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Registered Office: 3A2 Varadarajulu Nagar, FCI Road, Ganapathy, Coimbatore, Tamil Nadu 641006, India
Ph: +91 9385339863 | www.threatenedtaxa.org
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Cover: A Warty Hammer Orchid *Drakaea livida* gets pollinated by a male thynnine wasp through 'sexual deception' — a colour pencil reproduction of photos by ron_n_beths (flickr.com) and Rod Peakall; Water colour reproduction of Flame Lily *Gloriosa superba* — photo by Passakoran_14; and a bag worm and its architectural genius (source unknown). Art work by Pannagarsri G.



Exploring carapace phenotypic variation in female Fiddler Crab *Austruca annulipes* (H. Milne Edwards, 1837): insights into adaptive strategies and ecological significance

Vaishnavi Bharti¹ , Sagar Naik²  & Nitin Sawant³ 

¹⁻³School of Biological Sciences and Biotechnology, Zoology Discipline, Goa University, Goa 403206, India.

¹vb.vaishnavibharti@gmail.com, ²sagarnaik1018@gmail.com, ³nitin.sawant@unigoa.ac.in (corresponding author)

Abstract: Fiddler crabs (Ocypodidae: Crustacea: Arthropoda) are globally documented but relatively understudied along the Indian coastline. *Austruca annulipes*, common across Indian mangrove habitats, remains insufficiently explored in terms of female morphology. While male fiddler crabs are recognized for their prominent chelae, females of *A. annulipes* exhibit notable polymorphism. In this short-term study conducted in the mangroves of Sauta Vaddo (Baga), Goa, we documented 14 distinct female morphs, alongside observations of male moulting. The study highlights the scope for future research into the adaptive significance of female phenotypic variation in this species.

Keywords: Alternative reproductive tactics, behaviour, carapace pattern, colour variation, mangrove, morphology, moulting, Ocypodidae, polymorphism, sexual dimorphism.

Fiddler crabs are semi aquatic crustaceans (Arthropoda: Crustacea: Ocypodidae) found in the intertidal zones. They are found in dense numbers in mangroves, mudflats, salt marshes throughout the tropics, and subtropics. They form an important part of mangrove ecosystems and are considered flagship species, and ecosystem engineers (Peer et al. 2015). The fiddler crabs widely known as 'calling crabs' display characteristics of sexual dimorphism. The females have symmetrical, small-sized chelipeds while the males have asymmetrical chelipeds one exceedingly large and another much smaller, minor cheliped (Bouchard et al.

2013). The enlarged cheliped is used in nuptial display by males to impress the females before mating and the enlargement occurs at random, resulting in a right-handed or left-handed claw in about equal proportions (Yamaguchi 1977).

More than 100 species of fiddler crabs are recognized at present, many of which are studied for their behaviour, ecology, and systematics (Silva et al. 2024). One overlooked species is *Austruca annulipes* (H. Milne Edwards, 1837), commonly called the Porcelain Fiddler Crab (Fulmali et al. 2021). The species has been included in global studies of taxonomy, population biology, feeding, and burrow characteristics, however, these studies have nearly exclusively considered the male fiddler crab only, and a very little data is available on females. An exception is a study of South African mangroves where 14 variations in female patterns are documented showing female polymorphism in *A. annulipes* (Peer et al. 2015). Fiddler crabs, like many other animals, have dynamic carapace colour and pattern changes, especially during moulting, which can be timed to tidal or lunar cycles (Brown & Webb 1949). They are known to undergo rapid colour changes in response to stress, during courtship, and as a result of thermo-regulation (Hemmi et al. 2006). The colour

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changes that result are more noticeable in females than in males of the same size (Detto et al. 2008). Hence, in this study, we examine and document the phenotypic variation in female carapace morphology of *Austruca annulipes* and whether it represents ecologically adaptive polymorphism, potentially driven by selective pressures such as predation, habitat complexity, or mate recognition.

MATERIALS AND METHODS

The study was conducted in mangroves off Sauta Vaddo, Baga-Calangute, Goa (15.5661° N, 73.7581° E) (Image 1) during December 2023. The mangroves have expanded into the abandoned fields nearby creating mangrove edge ecosystems which are affected by the tidal cycle. These provide suitable habitat for fiddler crabs that have populated these areas over the past 20 years. The river Baga runs through the mangroves and the area has seen little human disturbance since the fields were abandoned (Image 2).

