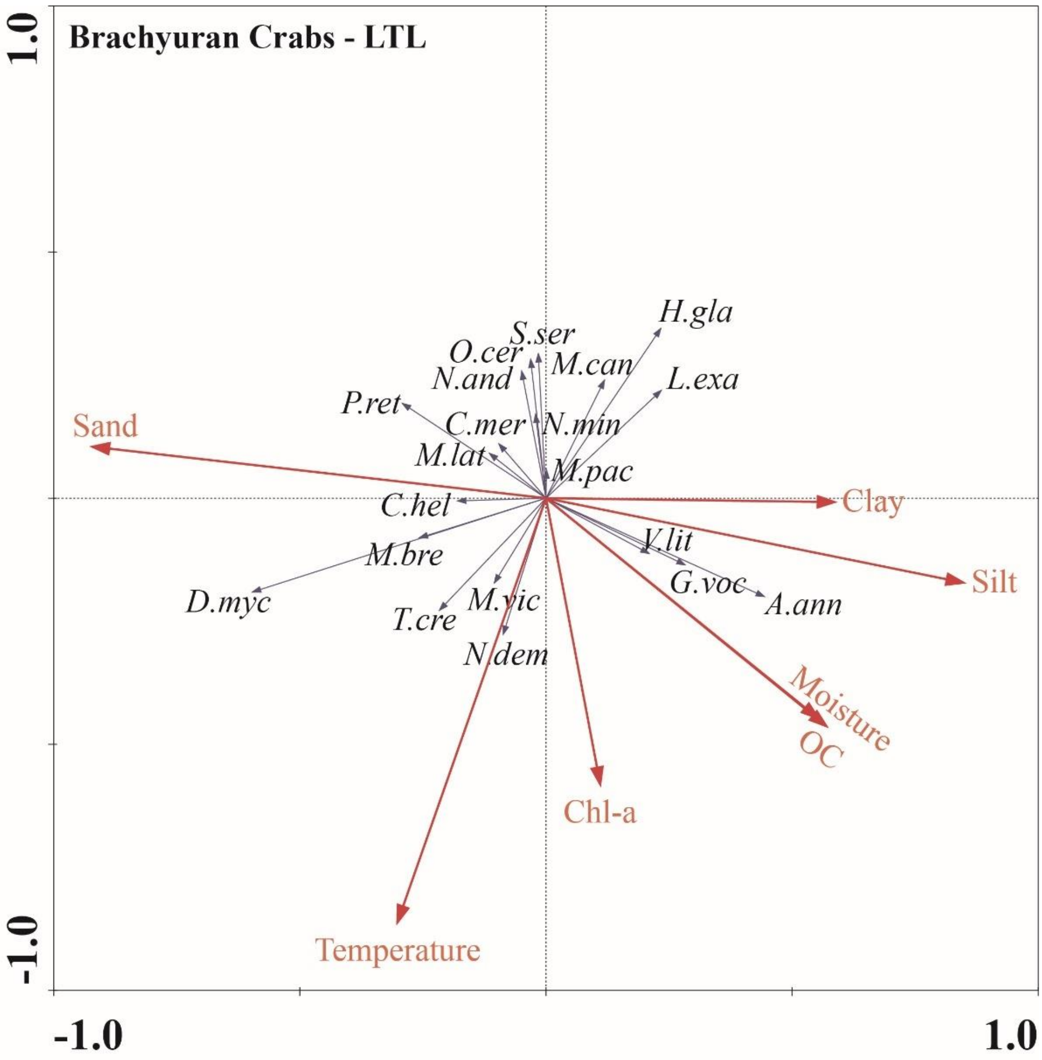

Figure 6.2. RDA bi-plot depicting the relationship between brachyuran crab species encountered at Low Tide Level (LTL) and associated substratum characteristics. **Abbreviations:** ***M.vic*** - *Matuta victor;* ***N.dem*** - *Neorhynchoplax demeloi;* ***C.her*** - *Charybdis helleri;* ***P.ret*** - *Portunus reticulatus;* ***S.ser*** - *Scylla serrata;* ***T.cre*** - *Thalamita crenata;* ***L.exa*** - *Leptodius exaratus;* ***H.gla*** - *Heteropanope glabra;* ***M.can*** - *Metopograpsus cannicci;* ***M.lat*** - *Metopograpsus latifrons;* ***C.mer*** - *Clistocoeloma merguiense;* ***N.and*** - *Nanosesarma andersonii;* ***N.min*** - *Nanosesarma minutum;* ***V.lit*** - *Varuna litterata;* ***D.myc*** - *Dotilla myctiroides;* ***M.bre*** - *Macrophthalmus brevis;* ***M.pac*** - *Macrophthalmus pacificus;* ***A.ann*** - *Austruca annulipes;* ***G.voc*** - *Gelasimus vocans;* ***O.cer*** - *Ocypode ceratophthalmus;* ***T.alc*** - *Tubuca alcocki;* **OC** – Organic Carbon.

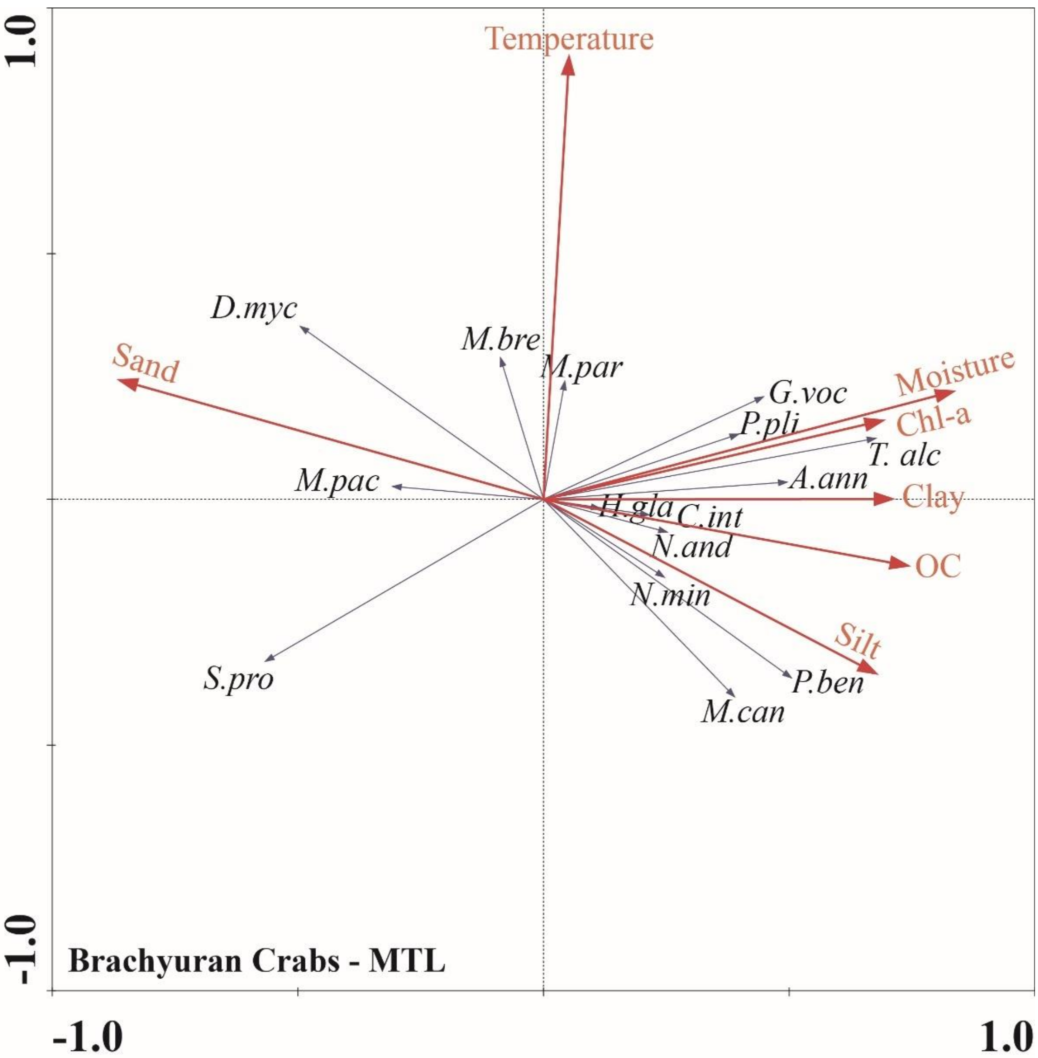

Figure 6.3. RDA bi-plot depicting the relationship between brachyuran crab species encountered at Mid Tide Level (MTL) and associated substratum characteristics. **Abbreviations:** ***H.gla*** - *Heteropanope glabra;* ***M.can*** - *Metopograpsus cannicci;* ***N.and*** - *Nanosesarma andersonii;* ***N.min*** - *Nanosesarma minutum;* ***P.ben*** - *Parasesarma bengalense;* ***P.pli*** - *Parasesarma plicatum;* ***C.int*** - *Chhapgarus intermedius;* ***D.myc*** - *Dotilla myctiroides;* ***S.pro*** - *Scopimera proxima;* ***M.bre*** - *Macrophthalmus brevis;* ***M.par*** - *Macrophthalmus parvimanus;* ***M.pac*** - *Macrophthalmus pacificus;* ***A.ann*** - *Austruca annulipes;* ***G.voc*** - *Gelasimus vocans;* ***T.alc*** - *Tubuca alcocki;* **OC –** Organic Carbon.

