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ORIGINAL PAPER

The contribution of Heterobranchia (Mollusca: Gastropoda) to the biodiversity of the Colombian Tropical Eastern Pacific

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Abstract

Mollusks are a very important component of the invertebrate faunal biodiversity in marine ecosystems. However, knowledge on this (and other groups) is still incomplete. Inventories of fauna are very important tools to learn the biodiversity associated with specific regions and of specific zoological groups. In this paper, I report 103 species of heterobranch mollusks occurring along the Pacific coast of Colombia, including previous peer-reviewed records and new information. Of these, 23 are new records for the Pacific coast of Colombia, and a total of 32 species are registered for the first time in at least one locality along this shore. The most species diverse family is Chromodorididae, followed by Ellobiidae. The most diverse locality is Gorgona Island, closely followed by Malpelo Island. There is still much to learn from this rather isolated region, the northern Pacific coast of the South American continent.

Keywords Mollusks · Sea slugs · Rocky shores · Intertidal · Shallow subtidal

Introduction

Marine mollusks are one of the best-known and most common invertebrate groups in the oceans. Within the mollusks, Gastropoda is the class with the highest species richness, with its approximately 70,000 described species accounting for some 85% of all the species known in this phylum (Brusca et al. 2016). Heterobranchia is one of the most species-rich groups within Gastropoda (Dinapoli and Klussmann-Kolb 2010). It has been shown that high heterobranch richness is correlated with healthy ecosystems and highly diverse communities (Kaligis et al. 2018; Undap et al. 2019). The reduction of heterobranch diversity might indicate climate changes and ecosystem deterioration (Nimbs and Smith 2018). Also, many species of heterobranchs may be potential sources of bioactive products (Fisch et al. 2017; Furfaro et al. 2020).

The Pacific coast of Colombia, one of the megadiverse countries in the world, is part of the Tumbes-Chocó-Magdalena bioregion, a well-known biodiversity hotspot (Mittermeier et al. 2004, 2011). Nevertheless, this honorific title is awarded basically due to terrestrial groups, such as plants, insects, birds, amphibians, and reptiles. In the marine realm, however, the Tropical Eastern Pacific (TEP), where the Pacific coast of Colombia is located, is relatively modest in terms of biodiversity (Costello et al. 2010). This is evidenced by, in the case of mollusks, the smaller number of newly discovered species in the TEP compared to other regions, such as the Indo-Pacific, Tropical West Atlantic, and Tropical East Atlantic (Bouchet et al. 2006). This pattern might hold for other taxa as well. Two possible reasons can be hypothesized for this fact: (1) The region has low marine biodiversity as compared to other regions, or 2) the marine biodiversity in the region is still poorly known, due to limited access and to the lack of specialists in marine biodiversity working in this part of the planet. Barber et al. (2014) emphasized that biodiversity research in developing countries faces conditions that might limit the advancement of knowledge in this paramount task. Either way, true low biodiversity or the need for more research, it is clear that many biological groups are still under-studied and that comprehensive inventories are still needed, especially in those countries where biodiversity is both poorly understood and

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endangered. Furthermore, many species of heterobranchs in the Colombian portion of the TEP tend to be numerically rare and seasonal, as has been shown for other regions in the eastern Pacific (e.g., Hermosillo 2006; Bertsch 2019) and proposed for heterobranchs in general (Schubert and Smith 2020).

