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SHORT PAPER

A New Record of *Morula anaxares* with a Description of the Radula of Three Other Species from Goa, Central West Coast of India (Gastropoda: Muricidae)

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Abstract

The present paper describes a new record of *Morula anaxares* (Kiener 1835) (Muricidae) from Goa, Central West coast of India aided by spiral cord ontogeny, aperture morphology of shell and SEM of radula. This species was previously reported from Andaman, Nicobar, Lakshadweep and Madras coasts. In addition, detailed structures of radula of other three species namely *Orania subnodulosa* (Melvill 1893), *Semiricinula konkanensis* (Melvill 1893) and *Purpura bufo* Lamarck 1822 from Goa are described for the first time using SEM photographs.

Keywords: Muricidae, Goa, new record, taxonomic diagnosis, radula, SEM.

Introduction

The Muricidae (Gastropoda: Neogastropoda) is a large group comprising almost 2500 Cenozoic and Recent species (Merle, 2005). Among the gastropods, this group exhibits highest degree of radiation with regards to shell morphology and sculptural patterns, which also illustrates its evolutionary importance (Merle and Houart, 2004). Muricids inhabit a wide array of coastal and other marine habitats (Radwin and D'Attilio, 1976; Apte, 1998; Tsuchiya, 2000; Mills et al., 2007) across inter – tidal mudflats (Tan, 2008) and rocky shore tide pools (Yamamoto, 1997) to oceanic coral reefs (Boucher, 1986) and deep sea environments (Egorov, 1993; Vermeij and Wesselingh, 2002) and are ubiquitous across all latitudes (Bouchet et al., 2002).

Ecologically, muricids occupy different niche in various environments and thereby enable coupling between primary and higher levels of production. These organisms are primarily carnivores (Abe, 1980, 1983; Carriker, 1981; Hughes, 1986; Harper and Morton, 1994; Navarette, 1996), however several species have evolved other modes of feeding such as omnivory, scavenging (Keable, 1995; Tsuchiya, 2000), detritivory (Vermeij and Carlson, 2000), parasitism (Vaïtilingon et al., 2004), corallivory (Taylor, 1983; Boucher, 1986; Turner, 1994), and even herbivory (Vermeij and Carlson, 2000; Kantor, 2002). Most species are seasonal spawners (Yamamoto, 1997) and deposit large aggregates of egg masses to avoid predation. Further, their high densities coupled with a voracious feeding habit serve to regulate the population dynamics of diverse prey such as corals, polychaetes, bivalves, chitons and barnacles (Tan, 2003) and often endanger the prey population. Published reports on their bio – geography (Rao and Rao, 1993) reveal patchy distribution worldwide. Houart (2002) attributed the patchy distribution either to scattered distribution or lack of adequate data. The Goan coast (West coast of India) owing to its inherent habitat complexity and productivity, offers a beneficial environment for the growth, proliferation and establishment of muricids.

Taxonomic studies on gastropods reveal that the Muricidae is one of the most – studied groups as evident from exhaustive literature being published during the past two hundred years (Tryon, 1880; Iredale, 1915; Radwin and D'Attilio, 1976; Kool, 1987; Wilson, 1994; Merle and Houart, 2004). These studies have carried out detailed investigations using shell morphology, sculpture, micro-structure, operculum, radula and anatomical characters. However, studies along Indian coasts (Rao and Rao, 1993; Rajagopal et al., 1998; Rao, 2003) are meagre and based primarily on shell morphology, operculum structure and meristic counts. Further, these studies lack details of radular structure, an important tool used in muricid systematics. Radular characters have also been widely used in diagnosis, even though

radular morphology has been shown to vary within species during ontogeny, with season and sex (Claremont et al., 2008) and radular characters are considered as valid indicators of phylogeny for thaidid gastropods (Kool, 1987). The spiral sculpture is often used to give taxonomic distinctions at different hierarchic levels (specific, generic and sub-familial levels, Merle, 2001). However, Hylleberg and Nateewathana, (1992) pointed that the spiral characters are not clearly identified, resulting to a potential difficulty to recognize and compare muricid taxa. In view of this, Merle (2001) provided the terminology and some methodological comments on the identification of the spiral characters for the muricid family.

