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Taxonomic assessment and diversity of sea slugs (Gastropoda: Heterobranchia) along the Karnataka Coast, India

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Abstract

Sea slugs in Karnataka's marine ecosystems have been understudied, resulting in limited documentation. To address this gap, extensive field surveys were conducted across the rocky reefs and off-shore patchy reefs of Karnataka, extending up to a depth of 38 m. During the surveys nine sea slug species were documented, representing four genera (*Goniobranchus*, *Phyllidia*, *Coryphellina*, and *Elysia*), belonging to four families (Chromodorididae, Phyllidiidae, Flabellinidae, and Plakobranchidae). Six of the nine species recorded are new additions to the sea slug fauna of the Karnataka Coast. By combining data from the current surveys with historical records, an annotated checklist of 36 species of sea slugs found in Karnataka was compiled.



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Sea slugs are fascinating marine molluscs belonging to the class Gastropoda. Over the course of evolution, they have undergone remarkable morphological and anatomical changes, including the complete loss or significant reduction of their shells. "Sea slug" is a broad classification encompassing various members from families within the former infraclass Opisthobranchia but currently they include members of the subclass Heterobranchia found in the marine and estuarine ecosystems. These are benthic organisms and perform important roles in marine ecosystems by grazing on macroalgae or bryozoans that colonise rocks and other hard surfaces. Reef areas are particularly rich in sea slugs, and their vibrant colours often signal other organisms and their predators about their toxicity or unpalatability (Winters *et al.*, 2018).

Sea slugs exhibit diversity in body shape, size, and colouration. Worldwide, about 6,000 species of sea slugs have been identified, with almost half of them documented in the Indo-Pacific region

(Wägele *et al.*, 2008; Gosliner *et al.*, 2015). A total of 611 species of sea slugs representing 183 genera and 62 families have been documented in India (Hussain *et al.*, 2022). The available documentation on diversity of sea slugs along the west coast of India is based on limited samplings from only selected locations (Apte and Desai, 2017; Chandran *et al.*, 2017; Vadhar *et al.*, 2020; Hussain *et al.*, 2022). Though previous studies have documented sea slugs in the coastal waters of Karnataka (Zacharia *et al.*, 2008; Apte and Desai, 2017; Veigas *et al.*, 2022), there is no comprehensive data available on sea slug diversity specifically along the Karnataka Coast. To address this gap, exploratory surveys were conducted in the rocky areas (Mulki Rocks) and patchy reef habitats (Netrani Reef) along the Karnataka Coast. These are ecologically unique reef habitats that provide critical niches for diverse marine invertebrates, including sea slugs. Mulki Rocks, is a series of submerged and emerged rocky outcrop located nearly 8 km off the coast of Kaup. Netrani Reef, located nearly 19 km off Bhatkal coast is a relatively pristine offshore patchy reef ecosystem,

that harbours a wide variety of flora and fauna. Both these locations have rich biota and structural complexity that provide favourable conditions for feeding and reproduction of marine organisms including sea slugs. The present surveys undertaken in the Mulki Rocks and Netrani Reef aimed to document the commonly encountered sea slug species in these habitats. As part of this study, an attempt was also made to compile an updated checklist of all sea slug species recorded from the Karnataka Coast.

Underwater visual census surveys were conducted in Mulki Rocks (13° 11' N; 74° 40' E) and Netrani Coral Reef (14.01° N; 74.3° E) from May 2018 to November 2022. The survey periods were restricted to the pre-monsoon (Feb-May) and post-monsoon (Sept-Jan) months annually, owing to the adverse weather conditions experienced during the monsoon season. Within these reef habitats, approximately 80 SCUBA-assisted dives were conducted, with visual surveys extending to depths of 38 m. Each dive lasted between 45 and 60 min, and care was taken to avoid resurveying the same sites within the same month to minimise duplication of records. Across sites and season, standardised line transects, each 30 m in length and 2 m in width, were established to systematically assess the benthic community. Given the patchy distribution and cryptic nature of sea slugs, opportunistic observations were also recorded during these dives to maximise species detection. Upon encountering individuals, *in situ* photographs were captured to facilitate subsequent taxonomic identification, and the associated benthic substrates were also documented. This approach allowed for accurate species-level recording while minimising habitat disturbance, and provided insights into habitat associations within the surveyed reef systems. Non-invasive species identification was performed using field diagnostic characters described by Apte and Desai (2017), supplemented with species-specific traits from the web portal *The Sea Slug Forum* (www.seaslugforum.net). These sightings from the present study were combined with the data on sea slugs documented as part of the citizen science projects of 'iNaturalist-Marine Life of Netrani Island' (<https://www.inaturalist.org/projects/marine-life-of-netrani-island>) as well as previous reports (Zacharia et al., 2008; Apte and Desai, 2017; Veigas et al., 2022, Viswambharan et al., 2022) to compile a checklist of sea slugs from the Karnataka Coast.

