Article

Burrow characteristics of the fiddler crab – *Austruca sindensis* (Alcock, 1900) from mudflats of Gulf of Khambhat, Gujarat, India

Niketa P. Maheta, **Kauresh D. Vachhrajani**
Marine Biodiversity and Ecology Laboratory, Department of Zoology, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara – 390002, Gujarat, India
E-mail: nikismit31@gmail.com

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Abstract
The present investigation was carried out on the structural characteristics of burrows of the fiddler crab – *Austruca sindensis* (Alcock, 1900) between March 2021 to January 2022 from the mudflats of Kamboi, Gulf of Khambhat, Gujarat, India. Burrows were selected randomly from upper and middle intertidal zones for burrow casting. The unsaturated resin was poured inside the burrow and allowed to get solidify. The resident crabs were captured for morphological identification and its morphometry (carapace length - CL and carapace width - CW) and sex were recorded. A total of 94 complete burrow cast were used for burrow morphological and morphometric analysis wherein, characteristics including burrow diameter, orientation, length, width, inclination, branching and volume were recorded. A total of 7 different burrow shapes were recorded in which Single tube (27) burrow was prominently observed followed by J-shaped (25), S-shaped (21), Spiral burrows (10), etc. The crab carapace length showed significant positive correlation with carapace width, burrow opening diameter, total burrow length, total burrow depth and burrow volume. Burrow diameters are significantly smaller in the foreshore compared to that of the backshore, suggesting that larger individuals reside along the backshore, where they excavate deeper and large-diameter burrows to minimize chances of desiccation. While, the juveniles were observed utilizing shallow burrows with small opening diameter located near water line. Specific pattern was observed in the burrow temperature in which the burrow temperature dropped significantly at the greatest depth which provides suitable environment to the crab to survive in the harsh environmental conditions.

Keywords burrow architecture; mudflats; seasonal variation; temperature.

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1 Introduction

Burrow architecture is common behaviour observed in many vertebrates (Moulton et al., 2006; Schwaibold and Pillay, 2006) as well as invertebrate fauna (Matsumasa et al., 1992; Lomovasky et al., 2006). Burrows created by benthic invertebrates are a common feature of many marine, estuarine and freshwater soft sediment habitats (Little, 2000; Huhta, 2007). Brachyuran crabs are active burrowers of intertidal soft sediment causing remarkable effect on benthos present in the sediments (Iribarne et al., 1997; Herman et al., 1999). Burrows are advantageous to get protection against predator, to refuges from disturbance, thermal extremes (Ansell, 1988) and to avoid adverse environmental conditions (Kinoshita, 2002; Thongtham and Kristensen, 2003). Burrow morphology varies from species to species (Griffis and Suchanek, 1991; Wolfrath, 1992) but sometimes variation in burrow morphology is observed within same species due to several physical and biological factors such as sediment composition, vegetation type, shore height, tidal variation, sex and age of the individual etc. (Takeda and Kurihara, 1987; Morrisey et al., 1999; Lim and Diong, 2003; Chan et al., 2006). Burrow architecture is ecologically important specially to maintain semi-terrestrial mode of habit (Dubey et al., 2013). Burrowing behaviour is commonly reported in the genera *Macrophthalmus* and *Heloecius* (Griffin, 1965, 1968), *Uca* (Pearse, 1912; Crane, 1941a; Altevogt, 1955), *Ocypode* (Cott, 1929; Crane, 1941b; Tweedie, 1950; Barrass, 1963; George and Knott, 1965; Hughes, 1966), *Dotilla* (Tweedie, 1950) and *Scopimera* (Tweedie, 1950; Fielder, 1970).

Fiddler crabs are among the most common and best known for their burrowing behaviour (Crane, 1975; Lim, 2006). They abound along the shores of tropical and subtropical regions around the world where they excavate simple dwellings (burrows) in intertidal areas (Gibert et al., 2013). These crabs are known to accommodate their burrowing exercise to a varying degree of conditions like substratum conditions, salinity, temperature, tidal periodicity, anthropogenic disturbances, predators etc (Dubey et al., 2013). During high tide crabs remain inside the burrow while emerging out during low tide for feeding or other surface activities (Gherardi et al., 1999). Such behavioural adaptation helps them to avoid the need of periodically return to a burrow to replenish its water supply (Hartnoll, 1973). Nowadays, ecological functions of burrowing behaviour in specific ecosystem have received increasing attention and crab burrowing has been considered as one of the major factors of bioturbation affecting the physical and chemical processes in ecosystems (Wang et al., 2010). Therefore, the present study was planned to understand the structural characteristics of burrows of the fiddler crab *Austruca sindensis* (Alcock, 1900) which is commonly distributed on coastal region of Gulf of Khambhat.

2 Materials and Methods

2.1 Study area

Gulf of Khambhat is one of the three Gulfs of India and having largest tidal amplitude on the West Coast of India. Gulf of Khambhat owes its own peculiarity in terms of its geomorphology, hydrodynamics and high tidal amplitude. Gulf, being funnel shaped with wide mouth and narrow head (width 200 km at mouth of Gulf terminating to 6 km at the extreme end of Gulf i.e. mouth of Mahi estuary), provides geo assistance to the tidal amplitude and turbulence. The coastal area of Gulf of Khambhat is having wide variety of intertidal habitats like mudflats, sandy shores, rocky-muddy shores, estuaries and mangroves (Pandya and Vachhrajani, 2010).

The present study was carried between March 2021 to January 2022at Kamboi coast-Gulf of Khambhat (Site 1-22º12'45.10" N, 72º36'06.26" E; Site 2- 22º13'00.27" N, 72º37'02.34" E) located in Bharuch district, Gujarat, India (Fig. 1). Kamboi coast is one of the important habitats located on the narrow head region of Gulf of Khambhat, which is reach in diversity of brachyuran crabs. The intertidal area of Kamboi coast is muddy in nature. The upper intertidal zone is made up of silt and clay which is dominated by *Austruca sps*, the middle zone contains undulating muddy area which is dominated by *Ilyoplax sayajiraoi* (Trivedi et al., 2015) and lower intertidal zone is made up of sand which is dominated by brachyuran crab *Dotilla blanfordi* (Alcock, 1900) (Pandya and Vachhrajani, 2013).

Fig. 1 Location of study site: Kamboi, Gujarat, India.

2.2 Burrow architecture

The burrows of crabs were selected randomly from upper intertidal and middle intertidal zone. The burrow opening diameter was recorded with the help of digital vernier callipers (Yuri YUR01 Digital Vernier Calliper 0-150 mm). The mixture of unsaturated resin, cobalt and catalyst (3:1:1) was poured into the burrows until the burrows were totally filled. Crabs emerged from the burrows were collected, sexed and the carapace width and length measured using vernier callipers (±0.1 mm). When the burrow casts had solidified (~2 h), they were dug up for subsequent measurement of burrow dimensions (Fig. 2). The volume of the burrows were determined by weighing the burrow cast (±0.01 g) and dividing the weight by the density of the unsaturated resin (0.96 g/cm^3) (Trivedi and Vachhrajani, 2016).

2.3 Vertical temperature gradient in burrows

Variation in sediment temperature was measured along the depth of the burrow during low tides. Burrows were selected randomly and their opening diameter was measured using vernier callipers (±0.1 mm). The sand surface temperature at the burrow opening was measured using a digital thermometer (Eurolab ST9269B, ±0.1°C). The temperature of sediment was measured at every 5 cm depth interval up to the depth of 25 cm.

2.4 Statistical analysis

The regression was done to establish the relationship between carapace lengths of the crab and different morphological parameters of the burrow cast. In factor analysis univariate descriptive statistics was used. Whereas in correlation matrix, two selected attributes such as ‘coefficient’ and ‘significance level’ were used. In ‘factor analysis extraction’ attribute display selected was ‘unrotated factor’ solution and ‘scree plot.’ Method of extraction was based on ‘Eigen value > 1. All the statistical analysis was performed in “Statistical Package for the Social Sciences (version SPSS 22) software.

3 Results

3.1 Different shapes of the burrows

A total of 94 burrow casts were obtained, of which the 46 host crabs were captured (29 males and 17 females). A total of 7 different burrow shapes were recorded including J-shaped burrow (28), Single tube burrow (27), S-shaped burrow (21), Spiral burrow (10), J-shaped burrow with branch (5), U-shaped burrow with single opening (2) and Multi-branched burrow (1) (Fig. 2, 3). The relationship between various parameters was studied in three seasons.

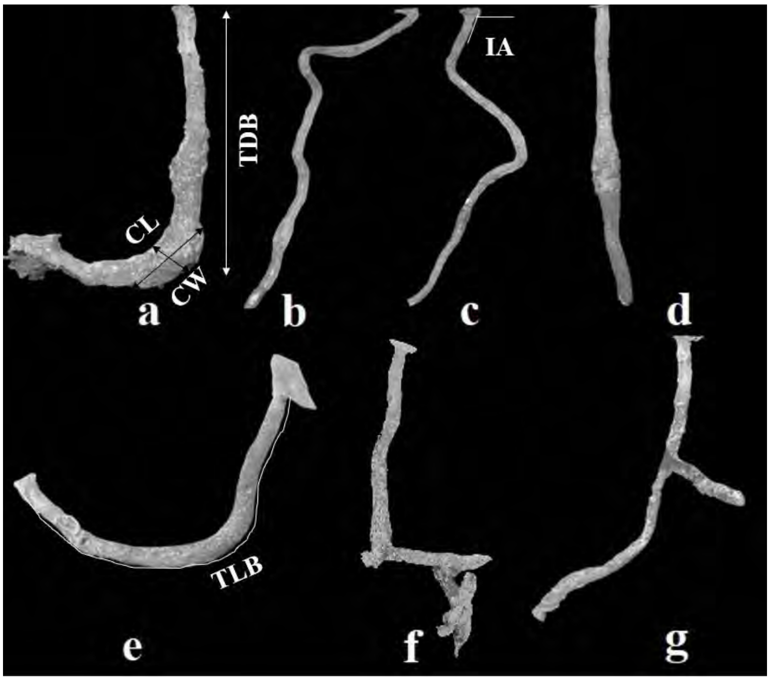

Fig. 2 Burrow architecture of *Austruca sindensis* with various measurements of burrow cast. a. J-shaped burrow, b. Spiral burrow, c. S-shaped burrow, d. Single tube burrow, e. U-shaped burrow, f. Multi-branched burrow, g. J-shaped with Branch burrow. (TDB – Total depth of Burrow; TLB – Total length of burrow; IA– Burrow inclination angle; CL – Chamber length; CW – Chamber width).

Fig. 3 Indicates number of burrow count with respect to shape of the burrow. J-shaped burrows (Fig. 2) (n = 28) had mean burrow volume of 44.59 ± 32.76 cm^3 with an average burrow opening diameter of 8.79 ± 2.29 mm. Burrows were vertically inclined with mean inclination angle of 120.2 ± 10.48°. J-shaped burrows were constructed by crab with mean carapace length of 7.87 ± 1.96 mm (n = 10). Mean length and depth of the burrows were 27.08 ± 10.12 cm and 22.43 ± 6.29 cm respectively. Mean length of the chambers situated on the centre and base was 2.45 ± 0.99 cm and 2.47 ± 0.50 cm. Mean width of the chambers situated on the centre and base was 4.37 ± 1.99 cm and 4.82 ± 1.39 cm.

Single tube burrows (ST) (Fig. 2) (n =27) had mean volume of 44.99 ± 27.66 cm^3 with mean opening diameter of 8.68 ± 2.01 mm. Burrows were constructed by the crabs having mean carapace length of 8.34 ± 2.01 mm (n =12). Burrows inclined vertically from the surface with the mean inclination angle of 118.04 ± 15.02° and ended with chamber (CL: 3.2 ± 0.58 cm CW: 9.02 ± 1.8 cm) at the base. One another chamber were constructed with mean length of 3.08 ± 0.84 cm and width 6.22 ± 2.05 cm. Mean length and depth of the burrows were 23.03 ± 7.96 cm and 21.46 ± 7.55 cm respectively.

S-shaped burrows (Fig. 2) (n = 21) had largest volume (47.12 ± 26.80 cm^3) with an average burrow opening diameter of 8.71 ± 2.20 mm. S-shaped burrows were constructed by the crabs with mean carapace length of 7.05 ± 1.66 mm (n = 10). Burrows were vertical with mean inclination angle of 117.47 ± 16.06°. In many S-shaped burrows two small chambers were constructed by the crabs either at base or in middle region of the burrow. Mean length of centrally located chamber and terminal chambers was 2.52 ± 0.63 cm and 2.6 ± 0.58 cm respectively. While Mean width of intermittent and terminal chambers was 5.53 ± 2.58 cm and 5.34 ± 1.64 cm respectively. Mean length of the burrows was 31.59 ± 9.79 cm and mean depth of the burrows was 23.77 ± 6.09 cm.

Spiral burrows (Fig. 2) (n = 10) had mean burrow volume of 37.35 ± 22.46 cm^3 with a mean opening diameter of 7.91 ± 1.80 mm and created by crabs with mean carapace length 6.33 ± 1.19 mm (n = 4). Burrows were vertically inclined with mean inclination angle of 137.5 ± 17.05°. Mean depth and mean length of the burrows was 22.73 ± 8.15 cm and 29.95 ± 10.31 cm respectively. Mean length and mean width of the chamber was 3.4 ± 0.28 cm and 5.5 ± 1.34 cm.

J-shaped burrows with branch (JB) (Fig. 2) (n = 5) had mean burrow volume of 21.09 ± 11.38 cm^3 with an average opening diameter of 9.03 ± 0.88 mm. Burrows were constructed by the crabs with mean carapace length of 7.27 ± 0.16 mm (n=3). Burrows were vertical in shape with mean inclination angle of 128.8 ± 8.54° and depth of 15.6 ± 4.13 cm. Main shaft of the burrow takes turn towards the surface in the form of branch which does not extend to the surface and ends in the forms of spherical blind end. Second branch is formed from the base of the main shaft and ends making small chamber at the base. The mean length of the burrows was 17.7 ± 2.95 cm.

U-shaped burrows with single opening (U with SO) (Fig. 2) (n = 2) had mean burrow volume of 40.63 ± 0.11 cm^3 with an average burrow opening diameter of 7.54 ± 0.87 mm. U-shaped burrows were constructed by the crab with carapace length of 7.55 mm (n = 1). Burrows were vertical with mean inclination angle of 138 ± 2°. Mean depth and mean length of the burrows were 17.5 ± 0.8 cm and 28.4 ± 0.9 cm. Mean length and width of the chamber at base was 2.9 cm and 8.3 cm.

Multi-branched burrow (MB) (Fig. 2) (n = 1) had mean volume of 79.58 cm^3 with opening diameter of 10.53 mm. The burrow looked almost similar to J-shaped with branch burrows, except one extra branch attached to the base of the secondary branch. In this burrow except primary arm no other branch reach the surface and they all ended with spherical blind lobe. The extra branch attached with secondary branch base, had multiple chambers. The burrow was constructed by the crab having carapace length of 7.72 mm (n=1). The burrow inclined vertically with inclination angle of 87°. The burrow had depth of 30.4 cm and total length of the burrow was 51.3 cm.

