Synopsis of the Thesis Entitled

# Ecological studies on Hermit crab *Clibanarius rhabdodactylus* Forest, 1953 in Rocky Intertidal zone of Saurashtra coast, Gujarat

Submitted to

**THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA**

सत्यं शिवं सुन्दरम्

For the Degree of

**DOCTOR OF PHILOSOPHY**

**IN**

**ZOOLOGY**

By

**PATEL KRUPAL JAGDISHKUMAR**

**(Registration No. FoS/2169, Date: 07/12/2019)**

**UNDER THE SUPERVISION OF:**

**DR. KAURESH D. VACHHRAJANI**

Marine Biodiversity and Ecology Laboratory,
Department of Zoology, Faculty of Science,
The Maharaja Sayajirao University of Baroda,
Vadodara.390 002, Gujarat, India.

**June 2023**

## INTRODUCTION

The intertidal region is the transitional area from land to sea, and it presents enormous diversity and richness in marine plants and invertebrate communities (Lalli and Parsons, 1997). For survival in different regions of the intertidal zone, organisms develop special types of adaptations. There is a general correlation between degree of tolerance to physical factors and shore position for most intertidal species. Organisms residing in the upper intertidal region face desiccation as the major limiting factor. While on the lower shores, competition becomes a major limiting factor as a result of the high density of organisms, which leads to inter- and intra-specific competition for suitable resources (Wethey, 1983). Also, the rate of predation increases in the lower intertidal region as compared to the spray zone and the upper intertidal region.

Crustacea is a subphylum that comes under the phylum Arthropoda and represents a highly diverse group of marine organisms in terms of morphology, physiology, life history, and ecological adaptation (Martin and Davis, 2001). The global diversity of crustacean species comprises around 67,000 species (Ahyong et al., 2010). Decapoda Latreille, 1802 is an order of the class Malacostraca of the subphylum Crustacea (Poore, 2004), which are also called the insects of the sea. While insects are diverse and common on land, decapods are diverse and common in the marine habitat. It is the most species-rich, diverse, visible, popular, and economically important group of all crustaceans (Abele, 1974). Recently, the decapod diversity was estimated around 14,756 species (2,725 genera) living while the fossil species stands at 3,300 species (De Grave et al., 2009). The greatest diversity of Decapoda is observed in the shallow waters, however, a few species have been reported from 5000–6000 metres of depth too. Every marine habitat includes major predatory species of decapod crustaceans that play an important role in regulating the trophic relationships of benthic communities, while the smaller species provide a food base for other marine creatures. Order Decapoda consists of the following infraorders: Stenopodidea Bate, 1888; Caridea Dana, 1852; Astacidea Latreille, 1802; Glypheidea Winkler, 1883; Axiidea de Saint Laurent, 1979; Gebiidea de Saint Laurent, 1979; Achelata Scholtz and Richter, 1995; Polychelida Scholtz and Richter, 1995; Brachyura Linnaeus, 1758; and Anomura MacLeay, 1838 (De Grave et al., 2009).

The infraorder Anomura represents a highly diverse group of decapod crustaceans, which includes hermit crabs, mole crabs, king crabs, squat lobsters, and porcelain crabs

(Bracken-Grissom et al., 2013). They are found inhabiting a variety of ecosystems, which include freshwater, anchialine cave, terrestrial, and hydrothermal vent habitats. They can also be found from the surface of the ocean to depths of over 5000 metres (Macpherson and Segonzac, 2005). Anomura contains seven superfamilies, 23 families, 242 genera, and more than 3300 species, however, these numbers may increase as a result of subsequent descriptive studies. Out of various Anomura groups, hermit crabs present an interesting group of crabs that lack a calcified pleon (Figure 1). Hence, in order to obtain protection from various biotic (predation) and abiotic (desiccation) factors, they occupy gastropod shells generally termed "portable homes". The occupied shells seem to satisfy a variety of essential survival and reproductive functions for hermits, including prevention from desiccation, protection against parasites and predators, and shelter from abrasive sand and other environmental stresses (Hazlett, 1981).

The hermit crab's body can be majorly divided into two morphological parts: the cephalothorax and abdomen. The cephalothorax is formed by the fusion of the head and thorax of the crab. The carapace is partially or completely calcified and is formed by brenchiostegites. The shield is a calcified structure that is delineated laterally and posteriorly by the cervical groove. The appendages in the cephalothoracic region include a pair of antennae, antennules, ocular peduncles, and five pairs of legs. The abdominal appendages are called pleopods. The numbers of these pleopods may vary from species to species of the hermit crab. As compared to males, the pleopods are well developed in females, as they are used for the purpose of holding the egg mass. Moreover, these pleopods are commonly used by both the sexes for the purpose of holding the occupied shell so that they cannot be dragged out by the predators easily (Figure 1).

Hermit crabs are common inhabitants of intertidal habitats such as rocky shores, mangroves, and mudflat areas, where they can occur in high abundance. For hermit crabs, intertidal habitats are favourable as there is continuous replenishment of detritus as a food source and refuge from specialised predators (Reese, 1969). To exploit these advantages, hermit crabs may also employ behavioural adaptations against desiccation (Reese, 1969). Almost all aspects of the biology of hermit crabs are greatly influenced by their strong association with their gastropod shells. Not so surprisingly, the majority of biological studies of hermit crabs are focused on their association with gastropod shells. Even studies on their behavioural ecology, which are primarily concerned with shell occupation, indicate that shell selection and shell exchange are unquestionably shelter-related (Hazlett, 1981). Hazlett (1981) suggests that most of the ecological studies on hermit crabs are focused on their interaction with gastropod shells, and comparatively very less work has been carried out on the hermit crab as a component of marine ecosystems.

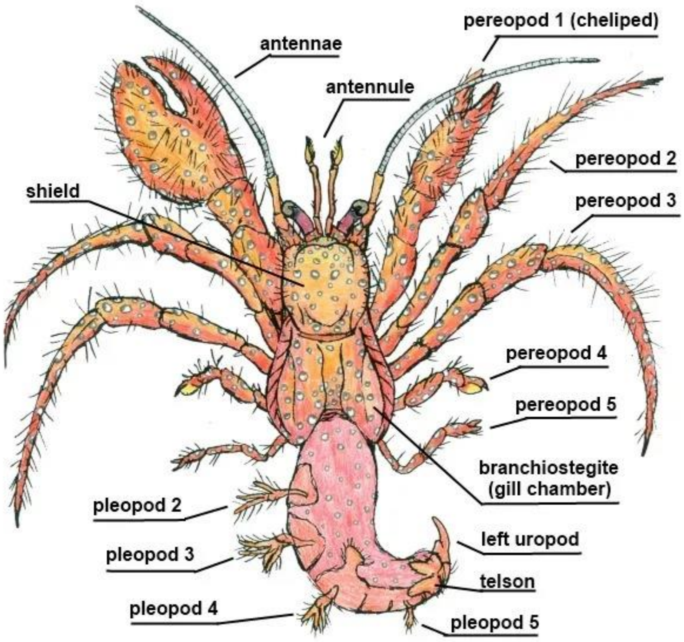


**Figure 1.** External morphology of hermit crab. (Source: https://la-france-qui-bosse.com/wear_rm).

Genus *Clibanarius* Dana, 1852, comes under the family Diogenidae of superfamily Paguroidea of infraorder Anomura, which currently comprises 60 species worldwide (McLaughlin et al., 2010). The species of the genus *Clibanarius* are mainly found in various types of tropical or subtropical intertidal habitats, including mangrove forests, coral reefs, rocky substratum, sand and mud flats, etc. (Ismail, 2010).

## REVIEW OF LITERATURE

### International review

Hermit crabs constitute one of the most visible groups of organisms successfully and efficiently flourishing in the intertidal environment. They can do so as a result of their behavioural adaptation, which includes the use of shells, which enables them to thrive in the intertidal habitat (Reese, 1969). The distribution of hermit crabs in the intertidal region is governed by the complex interaction of biotic and abiotic factors. Gastropod shells are an indispensable resource for hermit crabs (Asakura, 1991). The connection between hermit crabs and their shell affects almost all aspects of their biology (Hazlett, 1981).

Studies on the population structure of hermit crabs have been well described by some researchers (Fotheringham, 1975). In general, they suggested that in the population, males attain a larger size than females, resulting in a skewed sex ratio for females in smaller and intermediate sizes, whereas it is skewed for males in larger sizes (Bertini and Fransozo, 2000). Factors responsible for such an unequal sex ratio probably can be attributed to differential mortality and growth rates between sexes, migrations, or a faster growth rate of males in relation to females (Wenner, 1972). Females have lower growth rates than males due to the use of inadequate shells and a higher energy allocation to reproduction (Abrams, 1988). Also, the search for and utilization of shells is a major adaptation for hermit crabs, which influences the population size, with one sex (generally males) being more successful in obtaining the shells (Bertness, 1981).

Studies on the hermit crab reproductive biology have only started in recent years (Bertini and Fransozo, 2000). It suggests that hermit crabs may have seasonal or continuous reproduction and may exhibit sexual dimorphism, with males on average being larger than females (Mantelatto and Martinelli, 2001). Female-biased local populations of intertidal and shallow water hermit crabs have often been reported (Fotheringham, 1975; Abrams et al., 1986). Additionally, reproductive peaks might differ across populations in response to interspecies competition, shell availability, and the response of the hermit crab population to environmental conditions of the habitat (Fotheringham, 1976).

Hermit crab sex ratios have generally been recorded as deviating from 1:1 and being skewed towards females. Probable causes reported for this discrepancy are longevity and maturation time, differential migration, mortality, and sex reversal (Litulo, 2005). Seasonal migration in temperate hermit crabs has been reported to compensate for temperature fluctuations (Asakura, 1987). Migration protects the hermit crabs from freezing temperatures, desiccation risk, or decreased salinity (Fotheringham, 1975). Migration into deeper water in the reproductive season has been reported in hermit crabs (Asakura, 1987).