During the underwater surveys conducted on the Netrani patchy reefs and Mulki Rocks, occurrence of nine species of sea slugs were documented *in situ*. These species belonged to four genera (*Goniobranchus*; *Phyllidia*; *Coryphellina* and *Elysia* representing four families (Chomodorididae; Phyllidiidae; Flabellinidae and Plakobranchidae) (Fig.1). These species were recorded from both inshore and offshore reef areas. Even though the surveys were conducted up to 38 m depth, sea slugs were observed in very shallow waters, ranging from 1 to 18 m. Of the nine species of sea slugs recorded, six represented new records from Karnataka Coast.

Goniobranchus spp.

Phylum : Mollusca Linnaeus, 1758

Class : Gastropoda Cuvier, 1795

Subclass: Heterobranchia Burmeister, 1837

Order : Doridida

Family : Chomodorididae Bergh, 1891

Genus : *Goniobranchus* Pease, 1866

Species : *Goniobranchus trimarginatus* (Winckworth, 1946);

Goniobranchus geminus (Rudman, 1987); *Goniobranchus bombayanus* (Winckworth, 1946); *Goniobranchus conchyliatus* (Yonow, 1984); *Goniobranchus cavae* (Eliot, 1904); *Goniobranchus hintuanensis* (Gosliner& Behrens, 1998)

Goniobranchus trimarginatus (Winckworth, 1946): The mantle of the organism displays a white base adorned with irregular red patches and spots. Along the mantle edge, three narrow bands can be observed, exhibiting shades of yellow, wine red, and blue. The gills and rhinophore clubs appear as translucent white structures, accompanied by opaque white edging.
Location and depth: Mulki Rocks (6 m)

Goniobranchus geminus (Rudman, 1987): The mantle edge exhibits four distinct colourations, characterised by a thin white outline. Within this boundary, a slender line of grey is followed by creamy white, culminating in a vibrant, bright yellow hue. Moving towards the mid-mantle region, a light brown shade is observed, adorned with mauve ocelli encircled by a white margin.
Location and depth: Netrani Reefs (5-9 m)

Goniobranchus bombayanus (Winckworth, 1946): The mantle of the organism appears translucent white, with sizable, rounded spots in striking purple. Additionally, the mantle showcases raised, tiny white papillae. Along the outer margin of the mantle, there is a notable band of orange spots that merge to give a band like appearance.
Location and depth: Mulki Rocks (5-6 m)

Goniobranchus conchyliatus (Yonow, 1984): The mantle exhibits a pale violet colouration, adorned with rounded patches of creamy yellow pustules, as well as deeper violet and wine-red markings. These distinctive patterns follow the contours of bilaterally symmetrical yellow pustules. The gills and rhinophores display a reddish hue, while the stalk of the rhinophores appears white.
Location and depth: Mulki Rocks (5-6 m); Netrani Reef (5-6 m)

Goniobranchus cavae (Eliot, 1904): The mantle exhibits a yellowish hue and is adorned with prominent black blotches. These black blotches are encircled by a distinct white outline. The outer edge of the mantle displays a light violet shade. The gills and rhinophores showcase a vibrant purple colouration.
Location and depth: Mulki Rocks (5-6 m); Netrani reef (5-8 m)

Goniobranchus hintuanensis (Gosliner& Behrens, 1998): The mantle of the organism appears as a cream white shade, adorned with yellow blotches. Some of these yellow blotches located at the centre of the organism are encircled by a dark purple colour. The gills and rhinophores showcase a translucent blueish purple hue, accentuated by a dark line of the same colour along their edges.
Location and depth: Mulki Rocks (5-6 m)