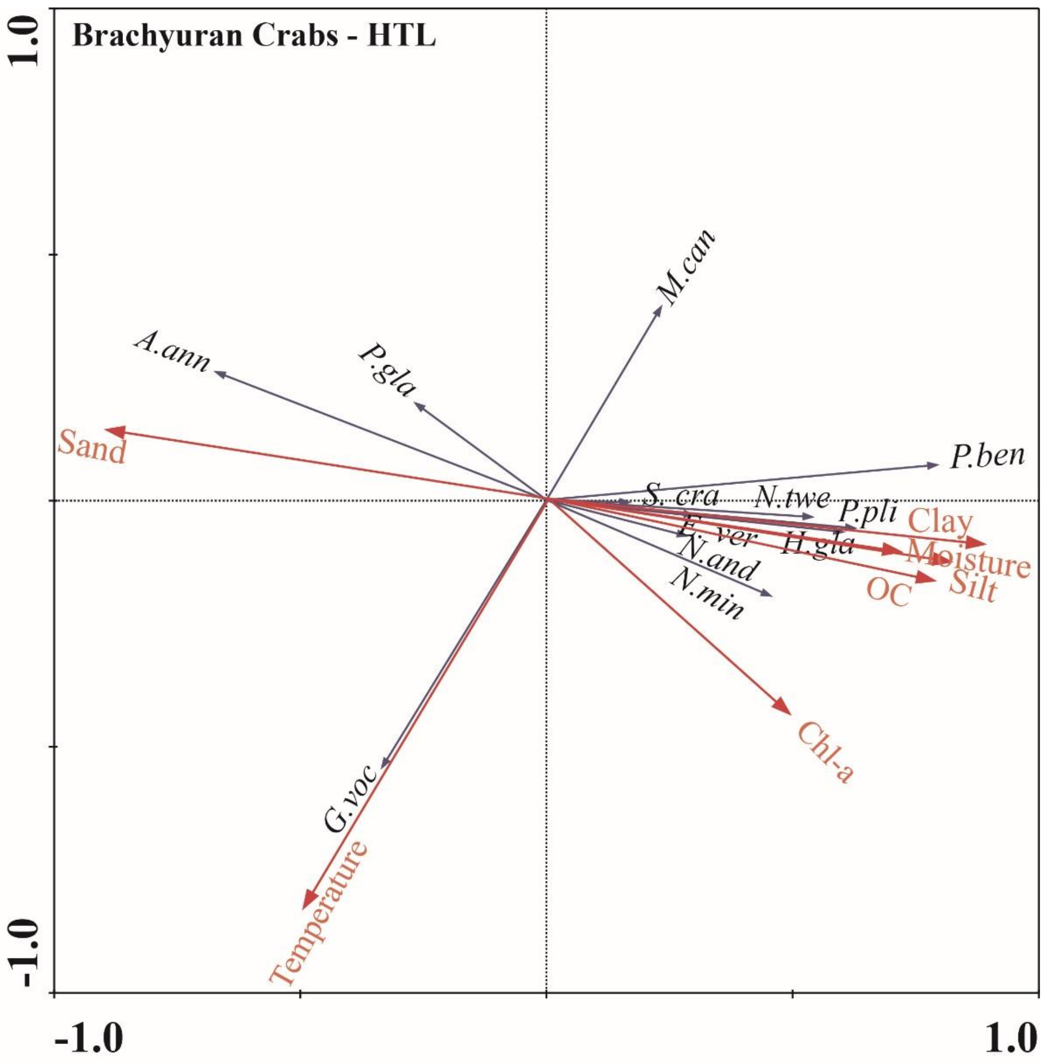

Figure 6.4. RDA bi-plot depicting the relationship between brachyuran crab species encountered at High Tide Level (HTL) and associated substratum characteristics. **Abbreviations:** ***H.gla*** - *Heteropanope glabra;* ***M.can*** - *Metopograpsus cannicci;* ***E.ver*** - *Episesarma versicolor;* ***N.and*** - *Nanosesarma andersonii;* ***N.min*** - *Nanosesarma minutum;* ***N.twe*** - *Nanosesarma tweediei;* ***P.ben*** - *Parasesarma bengalense;* ***P.pli*** - *Parasesarma plicatum;* ***P.gla*** - *Pseudosesarma glabrum;* ***S.cra*** - *Sarmatium crassum;* ***A.ann*** - *Austruca annulipes;* ***G.voc*** - *Gelasimus vocans;* **OC** – Organic Carbon.

6.2.4. Distribution of molluscs

A total of thirty-five species belonging to two classes (Gastropoda and Bivalvia), twenty-three families and thirty genera of molluscs were recorded during the present study. The highest number of species was recorded at station S2 (twenty-two), followed by C1 (twenty-one), S1 (nineteen), and C2 (fifteen). Species abundance data indicated lower abundance at MTL except at station S1 where in contrast maximum abundance was recorded at MTL.

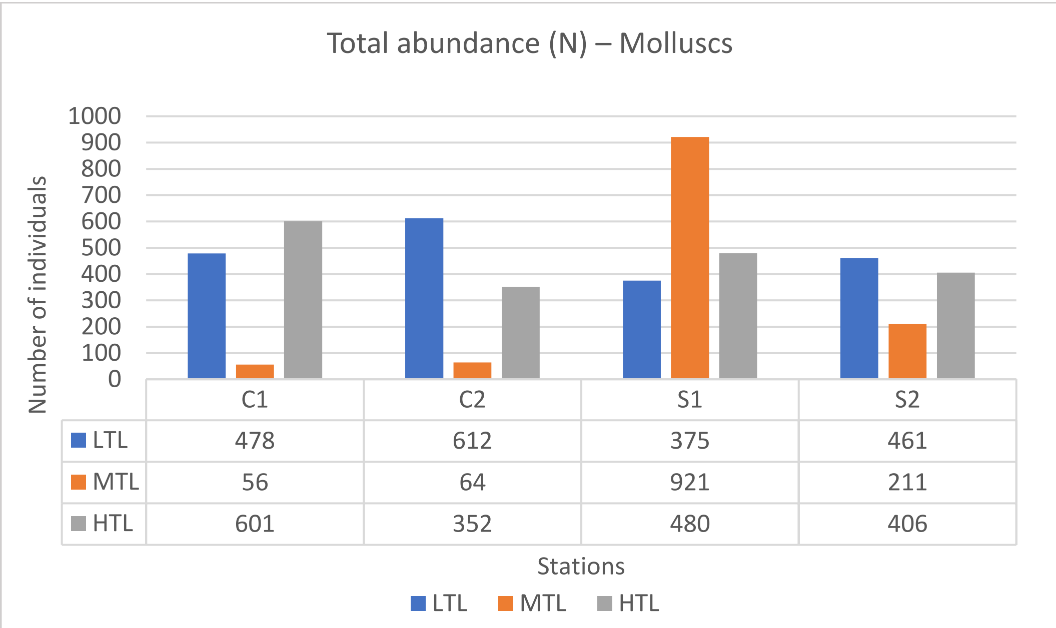

Figure 6.5. Total abundance of molluscs across four stations at LTL, MTL and HTL

A potamidid gastropod *P. cingulata* in general was the most dominant species in the entire study area, occupying different tidal levels at different stations. At stations C1, C2 and S1 it was dominant across all three tidal levels, although at stations C1 and C2 the total abundance was very low (Fig. 6.2). At station S2 *P. cingulata* was present only at HTL.

In addition to gastropod *P. cingulata,* bivalves, especially oyster colonies of *S. cuccullata* and *M. bilineata* contributed significantly to the total abundance at the LTL of station C1. At station S2, *S. cuccullata* and *M. bilineata* along with *I. isognomum* colonies were dominant at the LTL. The HTL saw the presence of a greater number of gastropods, although not a single species was dominant but together class Gastropoda dominated the HTL.

Table 6.4. Habitat preference and feeding habits of molluscs found at the four study stations. LTL – Low Tide Level; MTL- Mid Tide Level; HTL- High Tide Level.

Species	**Habitat preference**	**Feeding habit**
Class: Gastropoda		
C. oualaniense	LTL to MTL, sandy to silty substratum	Herbivore (microalgae) (Printrakoon et al., 2008)
N. violaceum	HTL, muddy substratum	Herbivore (microalgae) (Printrakoon et al., 2008)
C. batillariaeformis	MTL	Herbivore (microalgae) (based on family Cerithidae) (Printrakoon et al., 2008)
P. cingulata	LTL to HTL, mixed substratum	Herbivore (microalgae) (Printrakoon et al., 2008)
T. telescopium	HTL, muddy substratum	Herbivore (microalgae) (Printrakoon et al., 2008)
T. attenuata	MTL to HTL	Filter feeder (based on genus *Turritella*) (Allmon, 2011)
P. sulcatus	LTL	Herbivore (microalgae) (Houbrick 1987)
L. pallescens	HTL, mangrove trunks and leaves	Herbivore (microalgae) (Printrakoon et al., 2008)
L. carinifera	HTL, mangrove trunks and leaves	Herbivore (microalgae) (Printrakoon et al., 2008)
P. tigrina	LTL, sandy to silty substratum	Carnivore (Takeshita & Maekawa, 2020)
O. breviculum	HTL, muddy substratum, under mangrove canopy	Herbivore (microalgae) (Printrakoon et al., 2008), deposit feeder (Kamimura & Tsuchiya, 2004)
I. blanfordi	LTL, on oyster colonies	Carnivore (based on family Muricidae) (Tan, 2003)
I. lacera	HTL, on pneumatophores	Carnivore (based on family Muricidae) (Tan, 2003)

N. fuscus	MTL	Deposit feeder, herbivore, scavenger (Lucena et al., 2012)
N. jacksonianus	MTL, sandy substratum	Deposit feeder, herbivore, scavenger (Lucena et al., 2012)
E. bangtawaensis	HTL, mangrove tide puddles	Herbivore (algae) (Bhave et al., 2022)
B. leachii	LTL, shallow water	Herbivore (algae) (Ramos et al., 1995)
C. nucleus	HTL, mangrove trunks and floor	Herbivore (algae) (based on genus *Cassidula*) (Printrakoon et al., 2008)
P. martensi	HTL, mangrove trunks and floor	Herbivore (microalgae) (based on family Onchidiidae) (Printrakoon et al., 2008)
Class: Bivalvia		
B. pharaonis	LTL to HTL, in association with oyster colonies	Filter feeder (Sarà et al., 2008)
P. viridis	LTL, between oyster colonies	Filter feeder (Soon & Ransangan, 2014)
T. rhombea	MTL	Filter feeder (de la Ballina et al., 2022)
M. bilineata	LTL to MTL	Filter feeder (Thangavelu, 1988)
S. cucullata	LTL to HTL, preferably at LTL	Filter feeder (Printrakoon et al., 2008)
I. isognomum	LTL sandy to silty substratum	Filter feeder (Benthotage et al., 2020)
P. placenta	LTL, sandy substratum	Filter feeder (Rustia et al., 2023)
A. ala	LTL, sandy substratum	Filter feeder (based on family Tellinidae) (Printrakoon et al., 2008)
Q. gargadia	LTL, sandy substratum	Filter feeder (based on family Tellinidae) (Printrakoon et al., 2008)
H. diphos	LTL, sandy substratum	Filter feeder (Chou et al., 2005)
P. katiawarensis	LTL, sandy substratum	Filter feeder (based on family Veneridae) (Printrakoon et al., 2008)

M. aurora	LTL to MTL, sandy substratum	Filter feeder (based on family Veneridae) (Printrakoon et al., 2008)
M. casta	LTL, sandy substratum	Filter feeder (based on family Veneridae) (Printrakoon et al., 2008)
M. opima	LTL to MTL, sandy substratum	Filter feeder (based on family Veneridae) (Printrakoon et al., 2008)
M. recens	LTL to MTL, sandy substratum	Filter feeder (based on family Veneridae) (Printrakoon et al., 2008)
G. bengalensis	HTL, among mangrove vegetation	Filter feeder (based on genus *Geloina*) (Printrakoon et al., 2008)

RDA biplot at LTL indicated a positive correlation between sand fraction with all recorded bivalve species, with a marginal positive influence from water quality parameters such as salinity, SPM, Chl-*a* and temperature (Fig. 6.6). Sand fraction and nitrate from the water column ($p < 0.01$) were statistically significant in influencing the distribution of molluscs at LTL. Chl-*a* from sediment which showed a negative correlation with most of the bivalves was also statistically significant ($p < 0.05$) in the distribution of molluscs at LTL.