3.2 Seasonal variation in burrow architecture

In winter, crab carapace length showed positive correlation with carapace width (R^2=0.90), burrow opening diameter (R^2=0.82), total burrow length (R^2=0.57), total burrow depth (R^2=0.56) and burrow volume (R^2=0.49) (Fig. 4). In summer, carapace length showed strong positive correlation with the carapace width (R^2=0.93), burrow opening diameter (R^2=0.96), total burrow length (R^2=0.74), total burrow depth (R^2=0.57) and burrow volume (R^2=0.63) (Fig. 5). Crab carapace length was positively correlated with the carapace width (R^2=0.92), burrow opening diameter (R^2=0.91), total burrow length (R^2=0.64), total burrow depth (R^2=0.57) and burrow volume (R^2=0.44) in monsoon season (Fig. 6). The crab carapace length did not show significant correlation with burrow inclination angle in all three seasons (R^2=0.06, 0.01, 0.01 respectively for winter, summer and monsoon) (Fig. 4, 5, 6).

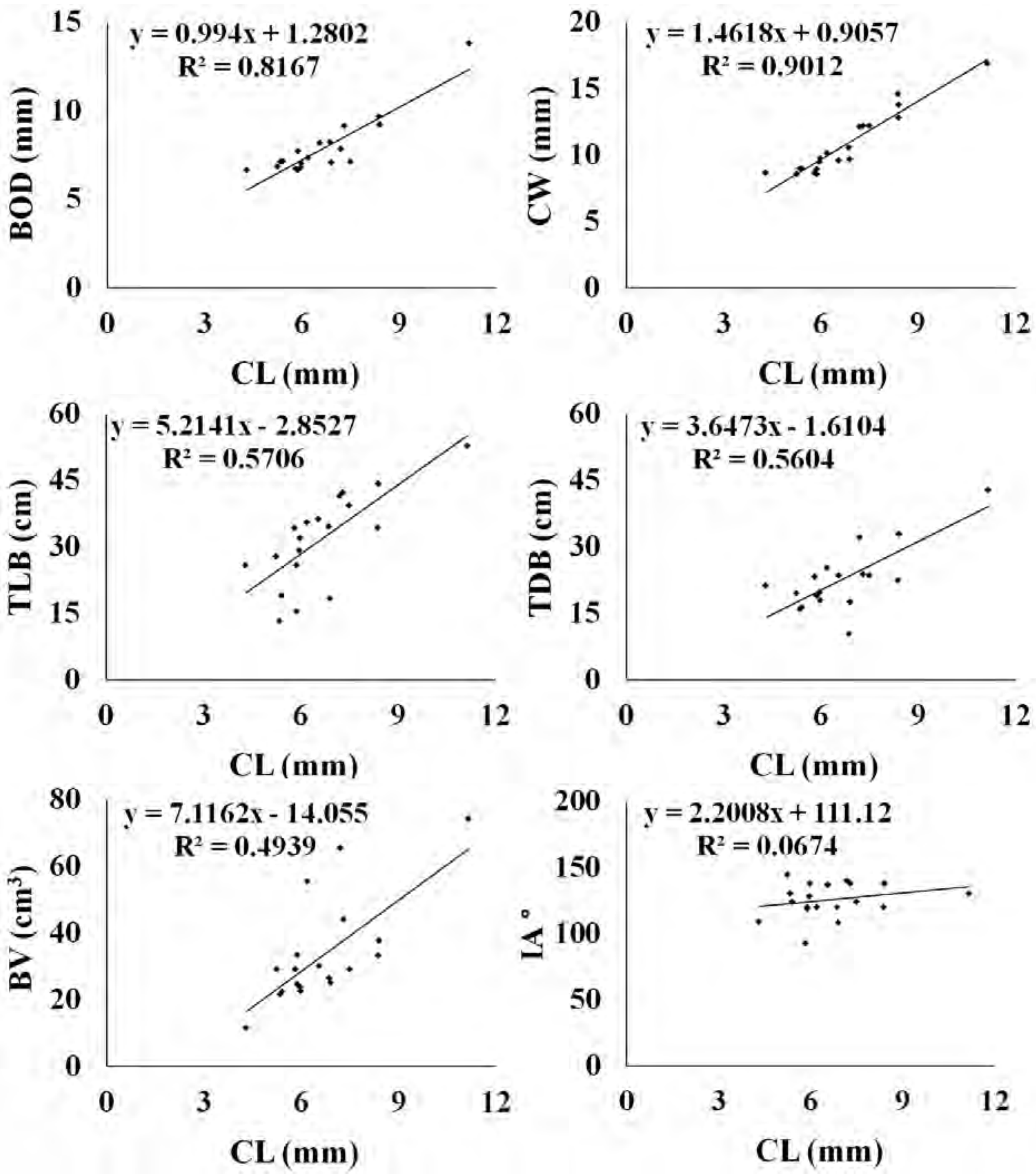

Fig. 4 Regression analysis for the relationship between crab carapace length and different morphological measurements of burrows in winter season.

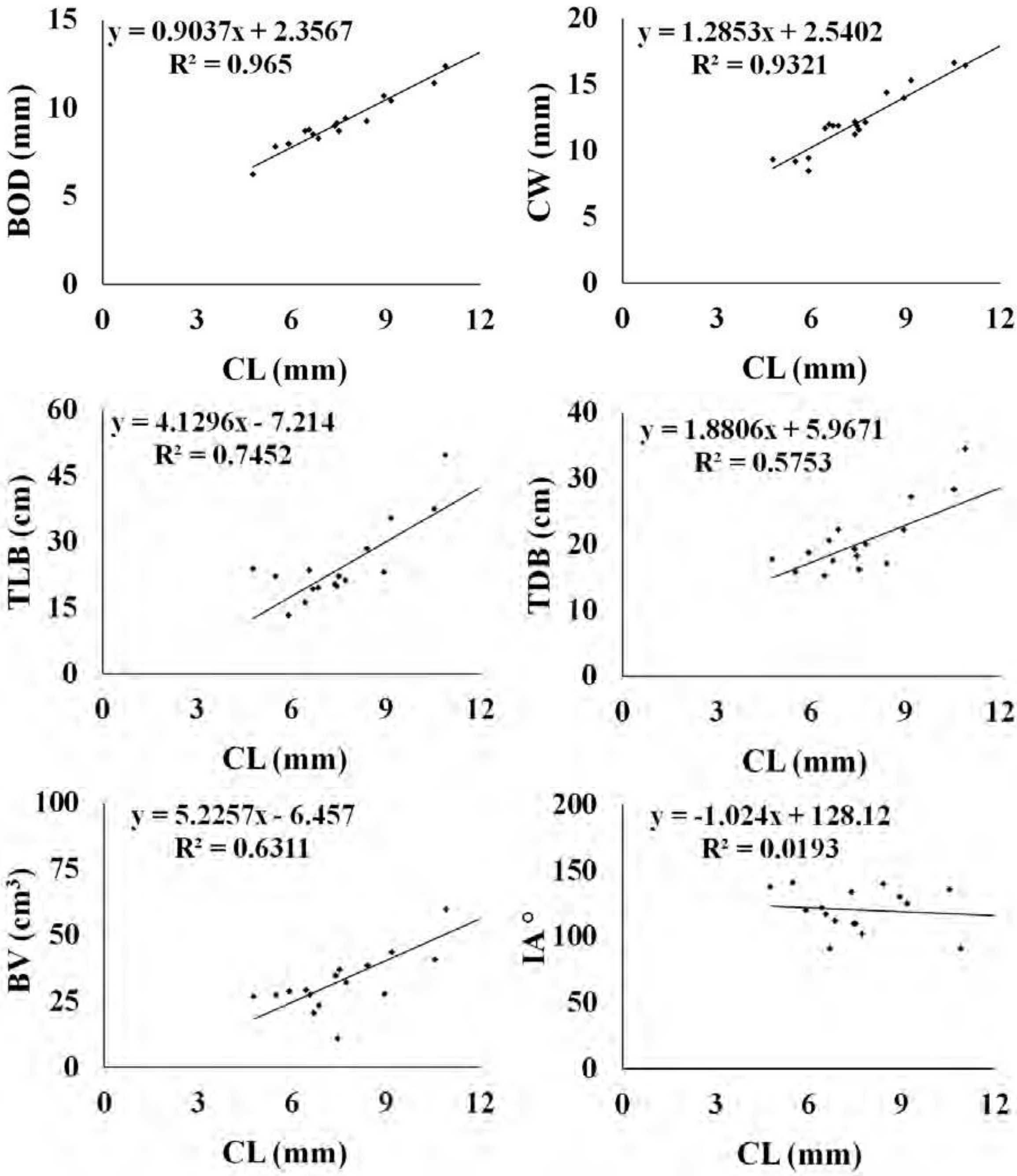

Fig. 5 Regression analysis for the relationship between crab carapace length and different morphological measurements of burrows in summer season.

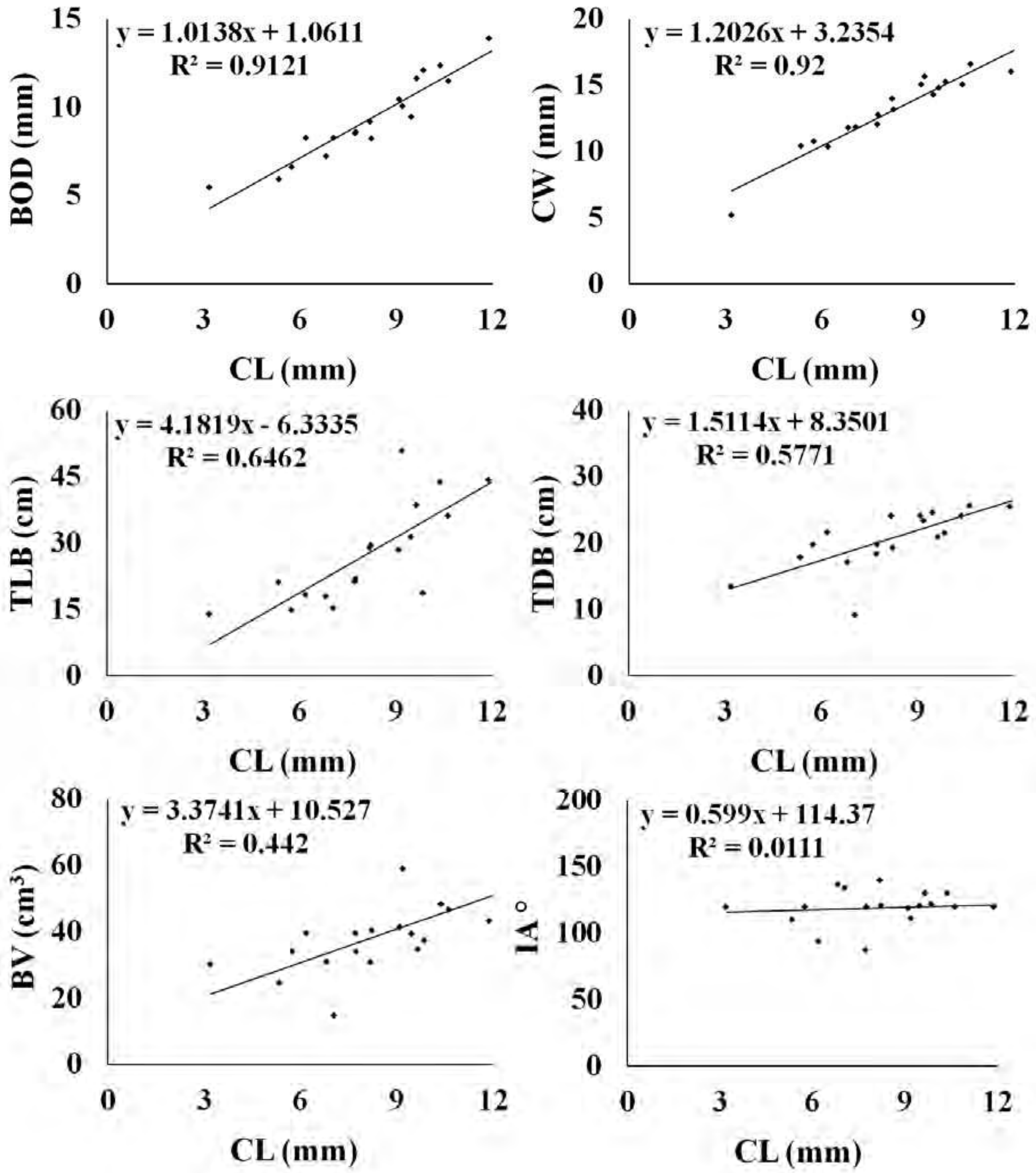

Fig. 6 Regression analysis for the relationship between crab carapace length and different morphological measurements of burrows in monsoon season.

3.3 Variation in burrow architecture in male and female crabs

The carapace length (mm) of the male and female crabs were not significantly different (males: 7.94 ± 1.8, females: 7.17 ± 1.87). In the case of burrow characteristics, both sexes constructed 6 different shaped burrows and their burrow shapes were not different. However, the diameters of male crab burrows were larger compared to the diameters of female crab burrows, male crab burrows were longer and more voluminous than those of the female crabs (Table 1).

Table 1 Burrow characteristics of *Austruca sindensis* (Alcock, 1900).

Burrow Morphology	**Male**	**Female**
Total shape	6	6
Total burrow	29	17
carapace length (mm)	7.94 ± 1.8	7.17 ± 1.87
Burrow opening diameter (mm)	9.22 ± 1.97	8.47 ± 1.77
Burrow length (cm)	30.55 ± 10.94	27.56 ± 10.56
Burrow depth (cm)	21.81 ± 6.34	21.18 ± 5.04
Inclination angle °C	123.28 ± 13.29	124.71 ± 11.22
Volume (CM^3)	39.19 ± 13.33	30.62 ± 8.99

3.4 Vertical temperature profile of burrows

The depth wise variation in burrow temperature was studied for various burrow shapes recorded in the present study. Results revealed similar pattern in temperature variation for all the burrow shapes. In winter, the sand surface temperature recorded 26-30°Cwhich remained similar for all the burrow types (Fig. 7). The sand surface temperature was recorded 38-44°C and 32-40°C during summer season and monsoon season respectively (Fig. 8, 9). The temperature declined to 2 to 2.5°C at a depth of 5 cm. After the depth of 5 cm the rate of temperature drop decreased to 1 to 1.5°C at every 5 cm. The temperature recorded at the deepest part of the burrow that could be measured up to 25 cm was 22-27.5°C, which was cooler than the surface temperature in all the season.

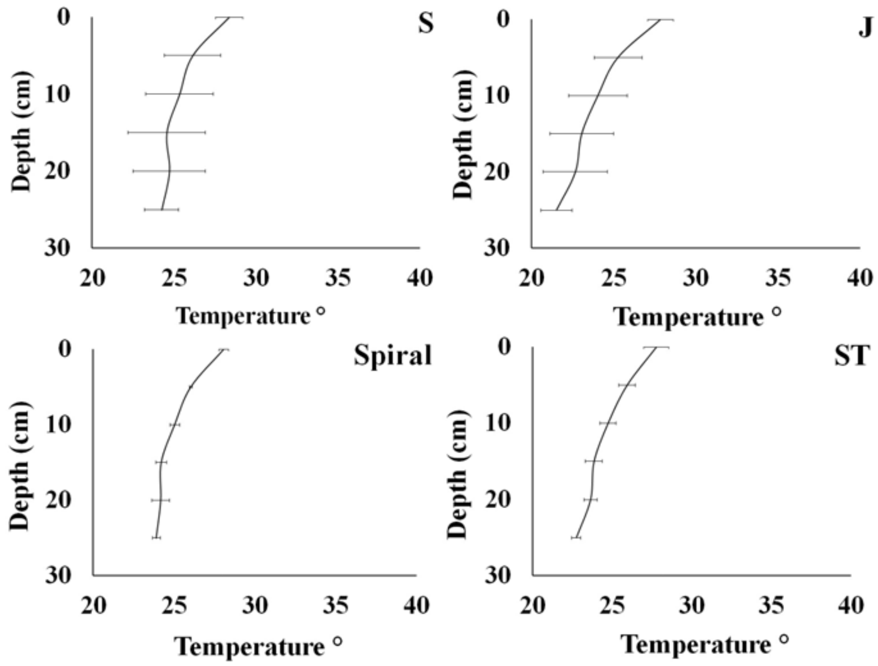

Fig. 7 Vertical temperature profiles with the burrow depth for different shapes of the burrows during winter season.

