Article

Burrow structure and distribution pattern of chestnut crab, *Cardisoma carnifex* (Herbst, 1796) around Parangipettai mangrove habitat, India

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Abstract
This study aimed to investigate the structural characteristics of burrows and other hiding places for the chestnut crab, *Cardisoma carnifex*, from March 2021 to April 2022 in the Parangipettai mangrove habitat, Tamil Nadu, India. Burrows were randomly selected along the northern bank of the Vellar estuary for casting. The resident crabs were captured for morphological identification, and their morphometry (carapace length [CL] and carapace width [CW]) and sex were recorded. A total of 56 burrows were selected for studying distribution patterns, and six burrows were used for morphological observations. The study found a significant positive correlation between crab carapace length, carapace width, and burrow mouth diameter. Additionally, the burrow temperature dropped significantly at greater depths, providing a suitable environment for the crabs to survive in harsh conditions.

Keywords chestnut crab; distribution pattern; burrow architecture; mangrove; temperature

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1 Introduction

Semi-terrestrial crabs, though often not commercially significant, play crucial roles in coastal ecosystems. They contribute to nutrient cycling, process matter deposition, and facilitate plant growth by enhancing nutrient exchanges between sediment and water (Aschenbroich et al., 2016). Crab burrows serve as valuable indicators in research, with burrow counting being a simple and rapid method for estimating crab populations (Weilhoefer, 2011; Schlacher et al., 2016; Stelling-Wood et al., 2016; Min et al., 2023). For example, fiddler crab burrows have been used to evaluate salt marsh recovery from the Deepwater Horizon oil spill (McCall and Pennings, 2012). Previous studies have examined crab burrow distribution patterns across various habitats to assess factors such as water depth, plant communities (Mouton and Felder, 1996), soil water content (Reinsel and Dan, 1995), light, salinity (He and Cui, 2015), sediment characteristics (Spivak et al., 1994), food resources (He and Cui, 2015), and tides (Luppi et al., 2013; Paul et al., 2019) that affect crab distribution.

Cardisoma carnifex, a common species of semi-terrestrial Gecarcinidae crabs, is widely distributed in the Indo-Pacific region. It is typically found on muddy shores, mangrove swamps, or saline lowland soils near the coast (Hogue and Bright, 1971). These crabs excavate individual burrows into soft sediments throughout the high intertidal zone and in areas where groundwater is available during the dry season (Micheli et al., 1991; Vannini et al., 2003). The burrowing activities of crabs in mangroves and salt marshes can significantly impact substratum topography, granulometry (Warren and Underwood, 1986), and soil chemistry (Jones, 1984; Bertness, 1985).

Cardisoma carnifex is commonly found around the Vellar estuary, with their burrows typically having a single entrance and being occupied by a single crab. However, the distribution patterns in different zones of the mangrove in the Vellar estuary are not well understood. This study aims to characterize the spatial distribution patterns of male and female *C. carnifex* and the architectural patterns of their burrows in the study area.

2 Materials and Methods

2.1 Study area

The present study was carried out from March 2021 to April 2022 along the northern bank of the Vellar estuary on the southeast coast of India (lat. 11º 49' 15.638" N, lon. 79 º 76' 52.287" E and lat. 11º 29' 29.6304" N, lon. 79º 45' 54.8244" E). The mangrove forest which is located on northern side of the Vellar estuary is rich in brachyuran crab diversity.

2.2 Burrow distribution

The burrows of *C. carnifex* can be easily identified based on the earlier report by Micheli et al. (1991). In this study, a total of 56 burrows (15 male and 41 female) were randomly selected and marked using GPS. The burrow density, the distance between male burrows, the distance between female burrows, and the distance between male and female burrows in the study zone were documented. This method of GPS marking allows for precise mapping and analysis of burrow distribution, providing valuable insights into the spatial patterns and potential territorial behaviors of *C. carnifex*. The documentation of distances between burrows is crucial for understanding the social structure and habitat preferences of these crabs within the mangrove ecosystem.