The biodiversity of mollusks in certain regions of the Colombian Pacific has been assessed (e.g., Cantera K. et al. 1979; Cosel 1985; Kaiser and Bryce 2001; Lozano-Cortés et al. 2012; López de Mesa and Cantera 2015); however, the non-shelled heterobranchs have been mostly neglected. The most recent and up-to-date list of species to this group, to the best of my knowledge, is the work by Ardila et al. (2007). In their work, these authors reported 32 species of "Opisthobranchia" for the Colombian Pacific coast. In addition, field guides for the Pacific coast of the Americas, including the TEP region (Behrens and Hermosillo 2005; Camacho-Garcia et al. 2005), mention only 9 species of heterobranch sea slugs occurring in Colombia, although many others are distributed only to Panama or have a distributional gap, jumping to Ecuador and the Galápagos Islands. In a survey of the molluscan literature, I found reports of 84 species of "Lower Heterobranchia" and Heterobranchia from the Colombian Pacific region, including 18 species of Nudibranchia. Considering just the nudibranchs in each of the three biogeographical provinces of TEP, 116 species have been reported from the Cortezian province, 117 from the Mexican, and 137 from the Panamic sensu stricto (Bertsch 2010). This raised serious doubts regarding the true number of Heterobranchia species on the Colombian Pacific coast. It seemed reasonable that the true number of species for the Colombian Pacific must be higher than what is currently known. This report presents a more comprehensive species list of these amazing creatures.

Materials and methods

Study area

The Pacific coast of Colombia (Fig. 1) extends for ~ 1545 km from the border with Panama (7.2109° N; 77.8891° W) to the border with Ecuador (1.4333° N; 78.8167° W) (INVEMAR 2020). It reaches far westward into the Pacific Ocean because of Malpelo Island, located more than 470 km off the continental coast from Buenaventura Bay. The climatic and oceanographic conditions on the Colombian Pacific coast and basin vary annually and are affected by the Intertropical Convergence Zone. According to Rangel-Ch. and Arellano-P. (2004), precipitation varies annually between 3007 and 6480 mm, humidity ranges from 81.3 to 89.7% and annual mean air temperature varies between 26.1 and 27.2 °C. On the oceanic conditions, Málikov and Villegas-Bolaños (2005) reported an average sea-surface water temperature of 27.4 °C and an average sea-surface salinity of 28.1. Finally, the tidal range on the Pacific coast of Colombia revolves around 5.0 m (IDEAM 2019).

The Pacific coast of Colombia is divided into two physiographically different parts (INVEMAR 2020): a southern part (from the border with Ecuador to Cabo Corrientes) and a northern part (from Cabo Corrientes to the border with Panama). The southern part is bordered mainly by mangrove swamps, muddy flats, and sandy beaches; estuaries are also very common and large in this region. Sedimentary cliffs can be found at Isla del Gallo (in Tumaco) and Buenaventura and Málaga bays. In the northern part, the coast is mainly rocky of tectonic origin, with some pocket beaches and small mangrove forests. Rocky reefs and islets are also common in this region. Besides mangroves, muddy flats, and rocky shores, some coral reef patches and modestly developed fringing coral reefs are present in Gorgona and Malpelo Islands and Utria and Cabo Marzo on the continental shore. This variety of ecosystems provides a wide range of habitats to support a high biological diversity.

Sampling and identification

Since 2006, I have made casual records of heterobranch sea slugs during field practices of marine biology courses and field trips of research projects in five localities in the Pacific coast of Colombia (Fig. 1): Gorgona National Natural Park (Gorgona), Uramba-Bahía-Málaga National Natural Park (Málaga), Malpelo Fauna and Flora Sanctuary (Malpelo), San Pedro-Buenaventura Bay (Buenaventura), and few localities in the Chocó Department: Piñas and Cabo Marzo (Chocó). Most records were made in the intertidal (tide pools, under rocks, etc.) or snorkeling in the shallow subtidal regions of these localities. Very few were gathered during scuba dives. All species found were collected and identified alive in the field by visual examination and the use of specialized field guides (Behrens and Hermosillo 2005; Camacho-Garcia et al. 2005) and then returned to the ecosystem from which they were taken. No samples were collected for further examination in the laboratory. A recent permit has allowed some specimens of common species to be collected and stored in the Reference Marine Collection of Universidad del Valle (Biology Department).

