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FIRST RECORD OF NUDIBRANCHS AND ASSOCIATED SEA SLUGS AROUND TERENGGANU ISLANDS, MALAYSIA VIA CITIZEN SCIENCE OBSERVATION

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ABSTRACT

Conducted between January 10 and May 31, 2022, this study employed a citizen science approach to document Malaysia's understudied nudibranch species, providing critical ecological data necessary to evaluate regional conservation priorities. By leveraging contributions from virtual citizen scientists, particularly divers, this study compiled in-silico data, including localities, photographs, and site information. A total of 71 species (35 genera; 20 families) were identified and documented from 7 localities within Terengganu waters, based on contributions from 12 participants across various social media platforms. Among the recorded species, the majority belonged to the suborder Doridina (64.79% with 46 species) and Suborder Aeolidina (19.72% with 14 species) followed by Suborder Arminina (4.23% from 3 species), Suborder Dendronotina (2.82% from 2 species) and others which were the sacoglossans (4.23% with 3 species), cephalaspideans (2.82% with 2 species) and lastly aplysiidans (1.41% with 1 species).This study highlights the effectiveness of citizen science in advancing scientific knowledge, particularly during periods of restricted movement, and underscores its potential for building robust databases. Furthermore, with advanced statistical

and modelling analyses, the findings could inform marine conservation priorities and risk assessments for nudibranchs in Malaysian waters.

Keywords: citizen science, nudibranchs, conservation status, species composition, diversity, South China Sea

BACKGROUND

Nudibranchs are soft-bodied gastropods within the phylum Mollusca, closely related to sea slugs and sea hares. This diverse group of vividly coloured marine molluscs loses its shell during the larval stage and remains shell-less throughout its life (Dumdei et al. 1989; Dean and Princep 2017). The term "nudibranchia" comes from the Greek words *nudus* (naked) and *branchia* (gills), referring to their exposed, feathery gills and horns on their backs (Dharmawan et al. 2021). Nudibranchs lack a shell, mantle cavity, osphradium, and internal shell, with their mantle, foot, and visceral mass fused into a single, bilaterally symmetrical unit (Hyman 1967; Harris 1973). The vibrant, branch-like structures on their bodies contribute to their striking appearance, making them some of the most visually captivating marine creatures.

With over 4,700 known species (Gofas 2021), they occupy a wide range of habitats, including tropical and subtropical marine environments (Clark 1975; Debelius 1996; Johnson and Gosliner 2012), as well as brackish waters in some cases (Swennen 1996; Korshunova et al. 2018). However, only 193 species have been identified along the coast and islands of the South China Sea (Willan 2000). Despite their popularity among divers and photographers, nudibranchs remain relatively understudied. According to Chavanich et al. (2013), assessing nudibranch species diversity and abundance poses challenges due to their intricate camouflage, cryptic nature, and difficulties in identification. Nevertheless, nudibranchs play vital ecological roles in marine food chains, especially in understanding their trophic interactions in marine benthic ecosystems (Ekimova et al. 2019).

Current knowledge of nudibranchs and associated sea slugs in Malaysia is based on outdated literature and journal articles, with limited research on their population assessments and conservation status, highlighting the need for updated studies (Willan 2000; Koh 2008; Alqudah et al. 2016; Raja-Salleh et al. 2019). Like many other species in the region, most nudibranchs and associated sea slugs in Malaysia are listed as Not Evaluated (NE) on the IUCN Red List, indicating a significant data gap (IUCN 2024). Previous studies in Malaysian waters include a survey by Salleh et al. (2000), which examined the diversity and distribution of

chromodorid nudibranchs at seven sites on Sipadan Island, Borneo. They identified seven species, with *Chromodoris annae* being the most common, while other species such as *Chromodoris magnifica*, *Chromodoris coi*, and *Chromodoris elizabethina* were considered rare. The study also recorded two chromodorid species belonging to the genus *Ceratosoma* (Salleh et al. 2001). Another study by Koh (2008) documented 13 species (62 individuals) from Terengganu, with notable families including Chromodorididae, Phyllididae, Doridiidae, and Flabellinidae recorded from the Redang Island archipelago. Beyond diversity assessments, research on phyllidiid species in Malaysia, particularly *Phyllidia varicosa* and *Phyllidiella pustulosa*, documented their movement, mating, and egg-laying behaviours under laboratory conditions (Alqudah et al. 2016). Similarly, a study on the embryonic and larval development of *Phyllidiella nigra* from Bidong Island, Terengganu, found that its development closely resembled that of *Phyllidia varicosa* but exhibited a faster growth rate compared to previous studies on Phyllidiidae (Raja-Salleh et al. 2019). Collectively, these studies have contributed valuable insights into the diversity, distribution, behaviour, and early life-history traits of nudibranchs in Malaysian waters.

