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Morphology, growth and behaviour of *Ocypode ceratophthalma* (Pallas, 1772) (Decapoda: Brachyura: Ocypodidae) from Goa, west coast of India

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Original Article

Abstract
Intertidal brachyuran fauna of the estuarine sandy beaches of Goa are vulnerable to large-scale anthropogenic activities. The present study deals with morphology and growth patterns of the horned ghost crab *Ocypode ceratophthalma* (Pallas, 1772) from two impacted beaches (Bambolim and Siridao). Sampling surveys conducted at the two beaches during July 2015, September 2015 and January 2016 yielded 60 specimens of the species. A comprehensive taxonomic diagnosis of the species is provided aided by 22 morphometric characters, 16 morphometric ratios, one meristic count and genital characters. Assessment of morphometric parameters revealed marked sexual dimorphism with respect to proportions of abdomen and eyestalks. Assessment of growth patterns revealed positive allometric growth of male carapace as well as that of female abdomen indicating sexual maturity.

Keywords: *Brachyura, Ocypodidae, morphometry, growth patterns, Goa.*

Introduction

Goan sandy beaches are highly prone to anthropogenic activities such as tourism, sand mining, oil pollution and construction (Sawkar *et al*., 1998) which are potentially hazardous to the resident fauna. The study of eco-biology of the resident crab fauna could serve as a potential tool to determine ecosystem health (Barros, 2001). These studies entail use of tools such as morphometry, allometry and ethology to validate species identification (Mayr and Ashlock, 1991), understand physiological functioning (Pinheiro and Fransozo, 1993) and comprehend the level of adaptability of organisms to anthropogenic impact (Barros, 2001).

Ocypode ceratophthalma (Pallas, 1772) is an extremely active, air-breathing (Hoyle, 1976) inhabitant of reflective sandy shores and sheltered sand flats above the high water mark throughout the Indo-Pacific regions (Lucrezi and Schlacher, 2014). This species has been reported from India (Alcock, 1900; Chhapgar, 1957; Sankarankutty, 1961a, b; Silas and Sankarankutty, 1967; Harkantra and Parulekar, 1985; Dev Roy and Bhadra, 2005, 2008). In addition, Chakrabarti (1981) studied its burrowing patterns and revealed that the burrow shapes were a function of the temperature tolerance of the species, its digging ability and nature of the beach slope. De (1998) studied the effects of its burrowing activities and suggested that these could lead to shoreline erosion. It is apparent from review of literature that besides preliminary reporting (Harkantra and Parulekar, 1985; Dev Roy and Bhadra, 2008), there have been no attempts to provide an account of the morphology and eco-biology of ghost crabs from Goa, west coast of India. In view of the above, the present study focused on providing detailed analyses of the morphology, growth patterns and behavioral patterns of the horned Ghost crab, *O. ceratophthalma* from the region.

Material and methods

Sampling was carried out along sandy shores located at Siridao (15°26'N, 73°51'E) and Bambolim (15°27'N, 73°51'E) on the northern banks of the Zuari Estuary (Fig. 1). These beaches are gradually sloping sandy stretches of pocket type, with sandy stretches flanked on both sides by weathered laterite rocks. Substratum consists of well-drained medium to coarse grained sand. At Bambolim, the beach profile consists only of berm, as the dunes have been replaced by armouring walls of adjoining beach resorts, which directly release sewage into the estuary. At Siridao, the profile comprises both dune and berm features. The dune is composed of fine sand, whereas the berm contains all the sand gradients. The dune is covered with beach shacks.

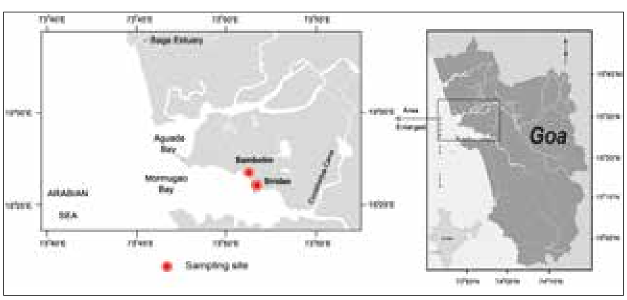

Fig. 1.Map of the study area indicating sampling site.