The pattern of shell use in nature is dependent on shell availability (Turra and Leite, 2001) as well as crab preferences (Bertness, 1980). Hermit crabs must search for the best available empty shells or fight inter- or intra-specifically to obtain an appropriate shell, which is a major limiting factor (Fotheringham, 1976; Hazlett, 1978). Several reasons are postulated for such differences in shell use pattern, including differences in the sizes of individuals among coexisting individuals (Turra and Leite, 2001), microhabitat segregation (Floeter et al., 2000), and particular abilities to obtain a new shell in competition (interspecific competition) or by active searching (exploitation competition) (Bertness, 1981).

**National review**

Hermit crab fauna in Indian waters accounts for a total of 115 species belonging to 26 genera and five families, out of which the most species are reported from the family Diogenidae (81 species, 11 genera). Ecological studies on the hermit crab fauna of Indian waters are very scanty. Ramesh et al. (2009) found that the distribution and availability of gastropod shells affect the distribution and abundance of *Clibanarius longitarsus*. In a study carried out on *Diogenes miles* (Herbst, 1791), it was observed that the species has a specific breeding season in the summer months (Sankolli and Shenoy, 1993). Varadarajan and Subramoniam (1982) compared the reproduction behaviour of *C. clibanarius* and found that on the east coast, the species was breeding continuously, while on the west coast, the species was breeding between the months of September and March as a result of variation in the sea water temperature.

The Gujarat coastline, being the longest of all the Indian states, extends about 1650 km, which comprises around 21% of the Indian coast line. The state coastline can be divided into three coasts as a result of two indentations, viz., the Gulf of Kachchh, the Saurashtra coast, and the Gulf of Khambhat (Singh, 2002). Out of these three major coasts, the Saurashtra coast possesses the richest diversity of organisms, including around 120 species of macrofauna (Vaghela, 2010). From the coastal regions of Gujarat, a total of 17 species (4 genera, 2 families) of hermit crabs are reported (Trivedi and Vachhrajani, 2017; Patel et al., 2020). A total of seven species of the genus *Clibanarius* were identified, of which *C. rhabdodactylus* Forest, 1953, is one of the most commonly occurring species on the rocky shores of the Saurashtra coast (Trivedi et al., unpublished data).

Only a few ecological studies have been carried out on hermit crab species on the Gujarat coast. Vaghela and Kundu (2012) studied the spatiotemporal variation in the hermit crab population on the Saurashtra coast. Desai and Mansuri (1989) studied the effect of various abiotic and biotic factors on the density, abundance, and temporal distribution of two hermit crab species, *C. zebra* and *C. nathii*, at the Saurashtra coast. Trivedi and Vachhrajani (2014), in their study, found that *C. zebra* was occupying 23 species of gastropod shells, with a maximum utilisation of six gastropod species. In a similar study by Patel et al. (2020), found that *Diogenes custos* occupied 49 species of gastropods with majorly occupying only six gastropod species. Although *C. rhabdodactylus* has a widespread distribution along the Gujarat coast, the ecological aspects of the species have not been well studied so far.

The species can be easily identified by the stripes on different body parts. Eye-stalk, shield and walking legs are marked with dark-brown stripes. Carapace has four longitudinal bands on the dorsal surface. Cheliped subequal; right slightly bigger. Ambulatory legs with merus and carpus having three stripes on lateral surface; propodus and dactylus are having five stripes; three on lateral surface and two on dorsal surface (Figure 2).

**Origin of the study**

The Saurashtra coastline of Gujarat State supports a diverse hermit crab population (Kachhiya et al., 2017), with substratum types ranging from rocky to sandy to muddy areas of intertidal zones (Trivedi et al., 2015). Some studies are available on the diversity and distribution of hermit crabs on the Gujarat coast (Desai and Mansuri, 1989; Vaghela and Kundu, 2012; Trivedi et al., 2015; Kachhiya et al., 2017), but very few studies are available on the ecology of hermit crabs in Gujarat (Trivedi and Vachhrajani, 2014). Out of the seven species of hermit crabs found on the Gujarat coast, *Clibanarius rhabdodactylus* is the most common species found along the rocky intertidal coast of Gujarat (Trivedi et al., unpublished data). The species is found on the Saurashtra coast starting from Veraval to Diu, with maximum abundance recorded from Veraval, Sutrapada, and Dhamlej, located on the coastal area of Gir Somnath district in Gujarat state (Trivedi et al., unpublished data). Although the species *C. rhabdodactylus* is a commonly occurring hermit crab species on the Saurashtra coast, however, the population ecology, behaviour, and biology of the species are not well studied.

**Figure 2.** Dorsal habitus of *Clibanarius rhabdodactylus* Forest, 1953.

**Objectives of the study**

1. To study population ecology of *Clibanarius rhabdodactylus*.
    a) To study population structure of *Clibanarius rhabdodactylus*.
    b) To study the seasonal variation in intertidal distribution pattern of *Clibanarius rhabdodactylus*.
2. Study of behavioural ecology of *Clibanarius rhabdodactylus*.
    c) To study the shell utilization pattern of *Clibanarius rhabdodactylus.*

## MATERIAL AND METHODS

### *Study Area*

Gujarat, being the westernmost state of India, possesses the country's longest coastline of around 1600 km, out of which the Saurashtra coast occupies an 850 km long stretch. The entire coastline of Saurashtra has been surveyed from Veraval to Diu for site selection, during which it was found that the maximum population of the species is found at Veraval (20° 54' 37" N, 70° 21' 04" E), Sutrapada (20° 49' 53" N, 70° 29' 17" E), and Dhamlej (20° 46' 29"

N, 70° 36’ 19" E) (Trivedi et al., unpublished data), which were selected for the present study (Figure 3). Out of these three sites, the maximum abundance of *C. rhabdodactylus* was recorded at Veraval as compared to Sutrapada and Dhamlej (Figure 4), hence Veraval was selected as the primary site for the present study.

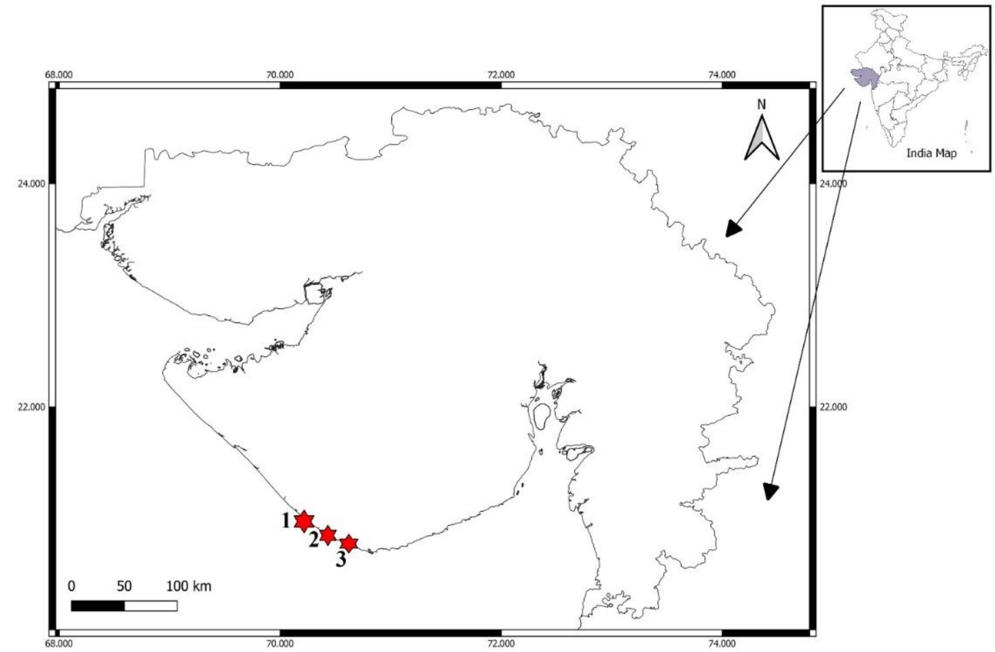


**Figure 3.** Location of study area (1. Veraval; 2. Sutrapada; 3. Dhamlej) (Image Source: QGIS)

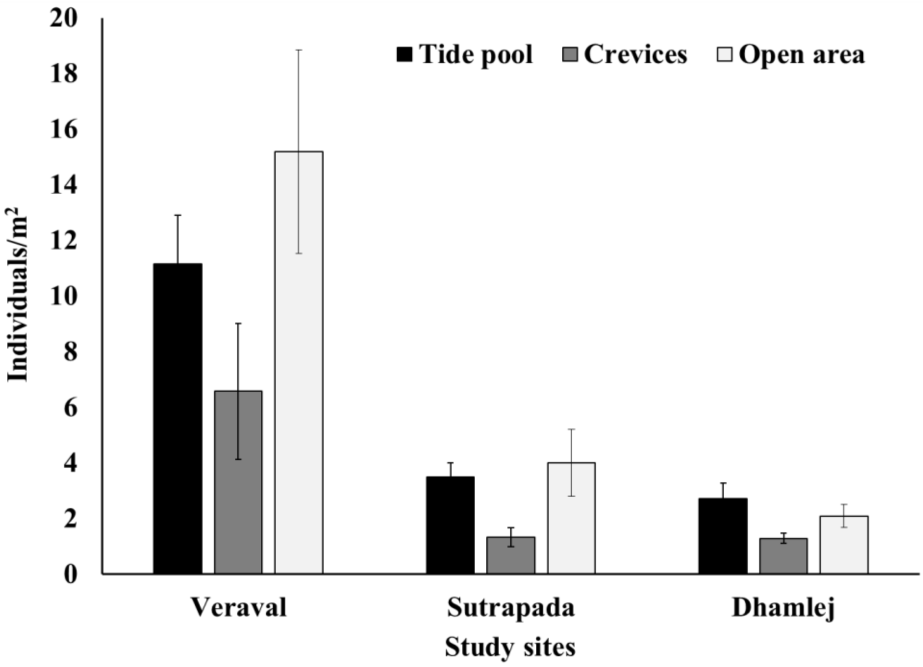


**Figure 4.** Abundance of *Clibanarius rhabdodactylus* Forest, 1953 in different microhabitats of study sites.

***Methodology***

**1. To study the population ecology of *Clibanarius rhabdodactylus*.**

**a) To study population structure of *Clibanarius rhabdodactylus*.**

- The monthly sample collection was carried out for 12 months (March 2021 to February 2022) to cover all the seasons, *viz*., winter (November to February), summer (March to June), and monsoon (July to October).
- Specimens were collected using catch per unit effort by one person during the period of 4 hours, covering an area of 500 $m^2$ during low tide. Collected specimens were kept in an ice box and brought to the laboratory.
- In the laboratory, the crabs were removed from their shells, and only intact individuals were used for the study.
- The hermit crabs were identified, sexed, and checked for the presence of eggs on female pleopods, and the proportion of ovigerous females in the samples was recorded.
- The shield length of each individual was measured using vernier callipers (±0.01mm accuracy). Individuals smaller than the smallest ovigerous female (< 2.98 mm SL) were considered juveniles (Baeza et al., 2013).
- The wet weight of ovigerous females, with and without egg mass (removed from pleopods), was measured, and the weight of the egg mass was calculated from the difference of both values.
- For fecundity, eggs were carefully removed from the pleopods of ovigerous female crabs (50 individuals) and mixed with 20 ml of sea water.
- 3 samples of 2 ml each from above solution were observed for counting of eggs.
- To calculate the total number of eggs, the average of three samples was multiplied by 10. The size range of eggs from each crab was measured by an ocular micrometre under a microscope.
- The monthly data collected on size (shield length) and sex was plotted to determine the monthly variation in size and gender composition. The occurrence of more

