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First report on the distribution of *Elysia bangtawaensis* Swennen, 1998 in the mangroves of Udupi district, Karnataka

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Mangroves are highly threatened tidal forests occurring along estuaries of coastal Karnataka. These forests support a high diversity of flora and fauna, including molluscs and crabs. A recently discovered species of mangrove leaf slug, *Elysia bangtawaensis* Swennen, 1998 belonging to the superorder Sacoglossa and family Plakobranchidae of Phylum Mollusca, was recorded for the first time in Karnataka from the two mangrove sites, *viz*. Kodithale and Kannada Kudru of Udupi district. These mangrove leaf slugs were recorded from the tidal pools during post-monsoon and pre-monsoon seasons.

[**Keywords**: *Elysia bangtawaensis*, Karnataka, Mangroves, Mangrove leaf slug]

Introduction

Mangroves are species of trees, shrubs and ferns which have adapted to live in saline and anoxic environments. About 70 species of mangroves exist in the world and together with associated plants (epiphytic and terrestrial ferns, orchids, lichens, non-mangrove halophytes, sea grasses and seaweeds) and animals (fish, shrimp, shellfish, crabs, lobsters, reptiles and birds) they form unique ecosystems along the coasts of tropical and subtropical zones[1-2]. The mangroves of South and South-east Asia form 40.3 % of the global mangrove area, while India contributes 3.3 %, having an area of 4,921 sq. km. Further, Karnataka has 10 sq. km of mangrove cover – 8 sq. km in Uttara Kannada and 2 sq. km in Udupi[3]. West coast of Karnataka has several estuaries and estuarine complexes which have the presence of mangroves including Kali, Belekeri, Ankola, Gangavali, Aghanashini, Alvekodi, Sharavathi, Venkatapur, Shiroor, Baindur, Haladi-Chakra-Kollur, Sita-Swarna-Kodi, Udyavara-Pangala, Mulki-Pavanje and Netravati-Gurpur[4].

Molluscs are soft bodied, unsegmented animals that usually possess head, muscular foot, visceral mass with organs and fleshy mantle which secretes calcareous shell[5]. Even though marine molluscs represent 23 % of extant marine taxa, their conservation has been largely neglected; least numbers of molluscs are included in the Red List of IUCN[6]. Sacoglossans are small slugs lacking shell or jaws, but possessing radula with a row of teeth. Most species are specialized to feed on siphonaceous algae, their mode of feeding include piercing algal cell walls using the teeth and sucking out the cell contents, hence the name Sacoglossa. Valid number of sacoglossan species in the world is 300. In the superorder Sacoglossa, the largest family is Plakobranchidae and the largest genus is *Elysia*, having 102 named species. *Elysia* species lack shell and oral tentacles, and have wing-like parapodia surrounding posterior portion of foot. They are known to segregate the live chloroplasts in their digestive diverticula which give the animals a bright green colour. Most species are smaller than 20 mm, while few species are much larger as adults, with size ranging between 25 – 50 mm. The larger species are also known as mangrove leaf slugs and include *Elysia leucolegnote*, *E. bangtawaensis*, *E. singaporensis* and *E. bengalensis*, which are found specifically in mangroves on mud in shaded pools of water, mostly with no visible algae nearby. Mangrove leaf slugs are found only in the tropical Indo-West Pacific area. *E. leucolegnote* and *E. bangtawaensis* are found in both hemispheres, ranging from west coast of India to north-east coast of Australia[7-10]. *Elysia* species reported from India include *E. abei*, *E. bangtawaensis*, *E. bengalensis*, *E. chilkensis*, *E. expansa*, *E. grandifolia*, *E. hirasei*, *E. leucolegnote*, *E. nealae*, *E. obtusa*, *E. ornata*, *E. punctata*, *E. pusilla*, *E. rufescens*, *E. tomentosa* and *E. thompsoni*. Of these, 10 species are recorded from the west coast[11]. Additionally, *E. carlsoni* and *E. asbecki* are two recently reported species from

India[12-13]. During an investigation into the diversity of molluscs in mangroves of Karnataka, the specimens of *Elysia bangtawaensis* were encountered and were reported herewith for the first time in the state of Karnataka. The study was conducted to understand some of the factors that influence its occurrence, since it shows an ephemeral nature and may expand its biogeographical extent of occurrence.