Ocypode ceratophthalma is a nocturnally active species hence sampling was done at night during mid and low tide levels. Torch light was used to observe their behaviour (foraging, burrowing, social conflicts and responses to external disturbances) and collect them. The specimens were placed in plastic containers and brought to the laboratory for detailed examination.

Morphological characteristics of the crabs were recorded photographically using an Olympus Digital Camera (model no. E-PL1), and line diagrams using Adobe Photoshop CS5 software. Altogether 22 morphometric parameters (Table 1) were measured up to the nearest 0.01 mm using vernier calipers (200 mm), and 16 ratios (Table 2) were derived from these parameters. Taxonomic identification was carried out by employing morphology, meristic counts, morphological

Table 1. Results of morphological measurements for *Ocypode ceratophthalma* (N=60).

S. No.	Body part	Morphological parameters	Data ($\mu \pm \sigma$) Male	Female
1.	Carapace	CW	2.99 ± 0.42	3.01 ± 0.16
2.	CL	2.54 ± 0.39	2.49 ± 0.16	
3.	FW	0.34 ± 0.05	0.32 ± 0.03	
4.	SW	2.16 ± 0.39	2.19 ± 0.11	
5.	AW	0.83 ± 0.18	1.68 ± 0.13	
6.	OPL	1.59 ± 0.54	1.30 ± 0.18	
7.	STL	0.73 ± 0.33	0.31 ± 0.10	
8.	Third	ML3m	0.37 ± 0.06	0.35 ± 0.02
9.	maxillipeds	MW3m	0.33 ± 0.05	0.31 ± 0.03
10.	IL3m	0.62 ± 0.12	0.58 ± 0.07	
11.	IW3m	0.46 ± 0.11	0.42 ± 0.04	
12.	Major	DLch	1.41 ± 0.21	1.31 ± 0.21
13.	Cheliped	PLch	2.30 ± 0.37	2.23 ± 0.15
14.	PDch	1.43 ± 0.26	1.33 ± 0.07	
15.	MLch	1.55 ± 0.24	1.43 ± 0.07	
16.	ChL	5.82 ± 1.02	5.45 ± 0.31	
17.	Minor	DLch	1.22 ± 0.25	1.21 ± 0.07
18.	Cheliped	PLch	1.82 ± 0.33	1.65 ± 0.28
19.	PDch	0.84 ± 0.19	0.76 ± 0.07	
20.	MLch	1.36 ± 0.24	1.31 ± 0.10	
21.	ChL	4.78 ± 0.95	4.53 ± 0.46	
22.	Pereiopods	PrL2	6.60 ± 1.03	6.20 ± 0.63
23.	PrL3	7.22 ± 1.08	6.92 ± 0.40	
24.	PrL4	6.96 ± 1.05	6.70 ± 0.46	
25.	PrL5	5.23 ± 0.96	5.03 ± 0.35	
26.	G1	G1L	1.21 ± 0.17	

measurements and genital structure following (Sakai and Türkay, 2013). The specimens were stored in 5% buffered formalin (hexamethylene tetramine to prevent fragmentation) in pre-labelled transparent plastic bottles. These are deposited at the Marine Biology laboratory, Department of Marine Sciences, Goa University, Goa.

The following abbreviations are used in the text and tables. AW–abdominal width; CL–carapace length; CW–carapace width; ChL–Cheliped length; DLch–Cheliped dactyl length; FW–frontal width; G1–first gonopod; G1L–first gonopod length; HTL–High tide level; IL3m–Third maxilliped ischium length; IW3m–Third maxilliped ischium width; LT–Low tide level; ML3m–Third maxilliped merus length; MLch–Cheliped merus length; MW3m–Third maxilliped merus width; MTL–Mid tide level; OPL–Ocular peduncle length; P–pereiopod; PrL- Pereiopod length; PDch–Cheliped propodus depth; PLch–Cheliped propodus length; STL–Stylus length; SW–Sternal width.