ovigerous females in the monthly samples indicates the breeding season of the species, while the occurrence of smaller specimens in the monthly samples indicates the juvenile settlement season.

- The chi-square test ($\chi^2$) was used to evaluate the sex ratio. Monthly estimates of the proportions of juveniles were tested for correlation with temperature using Pearson's correlation.

**b) To study the seasonal variation and intertidal distribution pattern of *Clibanarius rhabdodactylus.***

- The monthly sample collection was carried out for 12 months (September 2020 to August 2021) to cover all the seasons, viz., winter (November to February), summer (March to June), and monsoon (July to October).
- The rocky intertidal region of the study site was divided into three different zones: the upper intertidal (0 to 20 meters), middle intertidal (20 to 40 meters), and lower intertidal zones (40 to 60 meters).
- The quantification of *C. rhabdodactylus* individuals was carried out using the line-transect method, intercepted with quadrate. A total of three transects were laid 100 metres apart, perpendicular to the shoreline. On each transect, quadrates (0.25 $m^2$) were laid at an interval of every 5 metres from the upper intertidal region to the lower intertidal region.
- All the *C. rhabdodactylus* individuals occurring in each quadrate were collected in tagged zip-lock bags, kept in an icebox, and brought to the laboratory for further analysis.
- The temperature of tide pool water from the upper, middle, and lower intertidal regions as well as ambient temperature (every hour) were recorded during the sampling period using a digital thermometer.
- For microhabitat analysis, the rocky habitat was classified into tide pools, crevices, and open areas.
- In the intertidal region, a total of 10 transects were laid 50 m apart, perpendicular to the shoreline. On each transect, quadrates (1 $m^2$) were laid at every 5-metre interval,

starting from the upper intertidal region to the lower intertidal region. Each quadrate was further divided into 100 sub-quadrates of 10 × 10 cm.

- Percentage microhabitat cover was assessed by counting the number of sub-quadrates occupied by each microhabitat type and giving 1% cover to each sub-quadrate. All sampling was carried out by a single person to avoid potential observer influence.
- In the laboratory, for each quadrate sample, the hermit crabs were removed from the gastropod shell, and their shield length (SL) was measured using vernier callipers (±0.01mm accuracy). Furthermore, the hermit crabs were classified as male, non-ovigerous female, or ovigerous female.
- Monthly data for each season was compiled, and quadrate-wise abundance was calculated. The abundance data was used to plot kite diagrams to determine the variation in distribution of *C. rhabdodactylus* in different intertidal zones and seasons.
- A one-way ANOVA was used to examine variation in the mean values of shield length for different sexes as well as variation in the mean abundance of *C. rhabdodactylus* during different seasons. Seasonal variation in the tide pool water and ambient temperature between different intertidal regions was calculated using a two-way ANOVA.

**2. Study of behavioural ecology of *Clibanarius rhabdodactylus.***

**c) To study the shell utilization pattern of *Clibanarius rhabdodactylus.***

- The specimens of *C. rhabdodactylus* and *C. ransoni* were collected randomly during low tide, kept in an ice box, and brought to the laboratory.
- In the laboratory, hermit crabs were removed from their shells, and only intact individuals were used for the study.
- The gender of each individual was identified using a stereomicroscope (Metlab PST 901) and classified as male, non-ovigerous female, or ovigerous female.
- Two morphological characteristics, hermit crab weight (HW) (0.01 g) and shield length (0.01 mm), were measured using a digital weighing scale and vernier callipers, respectively, for each individual. Ovigerous females were weighed with the egg mass.
- Hermit crabs were sorted into different size classes based on their shield length (SL).

- The occupied gastropod shells were identified to species level using a monograph by Apte (2014).
- Five morphological parameters of gastropod shells were analyzed, viz., shell total length (SHL), shell aperture length (SHAL), shell aperture width (SHAW), shell dry weight (SHW), and shell volume (SHV).
- The abundance of five highly occupied gastropod shells was quantified using line transects intercepted with $0.25m^2$ quadrate every 5 m.
- A total of ten line transects were laid randomly, perpendicular to the shoreline, from the high tide to the low tide mark to quantify the abundance of live and empty shells.
- The morphological parameters of gastropod shells and hermit crabs were correlated using regression analysis to find out the relationship between them,
- A one-way ANOVA was used to examine the variation in mean shield length values between hermit crab sexes. The shell species occupation rate was estimated as a percentage.
- Mean values of different morphological parameters of five highly occupied gastropod shells by different sexes as well as reproductive stages of *C. rhabdodactylus* and *C. ransoni* were calculated to understand the sexes or reproductive stage wise shell occupation pattern.
- Canonical Correspondence Analysis (CCA) was carried out to analyse the relationships between hermit crab morphometry (SL and HW) and shell parameters (SHL, SHAL, SHAW, SHW, and SHV) and visualise the main features of crab (species, sex, and size) distribution according to the gastropod shell species and characteristics.
- The data set of the hermit crab species, comprised of sex and size class, was correlated, while the environmental data set consisted of the shell parameters (SHL, SHAL, SHAW, SHW, SHV). The data set for hermit crab species for different sexes and sizes was given specific codes as: CRH = *C. rhabdodactylus*; CRS = *C. ransoni*; M = male; F = female; whereas the size classes are represented by numerals. All the
- statistical analysis was performed using PAST 4.03 software.

## RESULTS AND DISCUSSION

### *a)* To study population structure of *Clibanarius rhabdodactylus.*

A total of 1640 individuals of *C. rhabdodactylus* were collected for the study of their population structure and breeding biology. The overall sex ratio (1:1.72) was significantly different from the expected 1:1 proportion ($\chi^2$=8.27, P<0.05) and was biased toward females in the majority of the months during the study. Several factors may contribute to the deviation from the ideal sex ratio of 1:1, including sexual differences in spatiotemporal distribution and mortality rate, differential life span, activity and out migration of one sex, sex longevity, differential predation on crab, and growth rates (Spivak et al., 2022). Moreover, the males were significantly larger than the females (Table 1).

**Table 1.** Carapace shield length values of different sexes of *Clibanarius rhabdodactylus* Forest, 1953. (ANOVA; ***p < 0.001; n = total individuals; SL= Shield length).

| Sex | n | Minimum SL (mm) | Maximum SL (mm) | mean ± SD |
|---|---|---|---|---|
| Male | 604 | 1.96 | 7.71 | 5.05±0.99*** |
| Non-ovigerous female | 615 | 1.66 | 5.06 | 3.80±0.52*** |
| Ovigerous female | 412 | 3.02 | 4.98 | 3.95±0.41*** |

In the present study, it was observed that the ovigerous females were obtained throughout the year, showing continuous reproduction with a high percentage of occurrence during January to June and September to October (Table 2). Reproductive periods often relate to fluctuations in abiotic factors like temperature, salinity, oxygen, photoperiod, and rainfall, among others that vary from region to region, or to biotic factors such as seasonal planktonic food, which is essential for larval development (Litulo, 2004).

**Table 2.** Total number of *Clibanarius rhabdodactylus* Forest, 1953 specimens collected at Veraval coast, Gujarat, India.

| Month | M | % | NOF | % | OF | % | NOF+OF | % | Male: Female |
|---|---|---|---|---|---|---|---|---|---|
| **January** | 90 | 40.00 | 61 | 27.11 | 74 | 32.89 | 135 | 60.00 | 1:1.5 |
| **February** | 68 | 43.04 | 40 | 25.32 | 50 | 31.65 | 90 | 56.96 | 1:1.32 |
| **March** | 55 | 28.65 | 63 | 32.81 | 74 | 38.54 | 137 | 71.35 | 1:2.49 |
| **April** | 42 | 31.11 | 49 | 36.30 | 44 | 32.59 | 93 | 68.89 | 1:2.21 |
| **May** | 57 | 32.76 | 83 | 47.70 | 34 | 19.54 | 117 | 67.24 | 1:2.05 |
| **June** | 93 | 28.88 | 173 | 53.73 | 56 | 17.39 | 229 | 71.12 | 1:2.46 |
| **July** | 30 | 31.25 | 64 | 66.67 | 2 | 2.08 | 66 | 68.75 | 1:2.20 |
| **August** | 15 | 75.00 | 3 | 15.00 | 2 | 10.00 | 5 | 25.00 | 1:0.33 |
| **September** | 52 | 48.15 | 14 | 12.96 | 42 | 38.89 | 56 | 51.85 | 1:1.08 |
| **October** | 28 | 48.28 | 8 | 13.79 | 22 | 37.93 | 30 | 51.72 | 1:1.07 |
| **November** | 24 | 39.34 | 30 | 49.18 | 7 | 11.48 | 37 | 60.66 | 1:1.54 |
| **December** | 50 | 54.95 | 27 | 29.67 | 14 | 15.38 | 41 | 45.05 | 1:0.82 |
| **Total** | **604** | **36.83** | **615** | **37.50** | **421** | **25.67** | **1036** | **63.17** | **1:1.72** |

It was observed that the males were reaching larger sizes (up to 8 mm SL) while females were comparatively smaller (up to 5 mm SL). Males attain larger size in a shorter period of time as they use most of their energy for physical growth, while females have to save their energy for the purpose of egg development and reproduction (Mantelatto et al., 2010) (Figure 5).