2.3 Burrow structure

Six burrows were evacuated to capture the crabs and measure their morphological characteristics. The locations of these burrows are shown in Fig. 2b. Burrows entrance diameter were measured using a digital calliper (Zhart, India) with 0.1 mm accuracy. Burrow casting was performed by pouring a slurry of Plaster of Paris (POP) (water: POP = 1:2) into each burrow mouth, allowing it to dry for 2 hours as described by Qureshi and Saher (2012). Once the casts were dry, they were carefully excavated using a spade, removing soil from all sides. Measurements of burrow diameter (BD), total burrow length (TBL), and total burrow depth (TBD) were recorded using a measuring tape. The patterns and shapes of the burrows were demonstrated through visual observations of the casts.

2.4 Physico-chemical parameters

The important physico-chemical parameters *viz*., air temperature, burrow temperature, salinity, pH, TDS and specific gravity of the burrow water was measured fortnightly in every month during the study period.

2.5 Statistical analysis

The data were analyzed by one way analysis of variance (ANOVA) (Zar, 1996; Zhang and Qi, 2024). All numerical data are represented as the mean ± standard deviation (SD) unless otherwise stated. Statistical differences were considered significant when $P = 0.05$.

3 Results

3.1 Distribution pattern

The results indicate that the *C. carnifex* (Fig. 1) population in the study area has a sex ratio of approximately 1:3 (male: female). Females were observed to live closer to each other than males. The distances between two male burrows ranged from 300 to 900 meters, while the distances between two female burrows ranged from 1.7 to 8 meters. This suggests that males are territorial, placing their burrows far from each other, whereas females are more social, living closer together. Fig. 2a illustrates the distribution pattern of *C. carnifex* burrows in the study area, highlighting these spatial relationships.

Fig. 1 *Cardisoma carnifex*.

3.2 Physico-chemical parameters

The physico-chemical parameters such as air temperature, burrow temperature, salinity, pH, TDS and specific gravity of the burrow water and soil is given in Table 1.

Table 1 Physico-chemical parameters of the study zone (mean ± SD)

Zone	A (*n*=15)	B (*n*=6)	C (*n*=7)	D (*n*=9)	E (*n*=7)	F (*n*=12)
Air temperature (ºC)	29 ± 4^{a}	29 ± 4^{a}	29 ± 4^{a}	29 ± 4^{a}	29 ± 4^{a}	29 ± 4^{a}
Burrow temperature (ºC)	25 ± 0.5^{a}	25 ± 0.5^{a}	25 ± 0.5^{a}	25 ± 0.5^{a}	25 ± 0.5^{a}	25 ± 0.5^{a}
TDS (ppm)	106 ± 5^{a}	211 ± 7^{b}	193 ± 7^{c}	404 ± 9^{d}	199 ± 8^{c}	91 ± 3^{e}
pH	8.2 ± 0.5^{a}	7.8 ± 0.5^{a}	8.3 ± 0.7^{a}	8.0 ± 0.7^{a}	8.2 ± 0.8^{a}	7.9 ± 0.4^{a}
Salinity (ppt)	7.5 ± 0.5^{a}	8.0 ± 0.5^{a}	8.0 ± 0.5^{a}	7.5 ± 0.5^{a}	8.5 ± 0.5^{a}	8.5 ± 0.5^{a}
Specific gravity	1.004 ± 0.002^{a}	1.006 ± 0.003^{a}	1.004 ± 0.002^{a}	1.007 ± 0.003^{a}	1.004 ± 0.003^{a}	1.005 ± 0.003^{a}

The values along the rows sharing the common superscript is dot significantly different at $p<0.05$ level.

3.3 Burrow structure

Totally six burrows were observed for their detailed architecture pattern. The burrow location map is given in Fig. 2b.