Phyllidia varicosa Lamarck, 1801

Phylum : Mollusca Linnaeus, 1758

Class : Gastropoda Cuvier, 1795

Subclass: Heterobranchia Burmeister, 1837

Order : Doridida

Family : Phyllidiidae Rafinesque, 1814

Genus : *Phyllidia* Cuvier, 1797

Species : *Phyllidia varicosa* Lamarck, 1801

Compared to other sea slugs in the region, this species is relatively

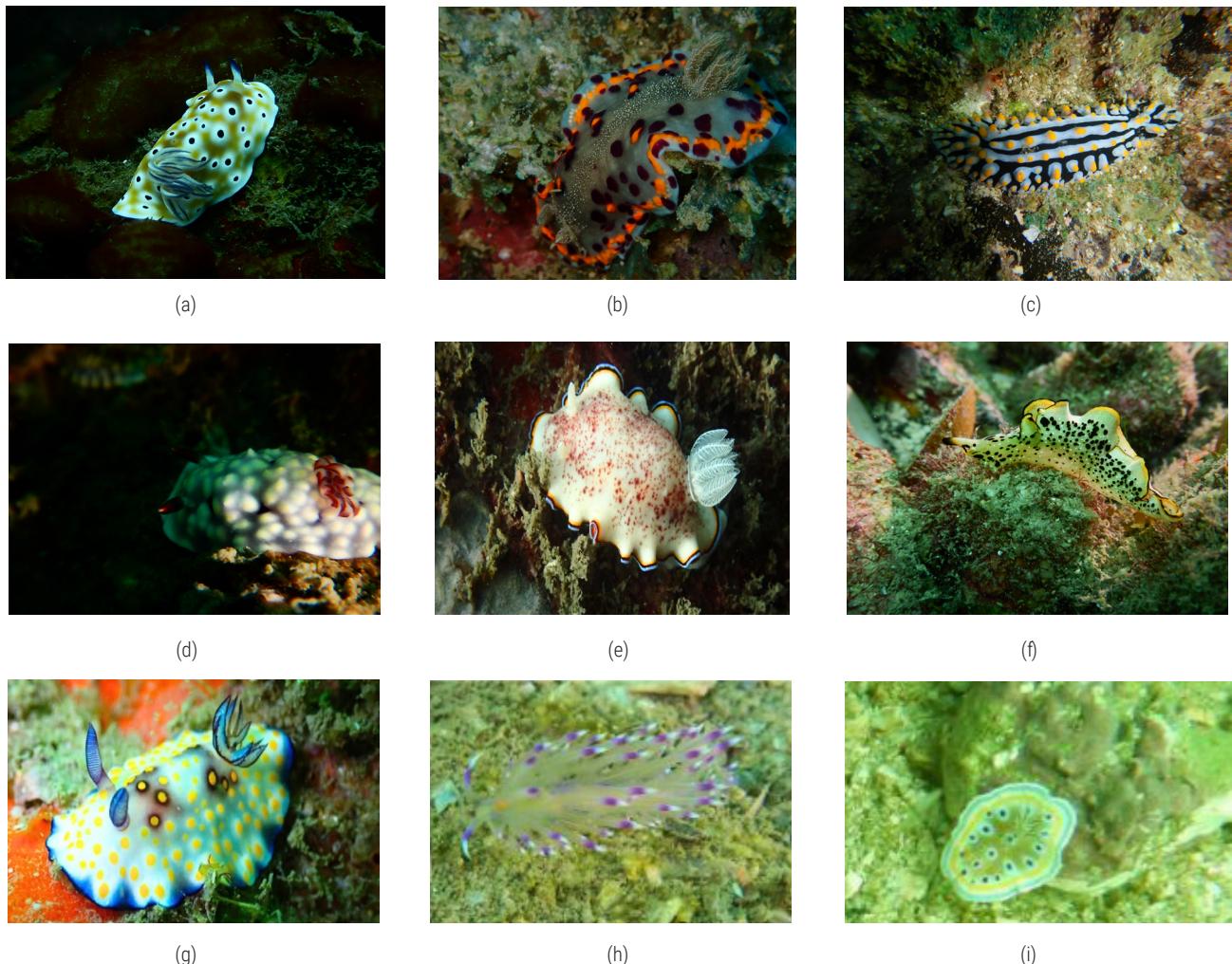


Fig. 1. Common sea slugs observed during the present study (a) *Goniobranchus cavae*; (b) *Goniobranchus bombayanus*; (c) *Phyllidia varicosa*; (d) *Goniobranchus conchyliatus*; (e) *Goniobranchus trimarginatus*; (f) *Elysia marginata*; (g) *Goniobranchus hintuanensis*; (h) *Coryphellina rubrolineata*; (i) *Goniobranchus geminus*.

large. It can be identified by the presence of longitudinal tuberculate notal ridges, typically numbering between 3 and 6. These ridges and the base of the tubercles exhibit a whitish colouration, while the cap of the tubercles appears orangish yellow.

