4.1 INTRODUCTION

The field of research related to the abundance and distribution of an organism within a specific geographic area during a particular time frame is known as organismal ecology. The examination of species' biogeography and distribution across ecosystems imparts greatest significance in order to integrate regional and broad-scale patterns of species response to global environmental changes. Additionally, it allows for the identification of both biotic and abiotic factors that influence the current distribution of marine taxa (Saeedi et al., 2017, 2019; Violle et al., 2014; Canonico et al., 2019).

In order to comprehensively understand the ecological dynamics of a given area, it is essential to investigate many factors, such as water temperature, salinity, organic matter, and sediment texture. These factors play a crucial role in influencing both the primary and secondary productivity of coastal regions and establishing the unique characteristics of the habitat (Buchanan and Stoner, 1988). The existence of the species over an environmental gradient must be taken into consideration when describing the distribution patterns of estuarine species.

Niche partitioning of various macrofaunal organism like crabs are mainly because of sediment zonation within coastal environment. Previous research has shown that looking at the make-up of sediment could be a useful way to understand the difference between various macrobenthic ecosystems (Sanders, 1958; Glémarec, 1973; Buchanan et al., 1978). It is well recognized that the physical properties of their surroundings have an impact on the dispersal of macrobenthos (Flint, 1981; Bolam, 2003). The textural properties of the grain size affect the longevity of sediment patches and, subsequently, the spatial patchiness of the benthos (Snelgrove and Butman, 1994).

Vertical distribution patterns of intertidal organisms play a crucial role in the assessment of biodiversity of marine ecosystems. These patterns provide valuable insights into the characteristics of the ecosystem and its species, including their ability to withstand extreme conditions, feeding behaviours, interactions with other organisms, preferences for specific habitats, and mobility

(Ellis, 2003). The distribution of brachyurans in different parts of the intertidal zone can be influenced by various factors, such as the characteristics of the substrate (Menendez, 1987; Lohrer et al., 2000; Ravichandran et al., 2001), their feeding preferences (Jones and Simons, 1982; Cannicci et al., 1999; Takeda et al., 2004; Yamada et al., 2007), the species' life cycle (Batie, 1982; Allen et al., 2010), and their mobility (Flores and Paula, 2001).

The sediment properties found on estuarine mudflats are subject to notable modifications due to the activity of burrowing crustaceans, specifically crabs (Botto et al., 2006). The assessment of population densities of soft-sediment infauna presents a considerable difficulty due to the inconspicuous burrowing behaviours exhibited by these animals and the distinctive characteristics of the sediments in which they inhabit (Morrisey et al., 1998). The quantification of burrow openings, also known as hole count, has been utilized in numerous research investigations as a means to assess the population density of macrofaunal species. The densities of two crab species, the ghost crab (*Ocypode cordimanus* Latreille, 1818) and the estuary crab (*Heloecius cordiformis* H. Milne Edwards, 1837), have been accurately measured using this method (Warren, 1990).

Numerous environmental factors have been found to be important for determining the presence or absence of a species within a specific location. The fluctuations in the population size and geographic range of crabs are associated with specific factors observed in both spatial and temporal domains (Mantelatto et al., 1995; Mantelatto and Fransozo, 1999). Numerous physical factors, such as temperature, light intensity, water availability, nutrient and oxygen levels, pH, salinity fluctuations, and other similar factors, can affect the distribution of organisms within a particular habitat (Sanchez and Raz-Guzman, 1997).

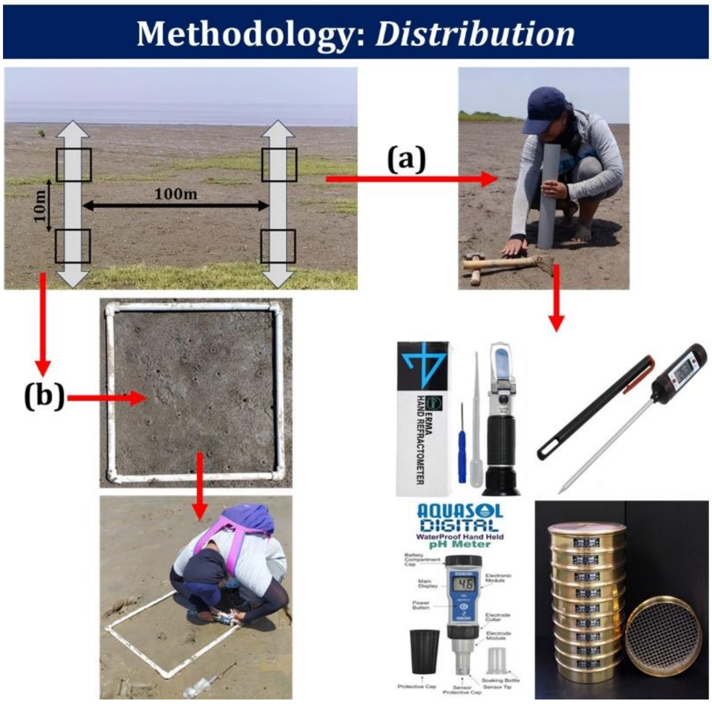
The distribution of sessile invertebrates in the intertidal zone is restricted by certain factors, which have been extensively studied and analysed through comprehensive descriptive models (Lewis, 1964; Stephenson and Stephenson, 1949; Little and Smith, 1980; Rafaelli and Hawkins, 1996). Nevertheless, mobile animals have the ability to mitigate the effects of unfavourable environmental conditions. Some crab species are very good at regulating their body temperature (Gross, 1964; Barnes, 1997; Schubart and Diesel, 1998), and their ability to move quickly may also help them get to different types of shelter (Cannicci et al., 1999), which makes it harder to see their overall zonation patterns.