Moreover, males had a bimodal distribution, with the majority of individuals recorded in the 5–8 mm SL size class. A unimodal size frequency distribution was observed in females, with the majority of individuals recorded in the 3–4 mm SL size class. The size–frequency distribution of a population is a dynamic characteristic that can change throughout the year as a result of reproduction and rapid recruitment from larvae (Thurman, 1985). Furthermore, breeding in the summer, when temperatures are higher and phytoplankton is more abundant, would shorten development time and reduce larval predation (Emmerson, 1994).

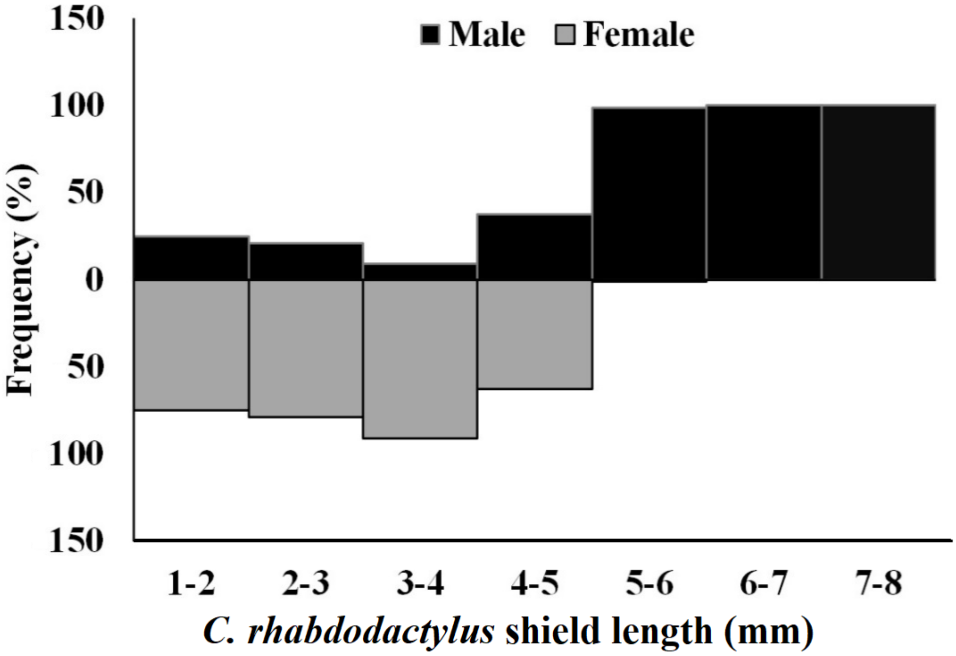


**Figure 5.** Overall size–frequency distribution of *Clibanarius rhabdodactylus* Forest, 1953, at Veraval coast, Gujarat, India.

Month-wise frequency distribution showed bimodal distribution of males during majority of months, whereas unimodal distribution was observed in a few (Figures 6 & 7). Unimodal distribution was observed for non-ovigerous females during majority of months while bimodal distribution was observed in February. Ovigerous females showed only unimodal distribution throughout the year. Factors such as differential mortality, migration, gender wise resistance to unfavourable environmental conditions, differences in foraging efficiency, acquisition or assimilation of food, and variation in behavioural pattern between sexes could be responsible for such variations (Johnson, 2003). It was also observed that juveniles occurred throughout the year, with the highest incidence of occurrence in February, April, and July to October showing juvenile recruitment season (Figures 6 & 7).