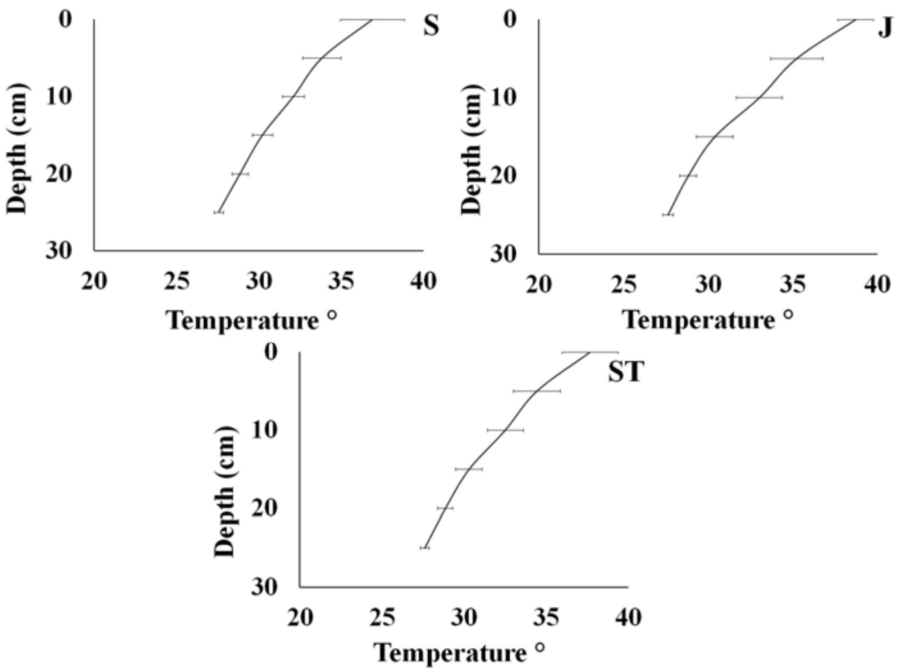

Fig. 8 Vertical temperature profiles with the burrow depth for different shapes of the burrows during summer season.

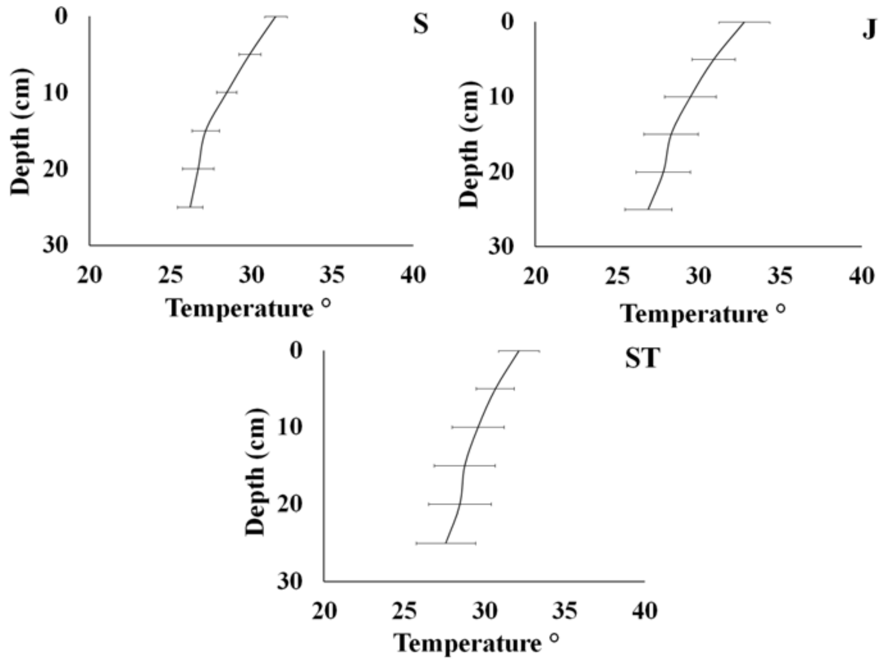

Fig. 9 Vertical temperature profiles with the burrow depth for different shapes of the burrows during monsoon season.

3.5 Principle component analysis (PCA) of burrow morphology

3.5.1 PCA of burrow morphology in winter season

In winter season the number of variables in upper intertidal zone (UTZ) (U1 to U21) are twenty-one and middle intertidal zone (MTZ) (M1 to M11) are eleven. Scree plot in figure 10 shows data has three major components as shown in Table 2. Per cent variance for component 1 is 77.837%, 2 is 17.369% and 3 is 4.795%.

Cumulative percentage for component 1 is 77.837%, component 2 is 95.205% and component 3 is 100% shown in Table 2. Fig. 11 indicates most of the burrow are concentrated in one quadrate and only M10, U8 and U12 are concentrated in another quadrate. All burrows are closely present giving out maximum correlation.

Table 2 Total variance in winter season.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	24.908	77.837	77.837	24.908	77.837	77.837
2	5.558	17.359	95.205	5.558	17.359	95.205
3	1.534	4.795	100	1.534	4.795	100

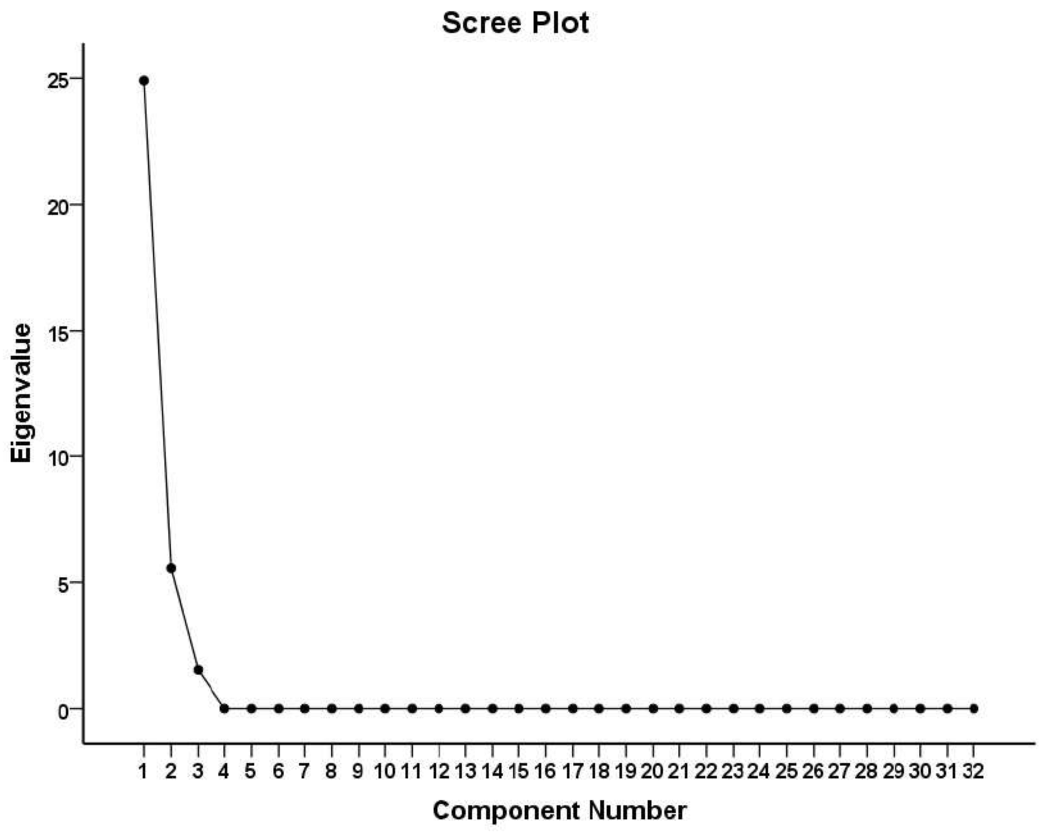

Fig. 10 Scree plot indicating major 3 plots for winter season.

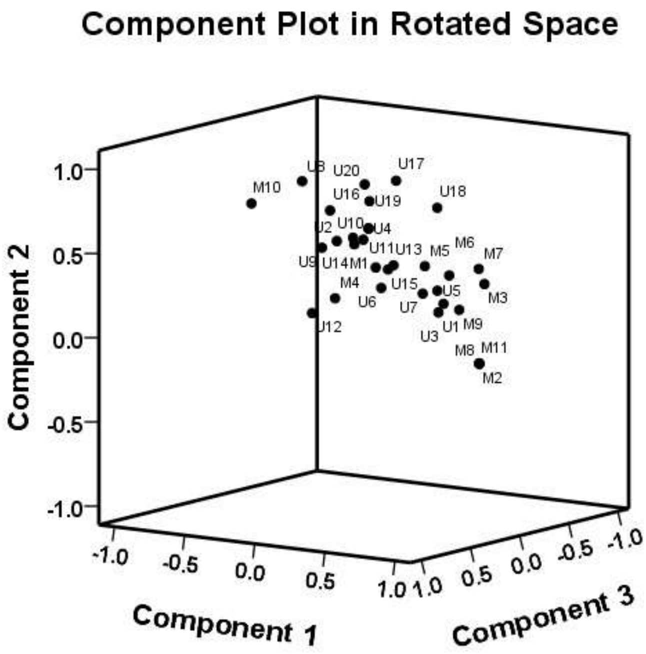

Fig. 11 Component plot in rotated space for winter season.

3.5.2 PCA of burrow morphology in summer season

In summer season number of variables in upper intertidal zone (UTZ) (U1 to U13) are thirteen and middle intertidal zone (MTZ) (M1 to M21) are twenty-one. Scree plot in Fig. 12 shows data has two major components as shown in Table 3. Per cent variance for component 1 is 85.503% and 2 is 16.497%. Cumulative percentage for component 1 is 85.503% and component 2 is 100% shown in Table 3. Fig. 13 indicates most of the burrow are concentrated in one quadrate and only M9 and M11 are concentrated in another quadrate. All burrows are closely present giving out maximum correlation.

Table 3 Total variance in summer season.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	28.391	83.503	83.503	28.391	83.503	83.503
2	5.609	16.497	100	5.609	16.497	100

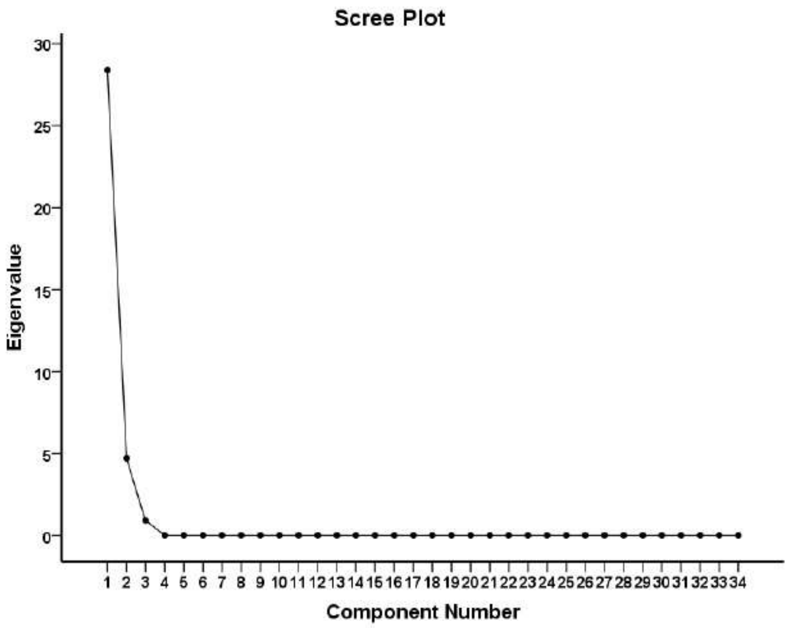

Fig. 12 Scree plot indicating major 2 plots for summer season.

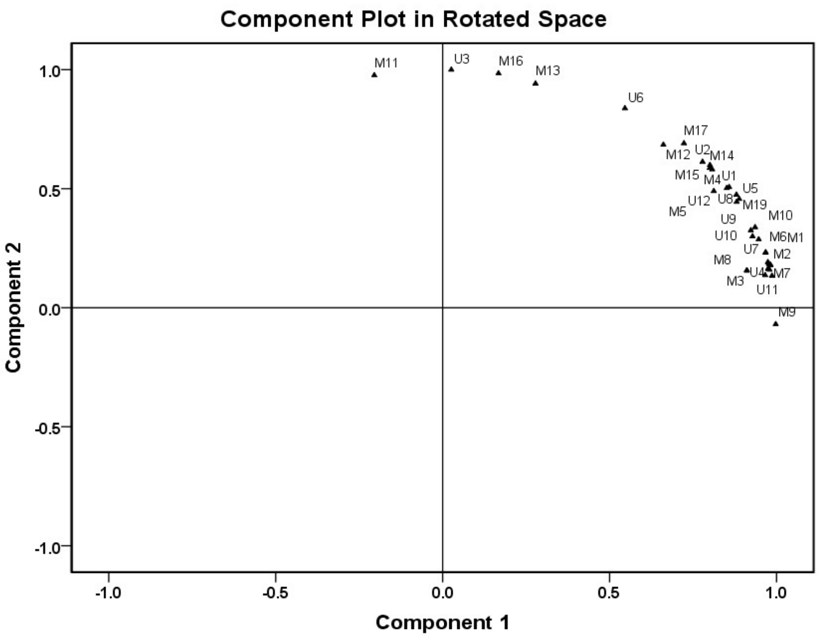

Fig. 13 Component plot in rotated space for summer season.

3.5.3 PCA of burrow morphology in monsoon season

In monsoon season number of variables in upper intertidal zone (UTZ) (U1 to U16) are sixteen and middle intertidal zone (MTZ) (M1 to M12) are twelve. Scree plot in Fig. 14 shows data has three major components as shown in Table 4. Per cent variance for component 1 is 91.679% and 2 is 8.322%. Cumulative percentage for component 1 is 91.679% and component 100% shown in Table 4. Fig. 15 indicates all the burrow are concentrated in one quadrate.