In view of this, the paper attempts to describe in detail one new record along Goa coast based on general shell morphology, spiral cord characters, aperture morphology, operculum and radula structure. In addition, radula structures of three other species have been described for the first time aided exclusively by SEM photographs. In addition preliminary information on the occurrence and distribution of the family Muricidae, a least studied group from the Goa coast is presented and discussed.

Materials and Methods

Goa with a coastline of about 105 km along the Central West Coast of India, lies between 14°48'N and 15°48'N latitudes and between 75°40'E and 74°20'E longitudes and comprises diverse topographical features (Wagle, 1993; Figure 1). The present study area encompassed 10 rocky shores along the entire coastal stretch of Goa those supported high densities of muricid gastropods (Figure 1).

The collection of muricid species consisting both live organisms and dead shells was carried out during July, 2008 to February, 2009. The sampling was carried out at low tide and the geographical position of each site was determined using GPS. At each sampling site, live specimens were detached from the substratum and injected with 7.5 % Magnesium chloride solution mixed with an equal volume of seawater (Reid, 2000) to anaesthetize the animal in order to facilitate easy removal of operculum and radula. Subsequently, these were transferred to pre-labeled zip-lock bags and temporarily stored in ice. In addition, empty shells or shells harbouring hermit crabs were collected and directly stored in pre-labeled zip-lock polythene bags and transported to the laboratory. At the laboratory, hermit crabs were dislodged from their shells, followed by washing shells with distilled water, drying at room temperature, whereas the empty shells were directly washed and dried. Morphological description of specimens was appropriately illustrated by Camera Lucida diagrams of operculum using Olympus SZX-DA 3M01330 microscope and photographs of shells (dorsal and ventral view) using 7.2 mega pixel digital camera (SONY DSC S750, 3X optical zoom). The specimens were subsequently identified up to species

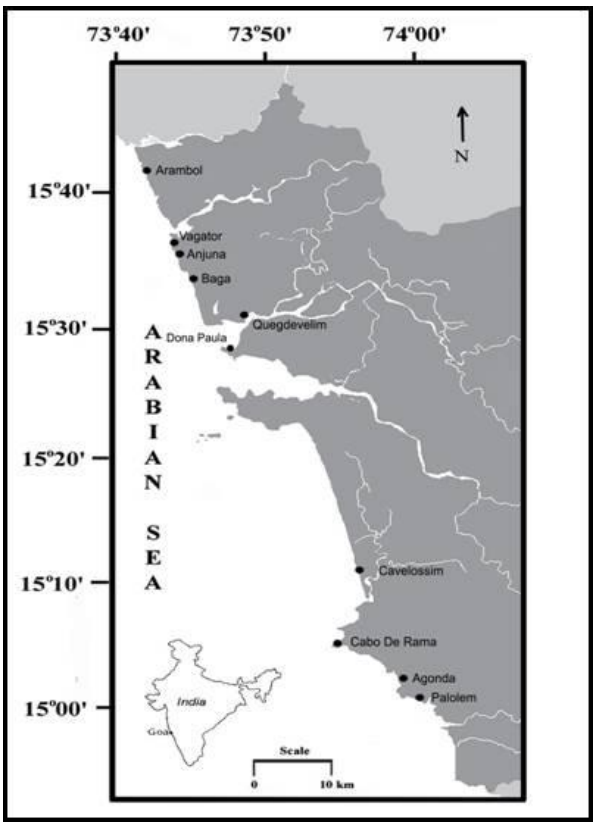


Figure 1. Map of study area indicating sampling sites

level using orthodox taxonomic methods based on shell morphology, colour, texture, sculpture and meristic counts of shells those aided by taxonomic literature (Rao and Rao, 1993; Wilson, 1994; Tan and Sigurdsson, 1996; Apte, 1998; Rao, 2003; Houart, 2002, 2004). The shells were subsequently stored in pre-labelled plastic containers. The terminology used in the description of shells follows (Wilson, 1994). The spiral cord and aperture morphology is described as given in Merle (2001).