At MTL, despite low overall abundance, *P. cingulata,* the most abundant species among the few present, exhibited a strong positive correlation with Chl-*a* from sediment. *N. jacksonianus* and *C.oualaensis* found at station S2, displayed a strong positive correlation with sand fraction and a moderate correlation with temperature (Fig. 6.7). Chl-*a* from sediment and temperature were statistically significant in the distribution of species ($p < 0.05$). Silt fraction, negatively correlated with most of the species was also found to be statistically significant in the distribution of molluscs ($p < 0.05$) at MTL.

RDA biplot at HTL indicated a positive correlation of most gastropods with clay and silt fraction, as well as moisture and organic carbon content (Fig. 6.8). Sand fraction ($p < 0.01$), along with temperature, moisture and organic carbon ($p < 0.05$) of the sediment were statistically significant on the distribution of molluscs at HTL.

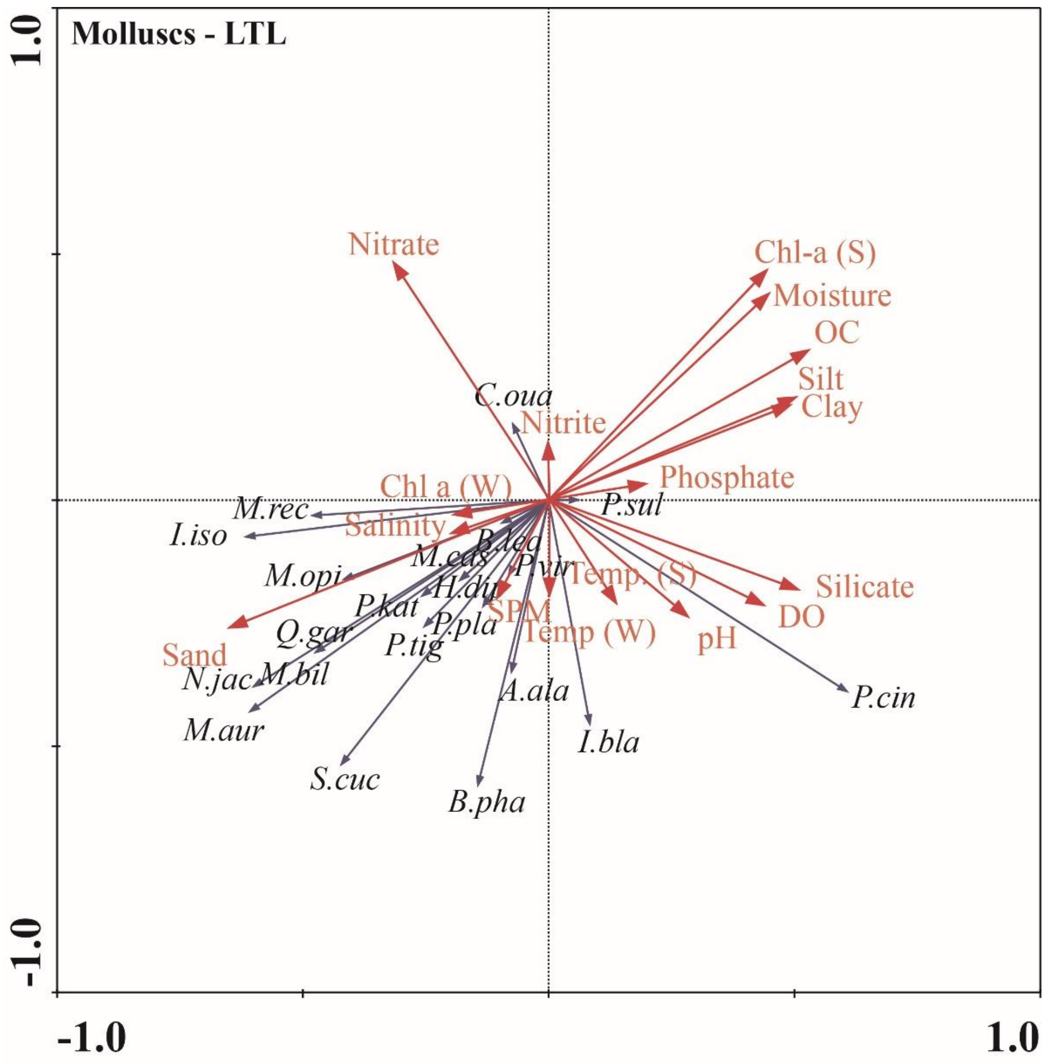

Figure 6.6. RDA bi-plot depicting the relationship between mollusc species encountered at Low Tide Level (LTL) and associated substratum characteristics. **Abbreviations:** ***C.oua*** - *Clithon oualaniense;* ***P.cin*** - *Pirenella cingulata;* ***P.sul*** - *Planaxis sulcatus;* ***I.bla*** - *Indothais blanfordi;* ***B.lea*** - *Bursatella leachii;* ***B.pha*** - *Brachidontes pharaonis;* ***P.vir*** - *Perna viridis;* ***M.bil*** - *Magallana bilineata;* ***S.cuc*** - *Saccostrea cucullata;* ***I.iso*** - *Isognomon isognomum;* ***P.pla*** - *Placuna placenta;* ***A.ala*** - *Alaona ala;* ***Q.gar*** - *Quadrans gargadia;* ***H.dip*** -*Hiatula diphos;* ***P.kat*** - *Pelecyora katiawarensis;* ***M.aur*** - *Meretrix aurora;* ***M.cas*** - *Meretrix casta;* ***M.opi*** - *Marcia opima;* ***M.rec*** - *Marcia recens;* **OC** – Organic Carbon.

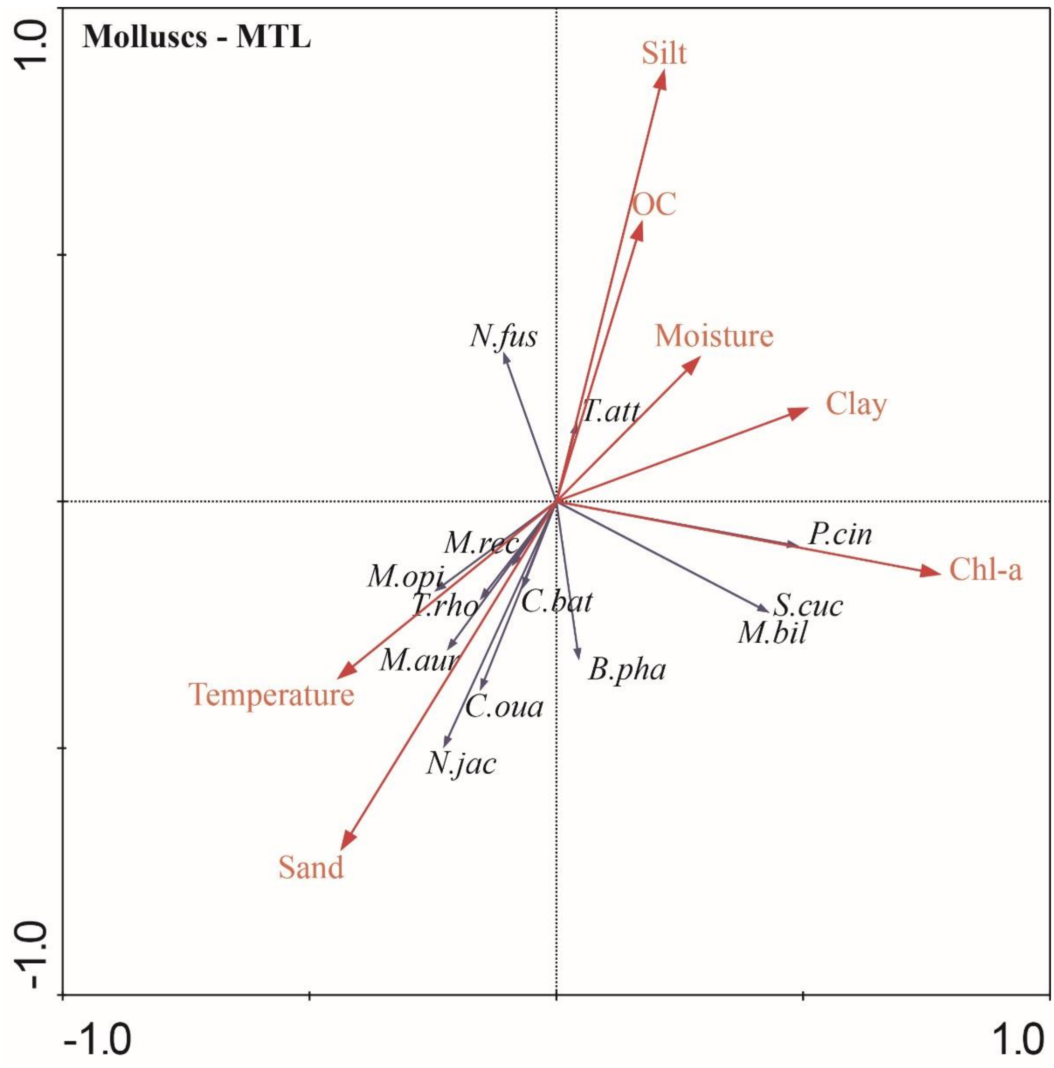

Figure 6.7. RDA bi-plot depicting the relationship between mollusc species encountered at Mid Tide Level (MTL) and associated substratum characteristics. **Abbreviations:** ***C.oua*** - *Clithon oualaniense;* ***C.bat*** - *Clypeomorus batillariaeformis;* ***P.cin*** - *Pirenella cingulata;* ***T.att*** - *Turritella attenuata;* ***N.fus*** - *Nassarius fuscus;* ***N.jac*** - *Nassarius jacksonianus;* ***B.pha*** - *Brachidontes pharaonis;* ***T.rho*** - *Tegillarca rhombea;* ***M.bil*** - *Magallana bilineata;* ***S.cuc*** - *Saccostrea cucullata;* ***M.aur*** - *Meretrix aurora;* ***M.opi*** - *Marcia opima;* ***M.rec*** - *Marcia recens;* **OC** – Organic Carbon.

