Chapter 2:

Seasonal variation in intertidal distribution pattern of *Clibanarius rhabdodactylus*

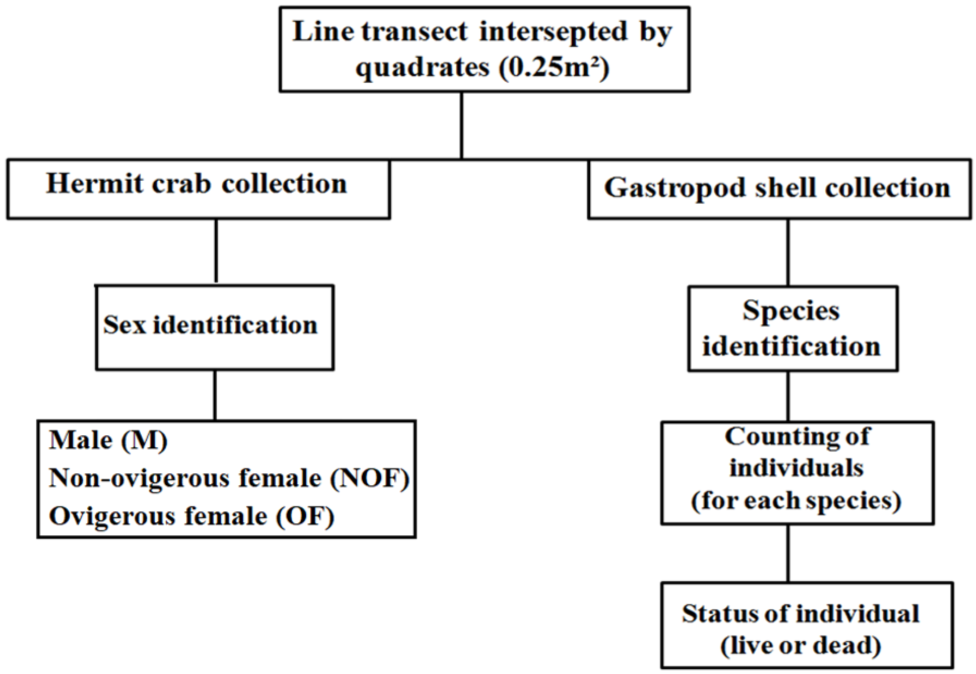
Hermit crabs represent a unique group of organisms that rely on empty gastropod shells in order to protect their non-calcified and soft pleon from various biotic and abiotic factors (Reese, 1969). The intertidal region is the most favourable habitat for hermit crabs as the detritus is continuously replenished, which is the food source for hermit crabs. Moreover, the intertidal region provides the best refuge from the vast number of predators (Reese, 1969). There are several factors that affect the distribution of hermit crabs in the intertidal region, including the risk of desiccation, the availability of empty gastropod shells in different intertidal zones (Kellogg, 1977), several abiotic factors like wave action that are involved in the transportation of the empty gastropod shells from one region to another (Hazlett, 1981), as well as the differences in larval settlement (Nyblade, 1974).

Several hermit crab species have been reported migrating along the different zones of the intertidal region in response to different environmental or physiological factors. Seasonal migration has been observed in some tropical intertidal and shallow subtidal hermit crab species, where the species migrates from the shallow and colder water conditions to the deep and warmer waters during the winter season (Fotheringham, 1975; Rebach, 1978, 1981). Moreover, migration has also been observed in several species during the reproductive season, where they migrate to deeper water (Allen, 1966), and hermit crabs are also among such species (Kikuchi, 1962; Asakura and Kikuchi, 1984; Asakura, 1987). In the monsoon season, the salinity of seawater in the upper intertidal zone of the rocky intertidal region decreases readily because of rainfall (Lewis, 1964; Carefoot, 1977; Newell, 1979), and in order to overcome this change in low salinity in the upper intertidal zone, the female hermit crab individuals migrate to the lower intertidal zone as a part of a behavioural adaptation (Abram, 1988; Imazu and Asakura, 1994). Another important factor that influences the migration of hermit crabs is the availability of an adequate and optimal gastropod shell in different intertidal zones (Fotheringham, 1975). The rocky intertidal region is one of the most species-rich habitats as it presents a heterogenous environment supporting greater diversity of life forms that further vary in their distribution from the upper intertidal zone to the lower intertidal region (Underwood, 1981; Ballesteros, 1995; Thompson et al., 2002; Araújo et al., 2005). Vertical zonation can be prominently observed in the rocky intertidal region from the upper intertidal zone to the lower intertidal region. The diversity and abundance of organisms change dramatically between the upper intertidal, middle intertidal, and lower intertidal zones (Stephenson and Stephenson, 1949; Bandel and Wedler, 1987).