Table 4 Total variance in monsoon season.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	25.670	91.679	91.679	25.670	91.679	91.679
2	2.33	8.322	100	2.33	8.322	100

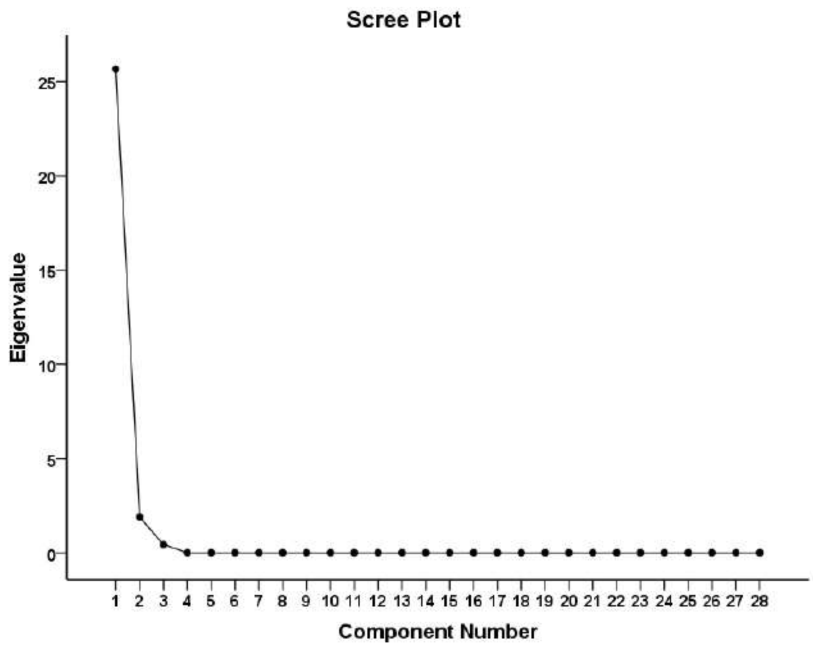

Fig. 14 Scree plot indicating major 2 plots for monsoon season.

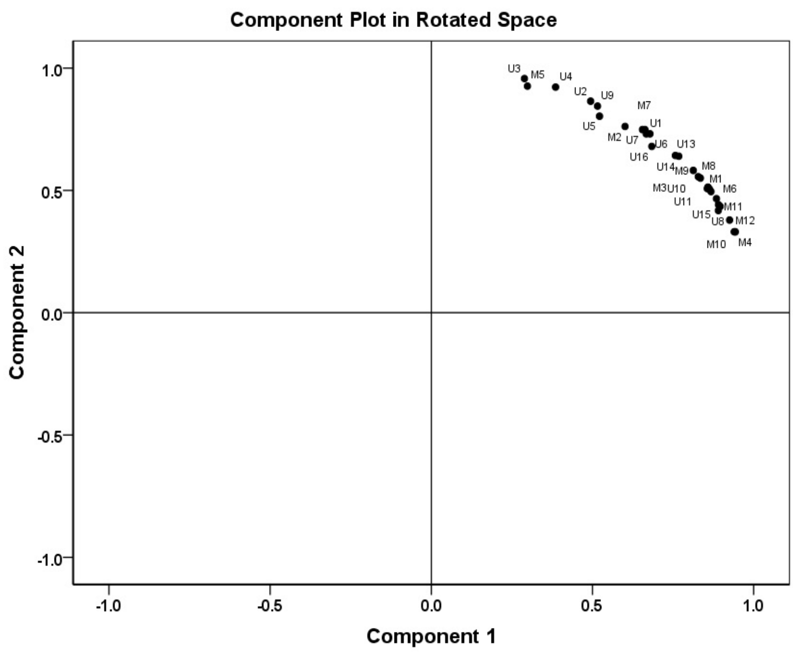

Fig. 15 Component plot in rotated space for monsoon season.

4 Discussion

Burrows constructed in soft sediments play a significant role in the reproductive activity of the burrowing crabs of Ocypodidae and Dotillidae families (Lim, 2006). The morphology of *Austruca sindensis* (Alcock, 1900) burrows showed considerable variation in shape, size and complexity, ranging from single entrance shafts with no branches to multiple entrances. In the present study, total seven different burrow shapes were recorded like J-shaped, Single tube, S-shaped, Spiral, J-shaped with branch, U-shaped with single opening and Multi-branched burrow (Fig. 2). Crabs with smaller carapace length had constructed single tube and J-shaped burrows, while larger sized had created single tube, J-shaped, J-shaped with branch, multi-branched, U-shaped with single opening and spiral burrows. According to Chakrabarti (1981) and Chan et al. (2006), the burrows like J-shaped and single tube burrows of juvenile crabs were shallow in depth with narrower opening diameter and lesser volume. Temporary burrows of the adult crabs are often shallow and single tubular structures.

In the present study, multi-branched and J-shaped with branched burrows were constructed by adult crab. The function of the branches of single tube and J-shaped burrows is still unknown but it has been assumed that the branch may provide shelter to the individual crab from the splash of the waves and predators (Chakrabarti, 1981). According to Chan et al. (2006), adult crabs can tolerate longer periods of exposure to air by digging deeper and more complex burrows. These crabs stay entirely in their burrows during daytime and as a result, their burrows were deeper and more complex as compared to the burrows of the juvenile crabs (Chan et al., 2006; Katrak et al., 2008, Gul and Griffen, 2018). More complex burrow provides greater underground surface area, which is favourable for increased gaseous exchange and microbial colonization. This also delivers greater access of resources to organisms inside the burrow (Thongtham and Kristensen, 2003).

Uca pugilator (Bosc), *Sesarma longipes* (Krauss), *Cardisoma carnifex* (Herbst) and *Macrophalmus parvimanus* (Guerin) has created temporary burrows like single tube and bulb shape for refuges during high tides or to get protection from the predator (Braithwaite and Talbot, 1972; Christy, 1982). During investigation, adult carb excavated spiral burrow with end chamber. Previously, crabs of *Ocypode ceratophthalmus* (Pallas, 1772) and *O. saratan* (Forskal, 1775) constructed spiral burrow with the sole purpose of providing a place for copulation (Hughes, 1973; Vannini, 1980). Nonetheless, simpler forms consisting of unbranched, subvertical to inclined, irregularly twisted to J-shaped shafts are very common among species of Macrophthalmidae, Myctiridae, Dotillidae, Gecarcinidae, Gecarcinucidae, and Portunidae (Gilbert et al., 2013).

In the present study, crab length showed significant positive relationship with burrow opening diameter, burrow length, burrow depth and burrow volume. Here, mean burrow length and depth were recorded around 30.55 ± 10.94 cm and 21.81 ± 6.34 cm respectively for the crab with mean carapace length of 7.94 ± 1.8 mm. Qureshi and Saher (2012) have also studied the burrow architecture of *Uca sindensis* (synonym of *A. sindensis*). They excavated burrows with mean length and depth of 22.02 ± 7.10 cm and 15.04 ± 6.2 cm respectively for crab with the mean carapace length of 2.212 + 0.591 mm. The burrow morphology is species specific (Griffis and Suchanek, 1991; Wolfrath, 1992; Griffis and Chavez, 1988) but variation in burrow morphology is observed within same species due to changes in physical and biochemical properties of the sediment (Lucrezi et al., 2009). Larger-sized crabs had greater burrow diameter, larger burrow volume and bigger chamber diameter than small and medium sized crabs (Upadhyay et al., 2022). Lim and Diong (2003) studied burrow morphology of the crab *U. annulipes* (Milne Edwards, 1837) and found that larger crabs generally excavated wider, more spacious burrows than small and medium-sized individuals.

Previous studies showed that burrow architecture get affected by several environmental factor such as temperature, moisture level, wind (Lucrezi et al., 2009), and geomorphological properties of the sandy shores like sand compaction, beach slope and sand grain size (Dixon et al., 2015; Pombo et al., 2017) and as well as erosion (Hobbs et al., 2008). Burrow architecture also varies based on size and sex of the resident crab (Lim and Diong, 2003). Present study revealed that both male and female *A. sindensis* built six different shaped burrow and male crabs burrows were longer and voluminous than the female crab burrows. Males build longer and deeper breeding burrows to attract females for mating purpose (Christy, 1982; Backwell and Passmore, 1996; Tina et al., 2018). Mate selection occurs mostly based on the quality of breeding burrows, because mating and egg incubation take place inside the male breeding burrows (Christy, 1982, 1987; Christy and Salmon, 1984; Christy and Schober, 1994; Ribeiro et al., 2010).

Vannini (1980) and Atkinson and Taylor (1988) discussed that burrow provides protection against high external temperatures and environmental extremes. Furthermore, Lim and Diong (2003) working upon fiddler crabs hypothesized that high intertidal areas might help to maintain lower burrow temperature during ebb tides. According to Dubey et al. (2013), temperature and moisture levels in the substratum could influence the burrow depth by playing an important ecological role in the life history and habitat dependency of *O. macrocera*. In the present study, the temperature of the sand surface dropped along the depths of the burrows which suggests that the burrows can provide the resident to the crab and helps to get refuges during the stressful period in summer. Temperature could be even lower when going further down the burrow, although measurement cannot be obtained at further depths. As burrows are important to get refuge from desiccation for intertidal crabs (Takeda and Kurihara 1987; Thongtham and Kristensen, 2003), the depth of burrows will be influenced by the water content of the sediment.

A few previous studies also observed that the burrows acted as refuge for fiddler crabs during very high or very low temperatures (Edney, 1961; Powers and Cole, 1976; Wolfrath, 1992). According to Wolfrath (1992), temperature variation inside the crab burrows was inversed with outside air temperature, and burrow temperature was lower during the day and higher during the night than the outside temperature. It was also concluded that temperatures higher than the optimal peak temperature reduces the ventilator and cardiac performance in crabs, resulting in a lesser supply of oxygen to the tissues and a reduced endurance capacity (Frederich and Portner, 2000; Allen et al., 2012). In PCA analysis, during summer and winter season less cluster formation was observed. While in monsoon season, PCA analysis demonstrated better cluster formation as all burrow parameters were closely correlated. This is may be because this season cab be a season for breeding and reproduction. Thus, burrows are highly developed for mating with appropriate breeding chambers and for an ovigerous female to stay inside the burrow for a longer time and with the least disturbance.

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ORIGINAL ARTICLE

On the Indian species of *Eurycarcinus* A. Milne-Edwards, 1867, *Heteropanope* Stimpson, 1858, and *Pilumnopeus* A. Milne-Edwards, 1867 (Decapoda: Brachyura: Pilumnidae)

Jigneshkumar Trivedi[1] orcid.org/0000-0002-1008-7104
Santanu Mitra[2] orcid.org/0000-0002-3241-9293
Pooja Patel[1] orcid.org/0000-0002-0832-A200
Niketa Maheta[3] orcid.org/0000-0003-1163-4015
Krupal Patel[3] orcid.org/0000-0002-0110-4210
Peter K. L. Ng[4] orcid.org/0000-0001-5946-0608

1 Hemchandracharya North Gujarat University, Department of Life Sciences. Patan, Gujarat, India.
JT E-mail: jntrivedi26@yahoo.co.in
PP E-mail: poojapatel1737@gmail.com

2 Zoological Survey of India. F.P.S. Building, 27 J. L. Nehru Road, Kolkata-700016, West Bengal, India.
SM E-mail: santanuzoo@gmail.com

3 The Maharaja Sayajirao University of Baroda, Faculty of Science, Department of Zoology, Marine Biodiversity and Ecology Laboratory. Vadodara, Gujarat, India.
NM E-mail: nikumit31@gmail.com
KP E-mail: krupalpatelkp8460@gmail.com

4 National University of Singapore, Faculty of Science, Lee Kong Chian Natural History Museum. 2 Conservatory Drive, 117377 Singapore.
PKLN E-mail: peterng@nus.edu.sg

ZOOBANK: http://zoobank.org/urn:lsid:zoobank.org:pub:51E70E2A-C089-4A53-9EA2-5841604AD1EE

ABSTRACT

Five species of pilumnid crabs assigned to *Eurycarcinus* A. Milne-Edwards, 1867, *Heteropanope* Stimpson, 1858, and *Pilumnopeus* A. Milne-Edwards, 1867, have been reported from India: *E. orientalis* A. Milne-Edwards, 1867, *E. bengalensis* Deb, 1999, *H. glabra* Stimpson, 1858, *H. neolaevis* Deb, 1995, and *P. convexus* (Maccagno, 1936). The identity of *E. bengalensis* is confused and the species had been provisionally transferred to *Heteropanope*. Examination of the types however, confirms the affinities of the species with *Eurycarcinus* and consequently extends the range of the genus to the eastern Indian

Corresponding Author
Jigneshkumar N. Trivedi
jntrivedi26@yahoo.co.in

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Ocean. A re-examination of the types of *H. neolaevis* show that it is a junior subjective synonym of *Aniptumnus quadridentatus* (De Man, 1895), and is the first record of the genus from India. *Eurycarcinus integrifrons* De Man, 1879, is also formally recorded for the first time from India.

Keywords

Aniptumnus, Eurycarcinus, Gujarat, *Heteropanope*, India, new records, *Pilumnopeus*, synonymy, taxonomy, West Bengal

Introduction

Davie (1989) revised the taxonomy of the Indo-West Pacific pilumnid genera *Heteropanope* Stimpson, 1858, and *Pilumnopeus* A. Milne-Edwards, 1867, and transferred several species to his new genus, *Benthopanope* Davie, 1989. The three genera were distinguished by carapace morphology, structure of the frontal margin, basal antennal article, male thoracic sternum, and male pleon (Davie, 1989). Until then, the taxonomy of these similar-looking genera was confused. Although Davie (1989: 130) noted that the Indian Ocean *Eurycarcinus* A. Milne-Edwards, 1867, was close to *Heteropanope*, but, as he did not have access to specimens, was unable to discuss the characters distinguishing these two genera.

In India, two species of *Eurycarcinus* have previously been recorded: *E. natalensis* (Krauss, 1843) Andhra Pradesh (Dev Roy and Nandi, 2007; Dev Roy, 2008); Tamil Nadu (Thomas, 1969; Dev Roy, 2008; Kathirvel and Gokul, 2010); West Bengal (Deb, 1995; Dev Roy and Nandi, 2012); Andaman and Nicobar Islands (Thomas, 1969; Bakus, 1994; Venkataraman *et al.*, 2004), and *E. orientalis* A. Milne-Edwards, 1867 Gujarat (Chhapgar, 1957; Trivedi *et al.*, 2012; Pandya and Vachhrajani, 2013); Maharashtra (Chhapgar 1957; Pati *et al.*, 2012); Goa (Dev Roy and Bhadra, 2008; Dev Roy, 2013); Karnataka (Chhapgar, 1957; Haragi *et al.*, 2010); Kerala (Dev Roy, 2013); Andhra Pradesh (Dev Roy and Nandi, 2007; Dev Roy, 2008; Rath and Dev Roy, 2009); Orissa (Dev Roy and Rath, 2017); West Bengal (Dev Roy and Nandi, 2012); Andaman and Nicobar Islands (Dev Roy and Nandi, 2012). Two species in these genera were later described from specimens collected in the Bay of Bengal, India: *Heteropanope neolaevis* Deb, 1995, and *Eurycarcinus bengalensis* Deb, 1999. Subsequently, Trivedi *et al.* (2015) and Gosavi *et al.* (2017) recorded *Heteropanope glabra* Stimpson, 1858, and *Pilumnopeus convexus* (Maccagno, 1936), respectively, from India.

Ng *et al.* (2018) revised *Eurycarcinus*, and distinguished it from *Heteropanope* by the following characters: thoracic sternite 8 remains clearly exposed when the male pleon is closed, male pleonal somite 3 is proportionately wider with the lateral margin distinctly projecting on lateral side, and male thoracic sternites 3 and 4 are transversely wider with the sterno-pleonal cavity close to the margin between sternites 3 and 4. On the basis of the published figures of Deb (1995, 1999), Ng *et al.* (2018) suggested that *E. bengalensis* can be assigned to *Heteropanope* on the basis of carapace shape but was uncertain about *H. neolaevis* because its gonopod structure was atypical for the genus. Trivedi *et al.* (2018: 59) noted that the records of *E. natalensis* from different parts of India were suspect and more likely belong to species of *Heteropanope* instead. *Eurycarcinus natalensis* is known for certain only from southern and eastern Africa (Ng *et al.*, 2018). Trivedi *et al.* (2018: 59) also expressed doubts about the records of *E. orientalis* from eastern India, a species otherwise only known for certain from the western Indian Ocean (Ng *et al.*, 2018).