Linear growth of abdomen, chelipeds and gonopods with respect to body size was determined by comparing six relationships namely CW vs. CL, CW vs. AW, CL vs. ChL, CL vs. PDch, CL vs. PLch and CL vs. G1L using logarithmic equation (1) following (Goldman *et al.*, 1990).

$\log10 y = \alpha \log x + \log \beta$.........................(1).

Where, y = dependent variable, x = independent variable, β = constant, α = allometric coefficient relating x-variable to the y-variable. 0.9 ≤ α ≤ 1.1 indicates strong tendency towards isometric growth, lesser α value indicates negative allometric growth and greater α value indicates positive allometric growth (Pinheiro and Fransozo,1993).

To determine whether the relationships among the above parameters deviated from linearity (i.e. exhibited allometric growth), a "two sample *t*-test assuming equal variances" was employed to test whether the estimated slope α deviated significantly (alpha = 0.05 or 95% confidence limits of the slope) from the expected slope.

Results

Taxonomy

Family Ocypodidae Rafinesque, 1815
Genus *Ocypode* Weber, 1795
Ocypode ceratophthalma (Pallas, 1772)

Material examined

Males (N = 30), range 2.11–3.65 cm; females (N = 30), range 2.63–3.34 cm.

Diagnosis

External orbital angles broadly triangular. Eyestalks prolonged distally beyond cornea. Stridulating ridge of male cheliped with 7 interspaced round tubercles, 12 thick striae and 25-27 closely spaced striae; in females, it consists of 4 interspaced round tubercles, 8-12 thick striae and 29 closely spaced striae. P2–P3 propodi with setae. G1 slender, bears sub-distal palp. Gonopore surrounded by sunken sternite (Sakai and Türkay, 2013).

Description

Male crab cherry red coloured on anterior dorsal (Fig. 2a) and ventral carapace, ocular stylus, mouth parts, anterior half of sternum, last two abdominal segments (Fig. 2b); branchial regions yellowish, blood red blotch on cardiac, intestinal regions (Fig. 2a). Male cheliped cherry red on upper surfaces of dactylus, propodus, entire surfaces of other segments; remaining parts white to dull grey (Fig. 2a, b). Females yellowish to golden brown dorsally, with pair of blood red blotches flanking cardiac and intestinal regions, ocular stylus dull brown (Fig. 2c), thoracic sternum, abdomen dull grey (Fig. 2d). Female cheliped cherry red on upper surfaces of dactylus, propodus, carpus, upper and anterior surfaces of merus; remaining parts dull grey (Fig. 2c, d). Pereiopod dactyli off-white coloured, other segments cherry red, hairy patches yellow (Fig. 2a-d).

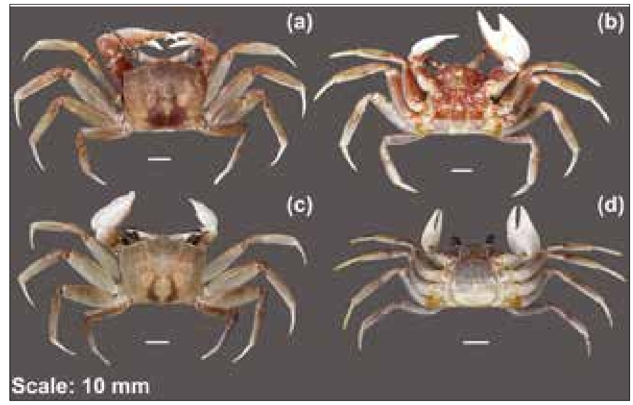

Fig. 2.*Ocypode ceratophthalma*: (a) Dorsal view of male (b) Ventral view of male (c) Dorsal view of female (d) Ventral view of female.

Carapace roughly trapezoidal, wider than long (Table 2). Dorsal surface longitudinally convex, covered with densely arranged fine granules. Regions well marked, two longitudinal grooves separate proto-gastric and hepatic regions; meso-gastric and cardiac regions separated by two depressions and connecting transverse grooves; pair of oblique grooves separates cardiac and branchial regions; transverse groove separates cardiac and intestinal regions. Lateral margins granulated, parallel along anterior one-thirds, slightly converging along posterior two-thirds (Fig. 3a). Front extremely narrow (Table 2), unilobed, deflexed, with granular elevated margin.