Until recently, observations of nudibranchs were primarily conducted through ground-truthing exercises or field surveys, which often face logistical, time, financial, and geographical constraints. For example, the COVID-19 pandemic further forced a re-evaluation of data collection methods, especially during restricted movement orders (RMO). In recent years, the recruitment of volunteers, or citizen scientists, for data collection has grown significantly (Silvertown 2009; Follett and Strezov 2015; Theobald et al. 2015), becoming a key component in studies with large spatial scales, focusing on charismatic species, or addressing widespread management issues (Cohn 2008). While citizen science in marine habitats has been slower to develop due to inaccessibility, there is increasing interest in engaging volunteers, particularly as it supports better management of threatened habitats (Martin et al. 2016a, b). The present study utilizes citizen science to collect ecological and biological data on nudibranchs and associated sea slugs from Terengganu waters, enabling the identification of new localities or habitats that have not been previously studied. This approach not only generates new observational data on the sea slugs in the study area but also engages participants, who are often motivated by the opportunity to enhance their own knowledge while contributing to scientific research. This study also serves as a foundational reference for describing and identifying nudibranchs and associated sea slugs in Terengganu and highlights the need for more extensive studies on various islands across Malaysia, shedding light on the rich

biodiversity and ecological significance of these captivating marine organisms. Furthermore, we aim to identify new locality records absent from existing platforms like iNaturalist, ultimately evaluating how citizen science data compares to formal biodiversity databases. Because conventional survey methods have historically under-sampled this area, leaving only 20 species currently documented on iNaturalist, we hypothesize that a structured citizen science approach will dramatically expand the known species inventory and establish new spatial records for the majority of the documented fauna.

MATERIALS AND METHODS

Data collection

Data collection was conducted over a five-month period, from January 10 to May 31, 2022. Observations from citizen scientists were gathered across five islands and two coastal rockeries in Terengganu, comprising Pulau Redang, Pulau Tenggol, Pulau Kapas, Pulau Bidong, Pulau Perhentian, and two non-island sites, Batu Rakit and Tok Jembal (Figure 1). A poster highlighting the nudibranch collaboration, featuring example images, was disseminated across various social media platforms starting January 10, 2022, and continuing through May 2022, encouraging citizen scientists to submit photographs of sea slugs observed in Terengganu waters.

Images were submitted to the project team for identification; no non-sea slug images were received, indicating that participants were generally well-informed in distinguishing sea slugs from other marine organisms. Submitted data were compiled into a custom-designed database, which also served as a photographic reference collection. Each submission included the image and associated metadata (depth and locality). All specimens were identified from image analysis using morphological references, including Gosliner et al. (2015), Behrens (2005), Coleman (2001), and the websites nudibranch.org, iucnredlist.org, and seaslugforum.net. No physical specimens were collected.

Comparison with iNaturalist records

To evaluate the contribution of this citizen science dataset relative to existing biodiversity records, species and locality data were compared against public observations retrieved from iNaturalist (www.inaturalist.org). Records were queried on for the taxon were searched e.g., "Nudibranchia" or "Heterobranchia" within a bounding box covering "Peninsular Malaysia" or

specific lat/long, and included records with a quality grade of "Research Grade" were included in the comparison. Species identifications from iNaturalist were cross-checked against the same taxonomic references used for the citizen science dataset to ensure consistency prior to comparison.

Species list and distribution

A comprehensive species checklist was compiled from all confirmed citizen science submissions, organized by suborder, family, genus, and species following current nudibranch taxonomy. For each species, occurrence was recorded across the seven survey localities (Pulau Perhentian, Pulau Bidong, Pulau Kapas, Pulau Tenggol, Pulau Redang, Batu Rakit, and Tok Jembal), and cross-referenced against existing iNaturalist records for the same localities to indicate whether each occurrence represented a citizen science-only record, an iNaturalist-only record, or a record confirmed by both sources.

Proportional composition of sea slug groups

To assess the proportional composition of sea slug diversity at each locality, all identified specimens were first classified to suborder level, following the seven recognized groups within the study: Aeolidina, Arminina, Dendronotina, and Doridina (Nudibranchia); Cephalaspidea and Sacoglossa (non-nudibranch heterobranchs); and Aplysiida. For each locality, the number of species recorded within each suborder was tallied, and the relative proportion of each suborder was calculated as the number of species in that suborder divided by the total number of species recorded at that locality, expressed as a percentage. This calculation was performed both at the locality level (for the seven survey sites individually) and at the study-wide level (pooling records across all localities) to characterize overall diversity structure. Proportional composition was visualized using pie charts.

Comparative overview of global citizen science initiatives

To contextualize the present dataset within existing citizen science efforts for sea slugs, records were compiled from published studies and public databases reporting nudibranch and associated sea slug diversity through citizen science or community-contributed platforms at regional and national scales. For each comparator dataset, the number of species, families, and (where reported) total observations were extracted from the original source and compared against the totals recorded in the present study.

Overlap between citizen science and iNaturalist records

To assess the degree of overlap between the present citizen science dataset and existing iNaturalist records for Terengganu, genus- and species-level checklists from both sources were compared. Taxa recorded exclusively in the present study, taxa recorded exclusively on iNaturalist for the same region, and taxa common to both sources were tallied separately at the genus level (Figure 3a) and species level (Figure 3b), and visualized as proportional Venn diagrams. Taxonomic names were standardized against WoRMS prior to comparison to avoid inflating unique-taxon counts through synonymy.