The present paper examines and describes new material of the above genera including the types of *H. bengalensis* and *H. neolaevis*. *Eurycarcinus integrifrons* De Man, 1879 is formally recorded here for the first time from India. *Eurycarcinus bengalensis* is shown to be a valid taxon but the type material contains two species, with the paratype females belonging to *E. integrifrons* instead. In addition, *H. neolaevis* is shown to be a junior subjective synonym of *Aniptumnus quadridentatus* (De Man, 1895).

Material and Methods

The specimens examined are deposited in the Zoological Reference Collection, Department of Life Sciences, Hemchandracharya North Gujarat University, Patan, Gujarat, India (LFSc.ZRC); Zoological Survey of India, Kolkata, India (ZSI); and the Zoological Reference Collection of the Lee Kong Chian Natural History Museum, National University of Singapore (ZRC). The terminology used in the description follows Davie *et al.* (2015) and Ng *et al.* (2018). The following abbreviations are used: CL = carapace length; CW = carapace width; G1 = male first gonopod; G2 = male second gonopod; coll. = collector. All the measurements are in millimeters (mm).

Taxonomy

Family Pilumnidae Samouelle, 1819

Genus *Eurycarcinus* A. Milne-Edwards, 1867

***Eurycarcinus orientalis* A. Milne-Edwards, 1867**
(Figs. 1, 9A–C)

Eurycarcinus orientalis A. Milne-Edwards, 1867: 277; Jones, 1986: 162, pl. 47; Vousden, 1987: 36, tabs. 4, 7; Apel and Türkay, 1992: 194, 204, 205; Ismail and Ahmed, 1993: 158; Apel 1994a: 43, 44; Apel, 2001: 97, 98; Al-Khayat and Jones, 1996: 806, fig. 5; Al-Khayat and Jones, 1999: 58, 61; Tirmizi and Ghani, 1996: 30–32, fig 10; Cooper, 1997: 168–170, figs. 4, 5, 15; Hornby, 1997: 16 (? part); Ng *et al.*, 2008: 140 (list); Naderloo and Türkay, 2012: 37; Al-Khafaji *et al.*, 2017: 363, fig. 3; Naderloo, 2017: 304, figs. 26.10c, 26.11, 26.13; Ng *et al.*, 2018: 484, figs. 1C, 3B, 4B, 5B, 6B, E, 7B, E, H, 8B, F, G; Trivedi *et al.*, 2018: 59 (list).

Eurycarcinus grandidieri — Alcock, 1898: 211, 212 [not *Eurycarcinus grandidierii* A. Milne-Edwards, 1867 = *E. natalensis* (Krauss, 1843)].

Eurycarcinus sp. — Basson *et al.*, 1977: 58, 228 (in list), fig. 38; Titgen, 1982: 131.

Type locality. Mumbai, India.

Material examined. 5 males (CW 27.6–41.5 mm, CL 17.5–26.9 mm), 4 females (CW 28.5–6.4 mm, CL 17.5–23.0 mm), LFSc.ZRC-64, Kamboi (22°12'50"N 72°36'59"E), Gujarat State, India, 11 April 2014, coll. J. Trivedi.

Remarks. The specimens examined in the present study agree with the description and figures of the species provided by Ng *et al.* (2018). *Eurycarcinus orientalis* resembles *E. natalensis* in carapace shape and dentition of the anterolateral border but can be separated from the latter in the following characters: the carapace is high (Fig. 1A) (not prominently raised in *E. natalensis*; *cf.* Ng *et al.*, 2018: figs. 1A; 6A, D); suborbital and pterygostomial regions are prominently granulated (Fig. 1B) (less granulated in *E. natalensis*; *cf.* Ng *et al.*, 2018: fig. 6D); G1 distal part gently recurved, tip gently curved (Fig. 9A, B) (distal part prominently recurved, tip hook shaped in *E. natalensis*; *cf.* Ng *et al.*, 2018: fig. 8A, D, E).

Eurycarcinus orientalis is so far reported from the Gulf of Aden, Persian Gulf, Gulf of Oman, Pakistan, India, and Thailand (Naderloo, 2017; Ng *et al.*, 2018). In India, the species is recorded from Gujarat, Maharashtra, Karnataka (Chhapgar, 1957) and Kerala (Dev Roy, 2013). Trivedi *et al.* (2018) commented that all the records of this species from the east coast including Andhra Pradesh (Dev Roy and Nandi, 2007), Orissa (Dev Roy and Rath, 2017), West Bengal (Dev Roy and Nandi, 2012), and Andaman and Nicobar Islands (Dev Roy and Nandi, 2012) require re-examination.

Trivedi *et al.* (2018) commented that the records of *E. natalensis* from India: Andhra Pradesh (Dev Roy and Nandi, 2007), Tamil Nadu (Thomas, 1969), West Bengal (Dev Roy and Nandi, 2012), and Andaman and Nicobar Islands (Thomas, 1969) are doubtful. Some of these may have been based on earlier incorrect identifications of Indian material by Alcock (1898) as *Eurycarcinus grandidieri*, the latter species being a junior synonym of *E. natalensis*. On the basis of the available specimens examined here, these records are probably a species of *Heteropanope* or *Eurycarcinus* and require re-examination, but, based on biogeography, they are likely to be *E. bengalensis* or *E. integrifrons* (see discussion for these species).

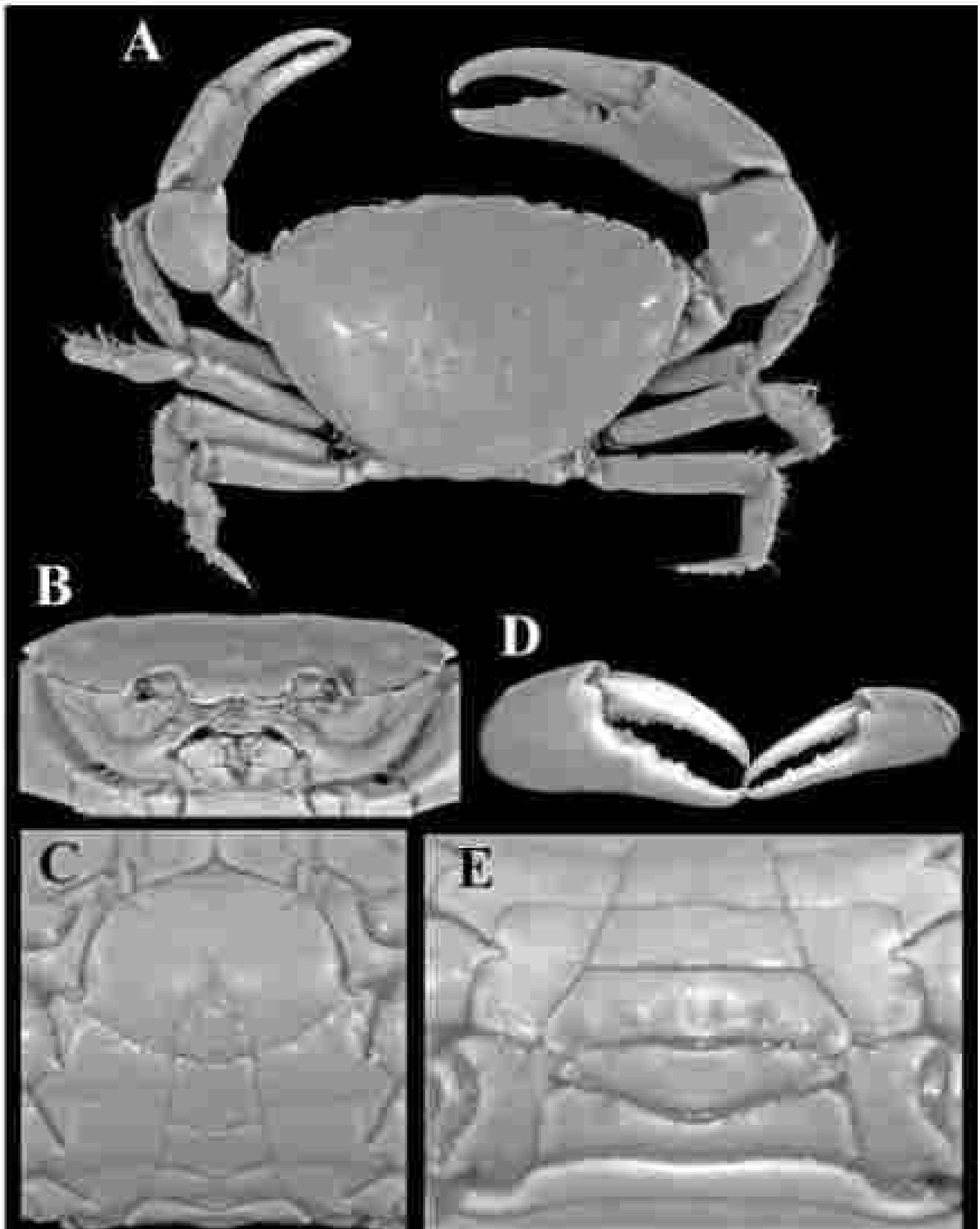

Figure 1. *Eurycarcinus orientalis* A. Milne-Edwards, 1867, male (CW 41.5 mm, CL 26.9 mm) (UFSc.ZRC-64), Kambon, India. A, habitus, dorsal view; B, frontal view; C, anterior thoracic sternum (sternites 1–4) and pleon; D, chelae, outer view; E, posterior thoracic sternum and pleon.

Eurycarcinus integrifrons De Man, 1879
(Figs. 2, 9D–F)

Eurycarcinus integrifrons De Man, 1879: 55, 56; Apel, 1994b: 415, 433, 434; Al-Ghais and Cooper, 1996: 425, 426; Apel, 2001: 97; Naderloo and Sari, 2007: 344, tab. 1; Ozcan *et al.*, 2010: 507, fig. 2; Naderloo and Türkay, 2012: 36; Naderloo *et al.*, 2013: 449, 456, tab 2; Naderloo, 2017: 303, figs. 26.10b, 26.11, 26.12; Ng *et al.*, 2018: 484, figs. 1C, 3B, 4B, 5B, 6B, E, 7B, E, H, 8B, F, G; Trivedi *et al.*, 2018: 59 (list).

Eurycarcinus orientalis — Alcock, 1898: 210, 211 (part); Chhapgar, 1957: 436, 437, pl. 11d–f; Tirmizi *et al.*, 1986: 8–10, fig. 3a–d; Tirmizi and Ghani, 1996: 30–32, fig. 10; ?Hornby, 1997: 16 (part) [not *Eurycarcinus orientalis* A. Milne-Edwards, 1867].

Litocheira (*amoyensis* Gordon?) — Stephensen, 1946: 169–171, fig. 46; Titgen, 1982: 252 (list) [not *Litocheira amoyensis* Gordon, 1931 = *Heteropilumnus amoyensis* (Gordon, 1931)].

Eurycarcinus sp. (? *integrifrons*) — Apel and Türkay, 1992: 194–195, 204–205.

Eurycarcinus bengalensis Deb, 1999: 376 (part).

Type locality. Unknown, probably India (*cf.* Naderloo 2017).

Material examined. 5 males (CW 13.2–28.2 mm, CL 9.66–9.9 mm), 5 females (CW 11.3–25.2 mm, CL 18.6–8.14 mm), LFSC.ZRC-63, Lakhpat (23°50′01″N 68°46′26″E), Gujarat State, India, 27 March, 2015, coll. J. Trivedi; 2 ovigerous females (CW 13.9 mm, CL 10.4 mm; CW 21.3 mm, CL 15.3 mm), ZSI-C3349/2 (part), Chamta Block, Sunderbans Tiger Reserve, West Bengal State, India (paratypes of *Eurycarcinus bengalensis* Deb, 1999).

Remarks. The specimens examined in the present study agree with the description and figures of the species in Ng *et al.* (2018). *Eurycarcinus integrifrons* differs from *E. natalensis* and *E. orientalis* in the following characters: carapace subquadrate (Fig. 2A) (transversely ovate in *E. natalensis* and *E. orientalis*; *cf.* Ng *et al.*, 2018: figs. 1A, B, C; 6A, B); frontal margin weakly bilobed (Fig. 2B) (distinctly bilobed in *E. natalensis* and *E. orientalis*; *cf.* Ng *et al.*, 2018: figs. 1A–C; 6A, B).

The species is so far reliably reported from Gulf of Aden, Persian Gulf, Gulf of Oman, and Pakistan (Naderloo, 2017; Ng *et al.*, 2018). The present study is actually the first confirmed record of the species from India, even though Naderloo (2017) suggested that the type may have originally been from there. The specimens from Gujarat (Kolak and Umarsadi) and Maharastra (Mumbai) (recorded as *E. orientalis*) in Chhapgar (1957) should be referred to *E. integrifrons*; his figures leave no doubt. These records of Chhapgar (1957) thus extend the known range of *E. integrifrons* nearly 900 kilometers further south along the coast of western India. The two ovigerous female paratypes of *E. bengalensis* Deb, 1999, are here also re-identified as *E. integrifrons*, extending the range of this species to West Bengal state (see remarks for next species).

Eurycarcinus bengalensis Deb, 1999
(Figs. 3, 4, 9G–I)

Eurycarcinus bengalensis Deb, 1999: 376 (part), fig. 2.

Heteropanope bengalensis — Ng *et al.*, 2018: 474; Trivedi *et al.*, 2018: 59.

Material examined. Holotype, male (CW 25.1 mm; CL 18.9 mm), ZSI-C3349/2, Chamta Block, Sunderbans Tiger Reserve, West Bengal State, India, coll. S. Bhuinya. Paratypes, 2 males (CW 11.5 mm; CL 7.8 mm, CW 11.7 mm; CL 8.6 mm), data as per holotype.

Remarks. Deb (1999) described *E. bengalensis* on the basis of a holotype and an unspecified number of specimens collected from Sundarbans Tiger Reserve, West Bengal state, India. Ng et al. (2018) provisionally transferred this species to *Heteropanope* on the basis of the figure and description of the type specimen given in Deb (1999). In the present study, the type specimens of the species were examined and identified as *Eurycarcinus* because the thoracic sternite 8 of the specimen remains exposed when the male pleon is closed (Fig. 3E) and pleonal somite 3 is relatively wider, with the lateral margin projecting (Fig. 3C), which are characteristics of *Eurycarcinus*.