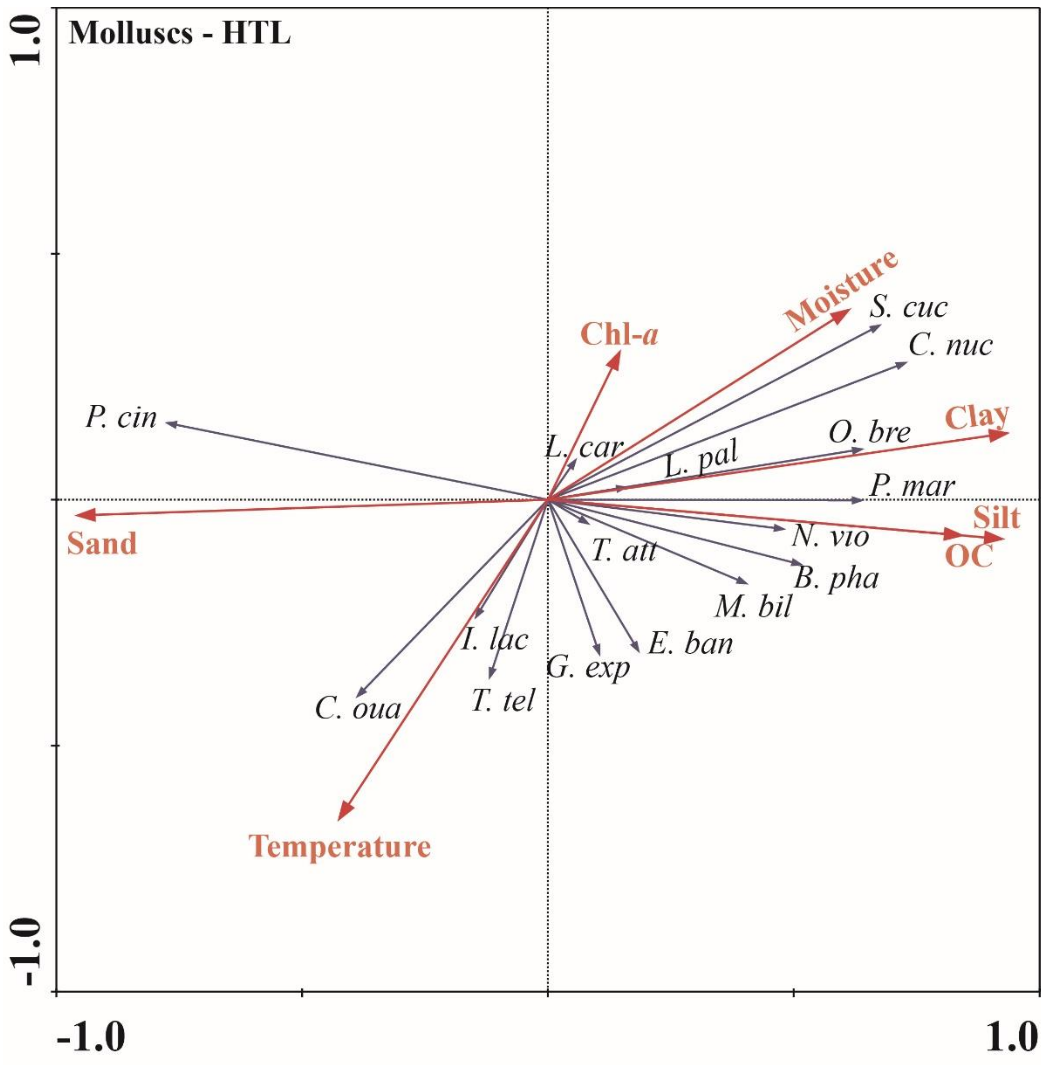

Figure 6.8. RDA bi-plot depicting the relationship between mollusc species encountered at High Tide Level (HTL) and associated substratum characteristics. **Abbreviations:** ***C.oua*** - *Clithon oualaniense;* ***N.vio*** - *Neripteron violaceum* ***P.cin*** - *Pirenella cingulata;* ***T.tel*** - *Telescopium telescopium;* ***T.att*** - *Turritella attenuata;* ***L.pal*** - *Littoraria pallescens;* ***L.car*** - *Littoraria carinifera;* ***O.bre*** - *Optediceros breviculum;* ***I.lac*** - *Indothais lacera;* ***E.ban*** - *Elysia bangtawaensis;* ***C.nuc*** - *Cassidula nucleus;* ***P.mar*** - *Platevindex cf martensi;* ***B.pha*** - *Brachidontes pharaonis;* ***M.bil*** - *Magallana bilineata;* ***S.cuc*** - *Saccostrea cucullata;* ***G. ben*** - *Geloina bengalensis;* **OC –** Organic Carbon.

6.3. Discussion

The distribution of brachyuran crabs from LTL to HTL exhibited high abundance at MTL except at station C2 where although the abundance was not maximum but was substantially high. This high abundance was merely due to the dominance of the fiddler crabs of the family Ocypodidae – *A. annulipes, G. vocans* and *T. alcocki* or sand bubbler crabs of the family Dotillidae – *D. myctiroides* and *S. proxima* at LTL and MTL all four stations. The habitat at these two tidal levels was characterised by comparatively high temperatures, higher sand fraction and lower OC coupled with frequent tidal inundation (in comparison to HTL). Fiddler crabs and the sand bubbler crabs can not only survive but achieve high densities in these environments, owing to their morphological, physiological and behavioural adaptations.

Morphologically both fiddler (Colpo & Fransozo, 2013) and dotillid crabs (Sankarankutty, 1961a; Silas & Sankarankutty, 1967) bear a high density of spoon-tipped setae on the second maxillipeds of the mouth appendages which creates an efficient tool to sort and obtain organic matter from the coarser sediment grains. The dotillid crabs display a physiological adaptation wherein they bear a special tympanic membrane on their legs and abdomen, capable of aerial respiration and osmoregulation (Matsumasa et al., 2001). The burrowing activity is pronounced in crabs of both families, however, *D. myctiroides* is known to build unique igloo-shaped burrows in semi-fluid, unstable sand and vertical burrows in well-drained and firm sand. These igloos enclose a small quantity of air together with the crab facilitating their reach below the water level thus helping them overcome high temperatures and frequent tidal inundation (Takeda et al., 1996; Padate et al., 2015). Moreover, the bare areas favour the deposit-feeding, burrowing behaviour and visual communication characteristics of these species (Vermeiren & Sheaves, 2015)

The HTL was primarily occupied by crabs of the family Sesarmidae – *P. bengalense*, *P. plicatum* (two dominant species) and Grapsidae – *M. cannicci* at stations C2 and S1. In contrast, at stations C1 and S2 the dominance of fiddler crabs continued, with *A. annulipes* being dominant at station C1 and *G. vocans* at station S2.

The dominance of the families Sesarmidae and Grapsidae at stations C2 and S1 can be attributed to favourable environmental conditions. These conditions include comparatively lower temperatures due to the shade provided by the mangrove canopy, high organic matter, high moisture content, and silty-clayey sediments enriched by mangrove leaf litter. The high

Chl-*a* content at these stations indicates a greater abundance of microphytobenthos, which, along with mangrove leaf litter and propagules, provides a rich food source for sesarmid crabs, which are predominantly herbivorous. Moreover, mangrove roots, trunks, and foliage offer shelter to these crabs from predators and the incoming tide (Geist et al., 2012; Dissanayake & Chandrasekara, 2014). In addition, sesarmids are generally cryptic, agile, excellent at camouflage, and some are nocturnal to avoid predators and high daytime temperatures. These adaptations make it difficult to capture them, which may result in their abundance being underestimated.

The distribution of molluscs from LTL to HTL showed the lowest abundance at MTL, except at station S1, where the maximum abundance was observed at MTL. The lower abundance at MTL is likely linked to inter-species competition, particularly given the high abundance of brachyuran crabs at this tidal level (Cannicci et al., 2018). However, at station S1, the higher abundance at MTL can be attributed to the presence of the potamidid gastropod *P. cingulata*, which was found at all three tidal levels.

P. cingulata was present at all four studied stations, with varying dominance across the three tidal levels. A study by Rao and Sukumar (1981) on substrate preference of *P. cingulata* revealed that the species prefers a mixed substratum, avoiding pure sandy and clayey substrates. Additionally, *P. cingulata* is an obligate deposit feeder, consuming macroalgae, bacteria, and diatoms (Table 6.4) (Kamimura & Tsuchiya, 2004). Therefore, the presence of a favourable substratum, along with sufficient food, plays a crucial role in the distribution of this species.

The distribution of molluscs further suggested that the LTL was predominantly inhabited by bivalves, while the (HTL was mainly dominated by gastropods. The filter-feeding nature of bivalves coupled with their gill breathing and preference for sandy substratum, restricts them to the narrow LTL zone (Table 6.4) (Kabir et al., 2014). *G. bengalensis* was the only burrowing bivalve species found in the muddy substratum under the mangrove trees. Bivalves of the genus *Geloina* can withstand prolonged dry spells by utilizing the interstitial water contained in the sediments of their burrows, filtering it through their mantle cavity, and also respiring through their mantle margin. This extreme adaptation allows them to survive the harsh conditions of mangrove habitats (Morton, 1976). On the other hand, gastropods preferred the HTL, where their mantle cavity is modified into a lung with reduced gills. These gastropods are herbivores (feeding on microalgae) and also detritivores (Table 6.4) (Kabir et al., 2014)

The RDA bi-plots highlighted the correlation between brachyuran crabs and molluscs with substratum characteristics. Sediment texture, temperature, Chl-*a,* organic carbon and moisture content played a significant role in their distribution. These findings align with the observations made in mangrove habitats of Kochi, India (Devi et al., 2021), the Philippines (Bandibas & Hilomen, 2016), the Persian Gulf (Hajializadeh et al., 2022) and French Guiana, South America (Aschenbroich et al., 2016).

Among these factors, sediment texture, specifically the sand fraction, played the most crucial role in the distribution of both brachyuran crabs and molluscs. The grain size of sediment governs the crawling and burrowing activities of benthic organisms (Devi et al., 2021), and its suitability influences their zonation (Joel et al., 1986). For example, *D. myctiroides* and *S. proxima* were found in sediments with a higher sand fraction, while fiddler crabs showed a preference for mixed substrates, and sesarmid crabs preferred muddy substrates. Similarly, bivalves showed an affinity for sandy substrates, whereas gastropods favoured muddy substrates.

Temperature is another significant factor that affects the reproduction system, neurosecretory system and survival rates of species (Saher & Qureshi, 2012; Colpo & Lopez-Greco, 2017). Fiddler crabs and ocypodid species are known to tolerate higher temperatures (Zolkhiflee et al., 2021), while the sesarmids prefer lower temperatures (Nobbs & Blamires, 2015).

Furthermore, the presence of Chl-*a* and organic carbon indicates the availability food sources for the herbivores that feed on microalgae, and detritivores that consume organic matter. Moisture content reflects the availability of water and along with that is also an indicator of oxygen in the sediment (Devi et al., 2021). Moist substrates typically indicate higher oxygen content, which is utilized by brachyuran crabs through setae at the bases of their legs (Ravichandran & Kannupandi, 2007).

SUMMARY

1. The present study revealed a total of thirty brachyuran crab species belonging to twenty-four genera from eleven families. The highlight of the study was eleven new records which included three species namely *Metopograpsus cannicci, Nanosesarma tweediei* and *Sarmatium crassum* new to India, one species namely *Episesarma versicolor* new to the west coast of India, and seven species namely *Macrophthalmus (Macrophthalmus) brevis, Macrophthalmus (Macrophthalmus) parvimanus, Metopograpsus latifrons, Parasesarma bengalense, Portunus reticulatus, Pseudosesarma glabrum*, and *Tubuca alcocki* new to the state of Goa.

2. A total of thirty-five molluscan species belonging to thirty genera from two classes, thirteen orders and twenty-three families were recorded during the present study. The highlight of the study was thirteen first records from Goa including seven gastropods namely *Littoraria carinifera, Littoraria pallescens, Nassarius fuscus, Nassarius jacksonianus, Optediceros breviculum, Cassidula nucleus* and *Platevindex* cf *martensi* and six bivalves namely *Brachidontes pharaonis, Isognomon isognomum, Quadrans gargadia, Hiatula diphos, Meretrix aurora* and *Pelecyora katiawarensis*.