Location and depth: Mulki Rocks (5-6 m); Netrani Reef (8-12 m)

Coryphellina rubrolineata O'Donoghue, 1929

Phylum : Mollusca Linnaeus, 1758

Class : Gastropoda Cuvier, 1795

Subclass: Heterobranchia Burmeister, 1837

Order : Nudibranchia Cuvier, 1817

Family : Flabellinidae Bergh, 1889

Genus : *Coryphellina* O'Donoghue, 1929

Species : *Coryphellina rubrolineata* O'Donoghue, 1929

The overall body colour, including the rhinophores, oral tentacles, and bases, is a translucent white. The apical region of the oral tentacles and rhinophores is opaque white, while sub-apically it takes on a deep violet hue. The digestive gland, visible through the skin, displays an orange colouration.

Location and depth: Mulki Rocks (8 m)

Elysia marginata Pease, 1871

Phylum : Mollusca Linnaeus, 1758

Class : Gastropoda Cuvier, 1795

Subclass: Heterobranchia Burmeister, 1837

Family : Plakobranchidae Gray, 1840

Genus : *Elysia* Risso, 1818

Species : *Elysia marginata* (Pease, 1871)

This species is relatively large. The mantle is characterised by a translucent, deep green colour with small white and black blotches. The broad parapodia are bordered by an orange band and a black margin, with a narrow white band in between the rhinophores display a greenish hue, featuring an orange band and a dark tip.

Location and depth: Mulki Rocks (5-8 m); Netrani Reef (8-18 m)

Despite the abundance of ideal habitats along the Karnataka Coast, sea slugs remain one of the least studied groups of marine molluscs. A total of 36 species of sea slugs from different coastal ecosystems in Karnataka were documented through the prepared checklist (Table 1). In Karnataka, the diversity of sea slugs is dominated by the order Doridida (52%) (Fig. 2) with the majority under the

genus *Goniobranchus*. These sea slugs are commonly observed in reef areas during the post- and pre-monsoon months from October to May. Since the surveys were not conducted during the monsoon months, their occurrence in these coastal ecosystems is not known. The sea slugs documented during the present study were frequently observed in association with their putative prey, predominantly macroalgae, encrusting sponges, and bryozoans, which are abundant in coastal reef habitats. Species-specific feeding associations were noted in certain cases; for instance, *G. cavae* was observed grazing on bryozoans, while *E. marginata* was recorded feeding on macroalgal substrates (Fig. 3). In addition to feeding observations, egg masses attributable to members of marine Heterobranchia were recorded from several survey sites (Fig. 3), although the precise taxonomic identity of the egg cases could not be ascertained. It is noteworthy that earlier studies have reported the occurrence of egg cases belonging to Anaspidea from estuarine waters of Karnataka (Viswambharan *et al.*, 2022), suggesting that diverse sea slugs reproduce across multiple habitats within the region. It has been demonstrated that the availability of food and habitat characteristics have an influence on the occurrence and distribution of sea slugs along the coastal habitats (Darumas *et al.*, 2007).

Of the six species of sea slugs newly documented from the coastal waters of Karnataka, one species, *G. hintuanensis* represents a novel distributional record for the entire west coast of India. Previously, this species had been reported only from the Andaman and Nicobar Islands within the Indian Exclusive Economic Zone (Apte and Desai, 2017), and its occurrence in Karnataka further extends its known biogeographic range. The remaining five species, although new records for Karnataka, have already been documented in neighbouring states along the west coast. Specifically, *C. rubrolineata* and *G. trimarginatus* have been reported from Maharashtra, *G. bombayanus* from Maharashtra and Gujarat,