These observations were compared with the published information assessed on heterobranch biodiversity along the Pacific coast of Colombia to generate a comprehensive list of heterobranchs. The many recent changes in the phylogeny and taxonomy that have been proposed for this group, based on studies using molecular DNA techniques and more detailed anatomical observations (Dinapoli and Klussmann-Kolb 2010; Carmona et al. 2014a, b; Valdés et al. 2018), have been incorporated into this list. These changes are

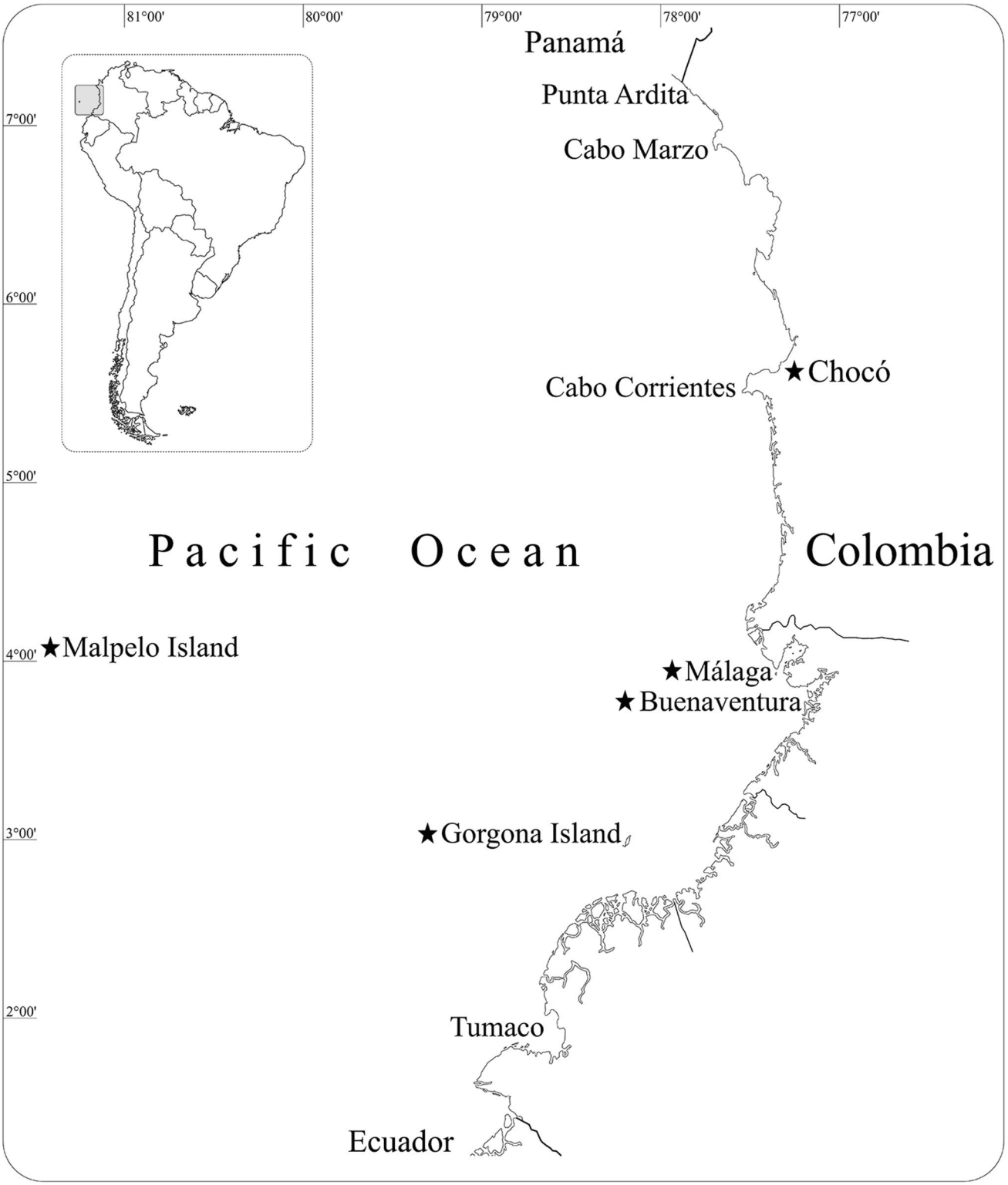

Fig. 1 The Pacific coast of Colombia (South America) with the localities mentioned in this work marked with a star. (Source: https://www.disruptivegeo.com/tag/large-scale-international-boundaries/)

shown in Table 1. Finally, Figs. 1 and 4–10 were prepared with Photoshop (Adobe Photoshop 2021) and Figs. 2 and 3 with R (R Core Team 2020).