3. Statistical analyses of variations in species diversity, abundance and biomass revealed significant variations between the sampling stations highlighting the importance of mangrove vegetation in their distribution.

4. Notable seasonal variation in biomass was observed for brachyuran crabs with maximum biomass during the pre-monsoon due to the migration and breeding of certain species of brachyura. Significantly lower abundance for molluscs observed during the monsoon was attributed to decrease in salinity with the influx of freshwater.

5. Quantitative analyses of faunal abundance and biomass revealed the dominance of ocypodids (fiddlers) and dotillids among brachyuran crabs, and a potamidid gastropod *P. cingulata* and oysters among the molluscs.

6. Distribution of brachyuran crabs from LTL and MTL exhibited dominance of ocypodid (fiddler) or dotillid crabs at all four stations. The HTL was primarily occupied by sesarmids and a grapsid (at stations C2 and S1) owing to the presence of dense mangrove canopy.

7. The distribution of mollusc species at different tidal levels revealed that the LTL was mainly inhabited by bivalves, while the HTL was dominated by gastropods due to variation in substratum characteristics.

8. Analysis of the habitat characteristics of brachyuran crabs and molluscs along the tidal gradient revealed that the substratum characteristics such as grain size, temperature, moisture, organic carbon and chlorophyll-*a* content play an important role in their distribution.

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APPENDIX

List of publications

Published manuscript

1. **Bhat, M.,** Rivonker, C.U, Patel, K., & Trivedi, J. N. (2021). First confirmed record of *Sarmatium crassum* Dana, 1851 (Crustacea: Decapoda: Sesarmidae) from India. *Nauplius. 29: e2021042,* 1-5.

2. **Bhat, M.,** Trivedi, J. N. & Rivonker, C. U. (2021). An annotated checklist of marine brachyuran crabs (Crustacea, Decapoda, Brachyura) from Goa, west coast of India with ten new records. In: *Proceedings of the Marine Biology Research Symposium – MBRS 2021* organized by Satyabhama Institute of Science and Technology, Chennai in association with ICAR-National Bureau of Fish Genetic Resources, Lucknow, 26-36.

Conferences

1. **Bhat, M.,** Trivedi, J. N., & Rivonker, C. U. (2021, 26 - 30 July). *An annotated checklist of marine brachyuran crabs (Crustacea, Decapoda, Brachyura) from Goa, west coast of India with ten new records* [Paper presentation]. Marine Biology Research Symposium – MBRS 2021 organized by Satyabhama Institute of Science and Technology, Chennai in association with ICAR-National Bureau of Fish Genetic Resources, Lucknow.

2. **Bhat, M.,** Padate, V. P., Carol, A. A., & Rivonker, C. U. (2017, 26 - 27 July). *Studies on the distribution of fiddler crabs from selected Mangrove ecosystems of Goa* [Paper presentation]. Silver Jubilee National Conference on Mangrove Ecosystem organized by Mangrove Society of India in association with CSIR- National Institute of Oceanography.

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SHORT COMMUNICATION

First confirmed record of *Sarmatium crassum* Dana, 1851 (Crustacea: Decapoda: Sesarmidae) from India

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ABSTRACT

The present paper confirms the occurrence of the sesarmid crab *Sarmatium crassum* Dana, 1851 in India. The species has so far been recorded from Samoa, Tahiti, New Caledonia, eastern Australia, Philippines, Madagascar, South Africa, Tanzania, and Eritrea (Red Sea). This is the first record of the species from India.

KEYWORDS

Brachyura, Goa State, mangrove, new record, West coast of India

The taxonomy of the genus *Sarmatium* Dana, 1851, has a very confused history and has been revised on several occasions (Tesch, 1917; Serène and Soh, 1970; 1971; Davie, 1992). The genus *Sarmatium* is closely related to *Neosarmatium* Serène and Soh, 1970 and *Metagrapsus* H. Milne Edwards, 1853 but can be differentiated on the basis of the following characters: ocular peduncle swollen basally, cornea constricted and reduced (*versus* ocular peduncle not swollen basally, cornea bulging and prominent in *Neosarmatium* and *Metagrapsus*; cf. Serène and Soh, 1970; Davie, 1992). *Sarmatium* is currently represented by five species which are distributed in the Indo-Pacific region (Davie, 1992): *Sarmatium crassum* Dana, 1851,

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the type species; *Sarmatium germaini* (A. Milne-Edwards, 1869); *Sarmatium striaticarpus* Davie, 1992; *Sarmatium hegerli* Davie, 1992; and *Sarmatium unidentatus* Davie, 1992. Alcock (1900) recorded *S. crassum* from India on the basis of a single female specimen from Nicobar Island. Davie (1992) commented that this record from India by Alcock (1900) is doubtful, as the diagnostic characters of *S. crassum* are present on male individuals only; the identification of a female specimen may not be precise. Since the specimen was not traceable in the crustacean collection of the Zoological Survey of India, Kolkata, we could not confirm the identity of the *S. crassum* female specimen collected by Alcock (1900). In the present study, we confirm the occurrence of *S. crassum* from mainland India on the basis of a single male specimen collected from Goa State, on the western coast of India.

Only one male specimen was collected from mangroves of the Chapora estuary in Goa. The specimen was cleaned, photographed and preserved in 90 % ethanol, and deposited in the Zoological Reference Collection (LFSc.ZRC), Department of Life Sciences, Hemchandracharya North Gujarat University, Patan, Gujarat, India. Abbreviations: CW, carapace width; CL, carapace length; G1, male first gonopod; coll., collector. Morphological terminology used in this article follows Davie (1992).

Taxonomy

Order Decapoda Latreille, 1802

Superfamily Grapsoidea MacLeay, 1838

Family Sesarmidae Dana, 1851

Genus *Sarmatium* Dana, 1851

***Sarmatium crassum* Dana, 1851**
(Fig. 1)

Sarmatium crassum Dana, 1851: 251; H. Milne Edwards, 1853: 189; De Man, 1887: 660; Barnard, 1955: 28, fig. 9; Crosnier, 1965: 74, figs. 121–124, pl. 5, fig. 1; Serène and Soh, 1970: 397, 405 (list); Fishelson, 1971: 128, 130 (list); Davie, 1992: 81, figs. 1A, 2A–C; Ng *et al.*, 2008: 223 (list).

Sarmatium crassum [doubtful identification, not confirmed]: Nobili, 1899: 505 (list); Alcock, 1900: 426; Tesch, 1917: 215; Dev Roy and Nandi, 2012: 216 (list); Trivedi *et al.*, 2018: 73 (list).

not *Sarmatium crassum*: Serène and Soh, 1970: pl. 4C, D; 1971; 237, fig. 2, pl. 2 [= *S. striaticarpus*]

Material Examined. One male, CL 9.6 mm; CW: 10.6 mm, LFSc.ZRC–155, India, Goa State, Chapora estuary (15º37.953'N 73º45.765'E), mangrove habitat, 12 July 2016, coll. M. Bhat.

Diagnosis (modified from Davie, 1992). Carapace (Fig. 1a) slightly broader than long, glabrous, deeply vaulted, punctate with setae arranged sparsely on branchial lines. Regions moderately defined with mesogastric distinct. Anterolateral margins regularly convex with 2 blunt teeth behind exorbital angle. Front bilobed. Branchial ridges prominent forming series of short broken granular striations. Inner orbital tooth well developed; ocular peduncle swollen basally, cornea constricted and reduced. Chelipeds (Fig. 1a) subequal, large, robust. Merus posterior border with minutely granular striations; distinct subdistal spine; carpus with small spine at inner angle. Palm upper surface with series of transverse grooves separating swollen ridges (Fig. 1d), distal margin of ridges granular with row of 8 pectinated comb-like teeth. Dactylus (Fig. 1c) dorsal surface of males bearing 4 large, broad, chitinous tubercles proximally; first proximal tooth placed distally from articulation. Male pleon relatively narrow, third somite widest, telson subequal to the sixth somite in length, longer than wide. G1 (Fig. 1e) moderately stout; slightly curved, dorsal surface of shaft flattened with poorly developed protuberance on the distal end; apical process (Fig. 1f) corneous; strongly produced; straight.

Remarks. The specimen examined in the present study agrees with the description given by Dana (1851) and Davie (1992) *viz.*, the cheliped carpus upper surface having a large patch of tiny, flattened, squamous granules situated distally behind articulation with the palm (Fig. 1d); Palm upper surface with subparallel ridges and grooves. Cheliped dactylus with first proximal tooth placed distally from articulation.