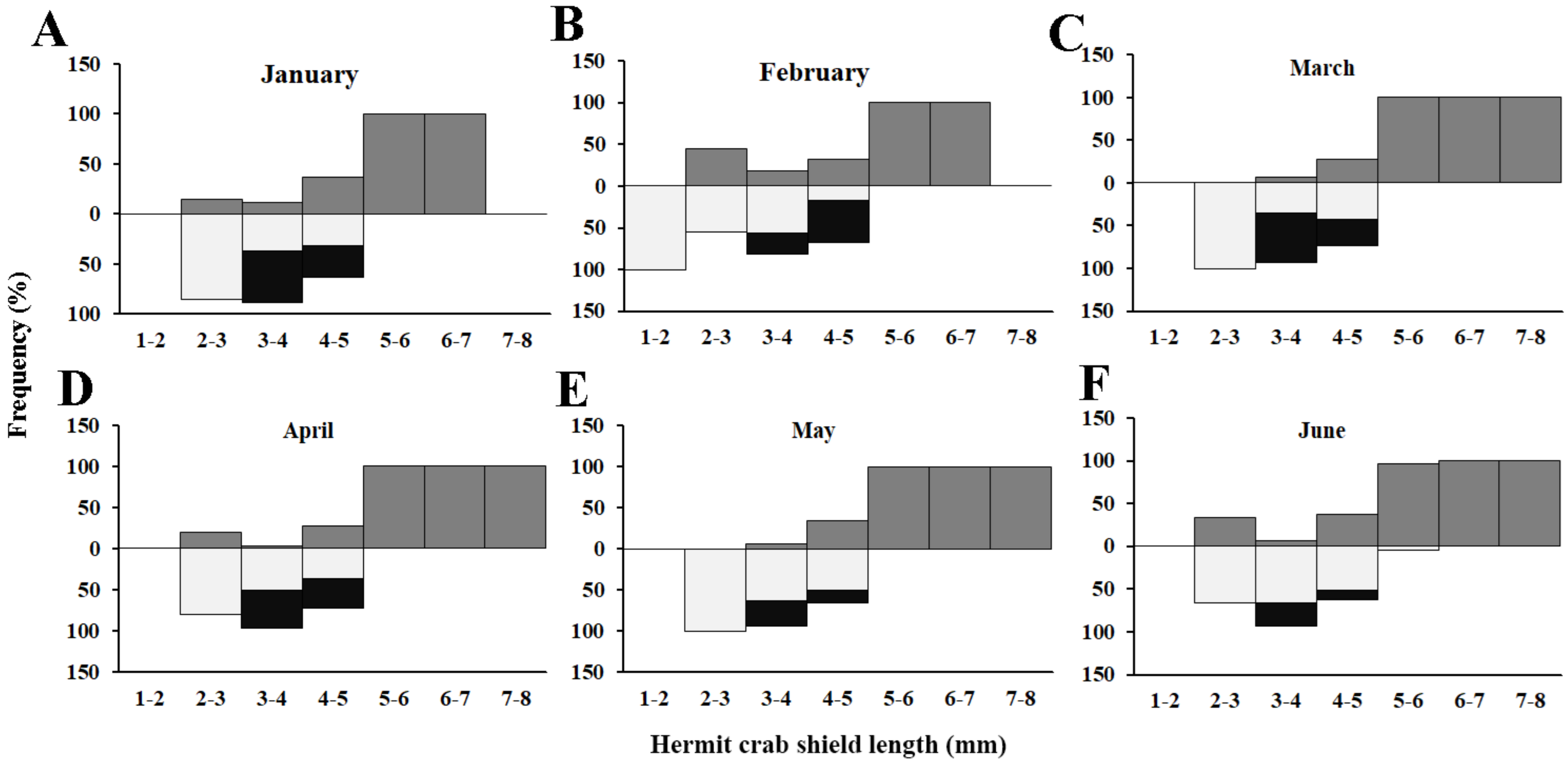


**Figure 6.** Size frequency distribution *Clibanarius rhabdodactylus* Forest, 1953 from January to June.

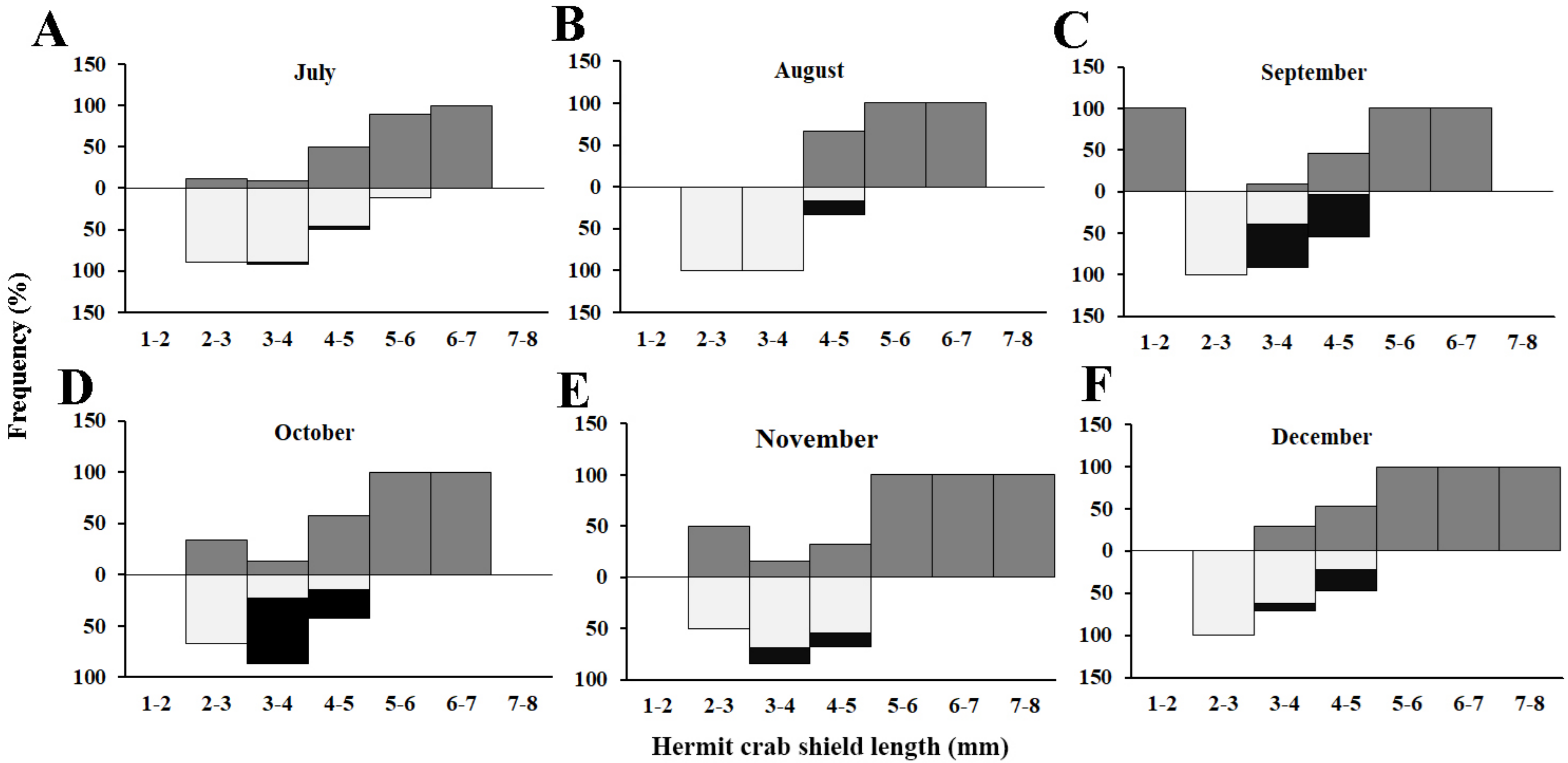


**Figure 7.** Size frequency distribution *Clibanarius rhabdodactylus* Forest, 1953 from July to December.

b) **To study the seasonal variation and intertidal distribution pattern of *Clibanarius rhabdodactylus.***

A total of 3,423 individuals were sampled during the study period. The tide pool water temperature and ambient temperature varied significantly between all three seasons (ANOVA: $F = 24.18$, $p<0.001$) (Figure 8). The ambient temperature was recorded at its maximum during the summer season, followed by the monsoon and winter. In case of the tide pool temperature of the upper intertidal region, a maximum temperature of 38.27 ± 0.45 °C was observed in the summer season, while a minimum temperature of 30.63 ± 0.65 °C was observed in the monsoon season. In the middle intertidal region, a maximum tide pool temperature of 35.63 ± 0.37 °C was observed in the summer season, while a minimum temperature of 29.87 ± 0.88 °C was observed in the monsoon season. Similarly, in the lower intertidal region, the maximum tide pool temperature of 31.09 ± 0.48°C was observed in the summer season, while the minimum temperature of 27.94 ± 0.65°C was observed in the winter season.

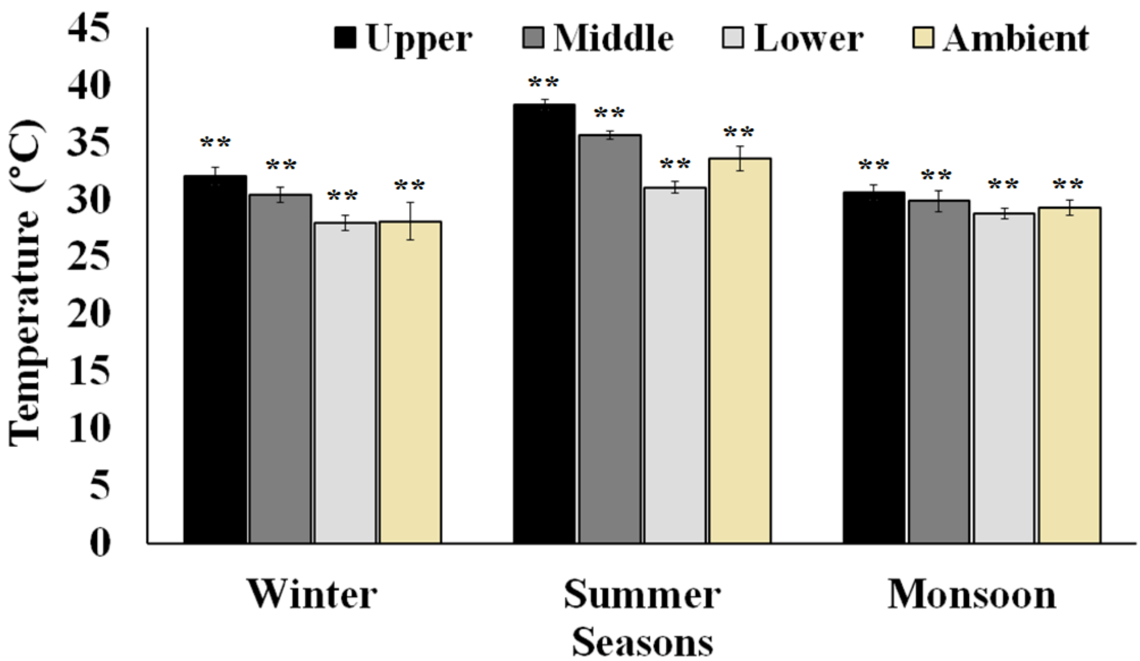


**Figure 8.** Seasonal variation in the mean values of temperature at different intertidal region of Veraval coast, Gujarat, India.

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, decreasing gradually to the lower intertidal region whereas, open areas occurred less in the upper intertidal zone and increasing gradually towards the lower intertidal region (Figure

9A). In winter, *C. rhabdodactylus* individuals were mostly distributed in the upper intertidal region, where the mean water temperature was 32.05 ± 0.73°C (Figure 9B). In summer, when the water temperature of the upper intertidal reaches 38.27 ± 0.45°C, the *C. rhabdodactylus* population is distributed in the middle and lower intertidal regions, where the water temperature is 35.63 ± 0.37°C and 31.09 ± 0.48°C respectively (Figure 9C). Furthermore, during the monsoon season, the water temperature did not vary from the upper to lower intertidal region, and the *C. rhabdodactylus* population was found to be distributed from the upper to lower intertidal region, with the greatest abundance in the upper intertidal region (Figure 9D). It was observed that the species was occupying the intertidal region, with a water temperature between 30–35°C.

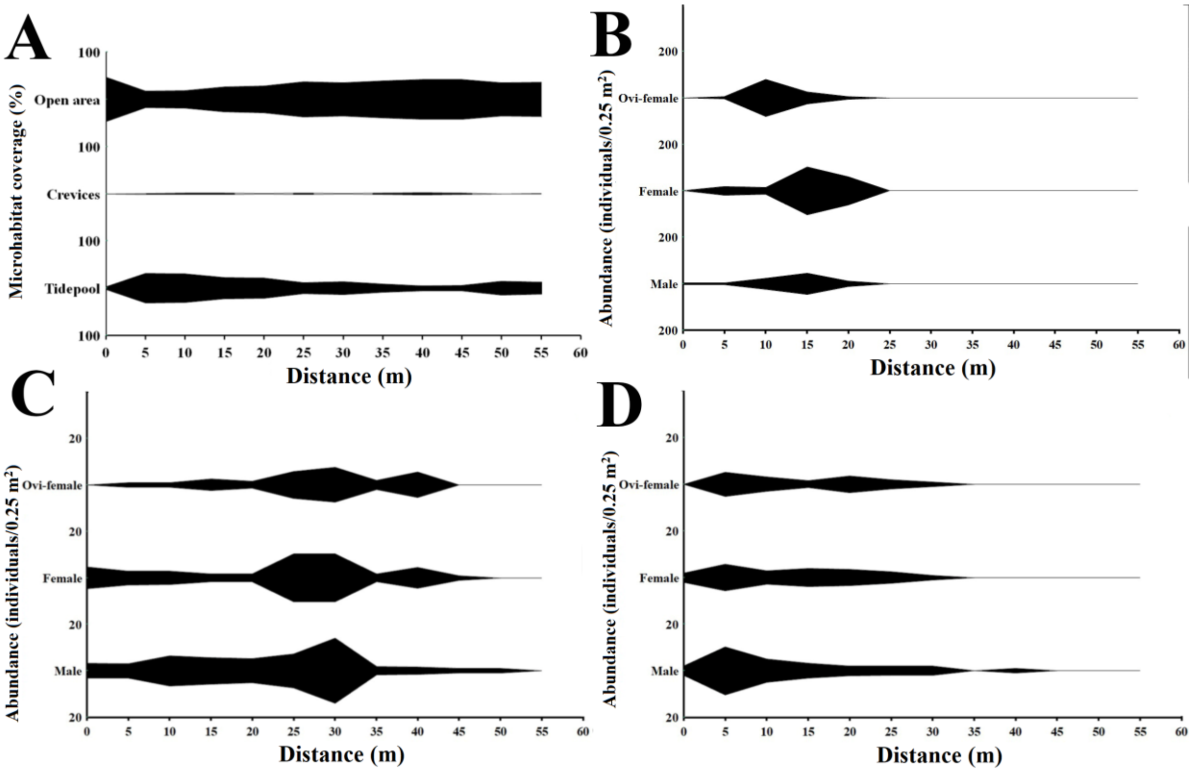


**Figure 9.** A. Microhabitat coverage of intertidal region in the study area; Intertidal distribution of *Clibanarius rhabdodactylus* Forest, 1953 at Veraval coast in B. winter season; C. Summer season and D. Monsoon season.

### c) To study the shell utilization pattern of *Clibanarius rhabdodactylus*

A total of 38 gastropod species were utilised by the hermit crab species. Individuals of *C. rhabdodactylus* were recorded occupying 29 gastropod shell species (males: 25 species, non-ovigerous females: 27 species, ovigerous females: 23 species), while *C. ransoni* were found occupying 28 gastropod shell species (males: 25 species, non-ovigerous females: 23 species, ovigerous females: 14 species) (Table 3). It was also found that both hermit crab species were frequently utilising only five gastropod species: *Cerithium caeruleum* G. B. Sowerby II, 1855, *Lunella coronata* (Gmelin, 1791), *Tenguella granulata* (Duclos, 1832), *Turbo bruneus* (Röding, 1798), and *Pollia undosa* (Linnaeus, 1758) (Tables 3). Studies suggests that the availability and abundance of gastropod shells greatly affects the shell utilization pattern of hermit crabs (Barnes, 1999). Also, the ovigerous females use specific shell as they have to accommodate and incubate their egg mass (Sallam, 2012).