Results

A total of 103 heterobranch species (including some species as sp.), in 40 families, are now recorded for the Pacific coast of Colombia (Table 2). From this list, only 5.8% are within the unresolved clade "Lower Heterobranchia"; the remaining 94.2% belong to Euthyneura. With 10 species, the Chromodorididae had the highest family-level richness (9.7% of all the species), followed by Ellobiidae, Pyramidellidae, and Discodoridiidae with 9, 8, and 6 species respectively. Of all the families, 19 (47.5%) are represented by only one species, 7 families are represented by two species, and 14 families are represented by 3 or more species (Fig. 2). This work reports 23 new records of heterobranch species, accounting for 22.3% of all the species now known from the Pacific coast of Colombia. The 20 species of Nudipleura account for the majority (87.0%) of these new records. The remaining

Table.1 Taxonomic changes of species (arranged in alphabetical order) in the subclass Heterobranchia reported for the Pacific coast of Colombia. References for reports: [1]Ardila et al. (2007), [2]Behrens and Hermosillo (2005), [3]Cosel (1985), [4]Kaiser and Bryce (2001), [5]López de Mesa and Cantera (2015), [6]Lozano-Cortés et al. (2012), [7]Robertson (1979)

Current name	Reported as and source
Alicalastrum exaratum	*Atys exarate*[1]
Boasia chierchiae	*Creseis virgula constricta*[4]
Bulla punctulata	*Bulla rufolabris*[1]
Chromolaichna sedna	*Glossodoris sedna*[1,2,4,6]
	Doriprismatica sedna[5]
Coryphellina marcusorum	*Flabellina marcusorum*[2]
Creseis conica	*Creseis virgula conica*[4]
Diacavolinia longirostris	*Cavolina longirostris longirostris*[4]
Diacavolinia strangulata	*Diacavolinia elegans*[4]
Dolabrifera nicaraguana	*Dolabrifera dolabrifera*[1,5,6]
Eulimastoma aff. *dotella*	*Odostomia* aff. *dotella*[3,5]
Felimida baumanni	*Chromodoris baumanni*[4]
	Glossodoris baumanni[1,2]
Felimare agassizii	*Hypselodoris agassizii*[1,2,4]
Felimare californiensis	*Hypselodoris californiensis*[5]
Felimare lapislazuli	*Hypselodoris lapislazuli*[1,4]
Felimare sechurana	*Felimare californiensis*[5,6]
Heliacus mazatlanicus	*Heliacus (Torinista) mazatlanicus*[4]
Heliconoides inflatus	*Limacina inflata*[4]
Pleurobranchus digueti	*Pleurobranchus areolatus*[1,2,4]
Psilaxis radiatus	*Philippia radiata*[3,7]
Telodiacria quadridentata	*Diacria quadridentat* [4]