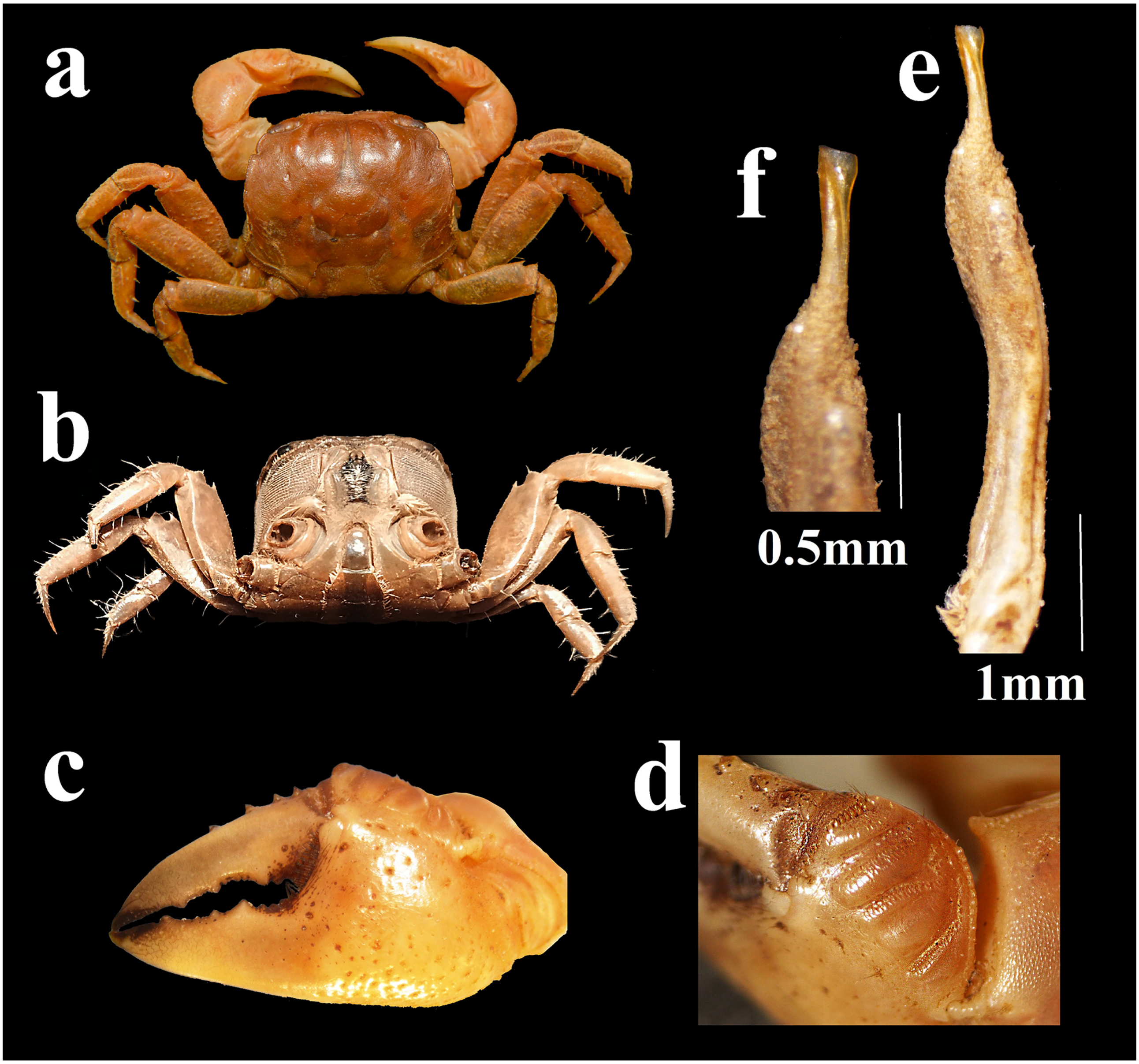

Figure 1. *Sarmatium crassum* Dana, 1851, male (LFSc.ZRC– 155), CL 9.6 mm; CW: 10.6 mm: **a**, dorsal habitus; **b**, ventral habitus; **c**, left chela, outer view; **d**, upper surface of palm of left chela; **e**, left G1, dorsal view; **f**, distal tip of G1, dorsal view.

Sarmatium crassum resembles *S. striaticarpus* in having the carapace broader than long (1.1 times), deeply vaulted; surface smooth, shiny, punctuate, chelipeds subequal, large and robust, ambulatory legs of medium size and compressed, G1 stout and slightly curved, dorsal surface of shaft flattened and completely calcified. However, *S. crassum* can be differentiated from *S. striaticarpus* based on the following characters: all the ridges on the upper surface of the palm subparallel (Fig. 1d) (*versus* the proximal-most corrugated ridge is separated from the next broad groove by a triangular space in *S. striaticarpus*, cf. Davie, 1992: fig. 4C), the first proximal tooth on the dactyl of the cheliped placed somewhat distally from the articulation (Fig. 1c) (*versus* the first proximal tooth on the dactyl of the cheliped placed almost on the very edge of the proximal end in *S. striaticarpus*, cf. Davie, 1992: fig. 4B) and G1 with poorly developed protuberance located at the distal end of the shaft (Fig. 1e, f) (*versus* G1 with well developed protuberance in *S. striaticarpus*, cf. Davie, 1992: fig. 3E).

Sarmatium crassum has thus far been reported from the type locality, Samoa (Dana, 1851; 1852); South Africa (Barnard, 1955); Madagascar (Crosnier, 1965); Tanzania (Hartnoll, 1975); Eritrean coast of the Red Sea (Fishelson, 1971; Holthuis, 1977); India (present study); Philippines (Davie, 1992); Australia (McNeill, 1968; Davie, 1992); New Caledonia (Serène, 1973), and Tahiti (Davie, 1992). The records of *S. crassum* by Nobili (1899) and Tesch (1917) are questionable due to the following reasons: Nobili (1899) did not provide the diagnostic characters of the specimen which was collected from Sumatra and hence it could be attributable to *S. striaticarpus*. Tesch (1917) reported the species from the 'Pacific' only on the basis of a single female specimen lacking diagnostic characters and hence the record becomes questionable (Davie, 1992).

In India, this species was recorded from the Nicobar Islands by Alcock (1900) on the basis of a single female specimen (CL 8 mm, CW 9 mm) (the specimen is not traceable in the Zoological Survey of India, Kolkata where it was deposited). This record made by Alcock (1900) also appeared in the brachyuran crab list of the Andaman and Nicobar Islands and India prepared by Dev Roy and Nandi (2012) and Trivedi *et al.* (2018), respectively. But according to Davie (1992), the record of *S. crassum* from Nicobar Islands is doubtful because the main diagnostic character of the species, such as the presence of distinct ridges and grooves on the upper surface of the palm of chelipeds, are only present in males and not in females and therefore cannot consider it as a confirmed record. In the present study, one male specimen was collected and examined, and the distinct taxonomic characters are illustrated and described to elucidate the first confirmed report of *S. crassum* from India.

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An annotated checklist of marine brachyuran crabs (Crustacea, Decapoda, Brachyura) from Goa, west coast of India with ten new records

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Abstract

An annotated checklist of marine brachyuran crabs occurring in coastal areas of Goa is compiled based on published accessible literature and specimens collected based on the survey carried out from the coastal areas of Chapora, Mandovi and Sal estuaries between 2016-2020. A total of 103 species belonging to 66 genera and 25 families are recorded so far. Out of the 25 families recorded, family Portunidae showed the highest species diversity (21 species, 7 genera) followed by Sesarmidae (15 species, 8 genera), Xanthidae (9 species, 7 genera). In the present study, we report ten new species: *Portunus reticulatus* (Herbst, 1799), *Metopograpsus latifrons* (White, 1847), *Clistocoeloma lanatum* (Alcock, 1900), *Neosarmatium malabaricum* (Henderson, 1893), *Parasesarma bengalense* (Davie 2003), *Perisesarma dussumieri* (H. Milne Edwards, 1853), *Pseudosesarma glabrum* Ng, Rani and Bijoy Nandan, 2017, *Macrophthalmus (Macrophthalmus) brevis* (Herbst, 1804), *Macrophthalmus (Macrophthalmus) parvimanus* Guérin, 1834 and *Tubuca alcocki* Shih, Chan and Ng, 2018, which are first time reported from the present study area.

Keywords: Brachyuran crabs, Checklist, Goa, West coast of India

Introduction

Goa, the smallest state of India has a coastline of 151 km and is traversed by nine tidal rivers (Kumar *et al*., 2006; Fernandes *et al*., 2018). The infraorder Brachyura (true crabs) is the most species-rich decapoda group, with 93 families and over 7000 species worldwide and 62 families and over 910 species in India (Ng *et al.*, 2008; Trivedi *et al*., 2018). Although the marine brachyuran crab fauna of India has been studied since the mid-1700s (Trivedi *et al.*, 2018), the first publication from Goa was only in the early 1900s by Kemp (1917, 1919a, 1919b) who reported seven species from three families. Later, with the establishment of the National Institute of Oceanography (NIO) in Goa, studies on the edible crab fauna and benthic macrofauna were carried out by Ansari and Harkantra (1975) and Parulekar *et al*. (1980). However, the major and most significant contribution was by the scientists from the Zoological Survey of India (ZSI) who carried out preliminary surveys in the early 2000s, data of which was published subsequently in later years as Dev Roy and Nandi (2005); Dev Roy and Bhadra (2008); Dev Roy (2008) and Dev Roy (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. Recently published studies provide a much better insight on the distribution of brachyuran crabs from Goa (Padate *et al*., 2010; Padate, 2010; Joshi *et al*., 2011; Padate *et al*., 2013; Hegde *et al*., 2013; Hegde, 2013; Velip and Rivonker, 2014; Kaullysing *et al*., 2015; Padate *et al*., 2015; Vijaylaxmi *et al*., 2016; Velip, 2017; Komarpant *et al*., 2018; Vijaylaxmi, 2020; Bhat and Trivedi, 2021; Bhat *et al*., in press). Considering the significant amount of publications in this field in the last 20 years, the present study aims to prepare a comprehensive checklist of the marine brachyuran crab fauna of Goa which will provide baseline information for future research.

Materials and Methods

The present study is a compilation of the information gathered by authors based on the review of all the accessible published documents regarding brachyuran crab diversity of the Goa state. Several field visits were carried out by the first author to Chapora and Mandovi estuary and Sal estuary in the North and South Goa district respectively from 2016 to 2020. All the collected specimens were washed properly, identified, photographed, preserved in 90% ethanol and deposited in the Zoological Reference Collection (LFSc.ZRC), Department of Life Sciences, Hemchandracharya North Gujarat University, Patan, Gujarat and in the collection of School of Earth, Ocean and Atmospheric Sciences, Goa University, Goa state.

Results and Discussion

A total of 103 species belonging to 66 genera and 25 families are recorded so far from the Goa state (Table 1). Out of the 25 families recorded, family Portunidae showed the highest species diversity (21 species, 7 genera) followed by Sesarmidae (15 species, 8 genera), Xanthidae (9 species, 7 genera), Leucosiidae (8 species, 6 genera), Ocypodidae (6 species, 4 genera) Hymenosomatidae (6 species, 3 genera), Pilumnidae (4 species, 4 genera), Epialtidae (4 species, 3 genera), Dotillidae (3 species, 3 genera), Matutidae and Grapsidae (3 species, 2 genera), Macrophthalmidae (3 species, 1 genus). Families like Oziidae, Majidae and Varunidae were represented by 2 species and 2 genera each. Families like Calappidae, Hexapodidae were represented by 2 species and 1 genus each. Eight families like Dromiidae, Raninidae, Carpiliidae, Dorippidae, Euryplacidae, Galenidae, Gecarcinidae and Plagusiidae were represented by 1 species, 1 genus each.

According to the published literature, seven species have their type locality in Goa state namely *Elamena xavieri* Kemp, 1917, *Neorhynchoplax alcocki* (Kemp, 1917), *Neorhynchoplax demeloi* (Kemp, 1917), *Neorhynchoplax octagonalis* (Kemp, 1917) *Scopimera proxima* Kemp, 1919, *Charybdis (Charybdis) goaensis* Padate, Rivonker, Anil, Sawant and Krishnamurthy, 2010 and *Hexapus bidentatus* Velip and Rivonker, 2014. Among these, *Charybdis (Charybdis) goaensis* and *Hexapus bidentatus* are endemic locally. Three species *Carupella banlaensis* Tien, 1969, *Sarmatium crassum* Dana 1851 and *Epigodromia gilesii* (Alcock, 1899), which in India have been reported only from Goa state.

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In the present study ten species namely *Portunus reticulatus* (Herbst, 1799), *Metopograpsus latifrons* (White, 1847), *Clistocoeloma lanatum* (Alcock, 1900), *Neosarmatium malabaricum* (Henderson, 1893), *Parasesarma bengalense* (Davie 2003), *Perisesarma dussumieri* (H. Milne Edwards, 1853), *Pseudosesarma glabrum* Ng, Rani and Bijoy Nandan, 2017, *Macrophthalmus (Macrophthalmus) brevis* (Herbst, 1804), *Macrophthalmus (Macrophthalmus) parvimanus* Guérin, 1834 and *Tubuca alcocki* Shih, Chan and Ng, 2018 are reported for the first time from the coastal waters of Goa (Table 1., Figure 1, 2). The observations revealed that Goa state with a comparatively small coastline support rich marine brachyuran crab fauna and have potential for a more diversified brachyuran community as some of the habitats are unexplored.