Gujarat presents a rich diversity of intertidal habitats, which support a great variety of marine organisms. Out of these, a total of 18 species (4 genera, 2 families) of hermit crabs have been reported from Gujarat State (Trivedi and Vachhrajani, 2017, 2016a; Patel et al., 2020a). The brachyuran crab fauna of the Saurashtra coast has been studied well for its diversity (Trivedi and Vachhrajani, 2012a, 2013a, 2014a; Trivedi et al., 2015d; 2017; 2018; Ng et al., 2015; Gosavi et al., 2017) and ecological aspects (Trivedi and Vachhrajani, 2012b, 2013b, 2016c), however, the hermit crab fauna has not been studied well for its diversity (Trivedi et al., 2015d, 2016; Kachhiya et al., 2017) as well as ecological aspects.

The majority of the ecological studies have been concentrated on their behavioural ecology, which mostly includes studies on shell utilisation patterns (Trivedi et al., 2013; Trivedi and Vachhrajani, 2014a; Patel et al., 2020b, c, 2021; Thacker et al., 2021). In fact, Saurashtra has a rich diversity of intertidal organisms, but studies on their intertidal distribution are very scarce (Vaghela and Kundu, 2012; Trivedi and Vachhrajani, 2014b). A hermit crab species, *Clibanarius rhabdodactylus,* is commonly found in the rocky intertidal region of the Saurashtra coast, Gujarat state, India (Kachiya et al., 2017). Although the species is found in the intertidal region, the seasonal variation in the intertidal variation of the species is still unknown, and therefore, the present study was carried out to understand the seasonal variation in the intertidal distribution of *C. rhabdodactylus* on the rocky shores of the Saurashtra coast, Gujarat State.

The detailed methodology for data collection has been described in Mmaterials and Methods chapter (page 53). The following flow chart shows the summary of the methodology used in the present chapter.



Results

In the present study, the tide pool water temperature and ambient temperature varied significantly between all three seasons (ANOVA: $F = 24.18$, $p < 0.001$). The tidepool temperature of the upper intertidal zone was recorded at its maximum in the summer season (38.27 ± 0.45°C), followed by the winter season (32.05 ± 0.73°C), while a minimum temperature (30.63 ± 0.65°C) was observed in the monsoon season. The tidepool temperature of the middle intertidal region was recorded at its maximum in the summer season (35.63 ± 0.37°C), followed by the winter season (30.45 ± 0.66°C), while a minimum temperature (29.87 ± 0.88°C) was observed in the monsoon season. Similarly, the tidepool temperature of the middle intertidal region was recorded at its maximum in the summer season (31.09 ± 0.48°C), followed by the monsoon season (28.8 ± 0.44°C), while a minimum temperature (27.94 ± 0.65°C) was observed in the winter season. In the case of the ambient temperature, the maximum temperature was recorded during the summer season (33.59

± 1.11°C), followed by the monsoon season (29.29 ± 0.70°C), and the winter season (28.12 ± 1.64°C) (Figure 21).