**Table 3.** Gastropod shell utilization by *Clibanarius rhabdodactylus* Forest, 1953 and *Clibanarius ransoni* Forest, 1953. (N: total individuals, M: Male, NOF: Non-ovigerous female, OF: Ovigerous female, NO: not occupied).

| Gastropod species | *Clibanarius rhabdodactylus* | | | | *Clibanarius ransoni* | | | |
|---|---|---|---|---|---|---|---|---|
| | **N** | **M** | **NOF** | **OF** | **N** | **M** | **NOF** | **OF** |
| *Cerithium caeruleum* G. B. Sowerby II, 1855 | 656 | 133 | 234 | 289 | 532 | 130 | 206 | 196 |
| *Lunella coronata* (Gmalin,1791) | 78 | 67 | 9 | 2 | 91 | 84 | 7 | 0 |
| *Tenguella granulata* (Duclos, 1832) | 57 | 3 | 21 | 33 | 43 | 10 | 13 | 20 |
| *Turbo bruneus* (Roding, 1798) | 44 | 38 | 4 | 2 | 73 | 59 | 11 | 3 |
| *Pollia undosa* (Linnaeus, 1758) | 38 | 29 | 5 | 4 | 39 | 29 | 9 | 1 |
| *Anachis terpsichore* (G. B. Sowerby ll, 1822) | NO | NO | NO | NO | 8 | 0 | 8 | 0 |
| *Astralium stellare* (Gmelin, 1791) | 13 | 9 | 3 | 1 | 28 | 16 | 11 | 2 |
| *Cerithium columna* Sowerby I, 1834 | 2 | 0 | 1 | 1 | NO | NO | NO | NO |
| *Cerithium coralium* kiener, 1841 | 2 | 0 | 1 | 1 | NO | NO | NO | NO |
| *Cerithium echinatum* Lamarck, 1822 | 3 | 1 | 1 | 1 | NO | NO | NO | NO |
| *Cantharus spiralis* (Gray, 1839) | NO | NO | NO | NO | 8 | 6 | 1 | 1 |
| *Cerithideopsilla cingulata* (Gmelin,1971) | NO | NO | NO | NO | 6 | 2 | 4 | 0 |
| *Chicoreus bruneus* (Link, 1807) | 12 | 11 | 1 | 0 | 23 | 23 | 0 | 0 |
| *Chicoreus maurus* (Broderip, 1833) | 9 | 7 | 1 | 1 | 14 | 12 | 0 | 2 |
| *Clypeomorus batillariaeformis* Habe & Kosuge, 1966 | 3 | 1 | 1 | 1 | NO | NO | NO | NO |
| *Chicoreus virgineus* (Röding, 1798) | NO | NO | NO | NO | 4 | 4 | 0 | 0 |
| *Ergalatax contracta* (Reeve, 1846) | 7 | 1 | 5 | 1 | 4 | 0 | 1 | 3 |
| *Ergalatax heptagonalis* (Reeve,1846) | 3 | 0 | 2 | 1 | NO | NO | NO | NO |
| *Euchelus asper* (Gmelin, 1791) | 6 | 4 | 1 | 1 | 18 | 12 | 6 | 0 |
| *Gyrineum natator* (Roding, 1798) | 5 | 3 | 1 | 1 | 8 | 7 | 1 | 0 |
| *Indothais lacera* (Born,1778) | 3 | 2 | 0 | 1 | 5 | 3 | 1 | 1 |
| *Indothais sacellum* (Gmelin, 1791) | 12 | 10 | 1 | 1 | 18 | 10 | 3 | 5 |
| *Mitra scutulata* (Gmelin, 1791) | 2 | 1 | 1 | 0 | NO | NO | NO | NO |
| *Monodata australis* (Lamarck, 1822) | 2 | 1 | 1 | 0 | 6 | 5 | 1 | 0 |
| *Morula uva* (Roding, 1798) | 6 | 2 | 1 | 3 | 8 | 4 | 3 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Nassarius marmoreus* (A. Adams, 1852) | 3 | 1 | 1 | 1 | NO | NO | NO | NO |
| *Nerita oryzarum* Recluz, 1841 | 3 | 2 | 1 | 0 | NO | NO | NO | NO |
| *Nassarius pullus* (Linneus 1758) | NO | NO | NO | NO | 1 | 0 | 1 | 0 |
| *Nassarius reeveanus* (Dunker, 1847) | NO | NO | NO | NO | 2 | 1 | 1 | 0 |
| *Natica picta* (Recluz,1844) | NO | NO | NO | NO | 3 | 1 | 2 | 0 |
| *Nerita oryzarum* Recluz, 1841 | NO | NO | NO | NO | 6 | 6 | 0 | 0 |
| *Orania subnodulosa* (Melvill,1893) | 5 | 1 | 2 | 2 | 7 | 4 | 2 | 3 |
| *Paradrillia patruelis* (E. A. Smith,1875) | 3 | 0 | 1 | 2 | NO | NO | NO | NO |
| *Poliia rubiginosa* (Reeve, 1846) | 4 | 3 | 1 | 0 | 13 | 2 | 6 | 3 |
| *Purpura panama* (Roding, 1798) | 11 | 9 | 1 | 1 | 13 | 10 | 3 | 0 |
| *Semiricinula tissoti* (Petit de la Saussaye, 1852) | 9 | 1 | 4 | 4 | 17 | 3 | 10 | 3 |
| *Tibia insulaechorab* Röding, 1798 | NO | NO | NO | NO | 2 | 2 | 0 | 0 |
| *Vanikoro cuvieriana* (Recluz, 1843) | 1 | 1 | 0 | 0 | NO | NO | NO | NO |
| **Gastropod species occupied** | **29** | **25** | **27** | **23** | **28** | **25** | **23** | **14** |
| **Total individuals** | **1000** | **341** | **304** | **355** | **1000** | **445** | **311** | **244** |

In the present study, it was observed that all the gastropod shell parameters (SHL, SHAL, SHAW, SHW, and SHV) showed a significant relationship with hermit crab size (SL), while the gastropod shell parameters (SHAL, SHAW, SHW, and SHV) showed a significant relationship with hermit crab weight (HW) (Table 4). Studies suggests that more spired shell protects the resident hermit crab from desiccation while larger and robust shells provide protection predators and strong wave action to the occupant crab (Brown and McLachlan, 2002). Studies suggest that hermit crabs carry out complex evaluation process before occupying it in which they analyse the shell aperture, size, weight, volume as well its condition for better survival (Caruso and Chemello, 2009).

**Table 4**. Regression equation in relation to the morphological parameters of different sexes of *Clibanarius rhabdodactylus* Forest, 1953 and *Clibanarius ransoni* Forest, 1953 and that of gastropod shells measures. (*p < 0.05; **p<0.01; ***p<0.001; Shield length= SL; Hermit crab wet weight= HW; Shell length= SHL; Shell aperture length= SHAL; Shell aperture width= SHAW; Shell dry weight= SHW; Shell volume= SHV).

| Species | Sex | N | Relationship | Y= axb | $R^2$ |
|---|---|---|---|---|---|
| *C. rhabdodactylus* | Male | 340 | SLxSHL | y = 4.4527x + 8.5038 | 0.37*** |
| | | | SLxSHAL | y = 2.0576x + 4.659 | 0.24*** |
| | | | SLxSHAW | y = 1.625x + 0.6086 | 0.22*** |
| | | | SLxSHW | y = 0.9784x - 1.3981 | 0.46*** |
| | | | SLxSHV | y = 0.2469x - 0.3021 | 0.23*** |
| | | | HWxSHL | y = 16.423x + 19.097 | 0.31*** |
| | | | HWxSHAL | y = 7.3461x + 9.634 | 0.19*** |
| | | | HWxSHAW | y = 6.6233x + 4.2675 | 0.23*** |
| | | | HWxSHW | y = 4.0698x + 0.7782 | 0.49*** |
| | | | HWxSHV | y = 1.0657x + 0.2342 | 0.27*** |
| | Female | 660 | SLxSHL | y = 4.3381x + 8.1011 | 0.27*** |
| | | | SLxSHAL | y = 2.5232x + 2.9572 | 0.30*** |
| | | | SLxSHAW | y = 2.1274x - 0.4627 | 0.39*** |
| | | | SLxSHW | y = 1.8132x - 4.1818 | 0.52*** |

| | | | | | |
|---|---|---|---|---|---|
| | | | SLxSHV | y = 0.5261x - 1.2514 | 0.56*** |
| | | | HWxSHL | y = 12.438x + 19.828 | 0.30 |
| | | | HWxSHAL | y = 6.0764x + 10.535 | 0.23* |
| | | | HWxSHAW | y = 5.2355x + 5.8532 | 0.32* |
| | | | HWxSHW | y = 5.2152x + 0.709 | 0.58*** |
| | | | HWxSHV | y = 1.495x + 0.1796 | 0.60*** |
| *C. ransoni* | Male | 455 | SLxSHL | y = 6.2441x + 0.4477 | 0.57*** |
| | | | SLxSHAL | y = 2.8026x - 0.3961 | 0.53*** |
| | | | SLxSHAW | y = 2.1214x - 0.4868 | 0.58*** |
| | | | SLxSHW | y = 2.551x - 6.4568 | 0.59*** |
| | | | SLxSHV | y = 0.7986x - 2.113 | 0.60*** |
| | | | HWxSHL | y = 12.685x + 18.877 | 0.56*** |
| | | | HWxSHAL | y = 4.8788x + 8.4501 | 0.38*** |
| | | | HWxSHAW | y = 3.6365x + 6.249 | 0.40*** |
| | | | HWxSHW | y = 5.7064x + 0.7034 | 0.70*** |
| | | | HWxSHV | y = 1.7751x + 0.1365 | 0.71*** |
| | Female | 545 | SLxSHL | y = 5.7577x + 4.3753 | 0.54*** |
| | | | SLxSHAL | y = 2.3247x + 1.2253 | 0.39*** |
| | | | SLxSHAW | y = 1.5436x + 0.5425 | 0.39*** |
| | | | SLxSHW | y = 1.2133x - 1.9048 | 0.55*** |
| | | | SLxSHV | y = 0.2463x - 0.3144 | 0.35*** |
| | | | HWxSHL | y = 21.305x + 17.211 | 0.53*** |
| | | | HWxSHAL | y = 7.0202x + 6.9784 | 0.25 |
| | | | HWxSHAW | y = 5.3969x + 4.0972 | 0.34 |
| | | | HWxSHW | y = 4.743x + 0.7088 | 0.59*** |
| | | | HWxSHV | y = 0.915x + 0.2333 | 0.34*** |