RESULTS

The successful identification of these sea slugs' check list was achieved through the collaboration of 12 citizen-science contributors that came from different background such as diving instructors, divers, and researchers where a total of 141 sea slugs pictures were collected, and among them, 71 distinct species were identified from 20 families and 35 genera found (Table 2) from 7 sites. The diversity of the sea slugs (Figure 3) is dominated by nudibranchs from suborder Doridina (64.79% with 46 species) and Suborder Aeolidina (19.72% with 14 species) followed by Suborder Arminina (4.23% from 3 species), Suborder Dendronotina (2.82% from 2 species, and others which were the sacoglossans (4.23% with 3 species), cephalaspideans (2.82% with 2 species) and lastly aplysiidans (1.41% with 1 species) where all species recorded.

Among these 7 localities in Terengganu waters, Bidong Island had the highest recorded number of nudibranch species when compared to other locations (Table 1). Specifically, 44 sea slugs species were identified on Pulau Bidong, followed by 26 species on Pulau Perhentian. Pulau Redang was home to 25 different sea slug's species, while Pulau Tenggol had 11 species recorded from the images and the least sea slugs contributed from Pulau Kapas with only 9 species from 71 species recorded around Terengganu (Figure 3). The number of nudibranch species contributed by local divers with Tok Jembal and Batu Rakit, both coastal areas, contributing 2 and 1 species, respectively.

To place the present study within the broader context of sea slug citizen science research, a comparative overview of global citizen science initiatives is provided in Table 4. These studies demonstrate the growing importance of community-generated observations in documenting sea slug diversity, detecting range extensions, and supporting biodiversity monitoring. In this study,

a comparison between records obtained from the present study and those available through iNaturalist revealed complementary patterns of sea slug diversity. The Venn diagrams show the number of unique and shared genera and species recorded by the two datasets, highlighting the contribution of both field surveys and citizen-science observations to the regional checklist (Figure 3).

Checklist of sea slugs from Terengganu islands

Phylum: Mollusca

Class: Gastropoda Cuvier, 1795

Subclass: Heterobranchia Burmeister, 1837

Order: Nudibranchia Cuvier, 1817

Suborder: Arminina

Family: Arminidae Iredale & O'Donoghue, 1923 (1841)

1. *Dermatobranchus fortunatus* (Bergh,1888) (Fig 4c)
   Distribution: Tropical Indo-West Pacific, Western Pacific region
2. *Armina major* Baba,1949 (Fig.4d)
   Distribution: Mediterranean-Atlantic, Indo-Pacific, and Southwestern Pacific
3. *Armina semperi* (Bergh, 1866) (Fig. 4e)
   Distribution: Indo-West Pacific

Suborder: Aeolidina

Family: Aeolidiidae Gray, 1827

4. *Aeolidiopsis harrietae* Rudman, 1982 (Fig. 4a)
   Distribution: Southwestern Pacific (Great Barrier Reef, New Caledonia)

Family: Cuthonidae Odhner, 1934

5. *Cuthona* Alder & Hancock, 1855 (Fig. 4f)
   Distribution: South China Sea

Family: Facelinidae Bergh, 1889

6. *Herviella affinis* Baba, 1960 (Fig. 5a)
   Distribution: northwestern Pacific Ocean,
7. *Caloria militaris* (Alder & Hancock, 1864) (Fig. 5b)
   Distribution: Indian Ocean and the southwestern Pacific Ocean
8. *Caloria indica* (Bergh, 1896) (Fig. 5c)
   Distribution: Throughout the tropical Indo-West Pacific. Indo-Pacific region
9. *Pteraeolidia semperi* (Bergh, 1870) (Fig. 5d)

Distribution: tropical Indo-Pacific region

Family: Piseinotecidae Edmunds, 1970

10. *Piseinotecus* sp. Er.Marcus, 1955**(Fig. 6a)**

Distribution: Mediterranea sea, Atlanric Ocean, Indo Pacific

Family: Samlidae Korshunova, Martynov, Bakken, Evertsen, Fletcher, Mudianta, Saito, Lundin, Schrödl & Picton, 2017

11. *Samla bicolor* (Kelaart, 1858) (Fig. 6c)

Distribution**:** widely distributed in the Indo-Pacific

Family: Flabellinidae Bergh, 1889

12. *Coryphellina rubrolineata* O'Donoghue, 1929 (Fig. 6d)

Distribution: widely distributed in the Indo-Pacific region

13. *Coryphellina exoptata* (Gosliner & Willan, 1991) (Fig. 6e)

Distribution: Indian Ocean and the western Pacific.

Family: Trinchesiidae F. Nordsieck, 1972 (Fig. 7)

14. *Trinchesia sp 1* Ihering, 1880

15. *Trinchesia sp 2* Ihering, 1880

16. *Tenellia bughaw* A. Y. Kim & Gosliner, 2024

17. *Tenellia yamasui* (Hamatani,1993)

Distribution: Red Sea, Mediterranean Sea, Indian Ocean, and the Indo-West Pacific

Suborder: Dendronotina

Family: Lomanotidae Bergh, 1890

18. *Lomanotus vermiformis* Eliot, 1908 (Fig. 6b)

Distribution**:** widely distributed in the Indo-Pacific

Family: Bornellidae Bergh, 1874

19. *Bornella stellifera* (A.Adams & Reeve, 1848) (Fig. 4b)