Table 2. Results of morphometric ratios for *Ocypode ceratophthalma* (N=60)

S . No.	Body part	Morphometric	Data ($\mu \pm \sigma$)	
		Ratios	Male	Female
1.	Carapace	CW/CL	1.18 ± 0.04	1.21 ± 0.08
		FW/CW	0.12 ± 0.01	0.11 ± 0.01
		SW/CW	0.72 ± 0.08	0.73 ± 0.02
		AW/CW	0.28 ± 0.04	0.56 ± 0.05
		STL/OPL	0.46± 0.19	0.24 ± 0.05
2.	Third	ML3m/MW3m	1.14 ± 0.11	1.13 ± 0.09
	maxillipeds	IL3m/IW3m	1.38 ± 0.19	1.39 ± 0.13
		IL3m/ML3m	1.68 ± 0.18	1.66 ± 0.18
3.	Major	ChL/CL	2.28 ± 0.12	2.20 ± 0.11
	cheliped	DLch/PLch	0.61 ± 0.04	0.59 ± 0.07
	PDch/PLch		0.62 ± 0.02	0.60 ± 0.02
	MLch/PLch		0.68 ± 0.05	0.64 ± 0.02
4.	Minor	ChL/CL	1.87 ± 0.14	1.82 ± 0.19
	cheliped	DLch/PLch	0.67 ± 0.05	0.76 ± 0.15
	PDch/PLch		0.46 ± 0.03	0.48 ± 0.09
	MLch/PLch		0.75 ± 0.03	0.82 ± 0.16
5.	Pereiopods	PrL2/CL	2.60 ± 0.10	2.49 ± 0.23
		PrL3/CL	2.85 ± 0.13	2.79 ± 0.17
		PrL4/CL	2.74 ± 0.13	2.70 ± 0.16
		PrL5/CL	2.05 ± 0.14	2.03 ± 0.13
6.	G1	G1L/CL	0.48 ± 0.05	—

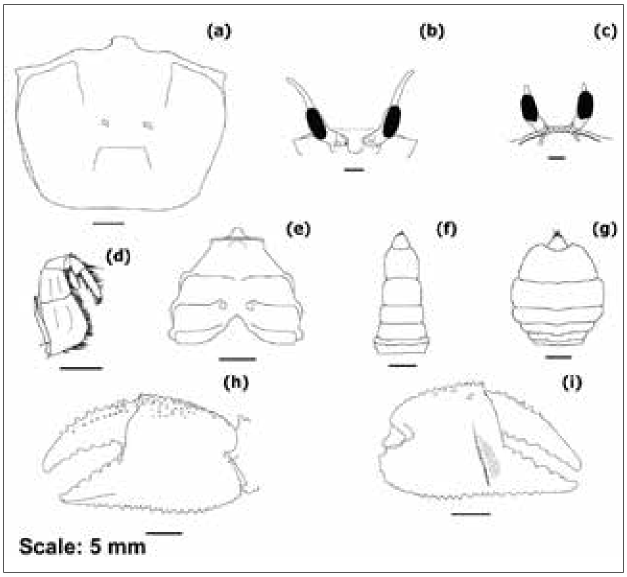

Fig. 3. *Ocypode ceratophthalma*: (Line diagrams): (a) Carapace dorsal surface (b) Male eyestalk (c) Female eyestalk (d) Third maxilliped (right) (e) Female thoracic sternum and position of gonopores (f) Male abdomen (g) Female abdomen (h) Cheliped dactylus and propodus (outer surface) (i) Cheliped dactylus and propodus (inner surface).