The CCA analysis between the hermit crab morphology and gastropod shell parameters is represented in Figure 10. It was revealed that the smaller sized males (CRHM1, CRHM2, CRSM1 and CRSM2) and females (CRHF1, CRHF2, CRSF1 and CRSF2) of *C. rhabdodactylus* and *C. ransoni* occupied the shells with smaller SHAL and lesser SHW and SHV such as *C. caeruleum*, *T. granulata*, and *P. undosa*, which protected them from the desiccation during low tide in the exposed rocky intertidal region of the study area. The larger males (CRHM3 and CRSM3) and females (CRHF3) of *C. rhabdodactylus* and *C. ransoni* occupied more globular shells with higher SHAW and SHV like *L. coronata* and *T. bruneus*, which can protect them from other predatory species.

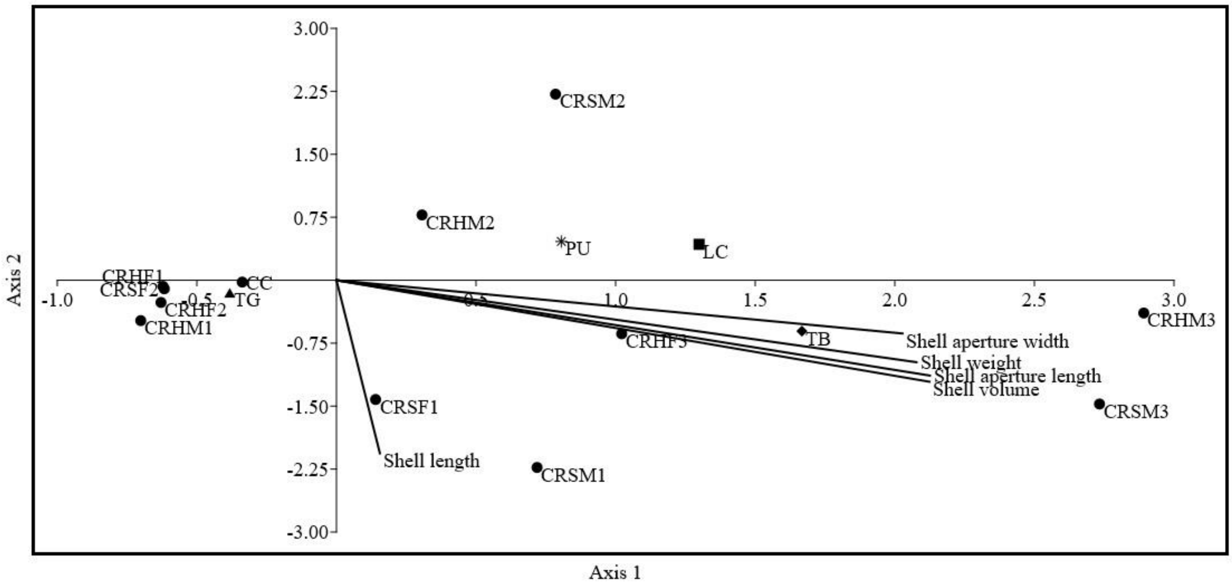


**Figure 10.** Canonical correspondence analysis (CCA) of shell use by *Clibanarius rhabdodactylus* Forest, 1953 and *Clibanarius ransoni* Forest, 1953 of different size classes as influenced by shell parameters. CC: *C. caeruleum*, LC: *L. coronata*, TG: *T. granulata*, TB: *T. bruneus*, PU: *P. undosa*. Lines indicate shell attributes in a direction of increasing magnitude. Filled circles indicate hermit crab species. (CRH = *C. rhabdodactylus*, CRS=*C. ransoni*) by sex (M = male, F = female) and size class (numeral, please refer to Table 5 for the explanation).

**Table 5.** Groupings of hermit crab individuals on the basis of species, sex and size classes (shield length) with their annotated codes for canonical correspondence analysis (CCA).

| Species | Sex | Size class (mm) | Code | n |
|---|---|---|---|---|
| *C. rhabdodactylus* | Female | 1.0–3.0 | CRHF1 | 114 |
| | | 3.0–5.0 | CRHF2 | 478 |
| | | 5.0–7.0 | CRHF3 | 5 |
| | Male | 1.0–3.0 | CRHM1 | 18 |
| | | 3.0–5.0 | CRHM2 | 172 |
| | | 5.0–7.0 | CRHM3 | 62 |
| *C. ransoni* | Female | 1.0–3.0 | CRSF1 | 59 |
| | | 3.0–5.0 | CRSF2 | 392 |
| | Male | 1.0–3.0 | CRSM1 | 59 |
| | | 3.0–5.0 | CRSM2 | 180 |
| | | 5.0–7.0 | CRSM3 | 72 |

## CONCLUSION

The present study was carried out understand the ecology of a commonly occurring hermit crab species *C. rhabdodactylus* in the rocky shores of Saurashtra. It was observed that the males were significantly larger than females since males use more energy for somatic growth while female remain comparatively smaller as they utilise their energy for gonadal development and incubation. The sex ratios of the population was skewed towards female. Moreover, it was also observed that the sex ratio was female-biased in the smaller and intermediate size classes (1 to 5 mm SL), whereas in the largest size classes it was male-biased (5 to 8 mm SL). Monthly size–frequency distributions in the male population of *C. rhabdodactylus* showed a bimodal pattern of distribution during the majority of the months of the year whereas, a unimodal pattern of distribution was observed in females during majority of months of the year. Ovigerous females occurred throughout the year showing that *C. rhabdodactylus* is a continuously breeding species.

The upper intertidal zone experiences the highest exposure to sunlight, leading to increased water temperature during low tide time, followed by middle and lower intertidal regions. The seawater temperature of the upper intertidal zone was reaching its maximum in the summer season. It was observed that the *C. rhabdodactylus* individuals were distributed in the intertidal region where the water temperature was ranging between 30–35°C considering it as the optimum temperature preferred by *C. rhabdodactylus*. Hence in winter, the species was distributed in the upper intertidal region having optimum rage of temperature whereas, the species distributed in the lower intertidal region in summer season. In monsoon the temperature remains almost similar in all the intertidal zones during the monsoon, and hence the *C. rhabdodactylus* individuals were distributed in all the intertidal zones.

It was observed that *C. rhabdodactylus* and *C. ransoni* utilised 29 species and 28 species of gastropod shells respectively which is quite higher as compared to some other hermit crab species most probably because the rocky intertidal region supports rich diversity of gastropods and hence their empty shells provide huge options for shell selection. Ovigerous females of both species were occupied significantly less species of gastropod shells as compared to the male and non-ovigerous female individuals of the same species. Ovigerous females are choosy for shells with larger inner space as they have to accommodate and incubate their egg mass. *Cerithium caeruleum* was the most preferred gastropod species by the individuals of *C. rhabdodactylus* and *C. ransoni*, possibly due to the high abundance of *C. caeruleum* in the study area. All the morphological parameters of gastropod shells showed a significant relationship with the hermit crab weight and shield length, suggesting that shell characters like shell total length, shell aperture length, shell aperture width, shell dry weight, and shell volume greatly affect the hermit crab's shell selection. It was observed that the smaller sized hermit crabs of both the species profoundly utilised the shell of *C. caeruleum* with more spires and smaller aperture that can conserve more water, protecting the occupant crab from desiccation. The larger individuals use a bigger, heavier, and more voluminous shell, which can protect from predators, protect from crushing wave actions, and aid in mating success.

## REFERENCES

Abele, L. G. (1974). Species diversity of decapod crustaceans in marine habitats. Ecology, 55(1): 156–161.

Abrams, P. A. (1988). Sexual Difference in Resource Use in Hermit Crabs; Consequences and Causes. In: *Behavioral Adaptation to Intertidal Life*. (eds.) Chelazzi, G., Vannini, M. Springer, Boston, MA, NATO ASI Series, 151: 283–296.

Abrams, P., Nyblade, C. and Sheldon, S. (1986). Resource partitioning and competition for shells in a subtidal hermit crab species assemblage. Oecologia, 69(3): 429–445.

Ahyong, S. T., Baba, K., Macpherson, E. and Poore, G. C. (2010). A new classification of the Galatheoidea (Crustacea: Decapoda: Anomura). Zootaxa, 2676(1): 57–68.

Apte, D. (2014). Sea Shells of India. Bombay Natural History Society, Mumbai, India, pp. 197

Asakura, A. (1987). Preliminary observations on the offshore mass migration of the sand–dwelling hermit crab, *Diogenes nitidimanus* terao (Crustacea decapoda: Anomura). Journal of Ethology, 5(2): 207–209.

Asakura, A. (1991). Population ecology of the sand-dwelling hermit crab *Diogenes nitidimanus*. IV. Larval settlement. Marine Ecology Progress Series, 78: 139–146.

Barnes, D. K. (1999). Ecology of tropical hermit crabs at Quirimba Island, Mozambique: shell characteristics and utilisation. Marine Ecology Progress Series, 183: 241–251.

Bertini, G. and Fransozo, A. (2000). Patterns of shell utilization in *Petrochirus diogenes* (Decapoda, Anomura, Diogenidae) in the Ubatuba region, São Paulo, Brazil. Journal of Crustacean Biology, 20(3): 468–473.