Distribution: Indo-Pacific region

Subclass: Heterobranchia Burmeister, 1837

Order: Nudibranchia Cuvier, 1817

Suborder: Doridina

Family: Chromodorididae Bergh, 1891

1. *Ardeadoris electra* (Rudman, 1990) (Fig. 8a)
   Distribution: Indo-West Pacific, as well as the Red Sea.
2. *Glossodoris rufomarginata* (Bergh, 1890) (Fig. 8b)
   Distribution: Tropical Indo-West Pacific
3. *Thorunna furtiva* Bergh, 1878 (Fig. 8c)
   Distribution: Found throughout the tropical western Pacific (Rudman, 1984)
4. *Mexichromis multituberculata* (Baba, 1953) (Fig. 8d)
   Distribution: Indo-Pacific
5. *Mexichromis trilineata* (A. Adams & Reeve, 1850) (Fig. 8e)
   Distribution: South China Sea and the Great Barrier Reef,
6. *Chromodoris colemani* Rudman, 1982 (Fig. 8f)
   Distribution: tropical Indo-Pacific
7. *Chromodoris annae* Bergh, 1877 (Fig. 8g)
   Distribution: tropical Indo-Pacific
8. *Chromodoris magnifica* (Quoy & Gaimard, 1832) (Fig. 8h)
   Distribution: tropical Indo-Pacific
9. *Hypselodoris obscura* (W. Stimpson, 1855) (Fig. 10a)
   Distribution: Indo Pacific - Southeastern Australia from Southern Queensland to southern New South Wales
10. *Hypselodoris apolegma* (Yonow, 2001) (Fig. 10b)
    Distribution: Western Pacific
11. *Hypselodoris bullockii* (Collingwood, 1881) (Fig. 10c)
    Distribution: Tropical western Pacific and eastern Indian Ocean
12. *Hypselodoris emma* Rudman, 1977(Fig. 10d)
    Distribution: Throughout the tropical Indo-West Pacific

13. *Hypselodoris krakatoa* Gosliner & R. F. Johnson, 1999 (Fig. 10e)

Distribution: Subtidal reefs in the western Pacific

14. *Hypselodoris decorata* (Risbec, 1928) (Fig. 10f)

Distribution: Found throughout the tropical western Pacific and Indian Oceans.

15. Hypselodoris tryoni (Garrett, 1873) (Fig. 10g)

Distribution: Tropical western pacific.

16. *Ceratosoma trilobatum* (J. E. Gray, 1850) (Fig. 10h)

Distribution: throughout the tropical and subtropical Indo-West Pacific region

17. *Goniobranchus aureopurpureus* (Collingwood, 1881) (Fig 11a)

Distribution: Tropical Western Pacific

18. *Goniobranchus coi* (Risbec, 1956) (Fig. 11b)

Distribution: Tropical Western Pacific

19. *Goniobranchus fidelis* (Kelaart, 1858) (Fig. 11c)

Distribution: Common in tropical Indo-West Pacific

20. *Goniobranchus geometricus* (Risbec, 1928) (Fig. 11d)

Distribution: Tropical Indo-West Pacific

21. *Goniobranchus tritos* (Yonow, 1994) (Fig. 11e)

Distribution: Maldives (Rudman, 1999)

22. *Goniobranchus kuniei* (Pruvot-Fol, 1930) (Fig. 11f)

Distribution: wide tropical Indo-West Pacific

23. *Goniobranchus reticulatus* (Quoy & Gaimard, 1832) (Fig. 11g)

Distribution**:** Indo-West Pacific Ocean,

24. *Goniobranchus leopardus* (Rudman, 1987) (Fig. 11h)

Distribution: Tropical West Pacific

25. *Goniobranchus kitae* (Gosliner, 1994) (Fig. 11i)

Distribution: Wester Pacific and Western Indian Ocean

Family: Phyllidiidae Rafinesque, 1814

26. *Phyllidia elegans* Bergh, 1869 (Fig.12a)

Distribution: Known from coral reef regions throughout the western Pacific and Indian Oceans including the Red Sea.

27. *Phyllidia coelestis* Bergh,1905 (Fig.12b)

Distribution: Known from the western Pacific Ocean, South China Sea, Timor Sea and across the Indian Ocean to South Africa.

28. *Phyllidia picta* PruvotFol, 1957 (Fig.12c)

Distribution: recorded from the western Pacific Ocean (Fiji, Solomons, Vanuatu, Papua New Guinea, Great Barrier Reef). Also, from Philippines, Thailand

29. *Phyllidia varicosa* Lamarck, 1801(Fig.12d)

Distribution: Throug hout the Indo-West Pacific Ocean (Kumar et al. 2011) including the central Pacific and the Red Sea

30. *Phyllidia ocellata* Cuvier, 1804(Fig.12e)

Distribution: Common throughout the tropical Indo-West Pacific Ocean, including the Red Sea.

31. *Phyllidia multifaria* Yonow, 1986 (Fig.12f)

Distribution: Southern Red Sea.

32. *Phyllidiopsis fissurata* Brunckhorst, 1993(Fig.12g)

Distribution: Known from southwestern tropical Pacific (Fiji, central Great Barrier Reef to Lord Howe Island).

33. *Phyllidiopsis shireenae* Brunckhorst, 1990 (Fig.12h)

Distribution: Tropical Indo-West Pacific.