Several studies have been written about where intertidal brachyuran crabs live (Hartnoll, 1975; Jones, 1976; Wada, 1983), but there aren't any exact models that show how population density is related to important environmental factors that affect the crabs' ability to survive in dry conditions. The investigation of crab burrow distribution patterns in different environments has been the focus of several previous research projects (Flores et al., 2005; Rosa and Borzone, 2008; Hamasaki et al., 2011). Previous research has indicated that the spatial arrangement of crabs is affected by a multitude of factors, such as water depth, plant communities, soil water content, light, salinity, food resources, tides, and sediment characteristics (Reinsel and Rittschof, 1995; Mouton and Felder, 1996). According to Sanchez and Raz-Guzman (1997), the initial component of the pattern represents its amplitude, while the subsequent component measures the degree of interaction between the species and its habitat. The comprehension of the distributional patterns of benthic populations presents difficulties related to the enormous area of the ocean and the complex relationship between biotic and environmental factors (Shirley et al., 1990). Therefore, conducting population studies in specific areas such as bays and inlets can provide valuable insights into the relationships between invertebrates and environmental conditions (Mantelatto et al., 1995; Braga et al., 2007).

The observed reactions of species distribution to global warming are primarily characterized by shifts in the distribution ranges of marine species towards higher latitudes (Saeedi et al., 2017; Saeedi et al., 2019; Saeedi and Costello, 2019). These shifts have led to elevated rates of local extinction and alterations in the composition of local community assemblages (Albouy et al., 2012). Therefore, the ecological responses discussed in this study may have significant implications for the functioning of marine ecosystems and the associated services they provide (Harborne and Mumby, 2011).

Large intertidal zones, which provide a variety of microhabitats for the biota, are a unique feature of the Gulf of Khambhat. Apart from its unique geomorphology, the Gulf's prominence in terms of suspended sediment loads is further strengthened by the existence of four principal rivers, namely the Tapi, Narmada, Mahi, and Sabarmati (Timmermans, 2002). The primary objective of this study is to analyse and describe the geographical distribution patterns and habitat preferences of brachyuran species within the open intertidal mudflats of the Kamboi coast, located on the upper north-eastern margin of the Gulf of Khambhat. The primary objective of this study was to enhance comprehension of the species by examining the distribution pattern, abundance, relative density, and level of niche partitioning among interspecific beach crabs that reside on the exposed intertidal mudflats of Kamboi Coast. The study aims to provide a comprehensive analysis of the spatial distribution of habitats and their vertical arrangement along the tidal zone, with a particular focus on the influence of temperature variations. To achieve these objectives, the research employed quantitative transect and quadrate sampling methods to measure factors such as burrow density and abundance.

The detail methodology for data collection has been described in materials and methods chapter (page no. 28). Following flow chart shows summary of methodology used in the present chapter.



4.2 RESULTS

4.2.1 Habitat characterization of the Coast of Kamboi, Gulf of Khambhat, Gujarat, India

Kamboi exhibited distinct zonation patterns due to sedimentological characteristics, as well as variations in microhabitats, which can be caused by hydrodynamic processes and morphological attributes (Pandya, 2011). The hydrodynamics, depositional and erosional processes of an area are directly influenced by its topographical features (Pandya, 2011). This process additionally regulates the sorting of sediment, resulting in the formation of distinct zones. A gradual change in beach slope was observed, extending from the upper to the lower intertidal area at Kamboi. Based on the examination of sediment composition and grain size analysis of sediment, four separate zones have been identified, arrayed in a sequential manner from the upper to the lower intertidal line. (Fig. 4.1).

Table 4.1. Represents four distinct zones at Kamboi coast

ZONE	Zone Type	SOIL TYPE	SOIL COMPOSITION
I	Upper intertidal zone	Silty	Sand (23%) + Silt (76%)-clay (1%)
II	Lower margin of upper intertidal zone	Silty-clayey	Sand (11%) + Silt (80%)-clay (9%)
III	Upper-mid intertidal zone	Clayey-silty	Sand (4%) + Silt (65%)-clay (30%)
IV	Lower-mid intertidal zone	Silty-sandy	Sand (19%) + Silt (80%)- clay (1%)

Zone I

During highest high tide, the uppermost surf zone experiences flooding. Whereas on remaining days, the area experiences arid conditions, characterized by the presence of loose silty/clayey sand that has been eroded by wind, as well as material eroded from the nearby cliff. The terminal part of this zone, characterized by its coastal grass cover and hard substratum, exhibits a limited range of fauna and a scarcity of terrestrial arthropods (Fig. 4.1).