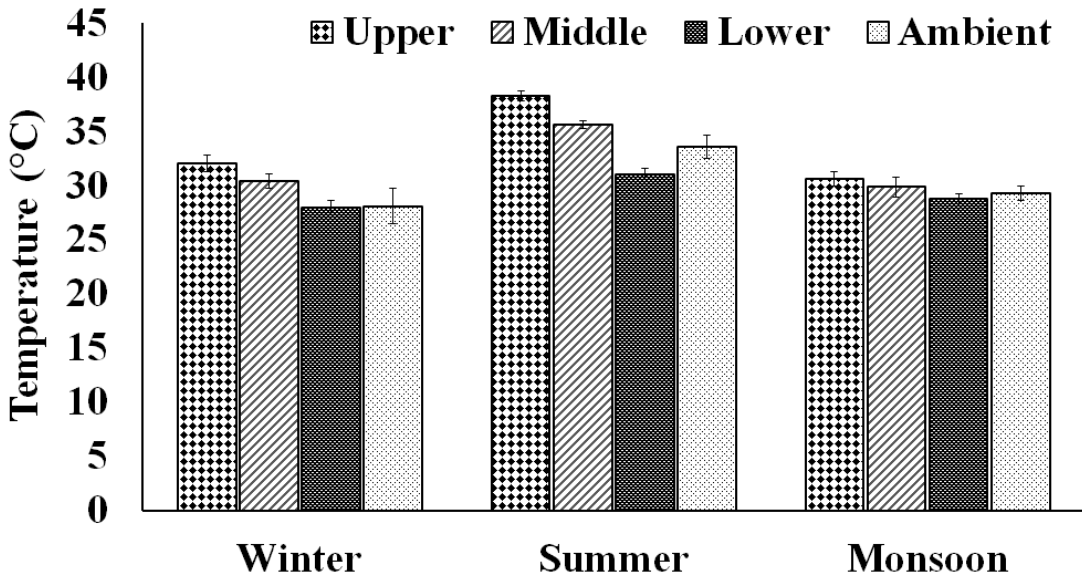


Figure 21. Seasonal variation in the mean values of ambient temperature and tidepool temperature at different intertidal region.

In the present study, the maximum abundance was observed in the winter season, followed by the summer and monsoon seasons (Figure 22). In the case of seasonal abundance of male individuals, maximum abundance was observed in the winter season (25 ± 8), followed by the summer season (8 ± 3) and the monsoon season (6 ± 3). In the case of seasonal abundance of non-ovigerous female individuals, maximum abundance was observed in the winter season (52 ± 19), followed by the summer season (8 ± 3) and the monsoon season (4 ± 2). Similarly, in the case of seasonal abundance of ovigerous female individuals, maximum abundance was observed in the winter season (43 ± 21), followed by the summer season (13 ± 8) and the monsoon season (9 ± 7) (Figure 22).

There was a prominent variation observed in the intertidal distribution of the *C. rhabdodactylus* population. Figure 23 represents the quadrate-wise mean abundance of *C. rhabdodactylus* individuals during different seasons. The distribution pattern recorded in the winter season of *C. rhabdodactylus* individuals showed that the majority of the individuals were distributed in the upper intertidal zone, where the mean water temperature was 32.05 ± 0.73°C.

On the other hand, during the summer season, when the temperature of the upper intertidal zone increased (38.27 ± 0.45°C), *C. rhabdodactylus* population was distributed in the middle and lower intertidal regions, where the water temperature was 35.63 ± 0.37°C and 31.09 ± 0.48°C respectively. During monsoon season, the weather remains mostly cloudy as a result the water temperature did not vary throughout the upper intertidal zone to the lower intertidal region. However, the *C. rhabdodactylus* population was observed to be distributed from the upper to the lower intertidal zone with maximum abundance in the upper intertidal zone.