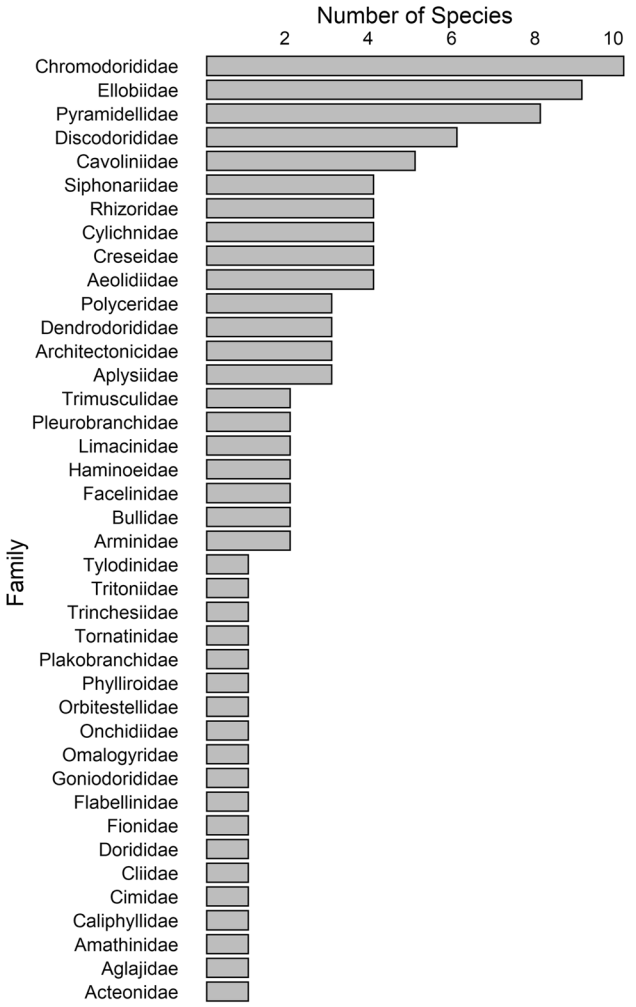

Fig. 2 Number of species in each of 41 families of Heterobranchia along the Pacific coast of Colombia

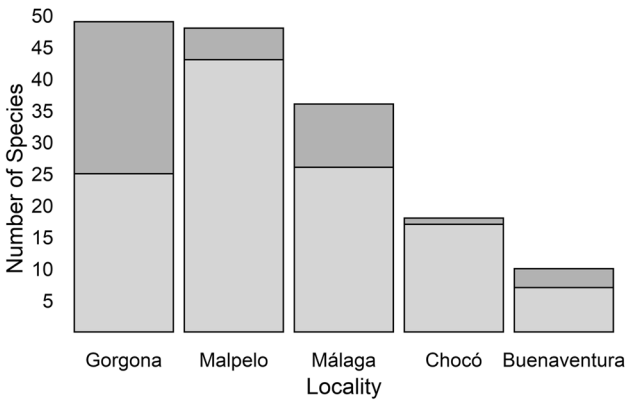

Fig. 3 Total number of species of Heterobranchia at each locality on the Pacific coast of Colombia. The number of new records for each locality is highlighted in darker grey

Table.2 List of species in the subclass Heterobranchia present in each of five localities (*GO* Gorgona, *MP* Malpelo, *MA* Málaga, *BU* Buenaventura, *CH* Chocó) of the Pacific coast of Colombia. Species that are new records for the Pacific coast of Colombia are marked with an N, and new records in a locality are marked with an O. References for occurrence: [1]Ardila et al. (2007), [2]Behrens and Hermosillo (2005), [3]Camacho-Garcia et al. (2005), [4]Cantera Kintz et al. (2011), [5]Cosel (1985), [6]Kaiser and Bryce (2001), [7]López de Mesa and Cantera (2015), [8]Lozano-Cortés et al. (2012), [9]Robertson (1979), and [10]this study