Zone II

The area exhibited a predominantly muddy composition and flat topography with minimal incline. The area exhibited high levels of biodiversity and population density due to its constant exposure to tidal cycles and the presence of suitable substrates. However, the area had a uniform mudflat composition, devoid of any discernible microhabitats (Fig. 4.1).

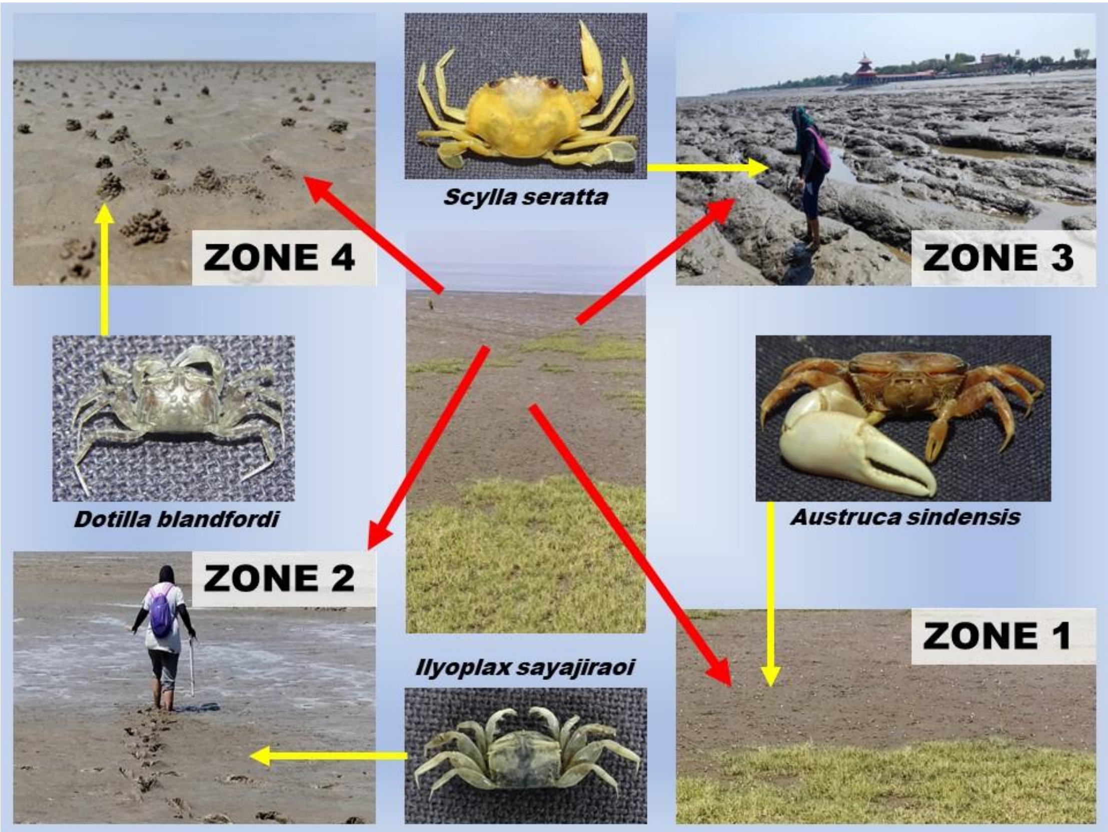


Figure 4.1: Different zones of intertidal area based on sediment composition at Kamboi Coast, Gulf of Khambhat, Gujarat, India

Zone III

The zone displayed a noticeable beach slope along with a muddy habitat mosaic interspersed with a plain sandy mosaic. The terminal portion of Zone III exhibited an area overflowing with water, characterized by a network of small channels and a muddy substrate (Fig. 4.1).

Zone IV

It is the lowest intertidal zone, primarily composed of fine sand. The first portion of the zone was intermittently disrupted by a few areas of hard substratum, characterized by partially cohesive sand. The region also exhibited intertidal pools that were observed amidst the solid substrate. The remaining region was primarily characterized by broad sandy plains exhibiting undulating patterns (Fig. 4.1).