For radula extraction, live specimens were initially anaesthetized using 7.5 % Magnesium chloride to relax and loosen the body muscles attached to the shell and facilitate easy removal of the organism. Subsequently, an incision was made on the dorsal surface of the head to expose the radular sac located within the mantle cavity. The radular sac was transferred to 19 % KOH solution for digestion of radular tissue. Subsequently, the radula was washed with distilled water and dehydrated using alcohol (Ramesh and Ravichandran, 2008). SEM photographs of the radulae were taken at the National Institute of Oceanography, Goa using a JEOL JSM-5800 LV Scanning Electron Microscope (SEM) at 15 to 20 KV accelerating voltage. Initially, the radulae mounted on brass stubs with a double-sided tape were coated with gold and placed into the specimen chamber of the SEM (Roberts, 2000). Subsequently, photographs were taken at various magnifications depending on the size of the radula. Radula length and rachidian width were measured from the photographs. The terminology used in the description of radula follows Kool (1987).

Results

M. anaxares is reported for the first time from Goa coast and is described in detail based on shell morphology, spiral cord characters, aperture morphology and radula structure. In addition, radula structures of other three species (*Orania subnodulosa, Semiricinula konkanensis, Purpura bufo*) from Goa coast are described in detail for the first time and aided by SEM photographs.

Abbreviations Used in Figures

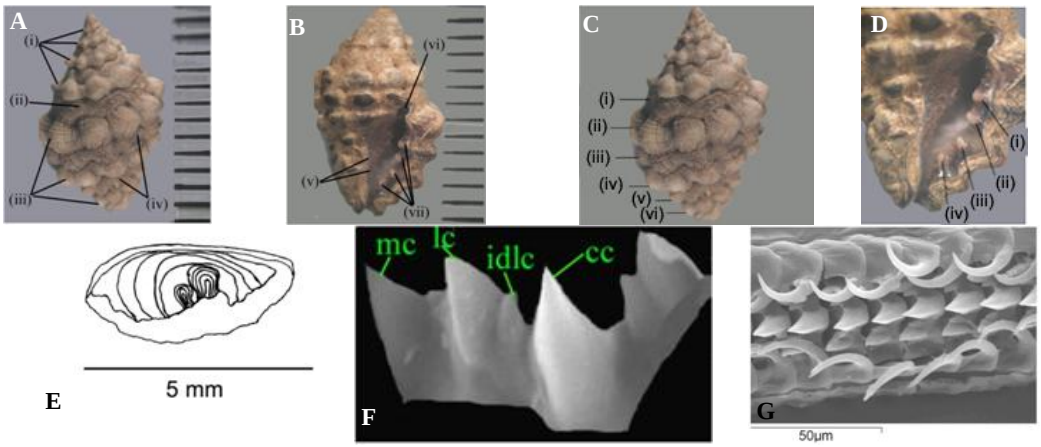
cc- central cusp, lc- lateral cusp, ld- lateral denticle, idlc- inner denticle on lateral cusp, odlc- outer denticle on lateral cusp, mc- marginal cusp, md- marginal denticle, ca- cavity, P- Primary cord, SP- Subsutural cord, ID- Infrasutural denticle.

Systematics

Phylum MOLLUSCA (Linnaeus, 1758)
Class GASTROPODA Cuvier, 1795
Sub Class ORTHOGASTROPODA Ponder and Lindberg, 1996
Super Order CAENOGASTROPODA Cox, 1960
Order SORBEOCONCHA Ponder and Lindberg, 1997
Sub Order HYPSOGASTROPODA Ponder and Lindberg, 1997
Infra Order NEOGASTROPODA Thiele, 1929
Super Family MURICOIDEA Rafinesque, 1815
Family MURICIDAE Rafinesque, 1815
Morula anaxares (Kiener, 1835) (Figure 2A-G)

Synonyms

Purpura anaxares Kiener, 1835 (cited from Houart 2009)
Sistrum anaxares- Melvill and Standen 1901
Drupa anaxares- Melvill 1928
Thais anaxares- Gravely 1942
Morula anaxares- Cernohorsky 1972, Ray



Morula anaxeres (Kiener, 1835),A) (i): 4 spire whorls with white nodules, (ii): Undulating suture, (iii): 3 spiral rows with white nodules, (iv): 2 spiral rows with dark brown nodules, B) (v): 2 anterior pustules, (vi): Inverted U-shaped anal sulcus, (vii): 2 pairs of denticles C) (i):Subsutural cord, (ii) to (vi): Primary cords D) (i) to (v): Denticles.