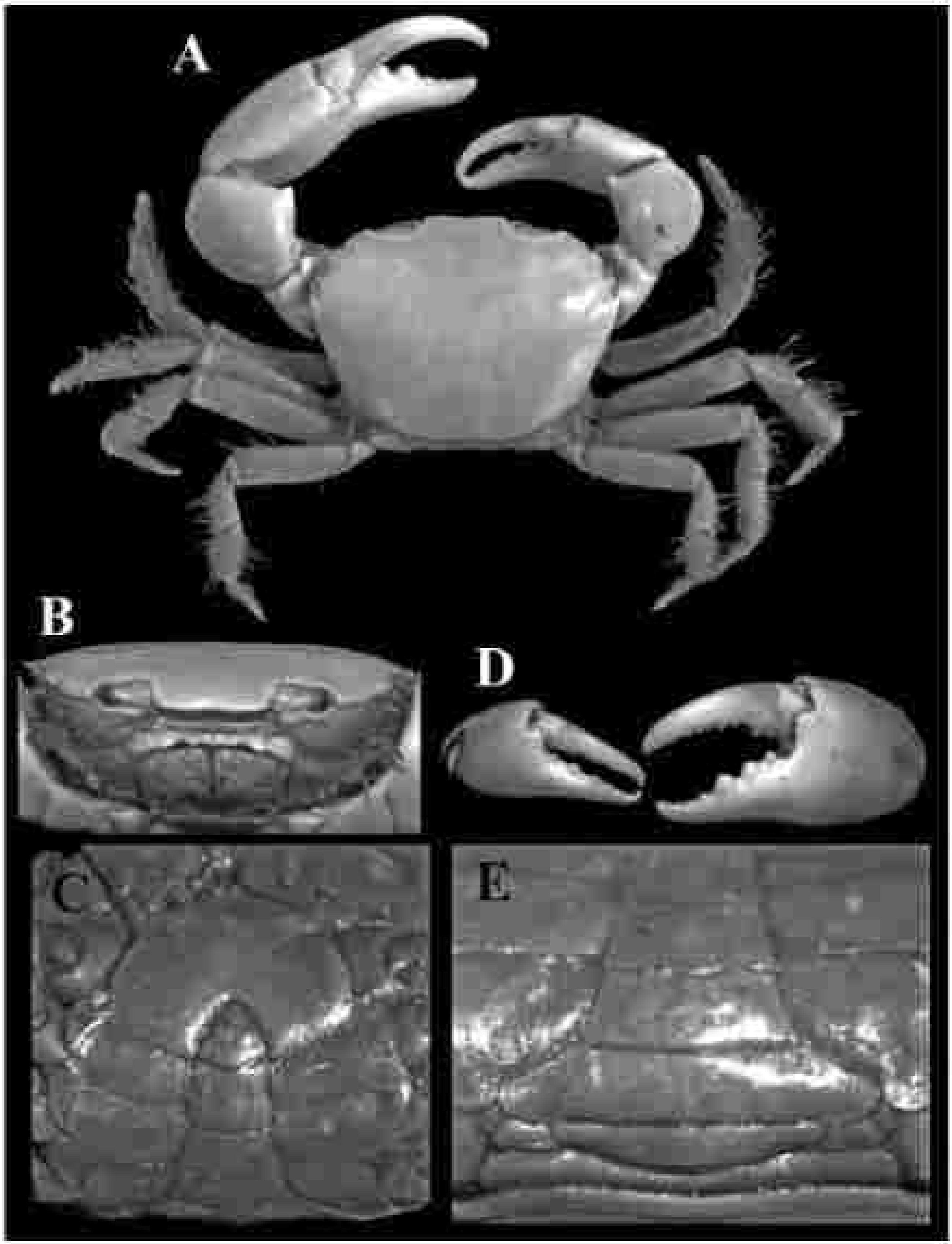

Figure 2. *Eurycarcinus integrifrons* De Man, 1879, male (CW 28.2 mm, CL 19.9 mm) (LJSc.ZRC-61), Lakhpat, India. A, habitus, dorsal view; B, frontal view; C, anterior thoracic sternum (sternites 1–4) and pleon; D, chelae, outer view; E, posterior thoracic sternum and pleon.

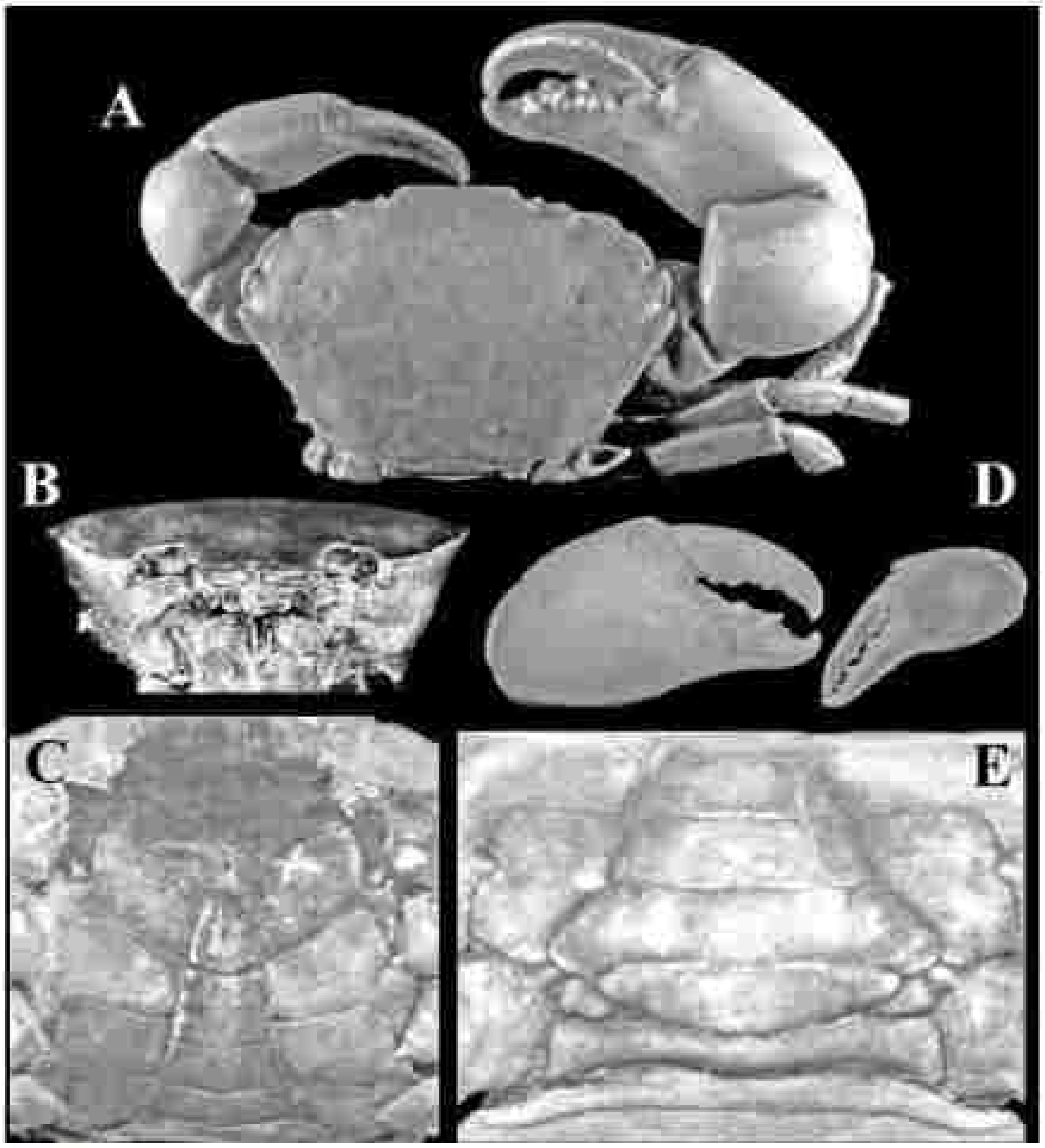

Figure 3. *Eurycarcinus bengalensis* Deb, 1999, holotype male (CW 25.1 mm, CL 16.9 mm) (ZSI C3349/2), Chainta Block, India. *A*, habitus, dorsal view; *B*, frontal view; *C*, anterior thoracic sternum (sternites 1–4) and pleon; *D*, chelae, outer view; *E*, posterior thoracic sternum and pleon.

The type series of *E. bengalensis* is mixed. Of the five specimens, the two paratype males agree well with the holotype male in most aspects and are clearly conspecific. The two ovigerous females (CW 13.9 mm, CL 10.4 mm; CW 21.3 mm, CL 15.3 mm), however, belong to *E. integrifrons* instead. The carapace shape and features (Fig. 4) are clearly of this species.

Eurycarcinus bengalensis s. str. is similar to *E. integrifrons* in the following characters: the carapace is not prominently swollen and high in frontal view

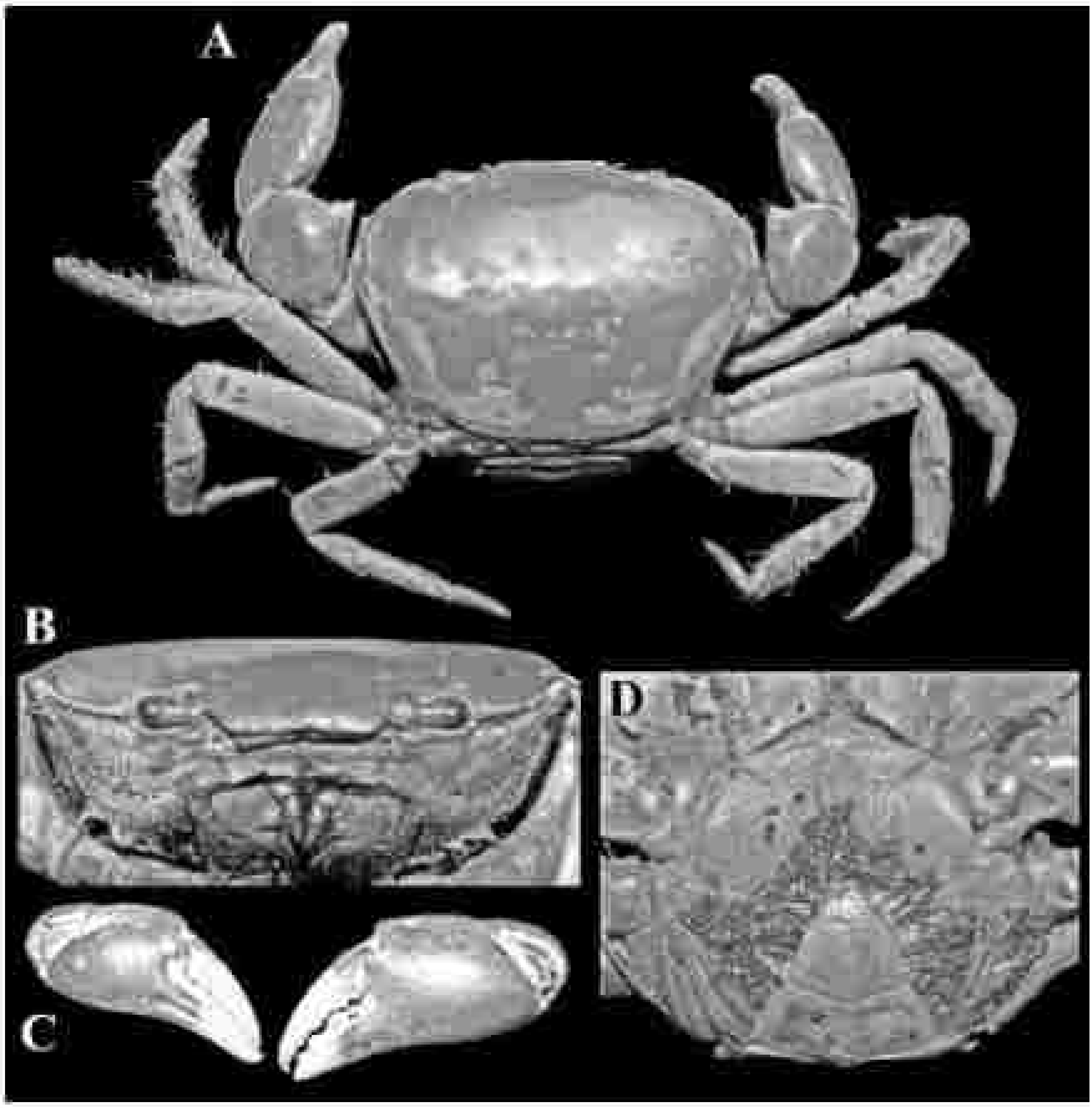

Figure 4. *Eurycarcinus integrifrons* De Man, 1879, paratype ovigerous female of *Eurycarcinus bengalensis* Deb, 1999 (CW 21.3 mm; CL 15.3 mm) (ZSI-C3349/2), Chatna Block, India. *A*, habitus, dorsal view; *B*, frontal view; *C*, chelae, outer view; *D*, anterior thoracic sternum (sternites 1–4) and pleon.

(Figs. 2A, 3A, 4A), the frontal margin is weakly bilobed (Figs. 2B, 3B, 4B), there are distinct clumps of short setae between the first to third anterolateral teeth (Figs. 2A, 3A, 4A), the supraorbital margin is smooth without granules, the sub-orbital and pterygostomial regions are smooth and glabrous with dense setae only along the sutures (Figs. 2B, 3B, 4B), and the posterior margin of the epistome has the median lobe truncate, protruding anteriorly and separated from lateral margin by distinct rounded angle (Figs. 2B, 3B, 4B). *Eurycarcinus bengalensis*, however, differs from *E. integrifrons* in several characters that cannot be explained by variation: the carapace of *E. bengalensis* is proportionately wider (Figs. 3A, 4A) (more quadrate in *E. integrifrons*; Fig. 2A); the anterolateral teeth are lobiform and wide, separated from each other by a fissure (Figs. 3A, 4A) (more narrow dentiform anterolateral margin with the teeth separated by a U-shaped hiatus in *E. integrifrons*; Fig. 2A); the male chela is proportionately shorter (Fig. 3D) (more elongate in *E. integrifrons*; Fig 2D); male pleonal somite 6 is distinctly trapezoidal in shape (Fig. 3C) (less so in *E. integrifrons*; Fig. 2C); male pleonal somites 1–3 are proportionately less broad (Fig. 3E) (proportionately wider in *E. integrifrons*; Fig. 2E); and the distal part of the G1 is relatively shorter with the tip gently upcurved (Fig. 9G, H) (G1 distal part relatively longer with the tip almost straight or gently curved downwards in *E. integrifrons*; Fig. 9D, E).

The relative width of the carapace and proportions of male pleonal somites 1–3 of *E. bengalensis* (Figs. 3A, 4A, 3E) are actually closer to the condition in *E. orientalis* (Figs. 1A, E) but the other characters (notably carapace shape, anterolateral armature, posterior margin of the epistome, male pleon shape and G1) do not match.

The characters possessed by *E. bengalensis* are interesting. While its carapace closely resembles species of *Heteropanope* as indicated by Ng *et al.* (2018), the male sternal and pleonal characters are those of *Eurycarcinus*. It is possible that some, if not all the records of "*Eurycarcinus natalensis*" and "*Eurycarcinus orientalis*" from the eastern Indian Ocean (e.g., Dev Roy, 2008; Rath and Dev Roy, 2009; see under *E. orientalis*) actually belong to *E. bengalensis* instead. The material will need to be examined.

Genus *Pilumnopeus* A. Milne-Edwards, 1867

Pilumnopeus convexus (Maccagno, 1936)
(Figs. 5, 10A–C)

Heteropanope convexa Maccagno, 1936: 176, 177.

Pilumnopeus salomonensis Ward, 1942: 96, pl. 6 fig. 11; Davie, 1989: 143; Ng *et al.*, 2008: 141 (list).

Pilumnopeus vauquelini — Stephensen, 1946: 141, fig 35a, b; Guinot, 1967: 275; Basson *et al.*, 1977: 228, 231; Türgen, 1982: 252 (list); Hornby, 1997: 15, Naderloo and Türkay, 2012: 37 [not *Pilumnus vauquelini* Audouin, 1826 = *Pilumnopeus vauquelini* (Audouin, 1826)].