The variation in female carapace colour and pattern was observed in the field and photographed using Sony HX400V, and Nikon Coolpix P1000. Microscopic

characters such as minor cheliped, abdomen, and walking legs were photographed using stereomicroscope Zeiss Stemi 508 with Axiocam camera. The study area map was created using Qgis 3.34. The species was identified using taxonomic keys given by White A (1847) and WORMS (World Register of Marine Species) online database (marinespecies.org). The crabs were handpicked and scooped by random sampling during low tide and collected & tagged in containers, and brought to the lab as prescribed by Darnell et al. (2019). Each specimen was assigned a unique identification code comprising the site abbreviation, date of collection (day-month-year), and an individual serial number (e.g., SV17122301–SV17122350). In total, 50 specimens were catalogued, including 25 males and 25 females. The specimens were then freeze-killed and immersed in 80% absolute ethanol (Hampton et al. 2013). This study was conducted with the Ethical permission no. GUZ/IAEC/23-24/N42. Basic morphometric analyses (Crane 2015) were performed for all specimens and the carapace length (CL), carapace breath (CB), & breadth of front (BF) was recorded for both sexes; major propodus length (MPL) & major dactyl length (MDL) for males; and

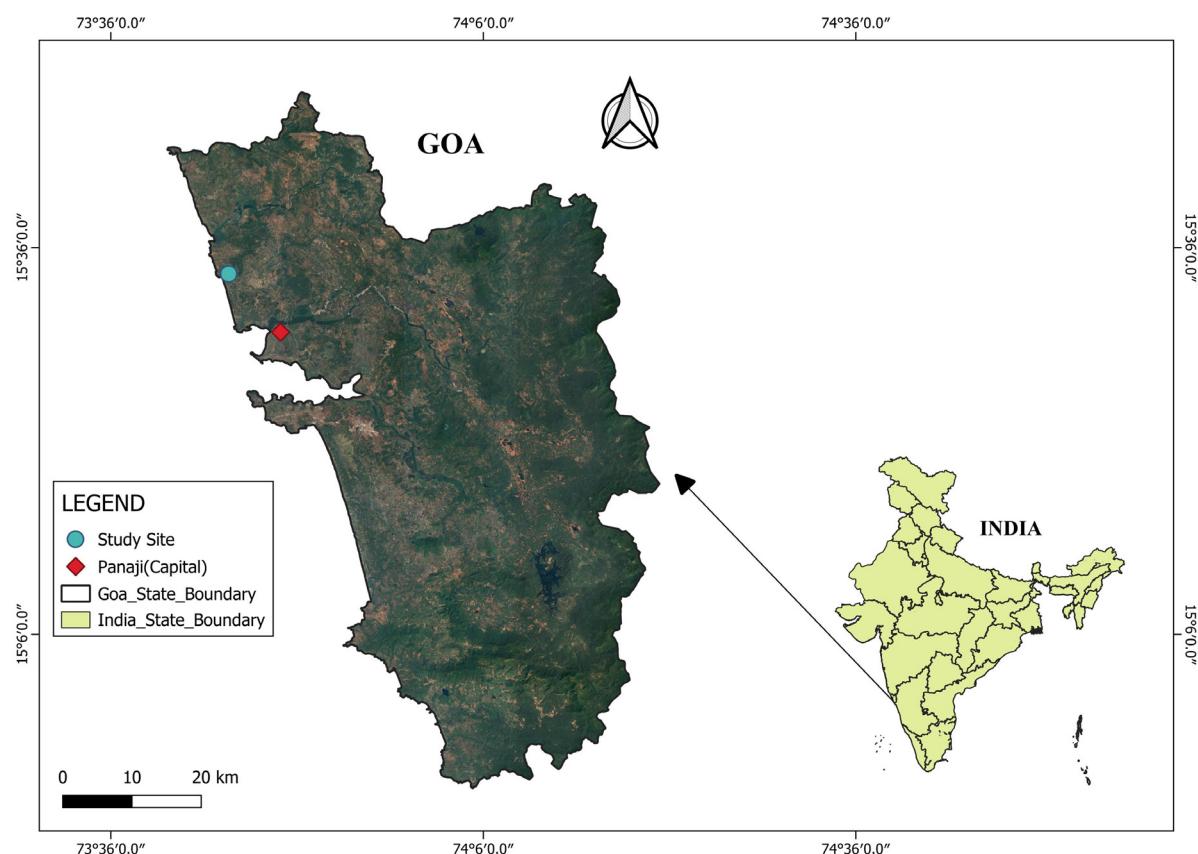


Image 1. Study area of Baga creek, Goa, India.

length of propodus (LP) & length of abdomen (LA) for females were recorded separately.

RESULTS

The morphometric data collected (Table 1) from these crabs support that all observed morphs, belong to the same species, *Austruca annulipes*. A total of 14 female variations (Table 2), adult males and four male moults (Image 3) were recorded during the present field study. The females were slightly smaller than the males in size and illustrated more colour, and pattern variations compared to males, while the males were similar in size but showed varied patterns on carapace as they underwent periodic moulting.