Antennulary rudiments lodged in two minute antennulary fossae separated by septum below the front. Orbits large, very deep, slightly oblique, with elevated, granular, sinuous supra-orbital margin. Inner orbital angle contiguous with frontal margin, exorbital angle acuminate, externally directed. Infra-orbital marginal elevated, granular with shallow median notch. Eyestalk extremely long, with stylus-like extension beyond cornea. Stylus of males longer than (Fig. 3b; Table 2) that of females (Fig. 3c; Table 2). Antennae very small, positioned in orbital hiatus.

Buccal cavity sub-quadrangular. Pterygostomial region marked with curved tuberculate ridge. Epistome projects medially into buccal cavity. Third maxillipeds not gaping. Ischium glabrous, longer than merus (Table 2); merus quadrangular, longer than wide (Table 2), both segments covered with two tuberculate patches near margins (Fig. 3d). Palp shorter than ischio-merus, setose (Fig. 3d). Exopod slender, longer than ischium (Fig. 3d).

Thoracic sternum wide (Table 2), lightly granulated, 8-segmented. Sternite 1 tuberculate, sternites 2, 3 very narrow, fused; sternites 4-8 much broader and larger. Sternites 3, 4 separated by conspicuous ridge. Sternal sutures not continuous. Sterno-abdominal cavity deep, covers sternites 4-8, with granular margin, gonopores on sternite 6 (Fig. 3e). Male abdomen sub-cylindrical, finely granular, narrow (Table 2), 7-segmented, lateral margins hirsute. Segment 6 longer than 5. Telson bluntly triangular, as long as broad (Fig. 3f). Female abdomen sub-oval, finely granular, broad (Table 2), 7-segmented, lateral margins hirsute. Segment 4 widest, segment 6 longest. Telson bluntly triangular, as long as broad (Fig. 3g).

Chelipeds unequal in both sexes (Table 1). ChLmajor $>$ 2.0 times CL, ChLminor $<$ 2.0 times CL in both sexes (Table 2). Fingers curved, bluntly pointed with curved tips; occlusal surface of large cheliped fingers with large sharp teeth, whereas that of smaller cheliped fingers with small teeth. Dactyli with two rows of granules each on outer and upper surfaces (Fig. 3h); inner surface minutely granular, with one groove. Pollex minutely granular on inner and outer surfaces, with a row of sharp pointed granules on lower margin that continues to the posterior end of palm (Fig. 3h, i). Propodi distinctly granular on outer, inner and upper surfaces (Fig. 3h, i). In males, stridulating ridge consists of 7 interspaced round tubercles, 12 thick striae and 25-27 closely spaced striae (Fig. 3i); in females, it consists of 4 interspaced round tubercles, 8-12 thick striae and 29 closely spaced striae. Major cheliped propodus more robust than that of minor cheliped (Table 2). Carpi conspicuously granular on outer surface with larger granules towards anterior margin, inner margin with one pointed tooth. Meri with several rows of granules on upper and lower surfaces, upper and lower anterior margins with rows of progressively larger pointed granules towards distal end; three spines at distal end separated from granular rows by a deep notch. Minor cheliped dactylus and merus proportionately longer than minor cheliped counterparts (Table 2).

P2-5 flattened, long, $>$ 2.0 times CL, P3 longest (Table 2). Dactyli slender, flattened, with rows of setae on anterior and posterior surfaces. Propodi compressed, with serrate surfaces and longitudinal groves on both surfaces. In males, P2-3 with two median longitudinal rows of long setae, another row of short setae near upper margin; lower margin with larger pointed granules. In females, P2-3 with one median longitudinal row of long setae, a second row with short setae, another row of short setae near upper margin. Carpi with serrated surface, with row of tubercles on anterior surface ending in sharp distal tooth. Meri wide, flattened with several transverse granular rows on