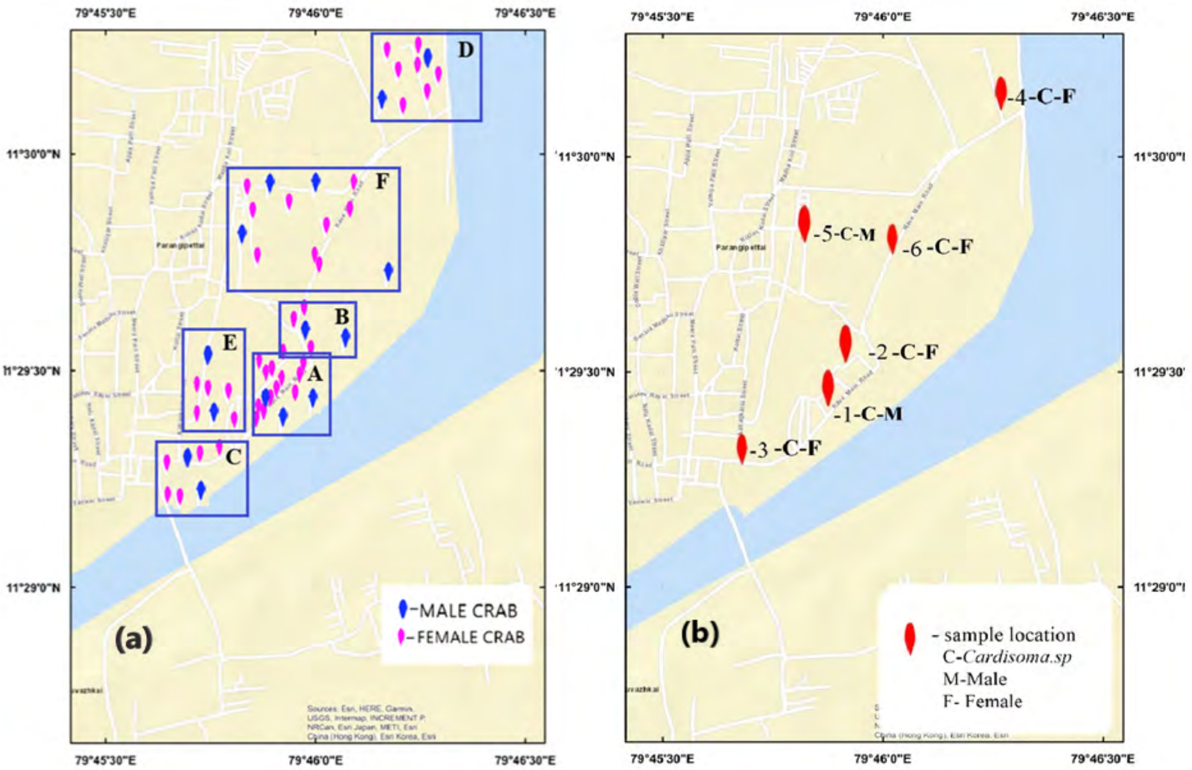

Fig. 2 (a) Distribution pattern of *C. carnifex* burrows in different zone; **(b)** Selected burrows for morphology study and their coordinates.

Pattern 1: This burrow belonged to a male crab and was located at 11°29’25.9"N 79°45’53.3"E beneath a man-made brick wall (Fig. 3A). The burrow was linear with two entries, one on either side of the brick wall. The burrow mouth was roughly circular, with a diameter of 10 cm. This linear burrow measured approximately 0.45 meters in length and 0.3 meters in depth and featured a broad central chamber. The crab was observed at the burrow entrance during dawn and dusk, retreating deeper during the hot hours of the day. The presence of gravel around the burrow appeared to limit its expansion, resulting in a unique shape and size. This type of burrow may be influenced by anthropogenic factors.