DISCUSSION

The study confirms pronounced sexual dimorphism in *A. annulipes*, with significant polymorphism observed in females. Male carapace patterns appear linked to periodic moulting, while female variation is more persistent, and diverse. The documentation of 14 female morphs in this Indian population parallels findings from South Africa (Peer et al. 2015), although with differing pattern types. Five morphs resemble male-like androchromic traits, while the remaining exhibit heterochromic features. The ecological and genetic underpinnings of such polymorphism remain unclear, warranting further investigation. Colour variation in fiddler crabs has been linked to light, stress, and social signalling (Crane 1944, 1958; Taborsky 2008; Tate & Amar 2017). While in females it is linked mostly with sexual selection and female ornamentation, indicating towards alternative reproductive tactics (Oliveira et al. 2008; Diamant et al. 2021). This study adds valuable observational data, supporting the case for more detailed ecological, and genetic research into female-specific traits in *A. annulipes*.

CONCLUSION

This study provides the first documentation of carapace polymorphism among female *Austruca annulipes* in the Baga mangroves of Goa, India. Observations indicate size-related variation and distinct colour morphs across individuals. Though moulting patterns might be influenced by lunar cycles, this was not a primary focus of the current study. Given their role as bioindicators and ecosystem engineers, deeper insight into the species' phenotypic diversity can contribute to broader mangrove conservation strategies. Future research should explore the genetic basis and ecological drivers of polymorphism in female *A. annulipes*.

Table 1. Morphometric data (mm) for males and females of *Austruca annulipes*.

	Morphometric character	Male (n = 25): Mean ± SD	Female (n = 25): Mean ± SD
1	Carapace length (CL)	16.42 ± 1.41	13.57 ± 1.57
2	Carapace breath (CB)	9.84 ± 0.61	8.16 ± 0.62
3	Breath of front (BF)	2.5 ± 0.19	2.21 ± 0.16
4	Major propodus length (MPL)	26.74 ± 2.30	-
5	Major dactyl length (MDL)	15.14 ± 1.62	-
6	Length of propodus (LP)	-	4.72 ± 0.515
7	Length of abdomen (LA)	-	6.13 ± 0.68

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Image 2. *Austruca annulipes*: A—Males surrounded by mangrove pneumatophores | B—Colony | C—Male (left) and heterochrome female morph (right) | D—Male (left) and androchrome female morph (right) on the burrow opening | E—Two males engaged in claw fight to defend its burrow | F—Colony during neap (low) tide feeding | G—Study site during neap (high) tide | H—Mangroves invaded fields occupied by fiddler crabs during neap tide. © Vaishnavi Bharti.

Table 2. The observed morphs of female *Austruca annulipes* in the study site. © Vaishnavi Bharti.

Morph	Photographic evidence	Description
Female morph 1		White carapace with dark to bright pink stripes on both sides of postero-lateral border touching the cervical groove. The pair of front legs are bright pink and back legs are white.
Female morph 2		White carapace with a dark pink cross mark at cervical groove. First two pairs of front legs are bright red and the third pair is half pink and half white. The back legs are completely white.
Female morph 3		White carapace with dark pink stripes on both sides of the postero-lateral border. A triangular dark pink mark ends the cervical groove. Last two- three pairs of walking legs are asymmetrically white while others are bright pink in colour.
Female morph 4		Light pinkish carapace ending with a bright white band. Dark pink lines outline the postero-lateral border. Dark red front and back legs with diffused white patterns on them.
Female morph 5		Carapace is tricoloured starting with a pale pink, bright red stripe, and a thick white stripe on the posterior end. All pairs of legs are dark pink in colour.
Female morph 6		Carapace is tricoloured starting with a pale pink, bright red stripe, and a thick white stripe on the posterior end. First four pairs of walking legs are bright red followed by a white fifth pair.
Female morph 7		White-grey carapace with a bright red posterior margin. Bright red coloured front and back legs.
Female morph 8		White-grey carapace with red and white posterior margins. Both front and back legs have similar patterns. The legs are covered with alternate bands of red and white segments.

Morph	Photographic evidence	Description
Female morph 9		The carapace has three bands with brownish frontal margin with white pattern on it, followed by black band in cervical groove with white pattern, and a bright, plain white posterior margin. First two pairs of front legs are bright red, and the third pair is white. The back legs are white in colour.
Female morph 10		Black carapace with sparse white pattern on anterior end and a bright white stripe at the posterior end. Walking legs vary in colour from white to red in colour.
Female morph 11		Plain black carapace with a white stripe at posterior end. All pairs of legs are black in colour.
Female morph 12		The upper carapace is dull white-greyish. A distinct black band forms below the cervical groove followed by a bright white band ending the posterior margin. The back legs are completely white.
Female morph 13		Carapace pattern is similar to males. Upper carapace is greyish with white patterns on it, followed by black band with white pattern in it below the cervical groove, and ends with a plain white band. Front and back legs are the same greyish in colour with random white patterns on it.
Female morph 14		The carapace is black with white patterns. A black line passes below the cervical groove. The posterior margin is a plain white stripe. Front and back legs are similar, with bright black colour, with small white spots on them.

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Image 3. *Austruca annulipes*: A–F—Observed colour morphology of males in Baga mangroves. A—Adult | B—C—Moulting | D—E—Juveniles | F—Adult. © Vaishnavi Bharti.

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