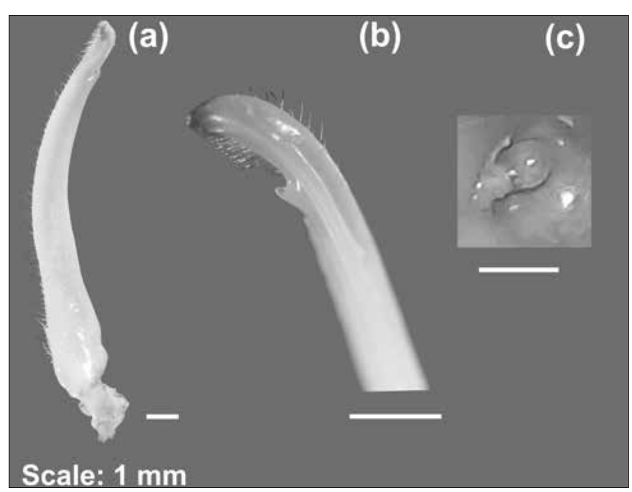

Fig. 4. *Ocypode ceratophthalma*: (a) Entire G1 (b) Distal portion of G1 (enlarged) (c) right gonopore and operculum (enlarged).

upper margin, row of sharp pointed granules on lower margin; P3 merus widest. Hairy pouch between P3-4 bases connected to branchial chamber.

G1 long (Table 2), originates at junction of sternites 7 and 8; distal tip slightly curved (Fig. 4a); abdominal surface with longitudinal groove terminating at distal tip, and distally directed palp located behind distal tip; outer margin with row of setae along entire length, tuft of setae flanked distal tip (Fig. 4b). Gonopores covered with stalked, globular operculum; sternite 6 sunken around operculum (Fig. 4c).

Growth patterns

An assessment of growth patterns of *O. ceratophthalma* revealed that males were almost as large as females (Table 1). Regression coefficient indicated strong positive correlation between CW and CL of both sexes (Fig. 5a). CW vs. CL relationship showed significant positive allometry ($P < 0.001$) in males and significant isometric growth ($P < 0.001$) in females (Fig. 5a). Female abdomens were larger than male abdomens in size (Table 1) and proportion (Table 2). Regression coefficient indicated strong positive correlation between CW and AW in males, and moderately positive correlation in females (Fig. 5b). CW vs. AW relationship showed significant isometric growth ($P < 0.001$) in males and significant positive allometric growth ($P < 0.001$) in females (Fig. 5b).

Male chelipeds were marginally larger in size (Table 1) and proportion (Table 2) than female chelipeds. Regression coefficient indicated strong positive correlation between CL and ChL in males, and moderately positive correlation in females (Fig. 5c). CL vs. ChL relationship showed significant isometric growth ($P < 0.001$) in males and significant negative allometric growth ($P < 0.001$) in females (Fig. 5c). Male propodi showed slightly more robustness ontogenically than female propodi as indicated by strong positive regression coefficient between CL and PDch (Fig. 5d). CL vs. PDch relationship showed significant isometric growth in males ($P < 0.001$) and negative allometric growth ($P < 0.001$) in females (Fig. 5d).

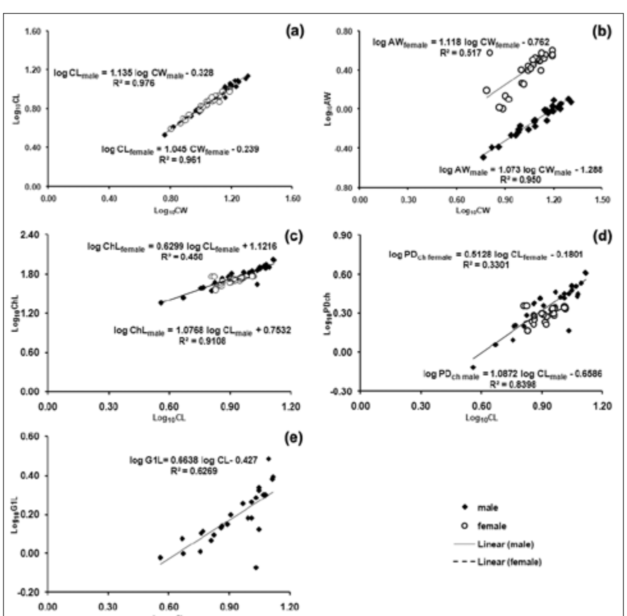

Fig. 5. Allometric relations in *Ocypode ceratophthalma* (a) CL vs. CW (b) AW vs. CW (c) ChL(major) vs. CL (d) PDch (major) vs. CL (e) G1L vs. CL).