Pattern 2: This burrow belonged to a female crab and was located at 11°29’32.7"N 79°45’54.7"E along a man-made brick wall (Fig. 3B). It was situated a few meters away from the high tide line. The burrow had a horizontal entrance with a steep angle, leveling off for a distance before taking a sharp 90-degree turn downward until it reached the water level. The burrow mouth was roughly circular with a diameter of 10 cm. This burrow measured about 1.5 meters in length and 0.8 meters in depth, with a broad terminal chamber. The crab was observed at the burrow entrance during dawn and dusk, retreating deeper during the hot hours of the day. It was noted that the internal temperatures of the burrow remained 3-5℃ cooler than the outside temperature.

Pattern 3: This burrow belonged to a female crab and was located at 11°29’17.1"N 79°45’41.3"E (Fig. 3C). It was situated near huts and houses, resulting in high human intervention and frequent changes in water levels.

The burrow was spiral with a “Y” type architecture and had a single opening. The burrow mouth was roughly circular with a diameter of 7.5 cm. The shaft descended obliquely at a 45° angle before splitting into two paths leading to circular and oblong chambers, both stopping at the water level. The burrow measured approximately 1.55 meters in length and 1.3 meters in depth, with the first chamber being smaller than the second. The crab was observed at the burrow entrance during dawn and dusk, retreating deeper during hot hours. The burrow temperature was observed to be 4-5℃ cooler than the outside temperature.

Pattern 4: This burrow was occupied by a female crab and was located at 11°30'06.4"N 79°46'15.6"E (Fig. 3D) in a dry, arid area near a lighthouse, surrounded by beach sand and high salinity. The burrow had a horizontal slide morphology, starting with a steep entrance angle that leveled off before taking a sharp 90-degree downward turn, not reaching the water level, likely due to the water level being below the burrow terminus. The burrow mouth was roughly circular with a diameter of 10 cm. This “J” architecture burrow was about 1.65 meters in length and 1.4 meters in depth, featuring a broad terminal chamber.

Pattern 5: This pattern was a hide structure occupied by a medium-sized male crab, located at 11°29’25.9"N 79°45’53.3"E (Fig. 3E). It was a hiding place rather than a burrow, as the crab was observed inside a rainwater drainage pipe. This indicates that some crabs have adapted to living in man-made structures due to anthropogenic intervention. Although these hides could be temporary, this particular specimen was observed in the pipe throughout the study period.

Pattern 6: This burrow belonged to a female crab and was located at 11°29’46.1"N 79°46'01.5"E (Fig. 3F) beside the road towards Annankovil beach. The burrow had a horizontal slide morphology, starting with a steep entrance angle that leveled off before taking a sharp 90-degree downward turn, reaching the water level. The burrow mouth was roughly circular with a diameter of 8 cm. This “J” shape architecture burrow was about 1.5 meters in length and 1.4 meters in depth, with a broad terminal chamber. The crab was observed at the burrow entrance during dawn and dusk, retreating into the burrow during hot and busy hours of the day. The burrow temperature was observed to be 4℃ cooler than the outside air temperature.