Figure 2. *Morula anaxares* – (A,C) Dorsal view of shell (B) Ventral view of shell (D) Enlarged view of aperture (E) Operculum (attached surface) (F) Radula (enlarged) (g) Radula (entire view)

1977, Rao and Rao 1991, Rao and Rao 1993.

Material Examined

Dona Paula, Goa: n = 55.

Diagnosis

Shell small-sized; spire elevated, acute, consists of four or five teleoconch whorls with large rounded white nodules. Body whorl with five spiral cords with large rounded nodules decreasing in size anteriorly, the first, third and fifth cords bear white nodules, those alternate with dark brown nodules along the second and fourth cords. Apertures narrow, with two pairs of white to bluish white denticles. Radula with single marginal denticle, marginal cusp present.

Description

Shell small-sized, protoconch of 3 to 3.5 whorls. Spire elevated, acute, consists of four or five teleoconch whorls with large rounded nodules, suture undulating.

Body whorl consists of five primary cords, P1, P2, P3, P4, P5 with large rounded nodules decreasing in size anteriorly; the large nodules giving an angular appearance to the whorls and an additional sub-sutural cord above first primary cord (Figure 2C).

Aperture narrow, elongately ovate, outer lip margin thick, interior denticulate with two pairs of evenly spaced denticles, D1, D2, D3, D4 (Figure 2D); columella with two pustules anteriorly; anal sulcus open, inverted 'U' shaped; siphonal canal short and narrowly open (Figure 2B).

Shell colouration varies from grey to brown, with white nodules on the spire and first, third, and fifth rows of the body whorl; aperture and columella light violet, denticles bluish white (Figure 2Aand D).

Operculum 2.5-3.5 mm long, oval, thin, transparent, yellow, with a sub-apical nucleus (Figure 2E). Radula length 1.92 mm, rachidian width 7.69 µm (Figure 2G), central cusp triangular with wide base, lateral cusp with straight orientation, single denticle between the central and lateral cusps; area between lateral cusp and side of rachidian wide and horizontal; single marginal denticle, marginal cusp present; lateral cusp and edge of the marginal cusp oriented in similar direction (Figure 2F).

This is the first new record of *M. anaxares* from Goa coast and along the entire West coast of India, except Lakshadweep Islands wherein a detailed description of the species is given using morphology, operculum and SEM of radular structure. This species was previously recorded from Andaman, Nicobar, and Lakshadweep Islands and Madras coast (Rao and Rao, 1993). However, the above study did not focus on the radula structure of this species.

Orania subnodulosa (Melvill 1893) (Figure 3A-F)

Synonyms

Ricinula (Sistrum) subnodulosa Melvill 1893.

Sistrum subnodulosum- Melvill and Standen 1901.

Thais subnodulosa- Gravely 1942.

Drupa subnodulosa- Hornell and Tomlin 1951.

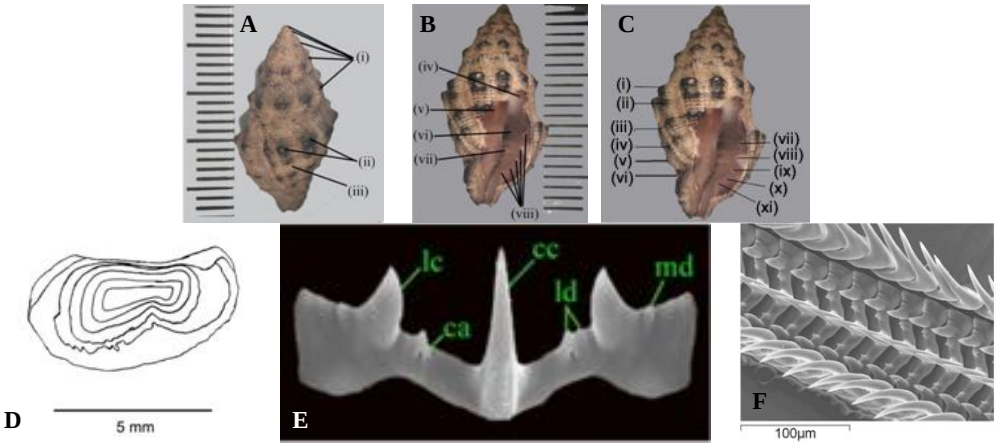
Cronia subnodulosa- Rao and Rao 1993, Rao 2003.