4.2.2 Distribution of burrowing brachyuran crab species along the Coast of Kamboi, Guld of Khambhat, Gujarat, India

In the present study, sediment temperature varied significantly between all three seasons (ANOVA: $F = 19.35$, $p<0.0001$), The sediment temperature of the upper intertidal zone (Zone I) was recorded at its maximum in the summer season (40.48±1.66°C), followed by the monsoon season (36.09±1.25°C), while a minimum temperature (31.28±1.21°C) was observed during winter season. Sediment temperature of the middle intertidal region (Zone II and 3) was recorded at its maximum in the summer season (33.22±1.59°C), followed by the monsoon season (32.16±0.87°C), while a minimum temperature (28.45±1.45°C) was observed in winter season. Similarly, sediment temperature of the lower intertidal region (Zone IV) was recorded at its maximum in the summer season (31.68±1.91°C), followed by the monsoon season (27.93±1.21°C), while a minimum temperature (25.71±1.61°C) was observed in the winter season (Fig. 4.2).

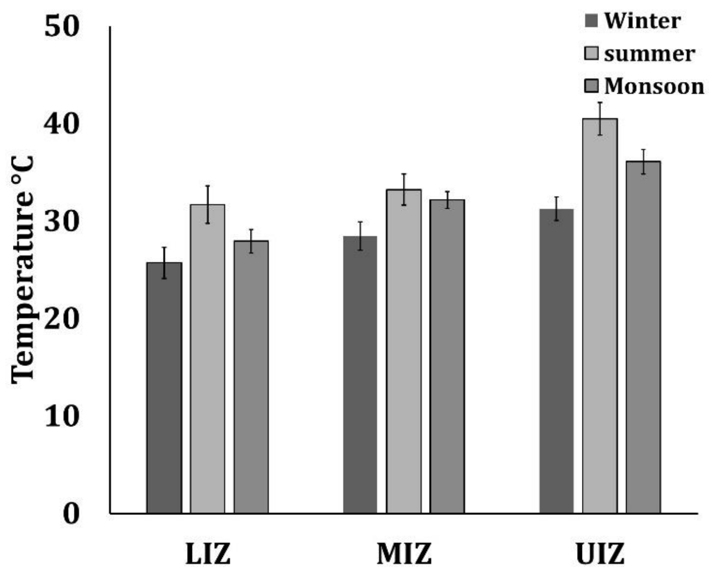


Figure 4.2: Seasonal variation in the mean values of temperature at different intertidal region

In the present study, burrow density, abundance and frequency of burrow occurrence were calculated for six different species viz., *Austruca sindensis* (Alcock, 1900); *Ilyoplax sayajiraoi* JN Trivedi, Soni, DJ Trivedi & Vachhrajani, 2015; *Dotilla blanfordi* Alcock, 1900; *Macrophthalmus* (*Macrophthalmus*) *sulcatus* H. Milne Edwards, 1852; *Eurycarcinus orientalis* A. Milne-Edwards, 1867; *Scylla serrata* (Forskål, 1775). Current investigation reveals that, *A. sindensis*, *I. sayajiraoi* and *D. blanfordi* were abundantly distributed within study area, whereas remaining species (*M. sulcatus*, *E. orientalis* and *S. serrata*) were not so abundantly recorded from the study site. For *A. sindensis*, maximum burrow density and burrow abundance were observed in the winter season (31±4 and 36±2) followed by the monsoon (20±5; 23±4) and summer (8±6; 10±5) seasons. Similarly, for *I. sayajiraoi* also maximum burrow density and burrow abundance were observed in the monsoon season (52±7; 54±4) followed by the summer (48±8; 34±6) and winter (30±5; 14±7) seasons. Whereas, for *D. blanfordi*, maximum burrow density and burrow abundance were observed in the summer season (52±10; 61±12) followed by the winter (37±10; 47±19) and monsoon (25±7; 32±12) seasons. For *M. sulcatus, E. orientalis and S. serrata*, there were no such various observed in burrow density and abundance with respect to the seasons (Fig. 4.3, 4.4)

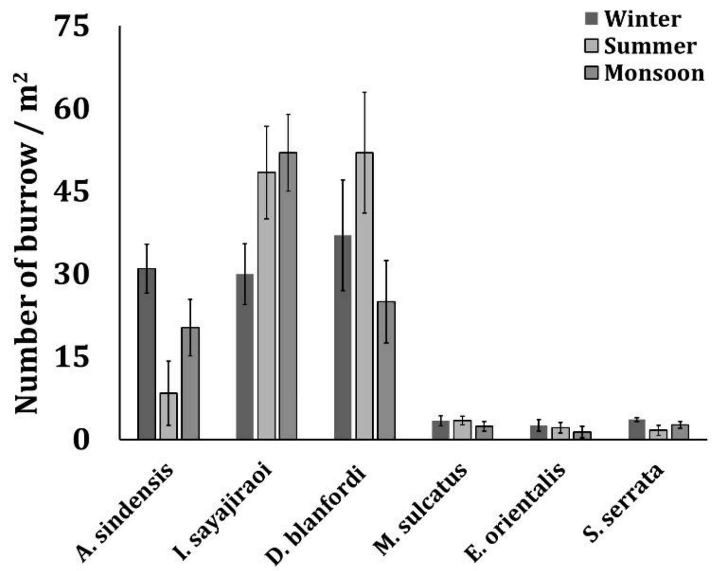


Figure 4.3: Seasonal variation in burrow density of different burrowing crab species along the intertidal region of Kamboi coast