34. *Phyllidiopsis krempfi* Pruvot-Fol, 1957(Fig.12i)

Distribution: Known from Vietnam, the Andaman Sea (eastern Indian Ocean) and Java, Indonesia, some suggest a wide Indo-West Pacific distribution

35. *Phyllidiella striata* (Bergh, 1889) (Fig. 13a)

Distribution: Known from the central and western Pacific Ocean and Indian Ocean.

36. *Phyllidiella pustulosa* (Cuvier, 1804) (Fig. 13b)

Distribution: Throughout the tropical Indo-West Pacific

37. *Phyllidiella nigra* (van Hasselt, 1824) (Fig. 13c)

Distribution: Indo-west Pacific

38. *Phyllidiella lizae* Brunckhorst, 1993(Fig. 13d)

Distribution: Indonesia Papu et al. 2020

39. *Phyllidiella annulata* (Gray, 1853) (Fig. 13e)

Distribution: Indonesia Papu et al. 2020

Family: Discodorididae Bergh, 1891

40. *Halgerda willeyi* Eliot, 1904 (Fig. 14a)

Distribution: Tropical Indo-West Pacific.

41. *Jorunna funebris* (Kelaart, 1859) (Fig. 14ab

Distribution: Tropical Indo-West Pacific.

42. *Goniobranchus aureopurpureus ramicola* M. C.Miller, 1996 (Fig. 14c)

Distribution: Indo- west Pacific Ocean

Family: Cadlinellidae Odhner, 1934

43. *Cadlinella ornatissima* (Risbec, 1928) (Fig. 14d)

Distribution: Tropical Indo-West Pacific

Family: Goniodorididae H. Adams & A. Adams, 1854

44. *Trapania darvelli* Rudman, 1987(Fig. 14e)

Distribution: Previously known only from Hong Kong,

Family: Polyceridae Alder & Hancock, 1845

45. *Nembrotha milleri* Gosliner & Behrens, 1997 (Fig. 14f)

Distribution: Tropical Western Pacific Indonesia

46. *Roboastra gracilis* (Bergh, 1877) (Fig. 14g)

Distribution: Tropical West Pacific.**Infraclass: Euthyneura**

Subterclass: Tectipleura

Superorder: Sacoglossa

Superfamily: Plakobranchoidea

Family: Costasiellidae K. B. Clark, 1984

1. *Costasiella kuroshimae* Ichikawa, 1993 (Fig. 15a)

Distribution: found near Japan, the Philippines, and Indonesia.

2. *Costasiella usagi* Ichikawa, 1993 (Fig. 15b)

Distribution: Tropical western pacific

Order: Aplysiida

Superfamily: Aplysioidea

Family: Aplysiidae Lamarck, 1809

3. Aplysia dactylomela Rang, 1828(Fig. 15c)

Distribution: Worldwide in tropical to warm temperate waters.

Order: Cephalaspidea

Superfamily: Philinoidea

Family: *Aglajidae pilsbry,* 1895 (1847)

4. *Chelidonura pallida* Risbec, 1951 (Fig. 15d)

Distribution: Known from New Caledonia and Western Australia.

5. *Chelidonura amoena* Bergh, 1905(Fig. 15f)

Distribution: Tropical western Pacific.

Family: Plakobranchidae Gray, 1840

6. *Thuridilla ratna* (Er. Marcus, 1965) (Fig. 15e)

   Distribution: Western Pacific

DISCUSSION

While peer-reviewed taxonomic literature on Malaysian nudibranchs and associated sea slugs remains sparse, citizen science data reveals a surprisingly rich regional diversity, with the iNaturalist platform recording 268 species nationwide, including 20 from the Terengganu islands. The detection of range extensions for 71 sea slug species within a limited survey timeframe further underscores that Terengganu supports a high, yet scientifically underreported, biodiversity, though detailed taxonomic and ecological documentation in formal literature remains available for only a small fraction of these taxa. In the present study, nudibranchs from the Suborder Doridina were the most well-represented group (46 species), followed by Aeolidina (14 species), Arminina (3 species), Dendronotina (2 species), and 6 species from other recognized sea slug groups (Cephalaspidea, Sacoglossa, and Aplysiida). Within Doridina, the families Chromodorididae and Phyllidiidae contributed significantly to the overall nudibranch diversity of the Terengganu islands; these dominant families, alongside Discodorididae, are globally abundant (Gosliner 1992) and highly conspicuous to divers due to the diurnal activity patterns of brightly colored groups like Phyllidiidae (Brunckhorst 1991; Cobb and Willan 2006; Gosliner et al. 2008). As indicated in Table 2, phyllidiid species are distributed across the Terengganu islands, including *Phyllidia varicosa* at a coastal breakwater in Batu Rakit, while the notable presence of *Goniobranchus kitae* at the Tok Jembal breakwater represents a significant localized record, given its initial confirmation in Northern Madagascar (Gosliner 1994) and its complete absence from nearby Malaysian island records on iNaturalist.