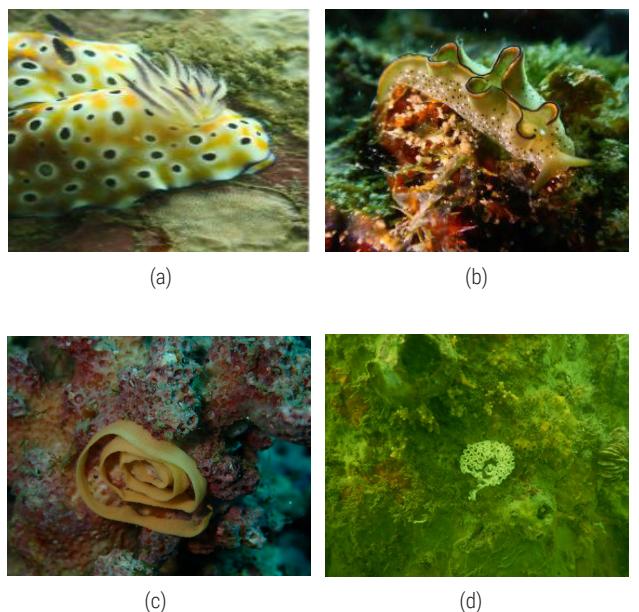


Fig. 3. (a) *G. cavae* feeding on bryozoans in Mulki Rocks; (b) *E. marginata* feeding on macroalgae in Netrani Reef; (c) Egg mass of Chromodorididae observed in Mulki Rocks; (d) Egg mass of unknown sea slug observed in Mulki Rocks

G. s conchyliatus from Goa, and *G. cavae* from Kerala (Apte and Desai, 2017; Chandran *et al.*, 2017). Thus, while the present study supplements the faunal inventory of Karnataka by adding six new records, the detection of *G. hintuanensis* is particularly significant, as it represents a noteworthy range extension for the species within Indian waters.

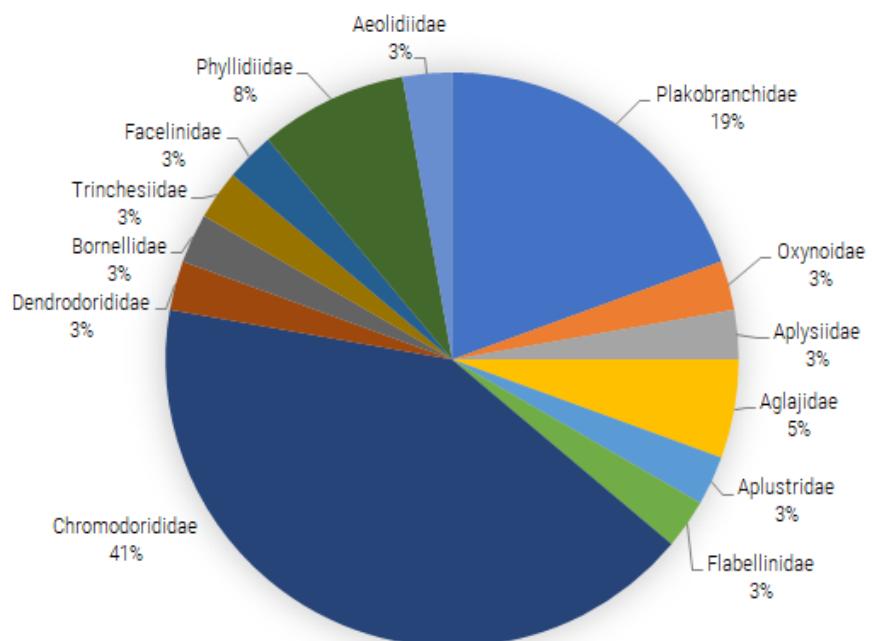


Fig. 2. Percentage composition of sea slug families recorded along the Karnataka Coast

Table 1. Checklist of sea slugs along the Karnataka Coast

Sl. No:	Phylum	Class/ Subclass	Order	Family	Species
1	Mollusca	Gastropoda/ Heterobranchia		Plakobranchidae	<i>Elysia bangtawaensis</i>
2					<i>Elysia bengalensis</i>
3					<i>Elysia marginata</i>
4					<i>Elysia ornata</i>
5					<i>Elysia cf hirasei</i>
6					<i>Elysia tomentosa</i>
7					<i>Thuridilla gracilis</i>
8			Oxynoidae		<i>Lobiger viridis</i> (currently valid as <i>Lobiger nevilli</i>)
9			Aplustridae		<i>Hydatina zonata</i>
10		Aplysiida	Aplysiidae		<i>Bursatella leachii</i>
11		Cephalaspidea	Aglajidae		<i>Chelidonura cf hirundinina</i>
12					<i>Chelidonura punctata</i>
13		Nudibranchia	Flabellinidae		<i>Coryphellina rubrolineata</i>
14			Bornellidae		<i>Bornella stellifera</i>
15			Trinchesiidae		<i>Trinchesia cf caerulea</i>
16			Facelinidae		<i>Phidiana militaris</i> (Currently valid as <i>Caloria militaris</i>)
17			Aeolidiidae		<i>Aeolidiopsis palythoae</i>
18		Doridida	Chromodorididae		<i>Glossodoris</i> sp.
19					<i>Goniobranchus annulatus</i>
20					<i>Goniobranchus bombayanus</i>
21					<i>Goniobranchus cavae</i>
22					<i>Goniobranchus conchyliatus</i>
23					<i>Goniobranchus geminus</i>
24					<i>Goniobranchus hintuanensis</i>
25					<i>Goniobranchus setoensis</i>
26					<i>Goniobranchus trimarginatus</i>
27					<i>Goniobranchus</i> sp.
28					<i>Hypselodoris maculosa</i>
29					<i>Hypselodoris pulchella</i>
30					<i>Miamira sinuata</i>
31					<i>Thorunna australis</i>
32			Dendrodorididae		<i>Chromodoris</i> sp.
33					<i>Dendrodoris fumata</i>
34			Phyllidiidae		<i>Phyllidia ocellata</i>
35					<i>Phyllidia varicosa</i>
36					<i>Phyllidiella zeylanica</i>