Bertness, M. D. (1980). Shell preference and utilization patterns in littoral hermit crabs of the Bay of Panama. Journal of Experimental Marine Biology and Ecology, 48(1): 1–16.

Bertness, M. D. (1981). Predation, physical stress and the organization of a tropical rocky intertidal hermit crab community. Ecology, 62(2): 411–425.

Bracken-Grissom, H. D., Cannon, M. E., Cabezas, P., Feldmann, R. M., Schweitzer, C. E., Ahyong, S. T. and Crandall, K. A. (2013). A comprehensive and integrative reconstruction of evolutionary history for Anomura (Crustacea: Decapoda). BMC Evolutionary Biology, 13(1): 128.

Brown, A. C. and McLachlan, A. (2002). Sandy shore ecosystems and the threats facing them: some predictions for the year 2025. Environmental Conservation, 29(1): 62–77.

Caruso, T. and Chemello, R. (2009). The size and shape of shells used by hermit crabs: a multivariate analysis of *Clibanarius erythropus*. Acta Oecologica, 35: 349–354.

Childress, J. R. (1972). Behavioral ecology and fitness theory in a tropical hermit crab. Ecology, 53: 960–964.

De Grave, S., Pentcheff, N. D., Ahyong, S. T., Chan, T. Y., Crandall, K. A., Dworschak, P. C., Felder, D. L., Feldmann, R. M., Fransen, C. H. J. M., Goulding, L. Y. D., Lemaitre, R. L., Martyn, E. Y., Martin, J. W., Ng, P. K. L., Schweitzer, C. E., Tan, S. H., Tshudy, D. and Wetzer R. (2009). A Classification of Living and Fossil Genera of Decapod Crustaceans. Raffles Bulletin of Zoology, 21: 1–109.

Desai, A. Y. and Mansuri, A. P. (1989). Salinity and desiccation tolerance of hermit crab of Veraval, West coast of India. Indian Journal of Current Biosciences, 8: 129–132.

Emmerson, W. D. (1994). Seasonal breeding cycles and sex ratios of eight species of crabs from Mgazana, a mangrove estuary in Transkei, southern Africa. Journal of Crustacean Biology, 14: 568–578.

Floeter, S. R., Nalesso, R. C., Rodrigues, M. M. P. and Turra, A. (2000). Patterns of shell utilization and selection in two sympatric hermit crabs (Anomura: Diogenidae) in south-eastern Brazil. Journal of the Marine Biological Association of the United Kingdom, 80(6):1053–1059.

Fotheringham, N. (1975). Structure of seasonal migrations of the littoral hermit crab *Clibanarius vittatus* (Bosc). Journal of Experimental Marine Biology and Ecology, 18(1): 47–53.

Fotheringham, N. (1976). Population consequences of shell utilization by hermit crabs. Ecology, 57(3): 570–578.

Hazlett, B. A. (1978)."Shell exchanges in hermit crabs: Aggression, negotiation, or both?." Animal Behaviour, 26(Part 4): 1278–1279.

Hazlett, B. A. (1981). The behavioral ecology of hermit crabs. Annual Review of Ecology and Systematics, 12(1): 1–22.

Ismail, T. G. E. K. (2010). Distribution and shell selection by two hermit crabs in different habitats on Egyptian Red Sea Coast. Acta Oecologica, 36(3): 314–324.

Johnson, P. T. J. (2003). Biased sex ratios in fiddler crabs (Brachyura, Ocypodidae): a review and evaluation of the influence of sampling method, size class and sex-specific mortality, Crustaceana, 76: 559–580.

Kachhiya, P., Raval, J., Poriya, P. and Kundu, R. (2017). Diversity and new records of intertidal hermit crabs of the genus *Clibanarius* (Crustacea: Decapoda: Diogenidae) from Gujarat coast off the northern Arabian Sea, with two new records for the mainland Indian coastline. Journal of Threatened Taxa, 9(6): 10334–10339.

Lalli, C. and Parsons, T. R. (1997). Biological oceanography: an introduction. Elsevier, pp.320

Litulo, C. (2004). Fecundity and breeding biology of the hermit crab *Diogenes brevirostris* (Stimpson, 1858) (Anomura: Diogenidae) from southern Mozambique. Invertebrate reproduction & development, 46(1): 41–46.

Litulo, C. (2005). Population structure and reproduction of the hermit crab *Dardanus deformis* (Anomura: Diogenidae) in the Indian Ocean. Journal of the Marine Biological Association of the United Kingdom, 85(4): 883–887.

Mantelatto, F. L. M. and Martinelli, J. M. (2001). Relative growth and sexual dimorphism of the South Atlantic hermit crab *Loxopagurus loxochelis* (Anomura, Diogenidae) from Ubatuba, Brazil. Journal of Natural History, 35(3): 429–437.

Mantelatto, F. L., Fernandes-Góes, L. C., Fantucci, M. Z., Biagi, R., Pardo, L. M. and de Goes, J. M. (2010). A comparative study of population traits between two South American populations of the striped-legged hermit crab *Clibanarius vittatus*. Acta Oecologica, 36(1): 10–15.

Martin, J. W. and Davis, G. E. (2001). *An updated classification of the recent Crustacea*. Natural History Museum of Los Angeles County, Los Angeles, 39, pp. 129

Martin, J. W. and Devis, G. E. (2002). *An Updated Classification of the Recent Crustacea*. National History Museum of Los Angeles County, Los Angeles, California, USA, pp. 124

McLaughlin, P. A., Komai, T., Lemaitre, R. and Rahayu, D. L. (2010). Annotated checklist of anomuran decapod crustaceans of the world (exclusive of the Kiwaoidea and families Chirostylidae and Galatheidae of the Galatheoidea) Part I–Lithodoidea, Lomisoidea and Paguroidea. The Raffles Bulletin of Zoology, 23(5): 107.

Pandya, P. J. and Vachhrajani, K. D. (2010). Spatial distribution and substratum preference of the brachyuran crab, *Macrophthalmus depressus* (Decapoda, Ocypodidae) along the lower estuarine mudflat of Mahi River, Gujarat, India. Crustaceana, 83(9): 1055–1067.

Patel, D., Patel, K. J., Patel, P. R. and Trivedi, J. N. (2020). Shell utilization pattern by the hermit crab *Diogenes custos* (Fabricius, 1798) along Gulf of Kachchh, Gujarat, India. Journal of Biological Studies, 3(2): 79–95.

Poore, G. C. (2004). *Marine decapod Crustacea of southern Australia: A guide to identification*. CSIRO publishing, pp. 616

Ramesh, S., Samipillai, S. S. and Elangomathavan, R. (2009). Habitat diversity of hermit crab *Clibanarius longitarsus* (De Haan) in vellar estuary, Southeast coast of India. Recent Research in Science and Technology, 1(4): 161–168.

Reese, E. S. (1969). Behavioral adaptations of intertidal hermit grabs. American Zoologist, 9(2): 343–355.

Sallam, W. S. (2012). Egg production and shell relationship of the land hermit crab *Coenobita scaevola* (Anomura: Coenobitidae) from Wadi El-emal, Red Sea, Egypt. The Journal of Basic & Applied Zoology, 65(2): 133–138.

Sankolli, K. N. and Shenoy, S. (1993). Larval development of the hermit crab *Diogenes miles* (Herbst, 1791) (Decapoda, Anomura, Diogenidae) in the laboratory. Crustaceana, 65(2): 253–264.

Singh, H. S. (2002). Marine protected areas in India: status of coastal wetlands and their conservation. Gujarat Ecological Education and Research (GEER) Foundation.

Spivak, E. D., Anger, K., Bas, C. C., Luppi, T. A. and Ismael, D. (2022). Size structure, sex ratio and breeding season in two intertidal grapsid crab species from Mar Chiquita lagoon, Argentina. Revista Nerítica, 10(1-2): 7–26.

Thurman II, C. L. (1985). Reproductive biology and population structure of the fiddler crab *Uca subcylindrica* (Stimpson), Biological Bulletin, 169: 215–229.

Trivedi, D. J., Trivedi, J. N., Soni, G. M., Purohit, B. D. and Vachhrajani, K. D. (2015). Crustacean fauna of Gujarat state of India: A review. Electronic. Journal of Environmental Science, 8: 23–31.

Trivedi, J. N. and Vachhrajani, K. D. (2014). Pattern of shell utilization in the hermit crab *Clibanarius zebra* (Dana, 1852) along the Saurashtra coast, Gujarat, India. Tropical zoology, 27(4): 129–139.

Trivedi, J. N. and Vachhrajani, K. D. (2017). An annotated checklist of hermit crabs (Crustacea, Decapoda, Anomura) of Indian waters with three new records. Journal of Asia-Pacific Biodiversity, 10(2): 175–182.

Turra, A. and Leite, F. P. (2000). Population biology and growth of three sympatric species of intertidal hermit crabs in south-eastern Brazil. Journal of the Marine Biological Association of the United Kingdom, 80(6): 1061–1069.

Turra, A. and Pereira Leite, F. P. (2001). Shell utilization patterns of a tropical rocky intertidal hermit crab assemblage: I. The case of Grande Beach. Journal of Crustacean Biology, 21(2): 393–406.

Vaghela, A. and Kundu, R. (2012). Spatiotemporal variations of hermit crab (crustacea: decapoda) inhabiting rocky shore along Saurashtra coast, western coast of India. Indian Journal of Geo-Marine Sciences, 41(2): 146–151.

Varadarajan, S. and Subramoniam, T. (1982). Reproduction of the continuously breeding tropical hermit crab *Clibanarius clibanarius*. Marine ecology progress series. Oldendorf, 8(2): 197–201.

Wenner, A. M. (1972). Sex ratio as a function of size in marine Crustacea. The American Naturalist, 106(949): 321–350.

Wethey, D. S. (1983). Intrapopulation variation in growth of sessile organisms: natural populations of the intertidal barnacle *Balanus balanoides*. Oikos, 14–23.

Patel Krupal J.
(Ph. D. student)

Dr. Kauresh D. Vachhrajanni
(Research Guide)