Conversely, families within Aeolidina and other less-represented groups were underrepresented, likely due to their small size, cryptic coloration, rarity (Gosliner and Draheim 1996; Jensen 1998, 2007), short life histories, or nocturnal lifestyles (Miller 1962; Clark 1975), emphasizing the need for increased sampling effort and extended survey periods (Chow et al. 2022). Table 3 situates these findings within a consistent global pattern: across every citizen science sea slug initiative compiled here, modest, low-cost efforts produced

disproportionate gains in documented diversity. The Galápagos Marine Reserve program, run through WhatsApp and Instagram, added 19 new records and 8 new localities for a single species while saving an estimated $13,000 in logistical costs (García-Calderón et al. 2026); Koh Tao's combination of scientific surveys and diver interviews recorded 87 species, including 25 first records for Thailand (Mehrotra and Scott 2015); and Hong Kong's dedicated reporting platform expanded the known regional fauna by 47% (Fu et al. 2026). The present study fits this pattern closely: 12 contributors using a simple Google Form recorded 71 species in five months, comparable in scale and yield to programs run through purpose-built apps and websites. This consistency across studies indicates that the choice of platform matters far less than the existence of a structured, sustained recording effort, a point directly relevant to scaling this approach elsewhere in Malaysia, where infrastructure and funding for dedicated biodiversity platforms may be limited but a simple submission channel would likely still yield comparable results. To evaluate local findings, sea slug species recorded through citizen science contributions in this study were benchmarked against regional iNaturalist occurrence records across the Philippines (532 species, 30.507 observations), Indonesia (519 species, 36,934 observations), Thailand (232 species, 4,916 observations), Singapore 158 species, 4119 observations) and Malaysia as a whole (268 nudibranch species, 4026 observations), with 33 observations of 20 species localized to Terengganu. Direct comparisons between this study and iNaturalist revealed both shared and unique taxa in Terengganu (Figure 3), demonstrating that different data sources capture distinct components of an incompletely documented fauna exemplified by *Asteronotus cespitosus* in Pulau Bidong and *Hypselodoris infucata* in Pulau Kapas, which were recorded on iNaturalist but absent from the current survey. While marine citizen science faces unique challenges regarding underwater observation and habitat accessibility compared to terrestrial systems (Smith and Nimbs 2022), successful frameworks like those by Chow et al. (2022) in Hong Kong, Garner and Oosthuizen (2023) in South Africa, and the broader Sea Slug Census (Smith and Davis 2019) demonstrate that combining public data collection with expert verification yields robust baseline datasets, monitors species relative abundance (Smith and Nimbs 2022), and aids long-term conservation monitoring.

Citizen science has proven invaluable for collecting large-scale ecological data, yet its application in marine environments remains limited by the inherent challenges of underwater observation and habitat accessibility (Smith & Nimbs 2022). Despite these hurdles, localized initiatives have successfully mapped data-poor marine taxa. For instance, Chow et al. (2022) leveraged 37 citizen scientists over 18 months to generate a comprehensive checklist of 1,400

sea slug records in Hong Kong. Similarly, Garner and Oosthuizen (2023) utilized community observations to establish critical baseline data on nudibranch diversity and bioindication in Sodwana Bay, South Africa. Programs like the Sea Slug Census further highlight how engaging everyone from recreational divers to rock-pool enthusiasts can dramatically expand the spatial and temporal scope of marine research (Smith & Davis 2019). While neighbouring regions such as Thailand (Chavanich et al. 2013) and Indonesia (Andrimida & Hermawan 2019; Undap et al. 2019) boast well-documented sea slug inventories, Malaysia's baseline biodiversity remains critically understudied. This geographical data gap can be directly addressed by mirroring successful regional models that pair citizen platforms like iNaturalist with expert verification to ensure taxonomic accuracy (Silvertown 2009; Dickinson et al. 2012; Smith & Nimbs 2022).

The present study addresses this local shortfall. Conducted over just five months, this project represents the most comprehensive checklist of sea slug species in Terengganu waters to date as an achievement made possible through community participation. By integrating the efforts of researchers, taxonomic experts, and citizen scientists, these findings advance our understanding of local nudibranch distributions and underscore the urgency of establishing long-term monitoring programs. Ultimately, scaling up these collaborative initiatives in Malaysia will not only reveal hidden biodiversity across unmapped depths but also unlock vital opportunities for regional marine conservation and habitat restoration.

CONCLUSION

This study provides the most comprehensive assessment to date of nudibranch and associated sea slugs diversity and distribution in Terengganu waters, shedding light on the richness of these understudied marine organisms. By incorporating a citizen science approach, this research not only expanded the scope of data collection but also strengthened the connection between local communities and scientific endeavours, fostering greater public engagement in marine biodiversity conservation. The findings contribute significantly to our understanding of nudibranch diversity in Malaysia and offer insights with broader relevance to regional and global marine research.

476 Sustained efforts are essential to further investigate the diversity, ecological roles, and
477 distribution patterns of nudibranchs, as well as the threats they face. Expanding surveys to
478 include unexplored benthic habitats and employing systematic, long-term citizen science
479 programs will be critical for advancing our understanding of benthic ecology in Malaysia's
480 marine ecosystems. Such efforts will not only enrich scientific knowledge but also support the
481 conservation and sustainable management of marine biodiversity in the region. By building on
482 this foundation, future research can unlock new opportunities to safeguard the health and
483 resilience of marine ecosystems.

484

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490

Statements & Declarations

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Competing Interests

The authors declare that they have no conflict of interest.

Author Contributions

NA and HB conceived and designed research. NA and HB analysed data. NA wrote the manuscript. All authors read and approved the manuscript.