Materials and Methods

Systematic sampling of shelled molluscs in five mangrove sites of coastal Karnataka in Dakshina Kannada and Udupi districts was conducted from June 2017 to May 2019. The sites are spread across ~ 94 km stretch of coastal Karnataka from Mangalore to Kundapur. During this period, *E. bangtawaensis* was encountered in two mangrove sites of Udupi, hence these two sites were fixed for seasonal sampling along with the ecological parameter studies. The sites are separated by a distance of about 24 km. Monthly sampling from October 2018 to May 2019 for *E. bangtawaensis* was conducted in Kodithale (13°27'33.04" N; 74°41'45.10" E) and Kannada Kudru (13°40'23.52" N; 74°40'44.35" E), located along the Sita-Swarna-Kodi and the Haladi-Chakra-Kollur estuaries of coastal Karnataka, respectively (Fig. 1). This tropical region is characterized by three distinct seasons, namely pre-monsoon (February–May), south-west monsoon (June–September) and post-monsoon (October–January).

GPS coordinates were recorded using Garmin eTrex 10 handheld GPS unit. Random sampling was conducted by placing four quadrats of 1 sq. m[14] in mangroves and individuals were counted. Monthly density was taken as the average of individuals in the quadrats. Photographs of the specimens were taken in the field and laboratory with the help of digital camera. Metric scale was used to measure length of the specimens. The reddish-orange gland spots were counted. Specimens were preserved using 5 % formaldehyde in seawater solution[8]. Identification of species was done according to Swennen[8,15]. Species description was also adopted from Swennen[8]. Water collected after digging the substratum up to 20 cm[(ref. 16)] was tested for parameters like temperature, pH, Electrical Conductivity (EC), Total Dissolved Solutes (TDS) and salinity. Water temperature was recorded using MEXTECH DT-9 digital thermometer. pH of water was tested using Systronics digital pH meter MK VI, while EC, TDS and salinity were tested using Systronics Water Analyser 371. The study area map was generated using ArcMap 10.1 software.

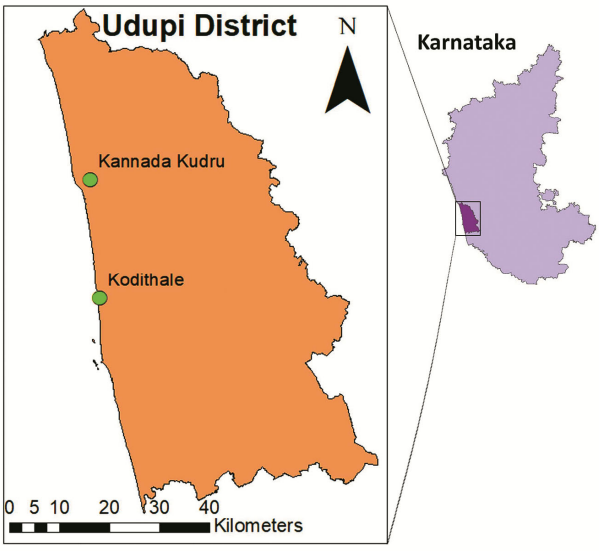

Fig. 1 — Sampling sites of *E. bangtawaensis* in mangrove regions of Udupi district, Karnataka

Results

Systematic position

Kingdom: ANIMALIA Linnaeus, 1758
Phylum: MOLLUSCA Linnaeus, 1758
Class: GASTROPODA Cuvier, 1795
Superorder: SACOGLOSSA H. von Ihering, 1876
Family: PLAKOBRANCHIDAE Gray, 1840
Genus: *Elysia* Risso, 1818
Elysia bangtawaensis Swennen, 1998