Among the surveyed reefs, the highest number of sea slug records in Karnataka were from coral reef areas, followed by rocky reefs (Table 2). These habitats support diverse and colourful groups of nudibranchs, attracting researchers, leading to a greater number of observations/records. Sea slugs in mangrove areas and estuaries, on the other hand, are generally smaller, less colourful, and often camouflaged, making them difficult to spot and are under-reported. Due to their cryptic nature, short life cycle, or nocturnal activity, sea slugs can be challenging to locate. Therefore, the number of sea slug species recorded from Karnataka waters is likely an underestimate, and continued surveys will likely reveal additional species. By documenting the diversity and distribution of sea slugs in this region, this study contributes to our understanding of these

fascinating marine organisms and emphasises the significance of protecting and conserving their unique ecosystems (Table 2).

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Table 2. List of sea slugs along with the area of occurrence (a: Zacharia et al., 2008; b: Veigas et al., 2022; c: iNaturalist; d: Apte and Desai, 2017; e. Viswambharan et al., 2022; ps: Present study. *New records from Karnataka)

Sl. No.	Species	Coral reef	Patchy reefs	Estuary	Muddy reefs	Deep sea	Not mentioned
1	<i>Aeolidiopsis palythoae</i>						d
2	<i>Bornella stellifera</i>		d				
3	<i>Bursatella leachii</i>			e			
4	<i>Chelidonura cf hirundinina</i>	c					
5	<i>Chelidonura punctata</i>	c					
6	<i>Chromodoris</i> sp.	a					
7	<i>Dendrodoris fumata</i>				d		
8	<i>Elysia bangtawaensis</i>			b			
9	<i>Elysia bengalensis</i>						d
10	<i>Elysia cf hirasei</i>						d
11	<i>Elysia marginata</i>	ps, c	ps				
12	<i>Elysia ornata</i>	a, d					
13	<i>Elysia tomentosa</i>						d
14	<i>Cryphellina rubrolineata</i> *		ps				
15	<i>Glossodoris</i> sp.	a					
16	<i>Goniobranchus annulatus</i>	c					
17	<i>Goniobranchus bombayanus</i> *		ps				
18	<i>Goniobranchus cavae</i> *	ps	ps				
19	<i>Goniobranchus conchyliatus</i> *	ps	ps				
20	<i>Goniobranchus geminus</i>	ps, d					
21	<i>Goniobranchus hintuanensis</i> *		ps				
22	<i>Goniobranchus setoensis</i>	c					
23	<i>Goniobranchus</i> sp.	c					
24	<i>Goniobranchus trimarginatus</i> *		ps				
25	<i>Hydatina zonata</i>					d	
26	<i>Hypselodoris maculosa</i>	c					
27	<i>Hypselodoris pulchella</i>	c					
28	<i>Lobiger viridis</i>					d	
29	<i>Miamira sinuate</i>	c					
30	<i>Phidiana militaris</i>	c, d					
31	<i>Phyllidia ocellata</i>	c					
32	<i>Phyllidia varicosa</i>	a, ps, d, c	ps				
33	<i>Phyllidiella zeylanica</i>	a, d, c					
34	<i>Thorunna australis</i>	a, d, c					
35	<i>Thuridilla gracilis</i>	d					
36	<i>Trinchesia cf caerulea</i>	c					

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