Table 1: Checklist of marine brachyuran crabs reported from Goa. (Modified from Trivedi *et al.* (2018))

Family and species list	**References**
Order **Decapoda Latreille, 1802**	
Infraorder **Brachyura Latreille, 1802**	
Section **Podotremata Guinot, 1977**	
Family **Dromiidae De Haan, 1833**	
Epigodromia gilesii (Alcock, 1899)	Alcock, 1901; Dev Roy, 2013, 2015
Family **Raninidae De Haan, 1839**	
Notopus dorsipes (Linnaeus, 1758)	Dev Roy, 2008
Section **Eubrachyura, Saint Laurent, 1980**	
Subsection **Heterotremata, Guinot, 1977**	
Family **Calappidae De Haan, 1833**	
Calappa guerini Brito-Capello, 1871	Parulekar *et al.*, 1980; Padate, 2010; Hegde, 2013; Velip 2017
Calappa hepatica (Linnaeus, 1758)	Parulekar *et al.*,. 1980
Family **Matutidae De Haan, 1835**	
Ashtoret lunaris (Forskål, 1775)	Parulekar *et al.*, 1980; Padate, 2010; Hegde, 2013; Velip, 2017
Ashtoret miersii (Henderson, 1887)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Matuta victor (Fabricius, 1781)	Alcock, 1896; Dev Roy and Bhadra 2008
Family **Carpiliidae Ortmann, 1893**	
Carpilius maculatus (Linnaeus, 1758)	Dev Roy, 2008
Family **Dorippidae MacLeay, 1838**	
Dorippoides facchino (Herbst, 1785)	Parulekar *et al.*, 1980; Padate, 2010; Hegde, 2013; Velip, 2017
Family **Oziidae Dana, 1851**	
Epixanthus frontalis (H. Milne Edwards, 1834)	Dev Roy and Bhadra, 2008; Dev Roy, 2013; Kaullysing, *et al.*, 2015; Vijaylaxmi, 2020
Lydia annulipes (H. Milne Edwards, 1834)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Family **Euryplacidae, Stimpson, 1871**	

Trissoplax dentata (Stimpson, 1871)	Velip, 2017
Family **Leucosiidae Samouelle, 1819**	
Euclosiana unidentata (De Haan, 1841)	Alcock, 1896; Dev Roy, 2013, 2015
Leucosia corallicola Alcock, 1896	Alcock, 1896; Dev Roy, 2013
Nursilia dentata Bell, 1855	Dev Roy, 2008
Philyra corallicola Alcock, 1896	Dev Roy, 2008
Philyra globus (Fabricius,1775) (Following Galil (2009), *Philyra globulosa* H. Milne Edwards, 1837, is a junior synonym)	Hegde *et al.*, 2013
Philyra scabriuscula (Fabricius, 1798)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Ryphila cancellus (Herbst, 1783)	Galil 2009
Seulocia pubescens (Miers, 1877)	Padate, 2010; Dev Roy, 2013; Hegde, 2013; Velip, 2017
Family **Hymenosomatidae MacLeay, 1838**	
Elamena truncata (Stimpson, 1858)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Elamena xavieri Kemp, 1917	Kemp, 1917; Dev Roy and Bhadra, 2008
Elamenopsis alcocki (Kemp, 1917)	Dev Roy and Bhadra, 2008
Neorhynchoplax alcocki (Kemp, 1917)	Kemp, 1917; Chopra and Das, 1930
Neorhynchoplax demeloi (Kemp, 1917)	Kemp, 1917; Dev Roy and Bhadra, 2008
Neorhynchoplax octagonalis (Kemp, 1917)	Kemp, 1917; Dev Roy and Bhadra, 2008; Dev Roy, 2013
Family **Epialtidae MacLeay, 1838**	
Acanthonyx euryseroche Griffin and Tranter, 1986	Joshi *et al.*, 2011; Dev Roy, 2013
Acanthonyx limbatus A. Milne-Edwards, 1862	Joshi *et al.*, 2011; Dev Roy, 2013
Doclea rissoni Leach, 1815	Padate, 2010
Rochinia riversandersoni (Alcock, 1895)	Alcock, 1900; Dev Roy, 2013
Family **Majidae Samouelle, 1819**	
Micippa thalia (Herbst, 1803)	Alcock, 1895; Dev Roy, 2013
Schizophrys aspera (H. Milne Edwards, 1831)	Hegde *et al.*, 2013; Velip, 2017
Family **Portunidae Rafinesque, 1815**	
Carupella banlaensis Tien, 1969	Vijaylaxmi *et al.*, 2016
Charybdis (Charybdis) affinis Dana, 1852	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Charybdis (Charybdis) annulata Fabricius, 1798	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Charybdis (Charybdis) callianassa (Herbst, 1798)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Charybdis (Charybdis) feriata (Linnaeus, 1758)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Charybdis (Charybdis) goaensis Padate, Rivonker, Anil, Sawant and Krishnamurthy, 2010	Padate *et al.*, 2010; Hegde *et al.*, 2013
Charybdis (Charybdis) lucifera (Fabricius, 1798)	Dev Roy and Bhadra, 2008; Dev Roy, 2013

Charybdis (Charybdis) riversandersoni Alcock, 1899	Alcock, 1899; Dev Roy, 2013
Charybdis (Charybdis) variegata (Fabricius, 1798	Hegde *et al*., 2013
Charybdis (Goniohellenus) hoplites (Wood-Mason, 1877)	Alcock, 1899; Dev Roy, 2013
Charybdis (Goniohellenus) vadorum Alcock, 1899	Padate, 2010; Hegde, 2013; Velip, 2017
Cycloachelous granulatus (H. Milne Edwards, 1834)	Alcock, 1899; Dev Roy, 2008
Lupocyclus philippinensis Semper, in Nauck, 1880	Alcock, 1899
Portunus reticulatus (Herbst, 1799) (Fig. 1A, B)	Present Study One male and one female were collected from Siolim fish market; four juvenile males and four juvenile females were collected from Chapora estuary.
Portunus sanguinolentus (Herbst, 1783)	Parulekar *et al*., 1980; Dev Roy and Bhadra, 2008; Padate, 2010; Dev Roy, 2013; Hegde, 2013; Velip, 2017; Vijaylaxmi, 2020
Portunus segnis (Forskål, 1775)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Scylla olivacea (Herbst, 1796)	Hegde *et al*., 2013; Padate *et al*., 2013
Scylla serrata (Forskål, 1775)	Parulekar *et al*., 1980; Dev Roy and Bhadra, 2008; Padate, 2010; Dev Roy, 2013; Hegde, 2013; Velip, 2017; Vijaylaxmi, 2020
Scylla tranquebarica (Fabricius, 1798)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Thalamita crenata (Latreille, 1829)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Thalamita oculea Alcock, 1899	Alcock, 1899
Family **Xanthidae MacLeay, 1838**	
Actiomera lophopa (Alcock, 1898)	Dev Roy, 2008
Atergatis integerrimus (Lamarck, 1818)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Atergatis laevigatus A. Milne-Edwards, 1865	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Atergatis roseus (Rüppell, 1830)	Dev Roy, 2008
Demania baccalipes (Alcock, 1898)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Epiactaea margaritifera (Odhner, 1925)	Deb, 1989
Leptodius exaratus (H. Milne Edwards, 1834)	Dev Roy and Bhadra, 2008; Dev Roy, 2013; Lee *et al*., 2013
Lophozozymus incisus (H. Milne Edwards, 1834)	Alcock, 1898
Odhnea echinus (Alcock, 1898)	Alcock ,1898; Deb, 1989
Family **Galenidae Alcock, 1898**	
Parapanope hextii (Alcock, 1898)	Dev Roy and Bhadra, 2008; Dev Roy, 2013; Guinot, 1985

Family **Pilumnidae Samouelle, 1819**	
Benthopanope indica (De Man, 1887)	Dev Roy and Bhadra 2008; Dev Roy 2013
Eurycarcinus orientalis A. Milne-Edwards, 1867	Dev Roy and Bhadra 2008; Dev Roy 2013
Heteropanope glabra Stimpson, 1858	Kaullysing *et al.*, 2015
Xenophthalmodes moebii Richters, 1880	Alcock, 1900; Dev Roy, 2013
Family **Hexapodidae Miers, 1886**	
Hexapus bidentatus Velip and Rivonker, 2014	Velip and Rivonker, 2014
Hexapus sexpes (Fabricius, 1798)	Hegde *et al*., 2013
Section **Eubrachyura, Saint Laurent, 1980**	
Subsection **Thoracotremata Guinot, 1977**	
Family **Gecarcinidae MacLeay, 1838**	
Cardisoma carnifex (Herbst, 1796)	Dev Roy and Nandi, 2005; Dev Roy, 2013
Family **Grapsidae MacLeay, 1838**	
Grapsus albolineatus Latreille, in Milbert, 1812	Alcock, 1900; Dev Roy, 2013
Metopograpsus latifrons (White, 1847) (Fig. 1C, D)	Present study Ten males and nine females collected from mangroves of Chapora and Mandovi estuary.
Metopograpsus messor (Forskål, 1775)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Family **Sesarmidae Dana, 1851**	
Clistocoeloma lanatum (Alcock, 1900) (Fig. 1E, F)	Present study One male and one female collected from mangroves of Divar island, Mandovi estuary.
Clistocoeloma merguiense De Man, 1888	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Episesarma mederi (H. Milne Edwards, 1854))	Dev Roy, 2013
Episesarma versicolor (Tweedie, 1940)	Bhat and Trivedi, 2021
Nanosesarma andersonii (De Man, 1888)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Nanosesarma minutum (De Man, 1887)	Vijaylaxmi, 2020
Nanosesarma batavicum (Moreira, 1903)	Vijaylaxmi, 2020
Neosarmatium malabaricum (Henderson, 1893) (Fig. 1G, H)	Present Study Three males and one female collected from mangroves around Dhauji ferry terminal, Mandovi estuary.
Parasesarma bengalense (Davie 2003) (Fig. 1I, J)	Present study Six males and six females collected from mangroves of Chapora and Sal estuary.
Parasesarma plicatum (Latreille, 1803)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Parasesarma bidens (De Haan, 1835) (Dev Roy and Bhadra (2008); Dev Roy (2013) recorded this species as *Perisesarma bidens* (De Haan, 1835) but a recent revision of the genus *Perisesarma*, De Man, 1895 now places this	Dev Roy and Bhadra, 2008; Dev Roy, 2013