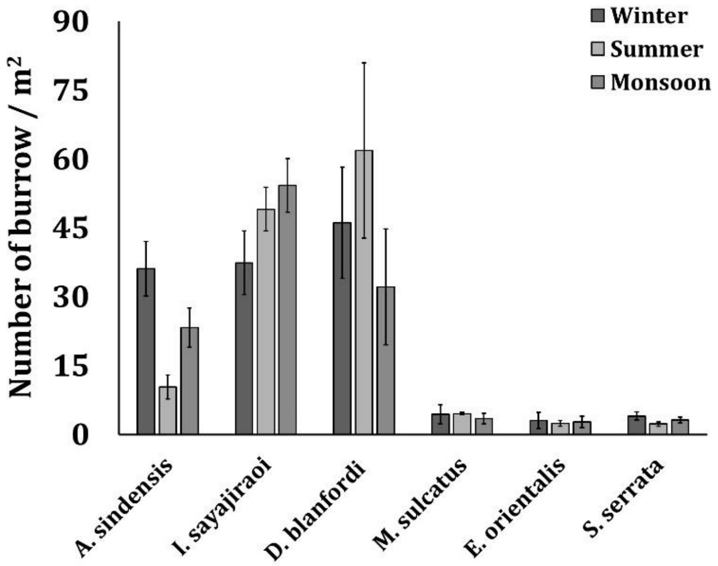


Figure 4.4: Seasonal variation in burrow abundance of different burrowing crab species along the intertidal region of Kamboi coast

The frequency of occurrence of *A. sindensis* showed variation between different seasons. Maximum frequency of occurrence was recorded higher in summer (88±11%) season followed by monsoon (85±7%) and winter (82±4%) seasons. For *I. sayajiraoi*, maximum frequency of burrow occurrence was recorded during winter (93±7%) season followed by summer (91±8%) and monsoon

(90±7%) seasons. Whereas for *D. blanfordi* frequency of burrow occurrence was recorded higher during winter (90±12%) season followed by monsoon (87±10%) and summer (86±9%) seasons (Fig. 4.5).

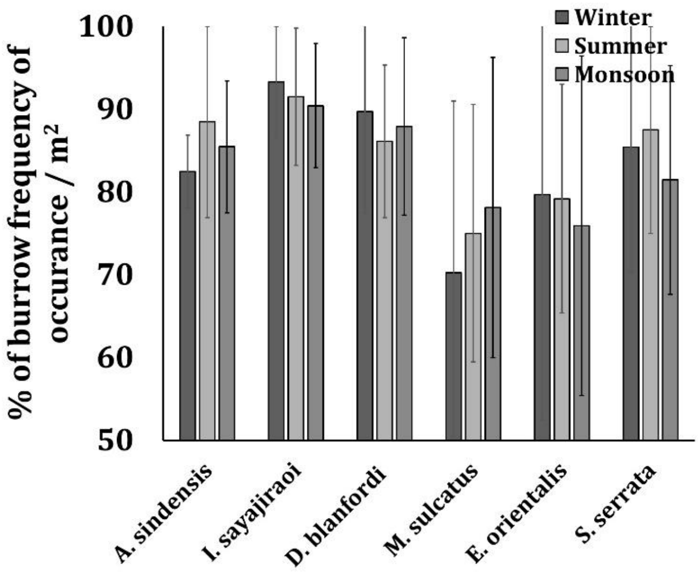


Figure 4.5: Seasonal variation in frequency of burrow occurrence of different burrowing crab species along the intertidal region of Kamboi coast

The results of the overall burrow distribution study showed that different species of brachyuran crabs were distributed in distinctive zones. *A. sindensis* exhibited a distribution range throughout the Zone I and Zone II. However, their distribution was sparse in the Zone I, their density increased initially and decreased at the end of the Zone II. It was observed that *I. sayajiraoi* was widely distributed in the Zone IIand few burrows were constructed within initial part of Zone III. Likewise, *E. orientalis*, a crab of moderate size, showed a distribution range extending from the Zone I to the early portion of the Zone III, with a steady decline in frequency. Moreover, the species showed a limited and scattered range. *S. serrata* exhibited a distinct distribution pattern, mostly inhabiting burrows located beneath the hard substratum inside the middle intertidal zone. *M. sulcatus* was restricted to the Zone IV and occupied the area extending towards the low tide line within this area. The species exhibited a preference for fine sandy substrates and constructed inclined burrows. Although the crab was not observed in high density, it had a consistently adequate distribution. *D. blanfordi* displayed dominance across the Zone IV, extending from the Zone III to the Zone IV, with a progressively increasing frequency of burrow construction (Fig. 4.6).