Taxa	Locality				
	GO	MP	MA	BU	CH
"Lower Heterobranchia"					
Family Architectonicidae					
Architectonica nobilis Röding, 1798[7]	X		X		
Heliacus mazatlanicus Pilsbry & H. N. Lowe, 1932[6]		X			
Psilaxis radiatus (Röding, 1798)[9]	X				
Family Cimidae					
Graphis sp. Jeffreys, 1867[6]		X			
Family Omalogyridae					
Omalogyra sp. Jeffreys, 1860[6]		X			
Family Orbitestellidae					
Orbitestella sp. Iredale, 1917[6]		X			
Euthyneura					
Acteonacea					
Cephalaspidea					
Family Acteonidae					
Acteon traskii Stearns, 1897[1]					X
Ringipleura					
Nudipleura – Pleurobranchomorpha					
Family Pleurobranchidae					
Berthellina ilisima Ev. Marcus & Er. Marcus, 1967[1,6,7,8,10]	X	X	X		X
Pleurobranchus digueti Rochebrune, 1895[1,2,6,10]	O	X			X
Nudipleura – Nudibranchia					
Family Goniodorididae					
Okenia cf. *academica* Camacho-Garcia & Gosliner, 2004[10]			N		
Family Polyceridae					
Limacia janssi (Bertsch & Ferreira, 1974)[10]	N				
Tambja eliora (Er. Marcus & Ev. Marcus, 1967)[10]		N			
Tyrannodoris leonis (Pola et al., 2005)[10]		N			
Family Discodorididae					
Diaulula aurila (Marcus & Marcus, 1967)[1]	X				
Diaulula greeleyi (MacFarland, 1909)[10]	N				
Tayuva lilacina (Gould, 1852)[1,10]	O	O			X
Geitodoris mavis (Marcus & Marcus, 1967)[10]	N		N	N	
Peltodoris lancei Millen & Bertsch, 2000[2]		X			
Peltodoris mullineri Millen & Bertsch, 2000[1,2,6]		X			
Family Doridiidae					
Doris pickensi Marcus & Marcus, 1967[10]		N	N		
Family Chromodorididae					
Felimare agassizii (Bergh, 1894)[1,6,7,10]	O	X	X	X	
Felimare californiensis (Bergh, 1879)[7,8]			X		
Felimare lapislazuli (Bertsch & Ferreira, 1974)[1,6]		X			
Felimare sp. Ev. Marcus & Er. Marcus, 1967[8]			X		
Felimida sphoni Ev. Marcus, 1971[7,10]	O		X		
Felimida baumanni (Bertsch, 1970)[1,2,6,10]	O	X	O		
Chromolaichma dalli (Bergh, 1879)[10]	N				
Chromolaichma sedna (Ev. Marcus & Er. Marcus, 1967)[1,2,6,7,8,10]	O	X	X		O
Mexichromis antonii (Bertsch, 1976)[10]	N				
Mexichromis tura (Marcus & Marcus, 1967)[10]			N		

Table.2 (continued)

Taxa	Locality				
	GO	MP	MA	BU	CH
Family Dendrodoridídae					
Dendrodoris albobrunnea Allan, 1933[1,3,6]		X			
Dendrodoris fumata (Rüppell & Leuckart, 1830)[1,2,10]	O	X	O		
Doriopsilla janaina Er. Marcus & Ev. Marcus, 1967[10]	N				
Nudipleura – Dendronotida					
Family Tritoniidae					
Marionia cf. *kinoi* Angulo-Campillo & Bertsch, 2013[10]	N	N			
Family Phylliroidae					
Phylliroe sp. Péron & Lesueur, 1810[6]		X			
Nudipleura – Arminida					
Family Arminidae					
Armina californica (J. G. Cooper, 1863)[1]				X	
Armina sp. Rafinesque, 1814[10]	N				
Nudipleura – Aeolidida					
Family Flabellinidae					
Coryphellina marcusorum (Gosliner & Kuzirian, 1990)[2]		X			
Family Aeolidiidae					
Bulbaeolidia sulphurea Caballer & Ortea, 2015[10]	N				
Anteaeolidiella chromosoma (Cockerell & Eliot, 1905)[10]			N	N	
Limenandra confusa Carmona, Pola, Gosliner & Cervera, 2014[10]	N				
Spurilla braziliana MacFarland, 1909[10]	N				
Family Facelinidae					
Favorinus elenalexiae Garcia F. & Troncoso, 2001[10]	N				
Phidiana lascrucensis Bertsch & Ferreira, 1974[10]	N		N	N	
Family Fionidae					
Fiona pinnata (Eschscholtz, 1831)[10]	N				
Family Trinchesiidae					
Phestilla lugubris (Bergh, 1870)[1,2,6, 0]	O	X			
Tectipleura					
Euopisthobranchia – Umbraculida					
Family Tylodinidae					
Tylodina fungina Gabb, 1865 [1, 6, 10]	X	X	O		
Euopisthobranchia – Aplysiomorpha					
Family Aplysiidae					
Dolabella auricularia (Lightfoot, 1786)[10]	N				
Dolabrifera nicaraguana Pilsbry, 1896[1,7,8,10]	X		X	X	X
Stylocheilus rickettsi (MacFarland, 1966)[10]	N				
Euopisthobranchia – Pteropoda					
Family Cavoliniidae					
Diacavolinia longirostris (Blainville, 1821)[6]		X			
Cavolinia uncinata (d'Orbigny, 1835)[6]		X			
Diacavolinia strangulata (Deshayes, 1823)[6]		X			
Telodiacria quadridentata (Blainville, 1821)[6]		X			
Diacria sp. J.E. Gray, 1840[6]		X			
Family Cliidae					
Clio sp. Linnaeus, 1767[6]		X			
Family Creseidae					
Creseis acicula (Rang, 1828)[6]		X			
Boasia chierchiae (Boas, 1886)[6]		X			