Materials Examined

Dona Paula, Goa: n = 30.

Diagnosis

Shell slender, spire high, longer than body



Orania subnodulosa (Melvill, 1893), A) (i): 5 angulated spire whorls, (ii): Axial ribs, (iii): Transverse white band, (iv): Inverted U-shaped anal sulcus. B) (v): Dark brown blotch on columella, (vi): Dark violet aperture, (vii): Transverse white band on interior of aperture, (viii): 5 denticles. C) (i) to (vi): Primary cords, (vii) to (xi): Denticles.

Figure 3. *Orania subnodulosa* – (A) Dorsal view of shell. (B, C) Ventral view of shell. (D) Operculum (attached surface). (E) Radula (enlarged). (F) Radula (entire view)

whorl. Body whorl with white band between the third and fourth rows of tubercles, also visible inside the aperture. Interior of aperture violet with four to five denticles, the posterior two lead to raised ridges inside the aperture. Radula with single marginal denticle, marginal cusp absent.

Description

Shell slender, protoconch unknown. Spire high, longer than body whorl, consists of five angulated whorls, with two spiral cords of compressed tubercles on each whorl with scabrous cords on either side.

Body whorl bears five spiral chords of compressed tubercles, P1, P2, P3, P4, P5, shoulder whorl being the most prominent (Figure 3C). Axial sculpture consists of eight to nine axial ribs (Figure 3A). Aperture with four to five denticles, D1, D2, D3, D4, D5 on outer lip, the posterior two leading to raised ridges inside the aperture; columella with two to three anterior plications just above the siphonal canal; siphonal canal short and narrow; anal sulcus deep, inverted 'U' shaped (Figure 3B and 3C).

Shell chocolate brown with dark brown tubercles, prominent white band present between the third and fourth rows of tubercles, and continuous with its inner counterpart, aperture light violet, columella with dark brown patch posteriorly, anterior portion violet (Figure 3A, 3C).

Operculum 3.5-4.5 mm long, thin, yellow, with a sub-apical nucleus (Figure 3D). Radula length 3.06 mm, rachidian width 11.1 µm (Figure 3F), central cusp thin, needle shaped, one or two denticles with a cavity at the base present between the central and lateral cusps, but closer to the lateral cusp, lateral cusp with concave outer edge, pointing outwards, area between lateral cusp and side of rachidian wide and horizontal, single marginal denticle present, marginal cusp absent (Figure 3E).

Semiricinula konkanensis (Melvill 1893) (Figure 4A-G)

Synonyms

Ricinula (Sistrum) konkanensis Melvill 1893.

Sistrum konkanensis- Melvill and Standen 1898, Melvill and Standen 1901.

Drupa konkanensis- Melvill 1928, Hornell and Tomlin, 1951

Cronia konkanensis- Rao and Rao 1993.

Material analysis

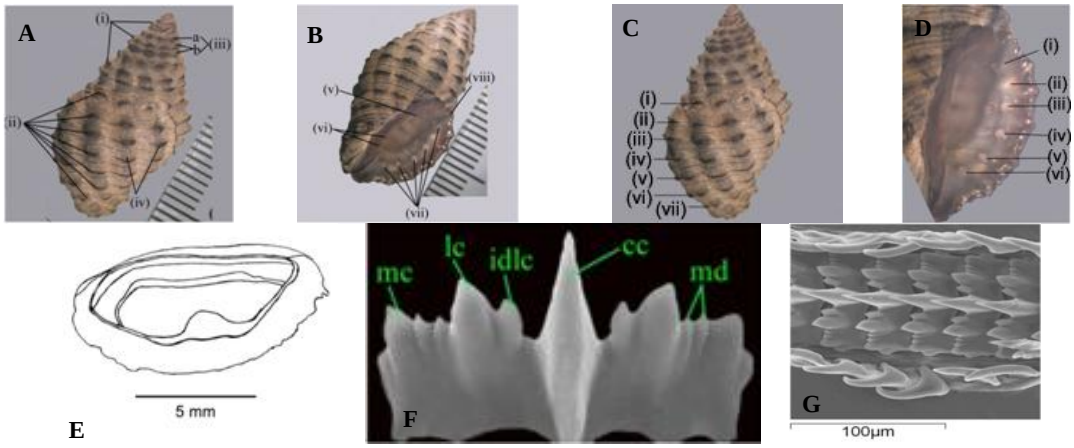
Dona Paula, Goa: n = 34; Quegdevelim, Goa: n = 3.