Description: *E. bangtawaensis*, maximum length: 25 mm, dorso-ventrally flattened, leaf-shaped with parapodia surrounding foot (Figs. 2 & 3). Renopericardial prominence oval, having two major dorsal vessels posteriorly. Digestive gland ductules

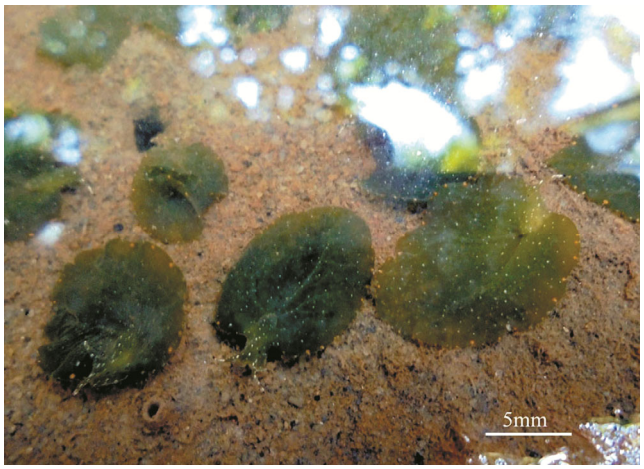

Fig. 2 — *E. bangtawaensis* on muddy substratum in shaded pool

extend over the renal area and give green colour, however they do not extend up till the rhinophores. 16 specimens were examined for colour, length, number of reddish-orange spots along the parapodial border and presence of small white spots and smaller reddish flecks (Table 1).

Habitat: This species was found specifically in mud in shaded pools of water in mangroves, mostly with no visible algae nearby.

Distribution: Elsewhere: *E. bangtawaensis* is known to extend from west coast of India till east Australia, reported from countries like Thailand[8], Malaysia[8], Singapore[17] and Australia[10].

India: The species was reported from Maharashtra[18], Goa[19], Andhra Pradesh[8] and Andaman and Nicobar Islands[13].

Abiotic and biotic parameters: A total of 494 individuals of *E. bangtawaensis* were recorded from the two mangrove sites.

At Kodithale, the range of temperature, pH, EC, TDS, salinity and density were 26.7 – 28.6 °C, 7.2 – 7.4, 38.5 – 50.4 mS cm^{-1}, 21.1 – 27.3 ppt, 20.7 – 27.2 ppt and 0 – 5 ind. m^{-2}, respectively during post-monsoon season (October 2018 to January 2019). While the range of temperature, pH, EC, TDS and salinity were 29.3 – 33.0 °C, 7.4 – 7.6, 52.2 – 54.8 mS cm^{-1}, 27.2 – 28.5 ppt and 27.2 – 28.5 ppt, respectively during the pre-monsoon season (February to May 2019). Density was not calculated since there was no observation of *E. bangtawaensis* at Kodithale in pre-monsoon. In case of Kannada Kudru, the range of temperature, pH, EC, TDS, salinity and density were 28.4 – 28.9 °C, 6.9 – 7.1, 35.8 – 43.2 mS cm^{-1}, 19.9 – 23.6 ppt, 19.5 – 23.2 ppt and 0 – 39 ind. m^{-2}, respectively during post-monsoon season (October 2018 to January 2019). Whereas, the range of temperature, pH, EC, TDS, salinity and density were 28.2 – 31.1 °C, 7.2 – 7.3, 40.4 – 43.5 mS cm^{-1}, 21.6 – 22.7 ppt, 21.3 – 22.8 ppt and 0 – 27 ind. m^{-2}, respectively during the pre-monsoon season (February to May 2019).