G1 length showed significant negative allometric relationship ($P < 0.001$) with CL (Fig. 5e).

Habitat and habit

Ocypode ceratophthalma inhabited J and U-shaped burrows at both the sampling sites. At Bambolim, most burrows were located in the berm region of the beach, while burrows between HTL and MTL were distantly spaced. At Siridao, most burrows were located in the berm region of the beach, and few on the dunes. However, there were comparatively fewer burrows between HTL and MTL. This species was nocturnally active in the region between HTL and LTL as evident from erect eyestalks and frequent scampering. On approaching, the crabs would move towards the incoming wave and disappear under the sand. Crabs observed on the berm and dunes would lie half-buried in the substratum. These crabs were observed to scavenge upon carrion as they responded to baited dead crabs, and also exhibited cannibalism. Competition for food was violent as observed from frequent conflicts over carrion. Conflicts between males were commonly observed, wherein the crabs would stand on their pereiopods and use chelipeds and other pereiopods to fight.

Discussion

The present study attempts to provide morphological, allometric and behavioral analysis of *Ocypode ceratophthalma* aided by 22 morphological measurements, 16 morphometric ratios, meristics, photographs, line diagrams, allometric equations and on-field observations.

An examination of taxonomic characters, particularly the presence of eyestalk stylus, counts of striae on the stridulating ridge of major cheliped palm, and genital structures of the crabs following Sakai and Türkay (2013) confirmed their identity as *O. ceratophthalma*. However, the present observations differed slightly from the latter with respect to stridulating ridge counts. The observed counts of interspersed tubercles in the dorsal part were lower (7 in males and 4 in females) than 10 reported by Sakai and Türkay (2013), and counts of thick striae in the middle part were higher (12 in males and 8-12 in females) than 8 reported by the latter. Comparison of G1 structure with Chhapgar (1957) revealed that the sub-distal palp was not reported by the latter.

Morphometric ratios are potential tools to infer about the morphological characteristics of a species (Mayr and Ashlock, 1991), which may be employed to infer the physiological implications for that species. A narrow male abdomen serves only to protect the G1 (Pinheiro and Fransozo, 1993), whereas a larger female abdomen functions to carry and incubate fertilized eggs (Hartnoll, 1974). Sexual differences with respect to eyestalk styli proportions indicated the development of secondary sexual characters (Haley, 1973).

Ontogenic growth of carapace was clearly evident in *O. ceratophthalma* suggesting that increase in gill chamber size resulted in expansion of carapace, with implication for greater respiratory rate in mature adults (Pinheiro and Hattori, 2006). Growth patterns of other parameters namely cheliped length, cheliped propodus depth and abdomen width indicated clear sexual dimorphism with separate behavioural implications for both sexes. Larger and more robust male chelipeds serve important roles in combat (competition for mate or social dominance), courtship, copulation and protection of females after copulation (Fernández-Vergaz *et al*., 2000). On the other hand, slender female chelipeds may not serve these purposes. Negative allometric growth of G1 is considered to be a reproductive advantage as it allows the male to copulate with females of wide range of sizes, thereby increasing the reproductive output (Hartnoll, 1974).

The presently observed spatial distribution of *O. ceratophthalma* along the berm region corroborated earlier reports (Silas and Sankarankutty, 1967). However, the construction of beach resorts in the dune region at Bambolim restricted the distribution of burrows to the berm and region between HTL and MTL. The predominance of active individuals between HTL and LTL suggested that these crabs imbibe moisture from the swash and surf zone sediments to facilitate oxygen uptake by their gills (Lucrezi and Schlacher, 2014). Their feeding mode depends on food availability on sandy shores, which are mostly devoid of plant or animal matter, and therefore, the crabs are highly opportunistic (Lucrezi and Schlacher, 2014). Competition over resources in harsh environments has resulted in the evolution of agonistic behaviour, considered to be an important spacing mechanism among burrowing crabs (Lighter, 1974).

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