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taxon under the genus *Parasesarma*, De Man, 1895 cf. Shahdadi and Schubart, 2018)	
Perisesarma dussumieri (H. Milne Edwards, 1853) (Fig. 2A, B)	Present study One male collected from mangroves of Divar island, Mandovi estuary.
Pseudosesarma edwardsii (De Man, 1887)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Pseudosesarma glabrum Ng, Rani and Bijoy Nandan, 2017 (Fig. 2C, D)	Present Study Three males and 3 females collected from embankments adjacent to mangroves from Chapora estuary.
Sarmatium crassum Dana, 1851	Bhat *et al.*, in press
Family **Varunidae H. Milne Edwards, 1853**	
Pseudograpsus intermedius Chhapgar, 1955	Vijaylaxmi, 2020
Varuna litterata (Fabricius, 1798)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Family **Plagusiidae Dana, 1851**	
Plagusia immaculata Lamarck,1818	Dev Roy, 2013
Family **Dotillidae Stimpson, 1858**	
Dotilla myctiroides H. Milne Edwards, 1852	Kemp, 1919a; Dev Roy, 2013; Padate *et al.*, 2015
Ilyoplax gangetica (Kemp, 1919)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Scopimera proxima Kemp, 1919	Kemp, 1919a; Dev Roy, 2013
Family **Macrophthalmidae Dana, 1851**	
Macrophthalmus (Macrophthalmus) brevis (Herbst, 1804) (Fig. 2E, F)	Present Study Three males and two females collected from open sand flats, Sal estuary.
Macrophthalmus (Macrophthalmus) parvimanus Guérin, 1834 (Fig. 2G, H)	Present Study Two males collected from open sand flats, Sal estuary.
Macrophthalmus (Mareotis) pacificus Dana, 1851	Kemp, 1919b; Dev Roy and Bhadra, 2008; Dev Roy, 2013
Family **Ocypodidae Rafinesque, 1815**	
Austruca annulipes (H. Milne Edwards, 1837)	Vijaylaxmi, 2020
Austruca lactea (De Haan, 1835)	Dev Roy and Bhadra, 2008; Dev Roy, 2013
Gelasimus vocans (Linnaeus, 1758)	Vijaylaxmi, 2020
Ocypode ceratophthalmus (Pallas, 1772)	Dev Roy and Bhadra, 2008; Dev Roy, 2013; Komarpant *et al.*, 2018
Tubuca alcocki Shih, Chan and Ng, 2018 (Fig. 2I, J)	Present Study Four males collected from mangroves of Chapora and Sal estuary
Tubuca dussumieri (H. Milne Edwards, 1852)	Dev Roy and Nandi, 2005; Dev Roy, 2013

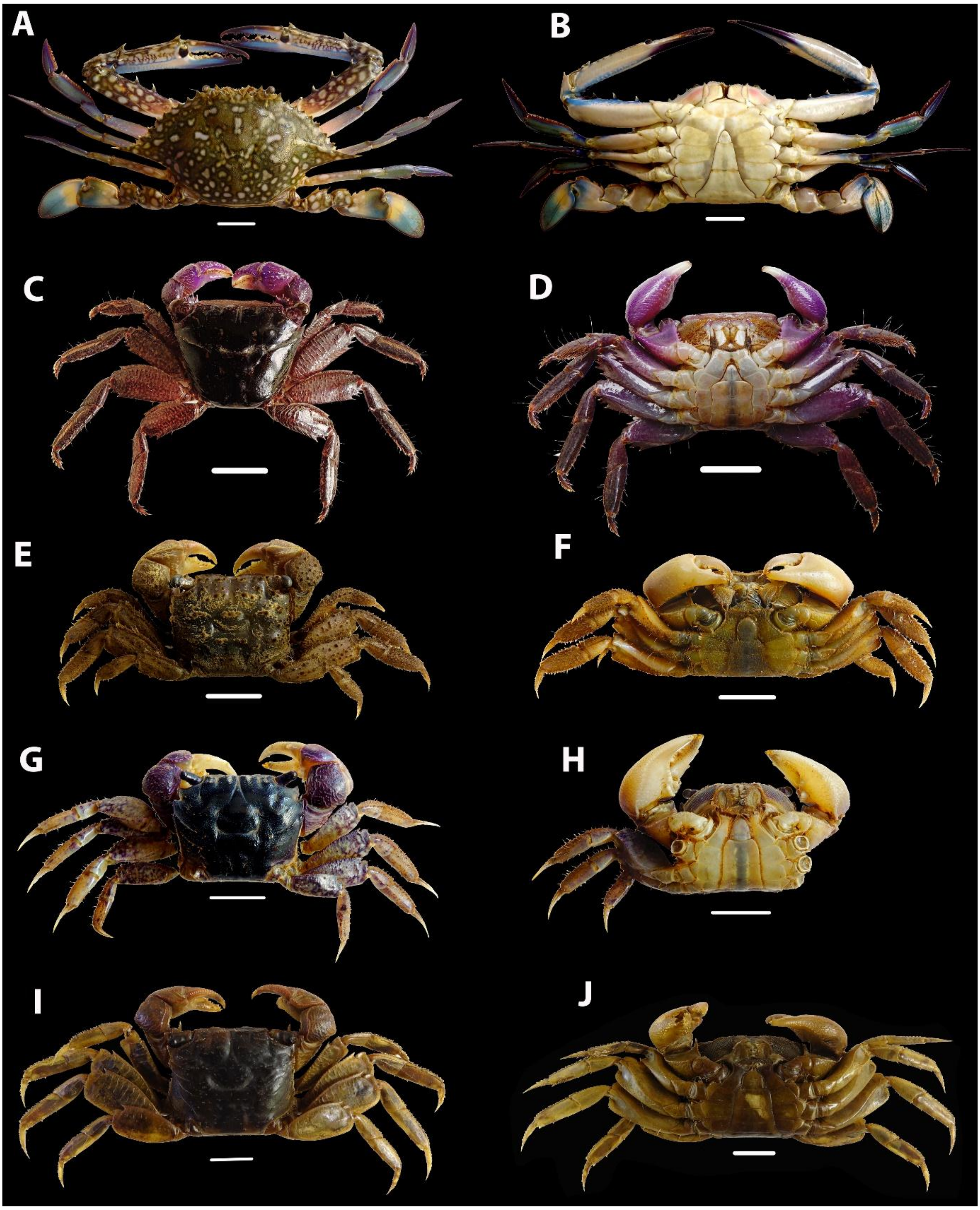

Fig. 1. *Portunus reticulatus* (Herbst, 1799), male, A. Dorsal habitus, B. Ventral habitus; *Metopograpsus latifrons* (White 1847), male, C. Dorsal habitus, D. Ventral habitus; *Clistocoeloma lanatum* Alcock, 1900, male, (Preserved colouration), E. Dorsal habitus, F. Ventral habitus; *Neosarmatium malabaricum* (Henderson, 1893), male,G. Dorsal habitus, H. Ventral habitus; *Parasesarma bengalense* (Davie, 2003), male, (Preserved colouration), .I. Dorsal habitus, J. Ventral habitus. Scale: A, B 20mm; C, D, G-J 10 mm; E, F 5mm.

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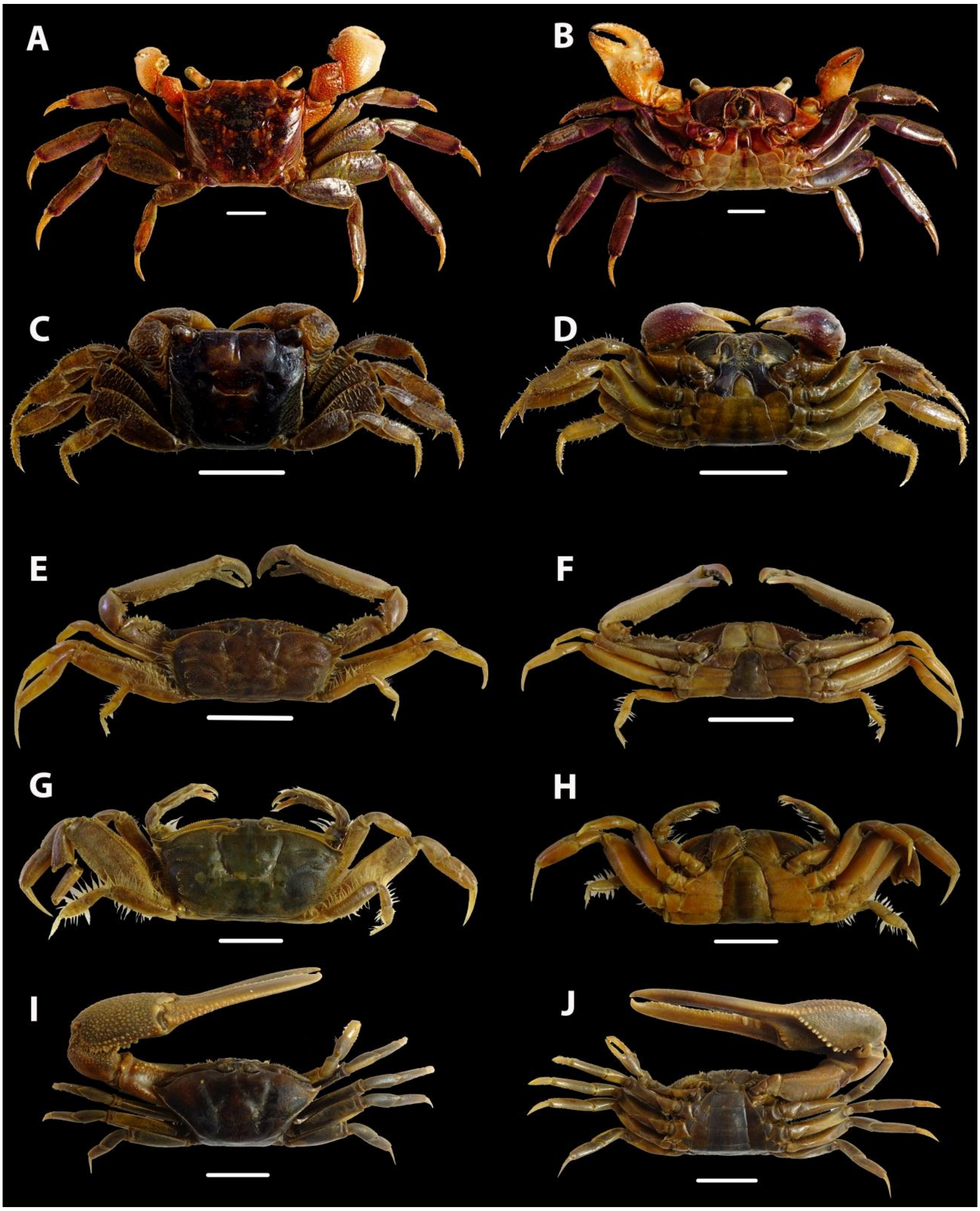

Fig. 2. *Perisesarma dussumieri* (H. Milne Edwards, 1853) male, A. Dorsal habitus, B. Ventral habitus; *Pseudosesarma glabrum* Ng, Rani and Bijoy Nandan, 2017, male, (Preserved colouration), C. Dorsal habitus, D. Ventral habitus; *Macrophthalmus (Macrophthalmus) brevis* (Herbst, 1804) male, (Preserved colouration), E. Dorsal habitus, F. Ventral habitus; *Macrophthalmus (Macrophthalmus) parvimanus* Guérin, 1834, male, (Preserved colouration), G. Dorsal habitus, H. Ventral habitus; *Tubuca alcocki* (Shih Chan, and Ng 2018), male, (Preserved colouration), .I. Dorsal habitus, J. Ventral habitus. Scale: A-J 10 mm.

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