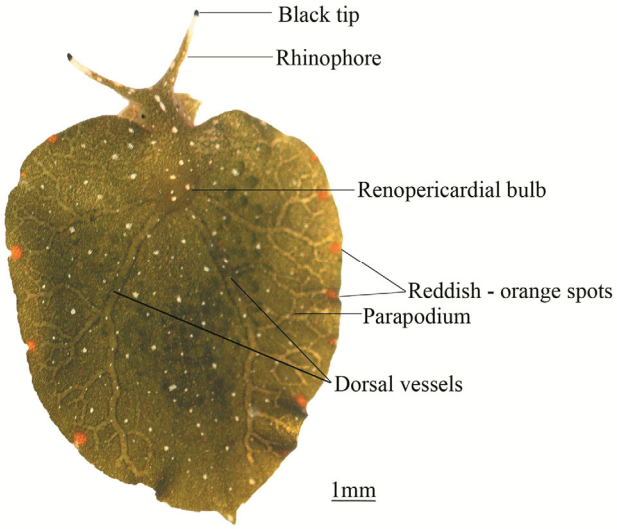

Fig. 3 — Dorsal view of *E. bangtawaensis*

Table 1 — Morphology and biometry of *E. bangtawaensis*

Characteristics	Present study
Colour	Dark green (due to algal ingestion)
Length (mm)	7 – 25 (14.8±3.8)
No. of reddish-orange spots	1 – 20 (13.7±4.6)
White spots and reddish flecks	Numerous on body and parapodia

Total specimens n = 16, Data as range (mean ± SD)

Correlation coefficients between biotic and abiotic parameters of Kodithale and Kannada Kudru are presented in Table 2. At Kodithale, the correlation analysis showed a strong positive significant relationship between pH and temperature (0.901). TDS and salinity were positively correlated with EC (strongly) (0.984 and 0.976, respectively), whereas salinity showed a strong positive correlation with TDS (0.995). The relationships between density and EC (-0.935), density and TDS (-0.962), and density and salinity (-0.968) showed a very strong negative correlation. At Kannada Kudru, the relationships between TDS and EC (0.936), salinity and EC (0.926) showed a very strong positive correlation. Salinity showed a strong positive correlation with TDS (0.975). However, the correlation analysis showed a strong negative relationship between density and EC (-0.726).

Discussion

E. bangtawaensis mangrove leaf slug is an ephemeral species found in polyhaline mangroves of Karnataka, recorded for the first time in the state. Presence of such ephemeral species shows evidence towards the importance of mangroves in these sites and should be protected.

Distinctively mangrove leaf slugs hold their parapodia open to resemble fallen mangrove leaves while other *Elysia* species fold their parapodia dorsally with the margins touching to make a wavy line. Functional chloroplasts from the algal food source are retained within the branched digestive diverticula to give a bright green colour[10].

Table 2 — Relationships between abiotic and biotic parameters

Kodithale

	Temperature	pH	EC	TDS	Salinity	Density
Temperature	1					
pH	0.901**	1				
EC	0.568	0.414	1			
TDS	0.430	0.263	0.984**	1		
Salinity	0.420	0.240	0.976**	0.995**	1	
Density	-0.325	-0.107	-0.935**	-0.962**	-0.968**	1

Kannada Kudru

	Temperature	pH	EC	TDS	Salinity	Density
Temperature	1					
pH	0.705	1				
EC	0.195	0.509	1			
TDS	-0.090	0.254	0.936**	1		
Salinity	-0.065	0.264	0.926**	0.975**	1	
Density	-0.170	-0.313	-0.726*	-0.690	-0.615	1

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed)