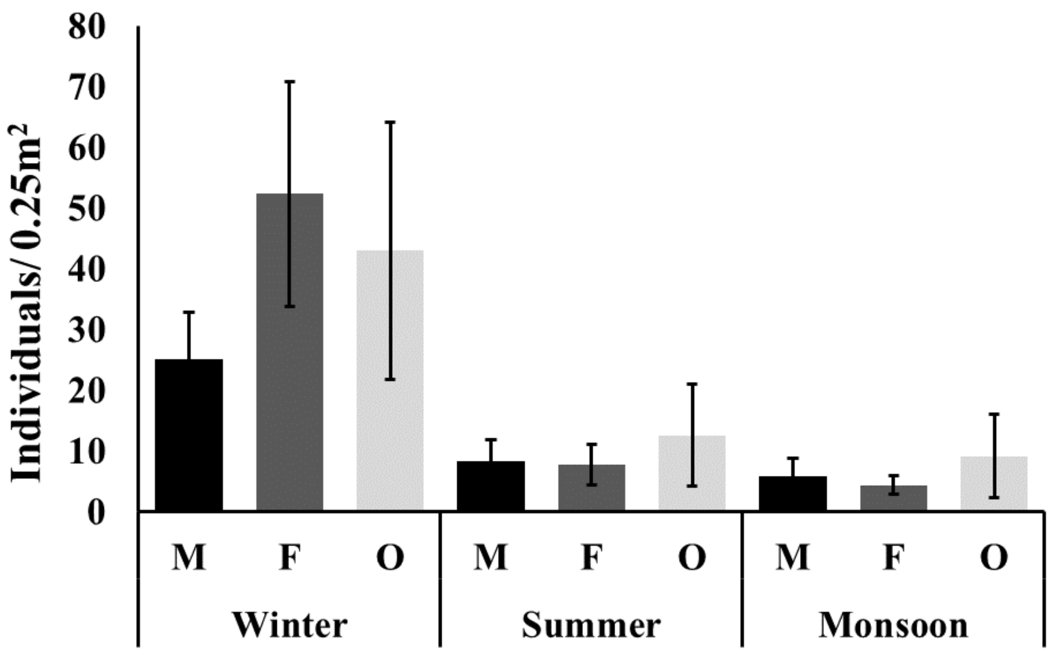


Figure 22. Seasonal variation in the mean values of abundance of different sexes of *Clibanarius rhabdodactylus*.

The rocky intertidal region of Veraval is mostly composed of tidepools, crevices and open-areas type of microhabitats. Habitat analysis was carried out to analyse the microhabitat composition in the study area, which revealed that the maximum number of tidepools occurred in the upper intertidal zone, which gradually decreased towards the lower intertidal region. On the other hand, open areas occurred less in the upper intertidal zone, which gradually increased towards the lower intertidal region. The overall area covered by crevices was very small, and its relative area remained almost similar from the upper intertidal zone to the lower intertidal region (Figure 23A).

Discussion

The present study focused on the intertidal distribution of *C. rhabdodactylus* in the rocky intertidal region of Veraval, from the upper intertidal zone to the lower intertidal zone. The upper intertidal zone receives the most sunlight, resulting in a higher water temperature during low tide, followed by the middle and lower intertidal zones. It was observed that the seawater temperature of the upper intertidal zone was reaching its maximum in the summer season. The upper intertidal zone experiences the highest exposure to sunlight which leads to an increased tidepool water temperature when the water has receded at low tide and the replenishment of water does not occur by the incoming waves.

In summer, the sun rays hit the earth at a steeper angle, while the sun exposure time also increases, causing an increase in temperature. This increased ambient temperature during the summer season also affects the intertidal region, causing a greatly increased temperature in the upper intertidal zone, followed by the middle intertidal zone and the lower intertidal zone. On the other hand, during the monsoon, the weather mostly remains cloudy, resulting in greatly decreased sunlight exposure, due to which the temperature of the upper intertidal and lower intertidal regions does not rise. Along with the decreased sunlight exposure, the wave action also increases dramatically during the monsoon season (Amrutha and Kumar, 2017), which results in continuous water replenishment in the middle and lower intertidal regions even during the low tide times.