Diagnosis

Shell pyramidally fusoid with rounded whorls. Each spire whorl bears three spiral cords of horizontal tubercles, two of these paired and separated from the third by fine ridges. Axial ribs with chocolate brown horizontal tubercles, with shallow interstices. Outer lip of aperture with five denticles leading to raised ridges interiorly. Radula with two marginal denticles, marginal cusp distinctly longer than marginal denticles.

Description

Shell pyramidally fusoid, protoconch two and one half whorls. Spire high, consists of four or five rounded whorls, each whorl bears three spiral cords of horizontal tubercles, two of them paired and separated from the third by three fine ridges.



Semiricinula konkanensis (Melvill, 1893) A) (i): 3 spire whorls, (ii): 6 spiral rows with compressed brown tubercles, (iii): a- single row, b- paired rows on each spiral whorl, (iv): Axial ribs. B) (v): Light violet aperture, (vi): 2 anterior plications on columella, (vii): 5 denticles leading to raised ridges, (viii): Inverted U-shaped anal sulcus. C) (i) to (vii): Primary cords. D) (i): Infrasutural denticle, (ii) to (vi): 5 denticles leading to raised ridges.

Figure 4. *Semiricinula konkanensis* – (A, C) Dorsal view of shell (B) Ventral view of shell (D) Enlarged view of aperture (E) Operculum (attached surface) (F) Radula (enlarged) (G) Radula (entire view)

Body whorl large, ovate, with seven spiral cords with horizontal tubercles P1, P2, P3, P4, P5, P6, P7 separated from each other by three fine spiral cords (Figure 4C). Axial sculpture consists of nine or ten low axial ribs on the body whorl (Figure 4A).

Aperture ovate, denticulate outer lip comprises an infra-sutural denticle (ID) and five denticles, D1, D2, D3, D4, D5 leading to raised ridges interiorly; two to three plications present anteriorly on the columella immediately above the siphonal canal; anal sulcus deep, inverted 'U' shaped (Figure 4B and D).

Shell light brown with chocolate brown tubercles, aperture light violet with white denticles (Figure 4A and D).

Operculum 5-6 mm long, broad D- shaped, light brown, with a lateral nucleus (Figure 4E). Radula length 4.90 mm, rachidian width 14.2 µm (Figure 4G), central cusp triangular, elongated and wide at the base, single denticle present between the central and lateral cusps, lateral cusp oriented slightly outwards, area between the lateral cusp and side of rachidian narrow and horizontal, two distinct marginal denticles present, marginal cusp distinctly longer and more robust than marginal denticles, lateral cusp and marginal edge oriented in same direction (Figure 4F).

Purpura bufo Lamarck 1822 (Figure 5A-E)

Synonyms

Purpura bufo Lamarck 1822, Reeve 1846, Tryon 1880.

Thais bufo - Crichton 1941, Gravely 1942, Ray 1948.

Mancinella bufo – Rippingale and McMichael 1961, Cernohorsky 1972, Rao and Rao 1993.

Materials Examined

Dona Paula, Goa: n = 10; Cabo De Rama, Goa: n = 9; Vagator, Goa: n = 7; Quegdevelim, Goa: n = 4.