Ethics approval

Ethical approval: No animal testing was performed during this study.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent to publish

The authors affirm that the citizen science participants in this study provided informed consent for publication of the images.

Sampling and field studies: The study does not contain sampling material or data from field studies.

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632

633 **Table 1**: Number of species recorded from different localities donated by contributors

Locality	No of sp Suborder: Aeolidina	No of sp Suborder: Doridida	No of sp Suborder: Arminina	No of sp Suborder: Dendronotina	No of sp Order: Aplysiida	No of sp Order: Cephalaspidea	No of sp Superorder: Sacoglossa	Total
PP	11	12	1	1	0	0	1	**26**
PB	4	34	0	1	1	2	1	**43**
PK	2	7	0	0	0	0	0	**9**
PT	2	9	0	0	0	0	0	**11**
PR	4	16	2	1	0	1	1	**25**
BR	0	1	0	0	0	0	0	**1**
TJ	0	2	0	0	0	0	0	**2**

634 Abbreviations: PP, Pulau Perhentian, PB Pulau Bidong, PK Pulau Kapas, PT Pulau Tenggol, PR Pulau Redang,
635 BR Batu Rakit, TJ Tok Jembal.

636 **Table 2** Species list and distribution of sea slugs pictures around Terengganu waters

Species	Distribution (Present study & iNaturalist)							
	PP	PB	PK	PT	PR	LT	BR	TJ
Aeolidiopsis harrietae Rudman, 1982	○							
Aplysia dactylomela Rang, 1828		◊						
Ardeadoris electra (Rudman, 1990)		◊						
Armina major Baba, 1949	◊							
Armina semperi (Bergh, 1866)					◊			
Bornella stellifera (A. Adams & Reeve, 1848)	●				◊			
Cadlinella ornatissima (Risbec, 1928)	●	◊						
Caloria militaris (Alder & Hancock, 1864)	○		●			●		
Caloria indica (Bergh, 1896)	○	◊		◊	◊	●		
Chelidonura amoena Bergh, 1905		◊	●	●	○	●		
Chelidonura pallida Risbec, 1951		◊						
Chromodoris annae Bergh, 1877		◊		●				
Chromodoris colemani Rudman, 1982		◊						
Chromodoris magnifica (Quoy & Gaimard, 1832)		○		○	○			
Coryphellina exoptata (Gosliner & Willan, 1991)	○	○	○		●			
Coryphellina rubrolineata O'Donoghue, 1929	◊			◊				
Costasiella kuroshimae Ichikawa, 1993	●	◊			◊			
Costasiella usagi Ichikawa, 1993	○							
Cuthona Alder & Hancock, 1855		●						
Dermatobranchus fortunatus (Bergh, 1888)					○			
Glossodoris rufomarginata (Bergh, 1890)	●	◊			●			
Goniobranchus aureopurpureus (Collingwood, 1881)	◊	◊						
Goniobranchus coi (Risbec, 1956)		◊		●	○			
Goniobranchus fidelis (Kelaart, 1858)	●	◊	●	●	○			
Goniobranchus geometricus (Risbec, 1928)	●	◊		●		●		
Goniobranchus leopardus (Rudman, 1987)	○	◊						
Goniobranchus kuniei (Pruvot-Fol, 1930)		○		●				
Goniobranchus kitae (Gosliner, 1994)								◊
Goniobranchus reticulatus (Quoy & Gaimard, 1832)	◊			○	◊			
Goniobranchus tritos (Yonow, 1994)		◊						
Halgerda willeyi Eliot, 1904					◊			
Herviella affinis Baba, 1960	◊							
Hypselodoris apolegma (Yonow, 2001)		◊		●				
Hypselodoris bullockii (Collingwood, 1881)	●	○			○	●		
Hypselodoris emma Rudman, 1977					◊			
Hypselodoris obscura (W. Stimpson, 1855)		◊						
Hypselodoris krakatoa Gosliner & R. F. Johnson, 1999		○			●			
Hypselodoris decorata (Risbec, 1928)		◊			◊			
Hypselodoris tryoni (Garrett, 1873)	◊							