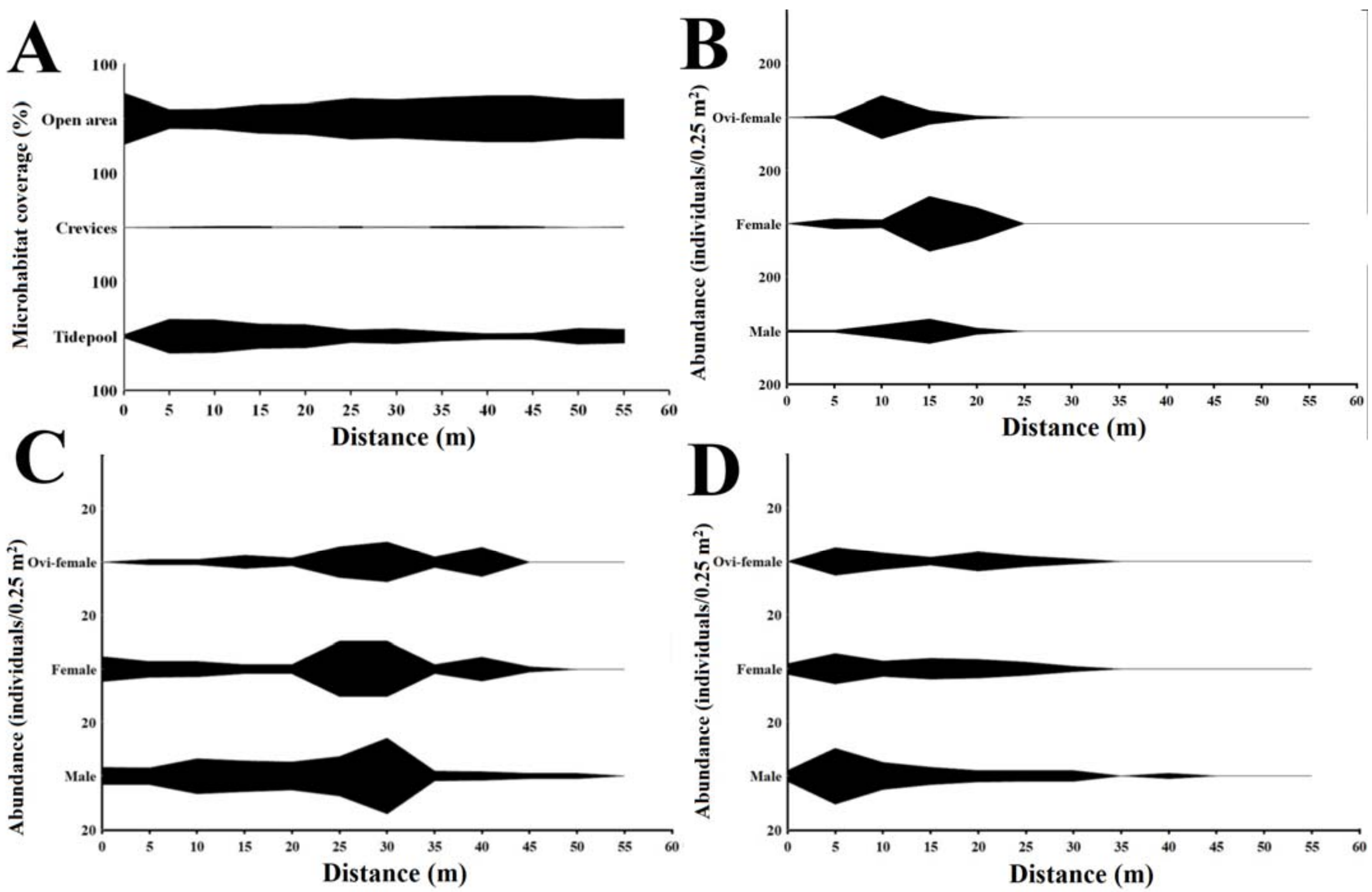


Figure 23. A. Intertidal microhabitat coverage of the study area; Intertidal distribution of *Clibanarius rhabdodactylus* at Veraval coast in B. winter season; C. Summer season and D. Monsoon season.

During the present study period, it was observed that individuals of the hermit crab species *C. rhabdodactylus* form aggregations in the intertidal region when the water recedes during low tide, which leads to patchy distribution in the study area (Figure 24). Barnes (1997) termed such aggregations "clusters," which are formed for the purpose of shell exchange. These clusters were mostly composed of a single species, which was also reported by Barnes (1997) in his study. Similar pattern behaviour of aggregation leading to patchy distribution has been recorded in the studies carried out on some gastropod species, including *Cerithium scabridum* (Trivedi and Vachhrajani, 2013c) and *C. caeruleum* (Gohil and Kundu, 2013), which are two of the most commonly occurring gastropod species in the intertidal region of the Saurashtra coast of Gujarat state. The studies suggested that the preference for specific microhabitats in the intertidal region could be one of the reasons for the patchy distribution of the organisms residing in the intertidal region. Apart from that, abiotic factors, including temperature and wave action pattern, could also be one of the major reasons affecting the distribution pattern of the organisms in the intertidal region. Another probable reason for the patchy distribution of *C. rhabdodactylus* in the intertidal region of the Veraval coast is their preference for specific shells. It has been observed in the present study that the *C. rhabdodactylus* individuals have specific preferences for *C. caeruleum* shells (Patel et al., 2021), which are mostly distributed in the upper intertidal and lower intertidal regions of the Veraval coast (Gohil and Kundu, 2013). Moreover, *C. rhabdodactylus* does have a specific preference for microhabitat (crevices and tidepools), which provides protection from wave action as well as predators.