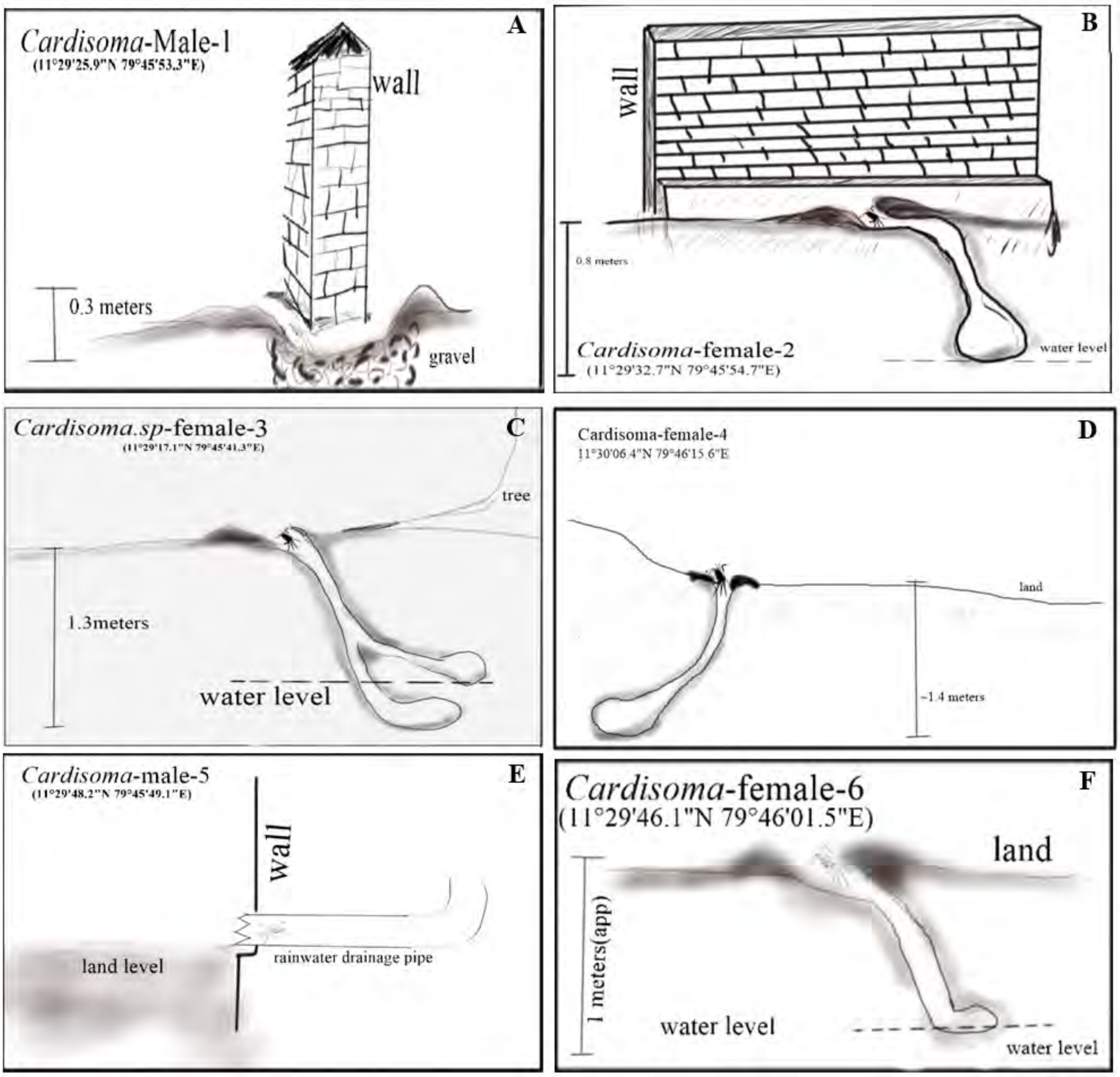

Fig. 3 Pattern of *C. carnifex* burrows.

4 Discussion

The morphology of *C. carnifex* burrows showed considerable variation in shape, size, and complexity, ranging from single entrance shafts with no branches to multiple entrances. In this study, six different burrow architectures were recorded (Fig. 3). According to Chakrabarti (1981) and Chan et al. (2006), the J-shaped and single-tube burrows of juvenile crabs were shallow in depth with narrower opening diameters and lesser volume. *Cardisoma carnifex* burrows are among the most distinctive and often the largest of all crab species' burrows. The burrow mouths were often perfectly round and notably larger in diameter than the width of the occupant’s carapace (Micheli et al., 1991). In the present study, we also found similar burrow mouths with diameters of 10-12 cm for *C. carnifex*.