Pilumnopeus indica — Barnard, 1955: 30, fig. 12 [not *Heteropanope indica* De Man, 1887 = *Benthopanope indica* (De Man, 1887)].

Pilumnopeus convexa — Davie, 1989: 142, 143, fig. 7A–C.

Pilumnopeus convexus — Cooper, 1997: 171–173, figs. 6, 16; Apel, 2001: 98; Ng *et al.*, 2008: 141 (list); Naderloo and Türkay, 2012: 37; Ghory *et al.*, 2013: 301–312, figs. 1–5; Naderloo *et al.*, 2013: 449, tab. 1; Gosavi *et al.*, 2017: 429–433, figs. 2–7; Naderloo, 2017: 311, figs. 26.21, 26.22a, 26.23.

Type locality. Ethiopia.

Material examined. 1 male (CW 15.3 mm; CL 11.3 mm), 2 females (CW 11.9 mm; CL 8.4 mm; CW 12.8 mm; CL 8.6 mm), LFSc.ZRC-70, Kuda (21°37′33″N 72°18′17″E), Gujarat State, India, 12 October, 2016, coll. J. Trivedi; 1 male (CW 9.6 mm; CL 6.4 mm), 1 female (CW 5.9 mm; CL 4.3 mm), ZRC 2012.0422, Sumar Goth, Pakistan, 26 January 2009, coll. F. Ghory; 1 female (CW 8.7 mm; CL 5.9 mm) ZRC 2018.0067, Buleji, Pakistan, 4 March 1986, coll. Q. Kazmi; 1 female (CW 14.4 mm; CL 9.8 mm) (paralectotype of *Pilumnopeus salomonensis* Ward, 1942), ZRC 2012.0794, Salomon Islands, Chagos Archipelago, 1936, coll. R. Viader and G. Antelme; 2 males (CW 9.0 mm; CL 6.3 mm; CW 8.0 mm; CL 5.6 mm) ZRC 2018.1364, Persian Gulf, Iran, May 2010, coll. M. Safaei.

Remarks. The specimens examined (Figs. 5, 10A–C) in the present study compared well with the description and figures in Ghory *et al.* (2013). *Pilumnopeus convexus* is close to *P. serratifrons* but varies from the latter in having a CW/CL ratio of 1.4 to 1.5 and a less projecting front with a shallow central notch (Davie, 1989). The specimens were collected (Figs. 6, 11D–F) from Ekkakula mangroves located in Odisha State.

The species is so far reported from South Africa, Red Sea, Gulf of Aden, Persian Gulf, and Gulf of Oman (Naderloo, 2017). In India, the species was recorded from Gujarat (Gosavi *et al.*, 2017) located on the west coast of India.

Genus *Heteropanope* Stimpson, 1858

Heteropanope glabra Stimpson, 1858
(Figs. 6, 10D–F)

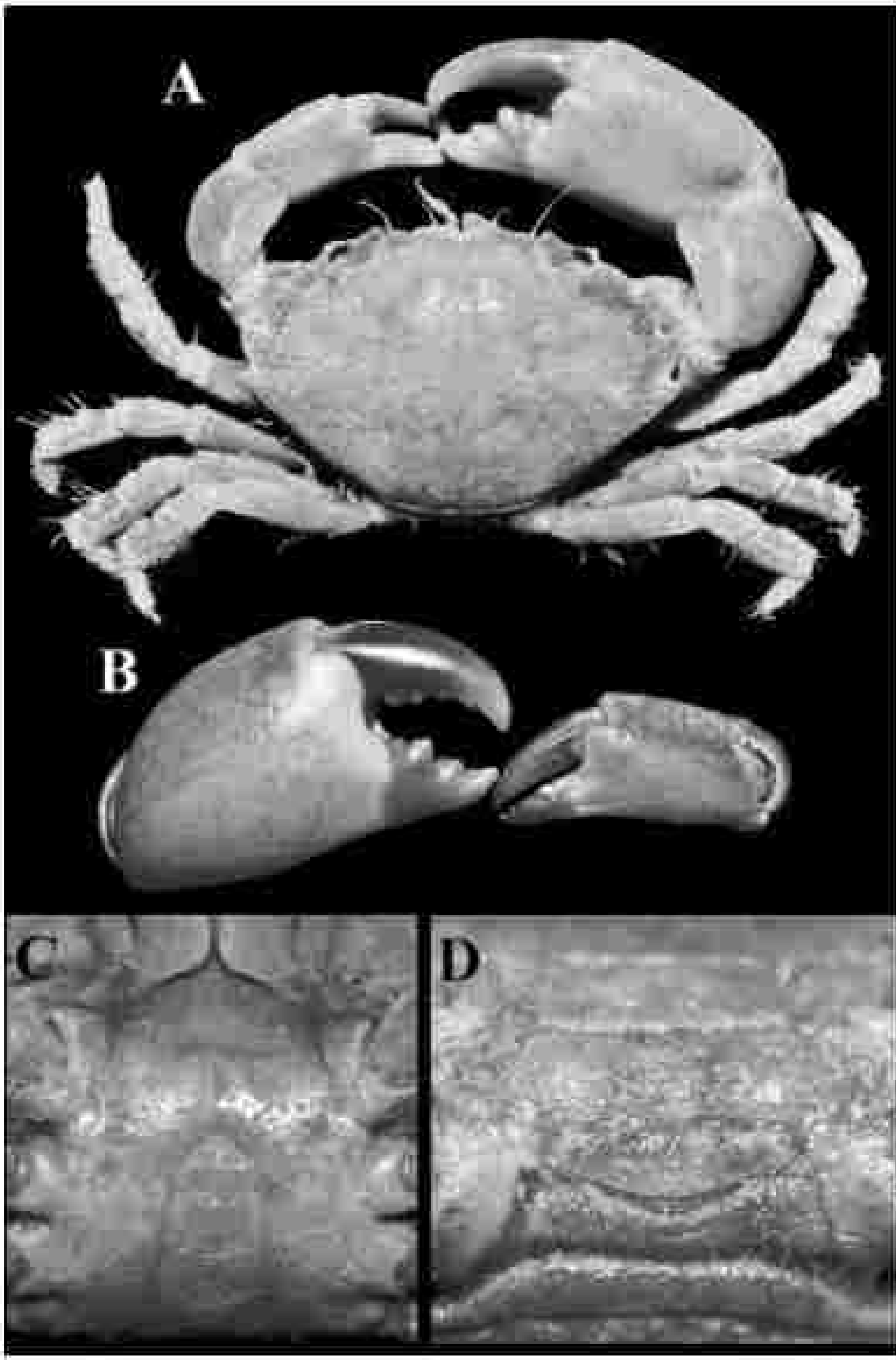

Figure 5. *Pilumnopeus convexus* (Maccagno, 1936), male (CW 15.3 mm, CL 11.3 mm) (LFSc.ZRC-70), Kuda, India. A, habitus, dorsal view; B, chelae, outer view; C, anterior thoracic sternum (sternites 1–4) and pleon; D, posterior thoracic sternum and pleon.

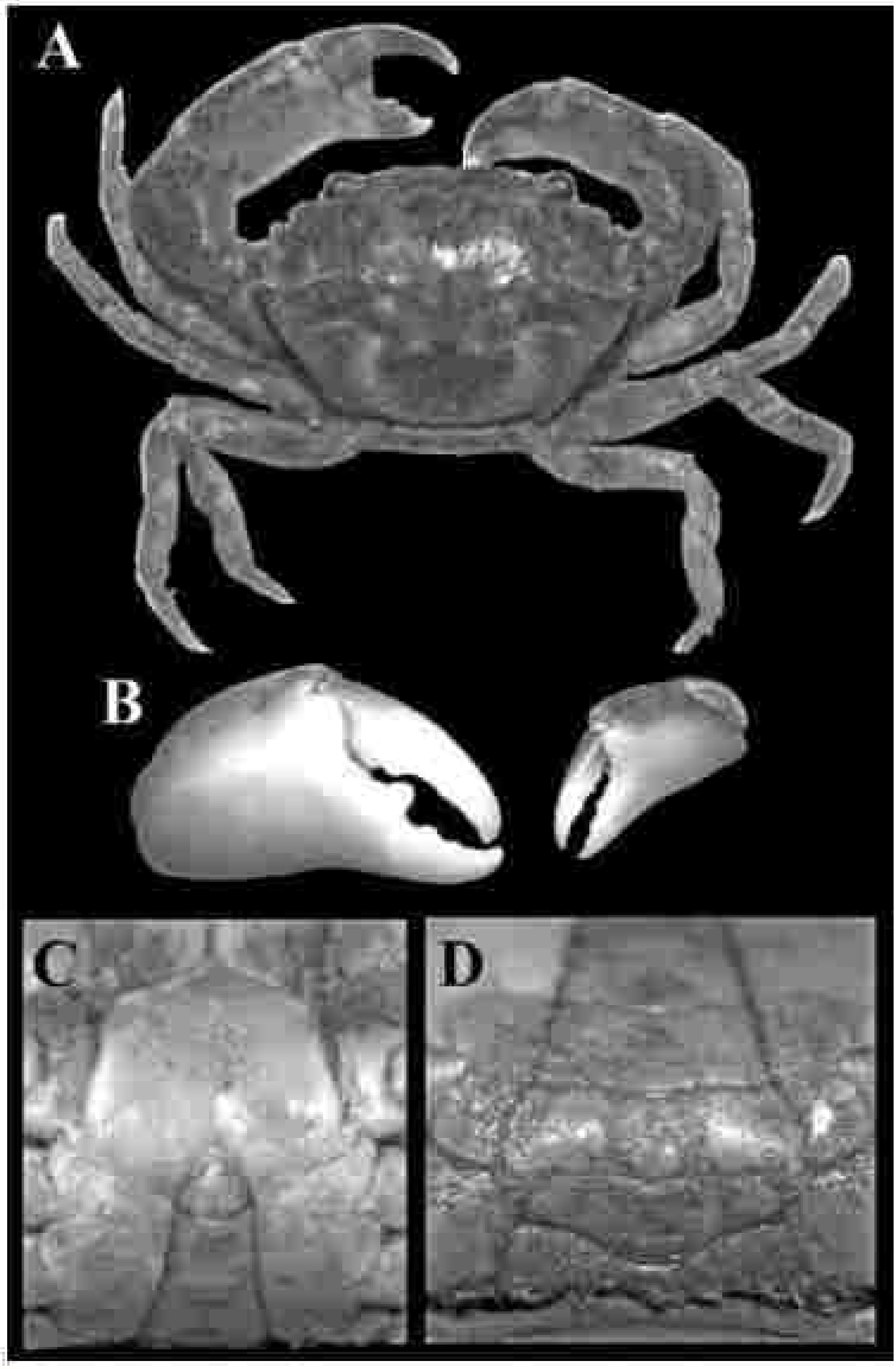

Figure 6. *Heteropanope glabra* Stimpson, 1858, male (CW 14.4 mm, CL 10.1 mm) (LFSc.ZRC-66), Ghogha mangroves, India. A, habitus, dorsal view; B, chelae, outer view; C, anterior thoracic sternum (sternites 1–4) and pleon; D, posterior thoracic sternum and pleon.

Heteropanope glabra Stimpson, 1858: 35.

Eurycarcinus maculatus Alcock, 1898: 212; Deb, 1999: 375.

Heteropanope glabra — Davie, 1989: 130–134, figs.1a–j, 2; Tan and Ng, 1994: 84 (list); Ng *et al.*, 2008: 140 (list); Naderloo and Türkay, 2012: 37; Naderloo *et al.*, 2013: 449, tab. 1; Trivedi *et al.*, 2015: 1–5, figs. 1, 2; Naderloo, 2017: 307, figs. 26.10d, 26.15, 26.16; Trivedi *et al.*, 2018: 59 (list). [For complete synonymy see Davie, 1989: 130; Sakai, 1976: 503; Dai and Yang, 1991: 377].

Type locality. Hong Kong.

Material examined. 4 males (CW 14.4–6.0 mm; CL 10.1–4.0 mm), 6 females (CW 12.3–7.2 mm; CL 8.3–5.4 mm), I.FSc.ZRC-66, Ghogha (21°40′41″N 72°17′06″E), Gujarat State, India, 14 April, 2014, coll. J. Trivedi.

Remarks. The specimens examined in the present study (Fig. 6) agree with the description and figures in Davie (1989). The G1 tip (Fig. 10D, F) is slightly longer compared to that figured in Davie (1989). This difference can easily be explained by the size of the present specimens.

This species is so far reported from East Africa, Persian Gulf, Gulf of Oman, Pakistan, India, Andaman Sea, Thailand, Hong Kong, Taiwan, Mergui Archipelago, Singapore, Australia, and New Caledonia (Sakai, 1976; Davie, 1989; Dai and Yang, 1991; Trivedi *et al.*, 2015; Naderloo, 2017).

Genus *Aniptumnus* Ng, 2002

Aniptumnus quadridentatus (De Man, 1895)

(Figs. 7, 8, 10G–I)

Pilumnus seminudus — De Man, 1887: 65 [not *Pilumnus seminudus* Miers, 1884 = *Glabropilumnus seminudus* (Miers, 1884)].

Pilumnus quadridentatus De Man, 1895: 537, fig. 6; Nobili, 1906: 278.

Parapilumnus quadridentatus Balss, 1933: 39 (list); Tan and Ng, 1994: 84 (list).

Heteropanope neolaevis Deb, 1995: 220; 1999: 374, figs. 3, 4; Ng *et al.*, 2018: 475, 481–482; Trivedi *et al.*, 2018: 59 (list).

Aniptumnus quadridentatus — Ng, 2002: 213, figs. 1, 2; Ng and Clark, 2008: figs. 13–18; Ng *et al.*, 2008: 140 (list).

Type locality. Pontianak, West Kalimantan, Indonesia.

Material examined. Lectotype, male (CW 13.9 mm; CL 9.6 mm), ZSI-C1503/2, Matla River, Gangetic Delta, West Bengal State, India, December 1916, coll. S.W. Kemp. Paralectotypes, 4 males (CW 8.0–9.3 mm; CL 5.8–6.5 mm), same data as holotype.

Remarks. Ng *et al.* (2018: 481–482) clarified the date of publication for *Heteropanope neolaevis*, noting that the correct spelling of the name and citation should be *Heteropanope neolaevis* Deb, 1995.

Deb (1995: 220) listed "50 examples" of this species (as *H. neolaevis*) from an estuarine area in the Matla River, Gangetic Delta, West Bengal State, India, and no types were designated. Deb (1999: 374) noted that she had "Several (about 50) specimens including holotype and paratypes from Gangetic delta, collected by S. W. Kemp, Z.S.I. Regd. No. C1503/2". She did not specify the sex or size of the holotype. In the ZSI, there is one male specimen labeled as holotype which has the same data as indicated by Deb (1999) and is here recognized as the lectotype since no holotype was noted in the original paper (Deb, 1995).