E. bangtawaensis has shown to perform photosynthesis using retained algal chloroplasts, which is called as kleptoplasty, chloroplast symbiosis or chloroplast retention, hence the term 'solar-powered slugs'. The slugs can retain the chloroplasts within their body for many months. However, they dislike strong sunlight and prefer to reside in the shade[8]. Food of *E. bangtawaensis* was found to be *Boodleopsis* c.f. *pusilla* and *Derbesia* cf. *marina* in the Gulf of Thailand which occurs on high mud between mangrove roots. During summer, the slugs can feed on these algae only during spring high tides. However, they can survive for longer periods without feeding; becoming smaller and yellowish from lack of feeding for several months while tested in the laboratory. *E. bangtawaensis* was found to be inedible for local shrimps and fish. The nudibranch *Gymnodoris pattani* Swennen, 1996 is known to swallow whole *E. bangtawaensis* animals in the Gulf of Thailand[8,15]. *E. bangtawaensis* was recorded from mid- and lower intertidal zones of Mandovi estuary in Goa, associated with algal beds, seagrass beds, shaded pools and swamps. Algae associated with these habitats included *Chaetomorpha linum*, *Enteromorpha flexuosa*, *Cladophora patentiramea*, *Rhizoclonium riparium*, *Oscillatoria* sp. and *Ulothrix* sp.[19].

Elysia bangtawaensis and *E. leucolegnote* were observed to be ephemeral in space and time. During systematic sampling in mangroves of Darwin Harbour for 20 years, the authors never encountered these species until 2015(ref. 10). This may be one of reasons why studies on *E. bangtawaensis* and information regarding their ecology are scarce in literature.

Several records of *E. bangtawaensis*, mostly from mangroves, have been reported from countries along the Indo-West Pacific. In Thailand, they were observed along the Gulf of Thailand and the Andaman Sea at Pak Phanag Bay, Bang Tawa, Ban Di, Inner Pattani Bay and Krabi[8,15]. In Malaysia, they were observed from Johor State along the Straits of Malacca[8], while in Australia they were reported from the states of Northern Territory, Queensland and New South Wales at mangroves of Darwin Harbour[10], Cairns[20], Tweed-Byron coast[21] and Coolangatta[22].

E. bangtawaensis has been reported from several coastal states of India, from mangroves in Mandovi estuary (Goa)[19], mangroves in Mumbai (Maharashtra)[18], a mangrove 20 km south of Kakinada (Andhra Pradesh)[8] and Andaman and Nicobar islands[13]. Ecological observations revealed its exclusive association to the mangrove swamps in Kodithale and Kannada Kudru estuarine regions of Karnataka, India. *E. bangtawaensis* has been reported to be seen along with *E. bengalensis* (in the Bay of Bengal) and *E. leucolegnote* (in the Gulf of Thailand)[8]. Interestingly, in the present study the rhinophore tips of *E. bangtawaensis* were black which is similar to that observed in specimens reported from Darwin Harbour, Australia[10], whereas the specimens examined by Swennen[8] appeared to have pale or spotted tips.

In the Gulf of Thailand *E. bangtawaensis* was found in mangroves having salinity 20 – 35 ‰ and

7 – 15 ‰. Laboratory experiments showed that they could survive salinities ranging from 4 – 37 ‰[15]. In mangroves of Mandovi estuary, Goa the maximum density of *E. bangtawaensis* was 400 ind. m^{-2} between November 2007 and January 2008. Salinity ranged from 10 – 26 psu showing polyhaline and mesohaline nature[19]. In the present study, the species was recorded from polyhaline mangroves in post-monsoon and pre-monsoon seasons. Maximum density was found to be 39 ind. m^{-2} at Kannada Kudru in October 2018. Dominant occurrence in the polyhaline zone of the estuary indicates its preference to moderate concentration of salinity. At both the sites, TDS and salinity are positively correlated with EC. Density is negatively correlated with EC. The present findings encourage further understanding regarding ecological adaptation and biotechnological potential of *E. bangtawaensis.*

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Conflict of Interest

Authors declare that there is no conflict of interest.

Author Contributions

JSV: Field survey, methodology and write-up; KSS: Concept and methodology; and SYT: Methodology and write-up.

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