Diagnosis

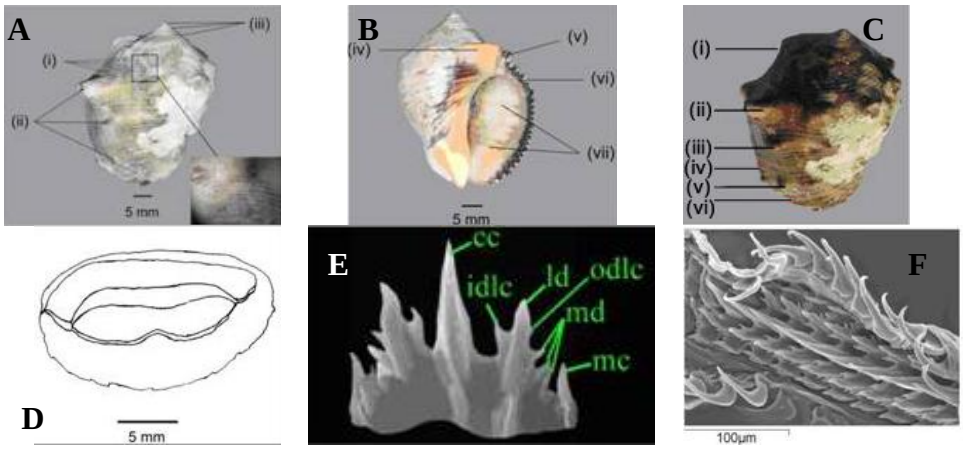
Shell large-sized, solid, heavy, globose. Protoconch unknown. Spire short, consists of three or four whorls. Body whorl large, consists of three or four prominent spiral cords with short blunt spines. Aperture large, ovate, interior lirate. Columella smooth, calloused, extends posteriorly above the shoulder. Outer lip margin chocolate brown, interior creamy white and columella creamy yellow. Radula with three or four distinct marginal denticles, marginal cusp distinctly longer than marginal denticles.

Description

Shell large-sized, solid, heavy, globose. Spire short with three or four rounded whorls. Body whorl large, consists of three or four prominent spiral cords, P1, P2, P3 with short blunt spines on the first and last spiral cords, and tubercles on one or two central cords (Figure 5C); six or seven fine spiral cords present above the shoulder rib on the sub-sutural ramp, and three cords between each of the spiral ribs (Figure 5A).

Aperture large, ovate, interior lirate, outer lip margin appears crenulate owing to the extensions of interstices between spiral cords on body whorl; columella smooth, calloused, extends posteriorly above shoulder; anal canal forming a distinct notch in the outer lip; siphonal canal short and broadly open (Figure 5B).

Shell dark brown with chocolate brown blunt spines and off-white to light orange patches in their interspaces; aperture creamy white, turns yellow near the margin, outer lip margin chocolate brown; columella creamy yellow (Figure 5A, 5B).



Purpura bufo Lamarck, 1822 A) (i): Subsutural cord (SP) and 6 fine cords on subsutural ramp, (ii): 5 spiral rows with or without short blunt spines, (iii): 5 spire whorls. B) (iv): Heavily calloused columella, (v): Anal sulcus – a distinct notch, (vi): Chocolate brown crenulate margin, (vii): Interior of aperture lirate. C) (i): Sub-sutural cord, (ii) to (vi): Primary cords

Figure 5. *Purpura bufo* – (A, C) Dorsal view of shell b) Ventral view of shell (D) Operculum (attached surface) (E) Radula (enlarged) (F) Radula (entire view)

Operculum 15-20 mm long, dark brown, outer margin thickened on one side, with a lateral nucleus (Figure 5D). Radula length 4.6 mm, rachidian width 14.51 µm (Figure 5F), central cusp triangular, elongated and wide at the base, single denticle present between the central and lateral cusps, lateral cusp straight with the tip oriented slightly outwards, outer denticles on lateral cusp long and distinct, area between lateral cusp and side of rachidian wide and horizontal, three or four elongated marginal denticles distinct, marginal cusp distinctly longer than marginal denticles, lateral cusp and edge of the marginal cusp oriented in similar direction (Figure 5E).

Published literature pertaining to body whorl sculpture of *P. bufo* reveals various structures including tubercles (Rao and Rao, 1993) and low nodules (Wilson, 1994). However, in the present study blunt spines were observed on the first and last spiral ribs and tubercles on the middle ones.

Gastropod Ecology

The occurrence and distribution of inter-tidal gastropods during the tenure of present study were found towards upper inter-tidal coast at the river mouth showing minor variations in the sea surface temperature (29.71 - 26.71°C) and salinity (30-32 ppm). The distribution of gastropods was found to be restricted to a particular horizontal band indicating that prevailing environmental factors such as degree of exposure to wave impact, duration of wetting by immersion and by splashes from waves, the presence or absence of competitors, predators, food source, air and sea temperatures anomaly and the duration of exposure (Purchon, 1968).

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