Table.2 (continued)

Taxa	Locality				
	GO	MP	MA	BU	CH
Creseis conica Eschscholtz, 1829[6]		X			
Creseis virgula (Rang, 1828)[6]		X			
Family Limacinidae					
Heliconoides inflatus (d'Orbigny, 1835)[6]		X			
Limacina trochiformis (d'Orbigny, 1835)[6]		X			
Euopisthobranchia – Cephalaspidea					
Family Aglajidae					
Navanax aenigmaticus (Bergh, 1893)[1,6,7,10]	X	X	X		X
Family Bullidae					
Bulla gouldiana Pilsbry, 1895[1,5,7]	X		X	X	
Bulla punctulata A. Adams in Sowerby, 1850[5,7,10]	X		X	X	X
Family Rhizoridae					
Volvulella catharia Dall, 1919[1]	X				X
Volvulella cylindrica (Carpenter, 1864)[1]	X				X
Volvulella panamica Dall, 1919[1]					X
Volvulella sp. Newton, 1891[1]	X				X
Family Tornatinidae					
Acteocina carinata (Carpenter, 1857)[1]	X				X
Family Haminoeidae					
Aliculastrum exaratum (Carpenter, 1857)[1]	X				
Atys sp. Montfort, 1810[5]	X				
Family Cylichnidae					
Cylichnella defuncta F. Baker & Hanna, 1927[1]					X
Cylichnella goslineri Valdés & Camacho-Garcia, 2004[1]	X				X
Cylichnidae sp. 1 H. Adams & A. Adams, 1854[6]		X			
Cylichnidae sp. 2 H. Adams & A. Adams, 1854[6]		X			
Panpulmonata – Sacoglossa					
Family Plakobranchidae					
Elysia diomedea (Bergh, 1894)[1,7,8,10]	X	X	X		X
Family Caliphyllidae					
Polybranchia mexicana Medrano, Krug, Gosliner, Biju Kumar & Valdés, 2018[10]			N		
Panpulmonata – Pulmonata					
Family Amathinidae					
Iselica sp. Dall, 1918[6]		X			
Family Pyramidellidae					
Herviera gliriella (Melvill & Standen, 1896)[6]		X			
Odostomia aff. *clathratula* (C. B. Adams, 1852)[7]			X		
Eulimastoma aff. *dotella* (Dall & Bartsch, 1909)[7]			X		
Odostomia sp. 1 J. Fleming, 1813[6]		X			
Odostomia sp. 2 J. Fleming, 1813[6]		X			
Odostomia sp. 3 J. Fleming, 1813[6]		X			
Odostomia sp. 4 J. Fleming, 1813[6]		X			
Turbonilla sp. Risso, 1826[6,7]		X	X		
Family Ellobiidae					
Detracia graminea J. P. E. Morrison, 1946[7]	X		X		
Detracia zeteki Pilsbry, 1920[7]	X		X		
Ellobium stagnale (d'Orbigny, 1835)[7]	X		X		
Marinula concinna (C. B. Adams, 1852)[7]			X		