As per our observations, the average burrow duration was 45 days for *C. carnifex*. However, Micheli et al. (1991) reported a duration of 25 days, which may depend on the season and soil conditions. Due to the dryness of the upper soil layers, burrow entrances frequently collapse and are dug again, while the deeper parts, which probably do not collapse as often, continue to be inhabited by the crabs. Thus, only entrances are continuously rearranged and often repositioned. Micheli et al. (1991), as well as Seiple and Salmon (1982), reported similar observations for *C. carnifex* and *Sesarma reticulatum* in salt marshes and suggested that crabs shift burrow entrances to approach new plants to feed on. This frequent digging may enrich the mud surface by oxygenating the soil and bringing organic material to the upper layers. The soil turnover achieved by burrowing is known to increase the productivity of *Spartina alterniflora* vegetation in salt marshes (Montague, 1982; Bertness, 1985).

Crabs like *Uca pugilator*, *Sesarma longipes*, *Cardisoma carnifex*, and *Macrophthalmus parvimanus* create temporary burrows like single tubes and bulb shapes as refuges during high tides or to protect themselves from predators (Braithwaite and Talbot, 1972; Christy, 1982). However, in our observation, most of the burrows were permanent and occupied by crabs throughout the study period. James (2007) notes that *Cardisoma* burrows are very deep and extend down to the water level, even during the dry season. Our study confirmed that most of the burrows are deep and reach the water level. Colonies of *Cardisoma* burrows discovered were randomly scattered on the ground in tree lines abutting marshes or beaches (James, 2007). There was no apparent relation of burrow placement to the protection of trees or rocks. In our study, the burrows were located in sand and mud soils in open ground, but burrow density was higher near tree trunks and walls. Beach colonies were recorded in the tree line off the beach and usually near river mouths. Swamp colonies were found along the estuary bank.

Earlier studies reported that crab burrow architecture is affected by several environmental factors such as temperature, moisture level, and wind (Lucrezi et al., 2009), as well as geomorphological properties of sandy shores like sand compaction, beach slope, sand grain size (Dixon et al., 2015; Pombo et al., 2017), and soil erosion (Hobbs et al., 2008). Burrow architecture also varies based on the size and sex of the resident crab (Lim and Diong, 2003). The present study revealed that both male and female *C. carnifex* construct differently shaped burrows, with male crab burrows being longer and more voluminous than female crab burrows. Similar findings were reported by Maheta and Vachhrajani (2023) for the fiddler crab *Austruca sindensis*. Males build longer and deeper breeding burrows to attract females for mating purposes (Backwell and Passmore, 1996; Tina et al., 2018).

Atkinson and Taylor (1988) discussed that burrows provide protection against high external temperatures and environmental extremes. According to Maheta and Vachhrajani (2023), the temperature of the sand surface dropped along the depths of the burrows, suggesting that the burrows provide refuge for the crabs during stressful summer periods. Temperature could be even lower further down the burrow, although measurements at greater depths were not obtained. As burrows are important for providing refuge from desiccation for intertidal crabs (Takeda and Kurihara, 1987; Thongtham and Kristensen, 2003), the depth of burrows is influenced by the water content of the sediment. In the present study, the burrow temperature was 4-5ºC cooler than the outside air temperature. According to Wolfrath (1992), temperature variations inside crab burrows are inversely related to outside air temperatures, with burrow temperatures being lower during the day and higher during the night than the outside temperature. If the temperature exceeds the optimal range, it reduces the ventilatory and cardiac performance in crabs, leading to a lesser supply of oxygen to the tissues and reduced endurance capacity (Allen et al., 2012).

5 Conclusion

The present observations reveal that the burrow architecture of *C. carnifex* varies significantly and that this species can adapt to extreme environmental changes. They utilize whatever natural materials and habitats are available, and their survival is not solely dependent on specific food sources. Previous studies have also found that *C. carnifex* burrows are remarkably resistant to disturbances. They can rebuild and restore their burrow entrances within a week, even after intensive blockage, resisting low-level surface developments by humans (Hurley, 2012). This adaptive nature helps them survive and thrive despite significant disturbances in their environment. Further research is needed to determine the extent of the impact of various environmental factors on burrow morphology and to understand the circumstances under which these crabs choose manmade structures as hiding places. This will provide a deeper understanding of their adaptive behaviors and the resilience of their burrowing activities in response to environmental challenges.

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