Ng *et al.* (2018: 475) commented that the species is neither *Heteropanope* nor *Pilumnopeus* or *Benthopanope*, and the G1 figured (Deb, 1999: fig. 4) was unusual, being short and stout with the tip rounded. The lectotype and paralectotypes of *H. neolaevis* were examined and the *Heteropanope neolaevis* of Deb is here identified as *Aniptumnus quadridentatus* (De Man 1895). De Man (1895) described *Pilumnus quadridentatus* from a good series of specimens from the port of Pontianak, West Borneo, Indonesia. He also referred a specimen earlier obtained from Mergui (De Man, 1887) to this species. Nobili (1906) reported the species from Djibouti in the Red Sea, but his specimen should be re-examined in order to confirm its identification. Balss (1933) first referred it to *Parapilumnus* De Man, 1895, but Ng (2002) reviewed the status of *Parapilumnus* and showed that this genus was actually not a pilumnid but an acidopsid. Ng (2002) selected a lectotype for *P. quadridentatus* and made it the type for a new genus, *Aniptumnus*, characterized by its subtruncate G1 tip, presence of sharp granules on the ventral margin of the basis-ischium and merus of the fourth ambulatory leg.

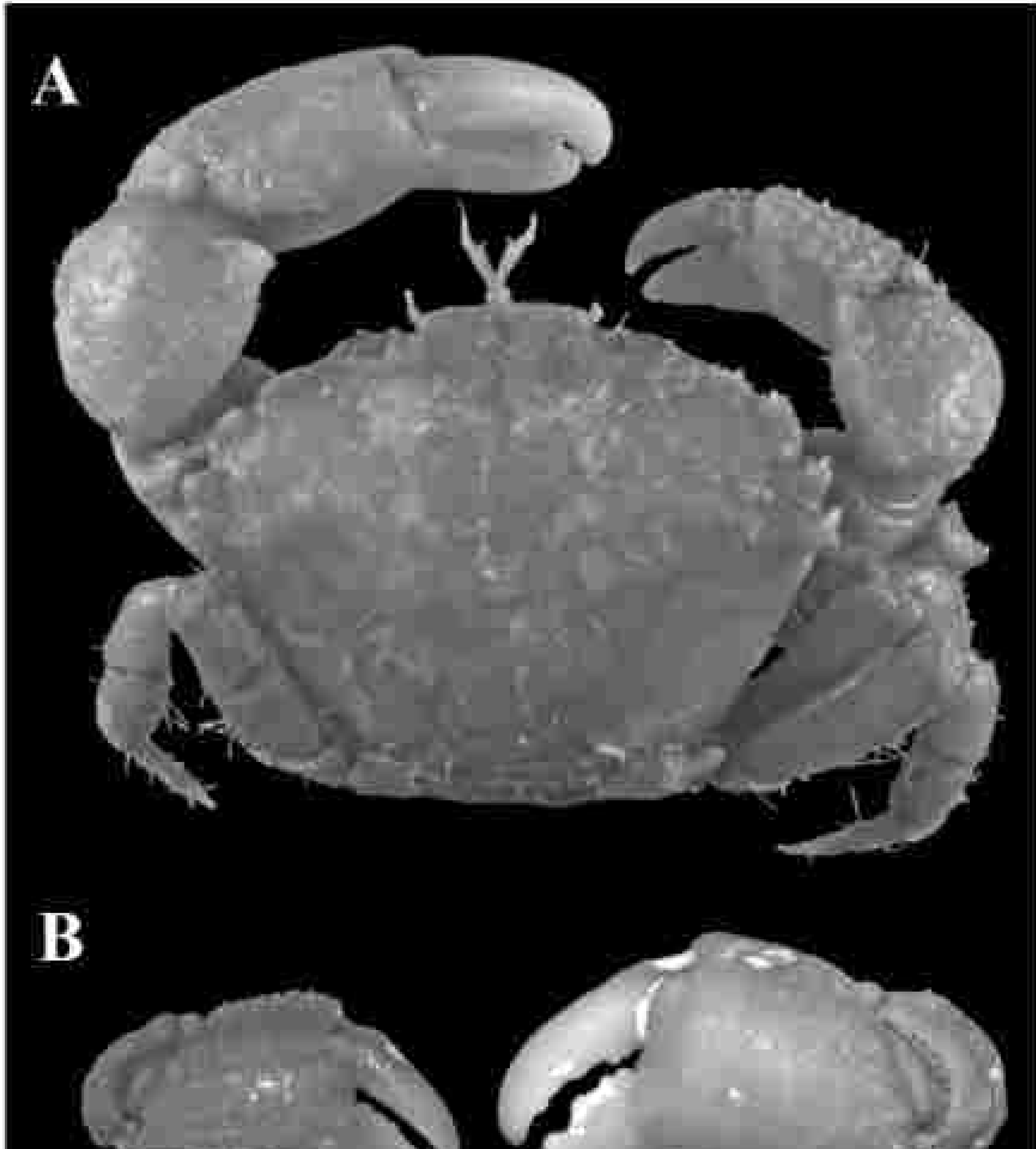

Figure 7. *Aniptumnus quadridentatus* (De Man, 1895), male (CW 13.9 mm, CL 9.6 mm) (ZSI C1501/2) Mahi River, India (lectotype of *Heteropanope* [illegible] Deb, 1995); A, habitus, dorsal view; B, chelae, outer view.

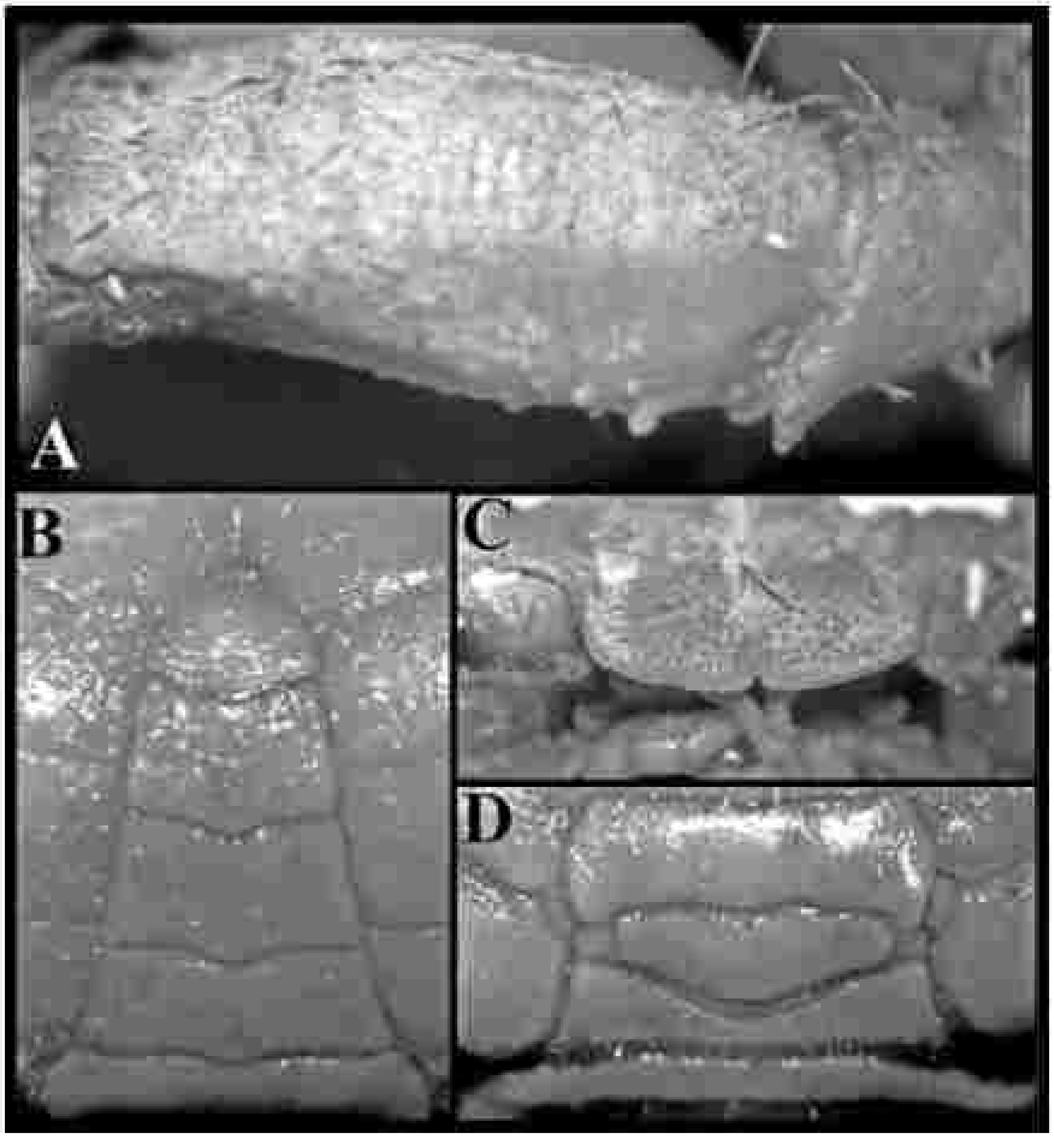

Figure 8. *Angatumnus quadridentatus* (De Man, 1895), male (CW 13.9 mm; CL 9.6 mm) (ZSI C1503/2) Matla River, India (lectotype of *Heteropanope neolaevis* Deb, 1999); A, fourth ambulatory leg merus and basis-ischium lateral view; B, pleon; C, frontal margin; D, posterior thoracic sternum and pleon.

The types of *H. neolaevis* agree with the descriptions and figures of *A. quadridentatus* by De Man (1895), Ng (2002), and Ng and Clark (2008) and are considered conspecific. The carapace, cheliped and ambulatory leg characters all agree (Figs. 7A, B, 8A). The G1 of *H. neolaevis* figured by Deb (1999: Fig. 4) is inaccurate, being much shorter and stouter in her illustration. The actual G1 closely resembles that of *A. quadridentatus*, except that the tip is more rounded and less produced (Fig. 10G, H), but this can easily be explained by variation. In addition, the male sternite 8 of the types of *H. neolaevis* are exposed when the male pleon is closed (Fig. 8D; see also Ng and Clark, 2008; Hsueh *et al.*, 2009).

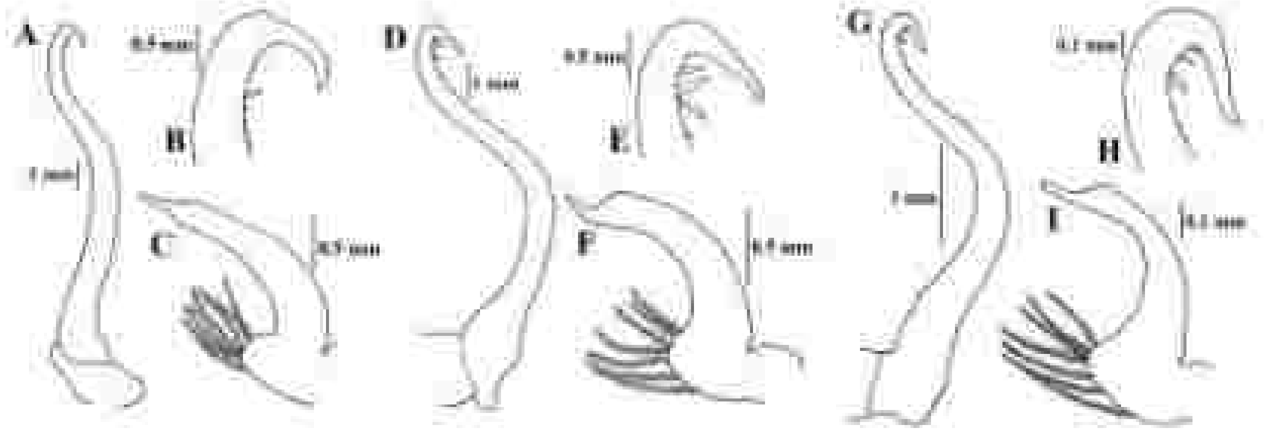

Figure 9. A–C, *Eurycarcinus orientalis* A. Milne-Edwards, 1867, male (CW 41.5 mm, CL 26.9 mm) (LJPSc-ZRC-64), Kandla, India; D–F, *Eurycarcinus integrifrons* De Man, 1879, male (CW 28.2 mm, CL 19.9 mm) (LJPSc-ZRC-63), Lakhpat, India; G–I, *Eurycarcinus bengalensis* Deb, 1999, holotype male (CW 25.1 mm, CL 16.9 mm) (ZSI-C3349/2), Chaunta Block, India. A, D, G, ventral view of left G1; B, E, H, ventral view of distal part of left G1; C, F, I, left G2.

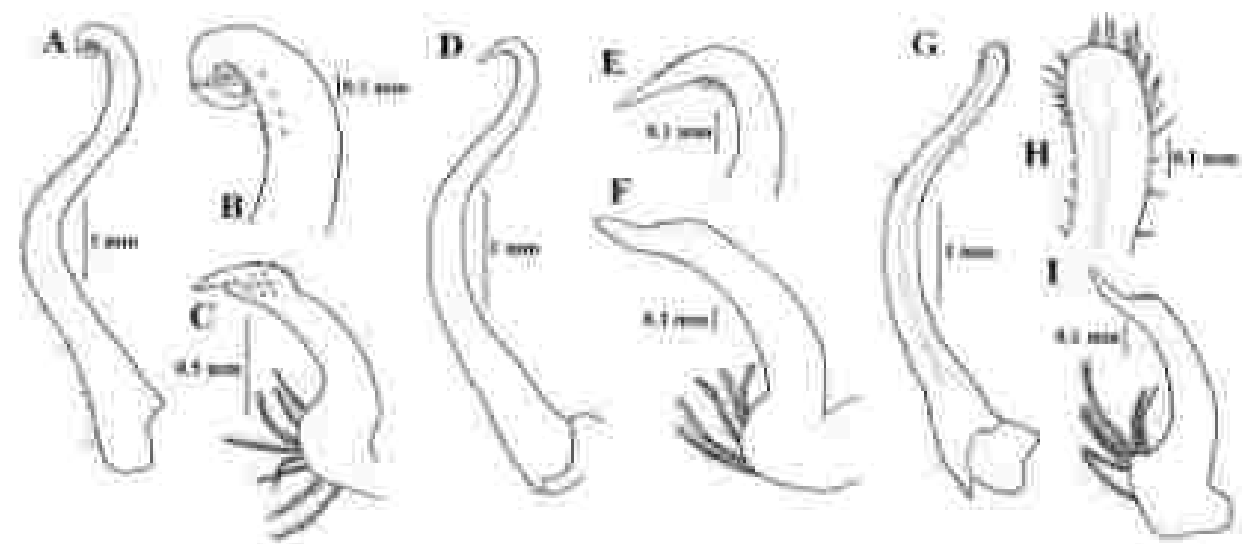

Figure 10. A–C, *Pilumnopeus convexus* (Maccagno, 1936), male (CW 15.3 mm, CL 11.3 mm) (LJPSc-ZRC-70), Kuda, India; D–F, *Heteropanope glabra* Stimpson, 1858, male (CW 14.4 mm, CL 10.1 mm) (LJPSc-ZRC-66), Ghogha mangroves, India; G–I, *Aniptumnus quadridentatus* (De Man, 1895), male (CW 13.9 mm; CL 9.6 mm) (ZSI-C1503/2) Matla River, India (lectotype of *Heteropanope* [illegible] Deb, 1995). A, D, G, ventral view of left G1; B, E, H, ventral view of distal part of left G1; C, F, I, left G2.

Aniptumnus quadridentatus is a mangrove species, occurring in brackish waters. The type locality, Pontianak, is a port at the opening of the Kapuas River in Borneo and is surrounded by mangroves. In Malaysia and Singapore, the species is often found among fouling communities in mangrove and estuarine habitats. When present, it often occurs in large numbers.

Acknowledgements

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