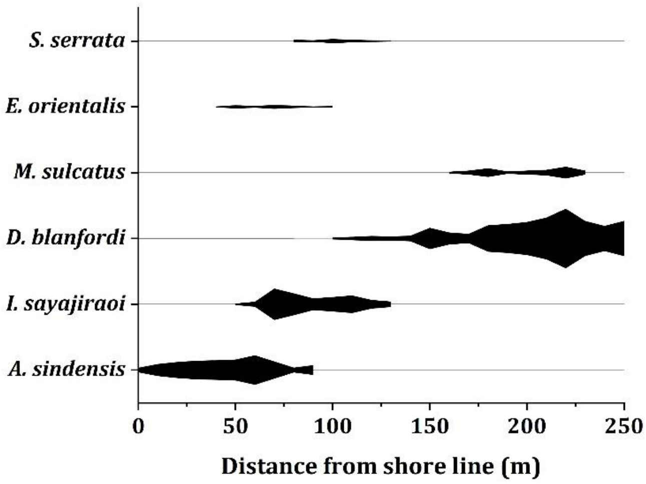


Figure 4.6: Intertidal distribution of six burrowing crab species at Kamboi coast

The present study showed the seasonal fluctuations in burrow distribution of three brachyuran crab species that are known for their great abundance, namely *A. sindensis*, *I. sayajiraoi*, and *D. blanfordi*. *A. sindensis* exhibited a distribution range between 0 to 100m during the monsoon and summer seasons, however during the winter season, this species was often found within a distribution range up to 75m. The distribution range of *I. sayajiraoi* was observed between 60 to 125m during both summer and winter seasons. However, during the monsoon season, a wider distribution range of 60 to 170m was observed. During the winter season, the distribution of *D. blanfordi* was observed within a range of 125 to 190m. In contrast, during the summer season, this species exhibited a distribution range extending from 130 to 240m. During the monsoon season, the distribution range of *D. blanfordi* was observed between 160 and 200m (Fig. 4.7).

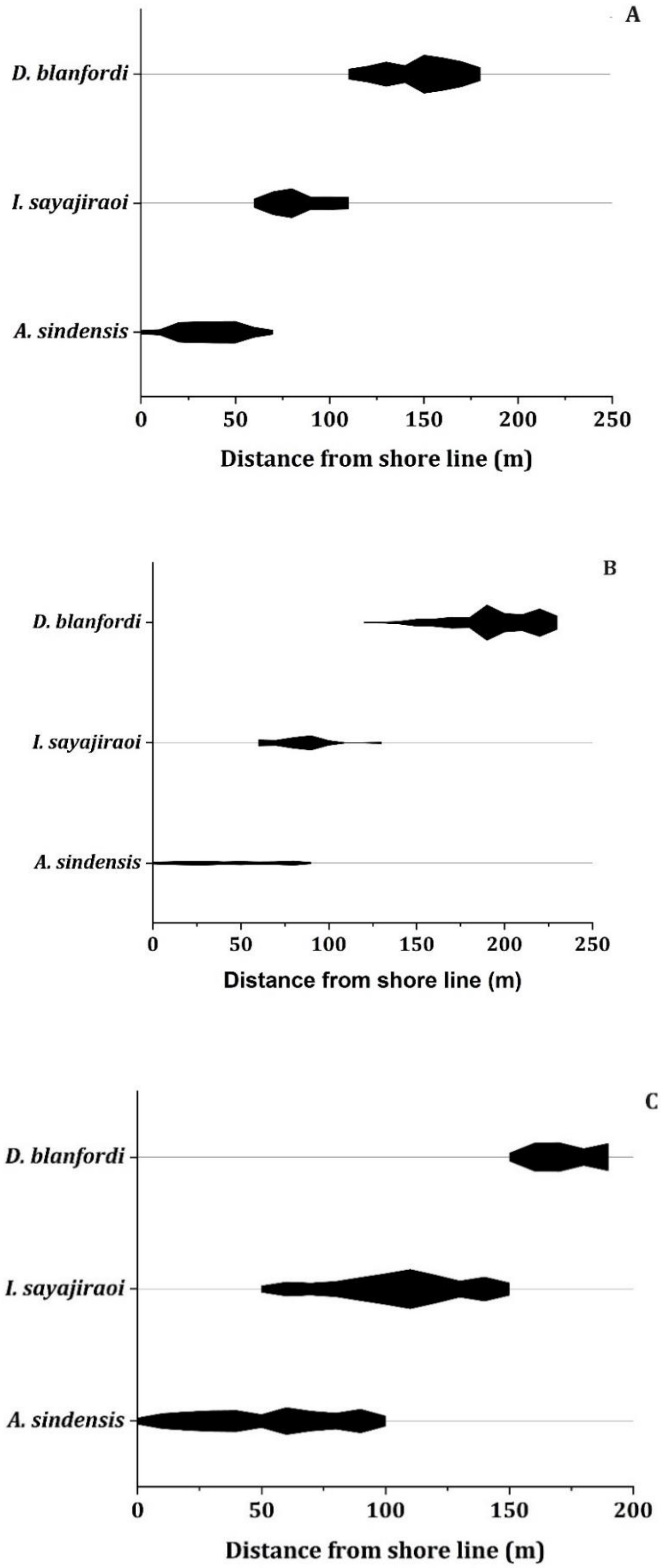


Figure 4.7: Intertidal distribution of three abundantly distributed brachyuran crab species at Kamboi coast in B. winter season; C. Summer season and D. Monsoon season