637

Species	Distribution (Present study & iNaturalist)							
	PP	PB	PK	PT	PR	LT	BR	TJ
Ceratosoma trilobatum (J. E. Gray, 1850)			○	●	◊	●		
Jorunna funebris (Kelaart, 1859)	○	○	◊		○			
Jorunna ramicola M. C. Miller, 1996	◊							
Lomanotus vermiformis Eliot, 1908	◊	◊						
Mexichromis multituberculata (Baba, 1953)	◊					●		
Mexichromis trilineata (A. Adams & Reeve, 1850)	◊							
Nembrotha milleri Gosliner & Behrens, 1997		◊		●				
Phyllidia coelestis Bergh, 1905	●	◊	●	●	○	●		
Phyllidia elegans Bergh, 1869	○	◊	◊	◊	◊	●		
Phyllidia multifaria Yonow, 1986	◊							
Phyllidia picta Pruvot-Fol, 1957	○	◊		○	○	●		
Phyllidia ocellata Cuvier, 1804	●	●		◊	◊	●		
Phyllidia varicosa Lamarck, 1801	○	○	●	○	○	●	◊	
Phyllidiella annulata (Gray, 1853)		◊	◊	◊	◊			
Phyllidiella lizae Brunckhorst, 1993			◊					
Phyllidiella nigra (van Hasselt, 1824)		○	◊		●	●		
Phyllidiella pustulosa (Cuvier, 1804)		◊	◊	●	○	●		
Phyllidiella striata (Bergh, 1889)		◊		◊				
Phyllidiopsis fissurata Brunckhorst, 1993		◊		●				
Phyllidiopsis krempfi Pruvot-Fol, 1957		○	●					
Phyllidiopsis shireenae Brunckhorst, 1990		◊						
Piseinotecus Er. Marcus, 1954					◊			
Pteraeolidia semperi (Bergh, 1870)	○	◊	○	○	○	●		
Roboastra gracilis (Bergh, 1877)				○				
Samla bicolor (Kelaart, 1858)		◊			◊			
Thorunna furtiva Bergh, 1878	◊	◊						
Thuridilla ratna (Er. Marcus, 1965)		◊		◊	◊			
Trapania darvelli Rudman, 1987		◊						
Trinchesia sp 1 Ihering, 1880	◊							
Trinchesia sp 2 Ihering, 1881	◊							
Tenellia bughaw A. Y. Kim & Gosliner, 2024	◊				●			
Tenellia yamasui (Hamatani, 1993)	◊							

638 Indicating sea slugs found ● iNaturalist ○ Both present study & iNaturalist ◊ Present study

639 Abbreviations: *PP,* Pulau Perhentian*, PB* Pulau Bidong*, PK* Pulau Kapas, *PT* Pulau Tenggol, *PR* Pulau Redang,

640 *BR* Batu Rakit*, TJ* Tok Jembal.

641 **Table 3** Comparative Overview of Global Sea Slug Citizen Science Initiative

Location	Data Collection Methodology	Citizen Sources (Platforms)	Key Species/Count	Key Findings & Impact	Reference
Hong Kong	Online reporting platform for opportunistic sighting data from subtidal and intertidal habitats.	findseaslugshk.com, social media (FB/IG), and posters at dive shops.	1,930 validated observations; 274 species, including 121 new records for Hong Kong.	Expanded known fauna by 47%; identified offshore biodiversity hotspots (e.g., East Ninepin) for conservation priority.	Fu et al. 2026
Australia (11 locations), Indonesia, Vanuatu	Focused "bioblitz" events where participants photograph species over set spatial/temporal scales.	iNaturalist), Facebook, and project reports.	7 tropical species recorded in a 9-day census; 1st Australian record of *Hypselodoris bertschi*.	Documented significant southward range extensions driven by the East Australian Current and La Niña events.	Smith & Nimbs, 2022
California and Oregon, USA	Researchers supplement long-term timed counts with reports and images mined from the web.	iNaturalist, Flickr, OCDiving, FB (SoCal Underwater Photographers), and blogs.	30 species documented with range shifts; *Okenia rosacea* reached unprecedented northern densities.	Proved sea slugs are excellent biological indicators of regional ocean climate shifts and warm water anomalies.	Goddard et al. 2016
South Malang, East Java, Indonesia	Integration of new intertidal surveys with historical data and citizen scientist reports since 2019.	Photographs provided via personal communication.	79 total heterobranch species; 14 new records (e.g., *Hexabranchus lacer*, *Moridilla brockii*).	Provided baseline data for monitoring anthropogenic pressures like forest conversion; identified potential for "muck diving" ecotourism.	Andrimida et al. 2025

Location	Data Collection Methodology	Citizen Sources (Platforms)	Key Species/Count	Key Findings & Impact	Reference
Galápagos Marine Reserve (GMR)	Distribution of digital flyers to divers to share sightings; review of historical citizen science records.	WhatsApp, Instagram, Facebook, and iNaturalist (2018–2024).	Tyrannodoris leonis (19 new records, 8 new localities).	Updated distribution maps; documented predation on endemic Tambja mullineri; saved ~$13,000 in logistical costs.	García-Calderón et al. 2026
Koh Tao, Gulf of Thailand	Combination of scientific benthic surveys and photo records obtained from the diving community.	Social media groups and personal interviews with divers.	87 species recorded, including 25 first records for Thailand.	Revealed high biodiversity in non-reef areas; encouraged non-reef tourism to reduce pressure on threatened coral reefs.	Mehrotra & Scott, 2015
Mediterranean Sea and Red Sea	Monitoring of Lessepsian migrants through underwater photography shared with taxonomists.	Sea Slug Forum, Mediterranean Slug Site, and direct communication.	Plocamopherus ocellatus (23 unique records in non-native Mediterranean).	Demonstrated that "rarity" in the native range is likely an artifact of observer bias rather than biological fact.	Hoeksema & Yonow, 2021
Terengganu, Malaysia	12 local divers, tourists, and researchers contributed their unidentified sea slug images	Google form	71 nudibranch species (47:Doridina; Aeolidina:14; Arminina:3; Dendronotina: 2; Sacoglossans: 3; Cephalaspideans: 2; Aplysiidans:1)	Modernized marine biodiversity databases using platforms like Google Forms and social media submission. Documented many species that previously lacked proper regional documentation, and formally recorded the first occurrence of Goniobranchus kitae in coastal ecosystem.	Present study

642

Supplementary Files

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