In the present study, the overall maximum abundance of the *C. rhabdodactylus* population was observed in the upper intertidal zone. Further, variations in the abundance of *C. rhabdodactylus* individuals were also observed between different genders and different seasons. The availability of gastropod shells in different zones can also be one of the possible reasons affecting the spatial distribution of *C. rhabdodactylus* individuals. For example, in a study, it was observed that *C. vittatus* individuals require larger gastropod shells, which are available in the sublittoral zone (Fotheringham, 1975). Similar results were observed in a study carried out on *C. zebra* occupying *C. scabridum* on the Saurashtra coast (Trivedi and Vachhrajani, 2013a), suggesting that the distribution of the gastropod shells in the intertidal region greatly affects the distribution pattern of the dependent hermit crab species. Moreover, a specific preference for a particular type of microhabitat could be another reason affecting the intertidal distribution of hermit crabs in the intertidal region. For example, the tidepools and crevices provide refuge during high tide when the wave action is stronger and can dislodge the hermit crabs, leading to the breakdown of their occupied shell. Also, the tidepools and crevices provide protection from their natural predators.

It was also observed that the *C. rhabdodactylus* individuals were distributed in the intertidal region, where the water temperature was between 30 and 35 °C. Since the water temperature of the upper intertidal zone in the winter season was within this range, the *C. rhabdodactylus* individuals were distributed in the upper intertidal region (32.05 ± 0.73°C) and their abundance was recorded maximum in this region as compared to the middle intertidal (29.45 ± 0.66°C) and lower intertidal regions (27.94 ± 0.65°C) which had lower water temperatures. Studies have suggested that there are various factors that are responsible for the distribution of hermit crabs in the intertidal zones, like exposure to desiccation risk due to increased temperature in the upper intertidal region, availability of empty gastropod shells in different zones of the intertidal region (Kellogg, 1977), abiotic factors responsible for the movement of empty shells (Hazlett, 1981), and differences in the larval settlement of hermit crab individuals (Nyblade, 1974). Moreover, migration from the shallow waters to the deeper waters during the reproductive season has been reported in several hermit crab species (Kikuchi, 1962; Asakura and Kikuchi, 1984; Asakura, 1987). Such migration into deeper waters is an important behavioural adaptation for avoiding fluctuations in abiotic factors such as temperature, pH, and salinity, which are required for successful hatching and development of offspring.

Figure 24. Clustering observed in *Clibanarius rhabdodactylus* at the rocky intertidal region of Veraval coast, Saurashtra.

During the summer season, when the temperature of the upper intertidal zone reaches 38.27 ± 0.45°C, it was observed that the *C. rhabdodactylus* individuals were distributed in the middle intertidal and lower intertidal zones, where the temperatures were 34.63 ± 0.37°C and 31.09 ± 0.48°C respectively. The distribution of *C. rhabdodactylus* individuals into the middle intertidal and lower intertidal zones can be attributed to behavioural adaptation by the hermit crab species in order to avoid desiccation and hyperthermia as a result of increased tidepool water temperatures in the upper intertidal zone (Reese, 1969; Bertness, 1981b; Taylor, 1981; Turra and Leite, 2000). Previous studies have recorded the migration of certain hermit crab species from the shallow intertidal region to deeper subtidal regions during their reproductive season in order to avoid extreme fluctuations in abiotic factors (Kikuchi, 1962; Asakura and Kikuchi, 1984; Asakura, 1987).

During the monsoon season, the *C. rhabdodactylus* population was observed to be distributed throughout the intertidal region, i.e., the upper intertidal zone, the middle intertidal zone, and the lower intertidal zone, with a greater abundance of *C. rhabdodactylus* individuals distributed in the upper intertidal zone. However, according to some studies, the salinity of the intertidal region readily decreases due to continuous rainfall and fresh water flow into the seas during monsoon season (Lewis, 1964; Carefoot, 1977; Newell, 1979). This leads to the distribution of female hermit crabs into the lower intertidal zone or subtidal region as an adaptation to avoid low salinity in the upper intertidal zone (Abram, 1988; Imazu and Asakura, 1994). In contrast, in the present study, the species was abundant in the upper intertidal zone. Probably a major reason for the *C. rhabdodactylus* individuals distribution in the upper intertidal zone is their preference for specific types of microhabitat, i.e., tidepools and crevices. The habitat analysis in the present study has revealed that the tidepools were more abundantly observed in the upper intertidal zone, which gradually decreased towards the lower intertidal zone. Moreover, as the wave action increases during the monsoon season (Amrutha and Kumar, 2017), leading to dislodgement and shell breakage, occupying tidepools in the upper intertidal zone would protect the hermit crabs from crushing.