4.3 DISCUSSION

For researchers to determine priority areas for conservation in a specific ecosystem, basic ecological insight needs to be acquired from an understanding of the patterns of spatial and temporal variability in biota abundances. The zonation pattern in many marine ecosystems has been a topic of attention among ecologists for several decades (Pandya and Vachhrajani, 2013; Shukla et al., 2013). The examination of zonation patterns is conducted in order to gain information regarding the range of ecological phenomenon, including predation, competition, larval settling, food availability, and desiccation. The presence of appropriate habitat or shelter mitigates the physiological stress experienced by animals. Additionally, it serves to protect the animal from various types of predators (Saeedi et al., 2018).

The present study, focused on the burrow distribution of six brachyuran crab species in the intertidal mudflats of Kamboi, from the Zone I (upper littoral zone) to Zone IV (lower-mid littoral zone). The current study demonstrates that the Kamboi coastline is inhabited by three primarily dominant species of brachyuran crabs, namely *A. sindensis*, *I. sayajiraoi*, and *D. blanfordi*. Additionally, three less prevalent species were also sighted from the study site, namely *M. sulcatus*, *E. orientalis*, and *S. serrata*. The analysis confirms that these species were confined to particular microhabitats within the intertidal zone. Chakraborty and Chaudhary (1992) concluded that various crab species exhibit unique zonation in response to varying levels of adaptation.

Numerous factors could potentially have an impact on the presence of species like *M. sulcatus*, *E. orientalis*, and *S. serrata*, which are sporadic encounters. Such variables may include migration patterns, the utilization of particular habitats (Braga et al., 2007), or unintentional transportation, as these taxa are commercially exploited in other geographical areas (Mantelatto and Fransozo, 2000). Since the majority of the taxa are more commonly found in mangroves, mudflats or sandy beaches, the presence of alternate substrates in the surrounding areas may have also contributed to the prevalence of the less prevalent species seen in the current study (Saint-Paul and Schneider, 2010).

Species with high abundance prefer particular conditions, such as a specific zone, profile, or season.

Considering that habitat influences animal distribution and abiotic state to some degree, assessing habitat has always been a crucial component of research projects. The hydrodynamics that follow geomorphic change in an estuarine environment allow for a range of habitats to be established in different tidal zones or even at point level. The spatial heterogeneity within ecosystems can be attributed to a mosaic of patches with varying environmental parameters at varying degrees of recovery (Hewitt et al., 2008). According to the current investigation, the composition of the sediment changed from the upper to the lower-mid intertidal zone (Table 4.1). As a result, the distribution of various species of brachyuran crabs that burrow along the coast varied.

The current investigation revealed that *A. sindensis* had a distribution range extending from Zone I to the upper portion of Zone II. Among these two zones, it was observed that Zone I exhibited greater numbers of burrows, whereas Zone II displayed a lower density and abundance of burrows. Additionally, the burrows in Zone II were seen to be randomly distributed alongside the burrows of *I. sayajiraoi*. Earlier studies concluded that, *A. sindensis* prefers a higher percentage of silt and sand and a lower amount of clay particles (Mokhlesi et al., 2011). Saeedi et al. (2018) also reported that *A. sindensis* exhibits a wide distribution within substrates characterized by a combination of mud and sand. Similarly, in the present study also the habitat preference of *A. sindensis* was reported (Table 4.1).

During, present investigation, few burrows of *E. orientalis* were sighted during the preliminary survey within Zone I and Zone II. Whereas, a greater number of burrows were recorded from Zone II. Previous studies concluded that *E. orientalis* mainly occurs in muddy intertidal area (Naderloo and Türkay, 2012; Naderloo, 2017). Likewise, similar kind of sediment composition were observed within present study site (Table 4.1).

D. blanfordi and *M. sulcatus* were frequently found to be dispersed in the Zone IV, whereas *I. sayajiraoi* and *S. serrata* were spread inside the Zone II and

Zone III respectively. In past, researches were carried out researches to check the effect of habitat on the distribution and diversity of brachyuran crabs, as well as on the habitat preference by some of the brachyuran crab species which supports the observation recorded during present investigation. According to Naskar (2018) *D. blanfordi* occurring abundantly in moist sand of lower intertidal whereas, *M. sulcatus* inhabits the intertidal zone, where it is found on shores with fine sand, sometimes mixed with mud (Naderloo et al., 2011). *I. sayajiraoi* occupies the intertidal mudflat habitat (Trivedi et al., 2015c), whereas, intertidal flat with soft mud and muddy substrate are mostly preferred by *S. serrata* (Sara et al., 2014). *S. serrata* as well as other mud crabs were distributed principally in relation to soil texture (Whiting and Moshiri, 1974).

One of the major elements influencing animal distribution is the composition of the substratum and the pattern of sedimentation, which may account for the variance in the burrow distribution of these species (Sunelgrove, 1999; Herman et al., 2001). Research indicates that several crab species along the intertidal zone have a habitat-specific distribution and occupancy (Chakrabarti et al., 2006). The study conducted by Zolkhifee et al. (2021) examined the temporal and spatial distribution of fiddler crabs in the mangroves of Penang Island in Peninsular Malaysia. Where researchers have identified that, variations in porewater salinity and sediment particle size can be the primary factors influencing the distribution. The spatial distribution of two fiddler crab species *A. iranica* and *A. sindensis* are frequently associated with sediment particle size (Mokhtari et al., 2015).

Seasonal variations in the density and abundance of the burrowing species may be influenced by temperature and light levels in the surrounding environment, which regulate their distribution (Reinsel and Rittschof, 1995; He and Cui, 2015). The winter season had the greatest number of *A. sindensis* burrows, which were then followed by the monsoon and summer seasons (Fig. 4.3). This variation in distribution may be observed because of the distribution range of the *A. sindensis*. *A. sindensis* were frequently found in the Zone I and Zone II (Fig. 4.6, 4.7), which receives the most sunlight and, at low tide, has a higher sediment temperature than the middle and lower intertidal areas.

Which may affect, the distribution pattern of the studied species (Reinsel and Rittschof, 1995; He and Cui, 2015).

Sediment temperature in the higher intertidal zone was recorded maximum in the summer during the current study (Fig. 4.2). Temperature have strong influence on the density and distribution of the brachyuran crab species within their habitat. The temperature rises in the summer because of the sun's rays striking the earth at higher angles and longer exposure times. Zone I experience a significant temperature increase, then the middle (Zone II and 3) and lower intertidal zones (Zone IV). Previous researches have emphasized the significance of temperature as a primary factor influencing the distribution and variety of marine species (Hattab et al., 2014; Reiss et al., 2015). Temperature exerts influence on various aspects of organisms' biology, including feeding and reproductive behaviour (Pörtner, 2001), as well as growth rate and developmental processes in Crustacea (Calcagno et al., 2003, 2005). According to the findings of Costello and Chaudhary (2017), there are three primary elements that play a crucial role in determining the species richness and endemicity of marine animals. These parameters include temperature, productivity, and habitat complexity.

Crabs inhibiting low littoral zone and lower portion of the midlittoral zone do not face issues related to water scarcity, which could lead to desiccation as their habitat is consistently covered by high tides during the fortnightly lunar cycle. The current study found that *I. sayajiraoi* was distributed across the middle intertidal zone, with the monsoon season showing the highest density. Whereas *D. blanfordi*, inhibiting the Zone IV showed highest burrow density during the summer season. This may be because upper-mid and lower-mid intertidal area receive less sunlight and experience a notable increase in wave action (Amrutha and Kumar, 2017). As a result, these zones are regularly replenished with water.

Seasonal variation was recorded in the distribution of *A. sindensis*, *I. sayajiraoi,* and *D. blanfordi* burrows along the intertidal zone in the current study. It was discovered that the burrow distribution range of *A. sindensis* stretched up to the Zone II during the summer and monsoon seasons. Previous studies suggest that the distribution of fiddler crab burrows in warm seasons were spread out over larger areas (Rosa and Borzone, 2008; Beheshti et al., 2021; Bopp et al., 2021; Souza et al., 2021). Since, during warmer month crabs are most actively participating in feeding, courtship and reproduction (Rosa and Borzone, 2008; Beheshti et al., 2021; Souza et al., 2021). Mokhlesi et al. (2011) reported that fiddler crabs were more likely to participate in mating and wooing behaviours during the summer, indicating that summer is breeding season and the monsoon may be an appropriate time for juvenile recruitment. The distribution area of *I. sayajiraoi* was also seen to be expanded during the monsoon season, and the rate of juvenile recruitment was reported to be quite high (Vaidya, 2022).

According to the current study, *D. blanfordi* also displayed fluctuation in the seasonal variation of burrow distribution in the studied area, where the summer months showed the greatest burrow distribution stretch. Whereas monsoon season saw the lowest density and most restricted burrow distribution may be due to high moisture content, which limits the burrowing activity in that area. According to Litulo et al. (2005), the majority of crabs belonging to genus *Dotilla* are continuous breeders; however, during the warmer months, there is an increased prevalence of ovigerous females and youngsters.

According to earlier research, crabs with smaller carapace length typically construct their burrows in the lower or middle intertidal zone in order to avoid harsh environmental conditions and to regularly replenish their water supply (Chan et al., 2006; Maheta and Vachhrajani, 2023). This explains why *A. sindensis* displayed a wider distribution range during the summer and monsoon seasons, *I. sayajiraoi* displayed extended distribution range during the monsoon season, and *D. blanfordi* had a wider distribution during the summer season.