Table.2 (continued)

Taxa	Locality				
	GO	MP	MA	BU	CH
Melampus carolianus (Lesson, 1842)[7]			X		
Melampus olivaceus Carpenter, 1857[7]			X		
Melampus tabogensis (C. B. Adams, 1852)[5]	X				
Pedipes liratus Binney, 1860[7]			X		
Pedipes unisulcatus Cooper, 1866[7]			X		
Family Trimusculidae					
Trimusculus peruvianus (G. B. Sowerby I, 1835)[5]	X				
Trimusculus stellatus (G. B. Sowerby I, 1835)[6]		X			
Family Onchidiidae					
Onchidella binneyi Stearns, 1894[4,10]			X		
Family Siphonariidae					
Siphonaria gigas G. B. Sowerby I, 1825[5,7]	X		X	X	X
Siphonaria maura G. B. Sowerby I, 1835[7]	X		X	X	X
Siphonaria palmata Carpenter, 1857[5]	X				
Williamia peltoides (Carpenter, 1864)[6]		X			

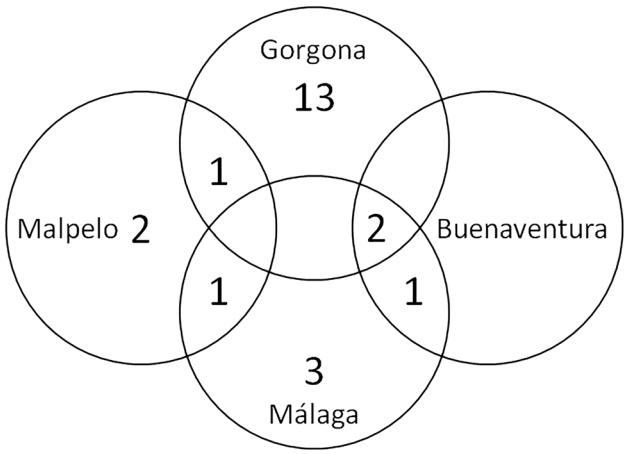

Fig. 4 Venn diagram showing the distribution of the 23 species recorded for the first time on four localities of the Pacific coast of Colombia

belong to the clades Euopistobranchia (2 species) and Panpulmonata (1 species).

At the five localities, Gorgona showed the highest species richness, followed by Malpelo and Málaga. Chocó with 18 and Buenaventura with 10 species showed the lowest richness. Forty nine percent of all the species recorded for Gorgona are new records. The ratio of new to total records decreased as follows: Buenaventura 30.0%, Málaga 27.8%, Malpelo 10.4%, and Chocó 5.6% (Fig. 3). From the 23 new records of Heterobranch species for the Colombian Pacific, 13 species were exclusive to Gorgona, 3 species to Málaga, and 2 species to Malpelo. *Phidiana lascrucensis* and *Geitodoris mavis* were common to Gorgona, Málaga, and Buenaventura; *Marionia* cf. *kinoi* was common to Gorgona and Malpelo; *Doris pickensi* was common to Malpelo and Málaga; and *Anteaeolidiella chromosoma* was common to Málaga and Buenaventura (Fig. 4). In addition to the 23 new records, another 9 species were recorded for the first time in at least one of the five localities; hence, 32 new records are reported (i.e., 31.1% of the 103 species).

Since the start of my data collection (ca. 12 years ago), the 23 new species reported for the Pacific coast of Colombia and the 32 new records for at least one locality along this coast render an annual average of new records of heterobranch sea slugs of 1.9 and 2.7 respectively. However, no special effort on heterobranch sea slugs sampling or collecting was implemented. It is important to mention that no quantitative species abundance studies on heterobranchs (such as those by Hermosillo 2006 and Bertsch 2019) have been undertaken on the Pacific coast of Colombia. Based on my experiences, the most common and abundant species are *Elysia diomedea*, *Dolabrifera nicaraguana*, and *Berthellina ilisima*, although there are other common but not abundant species (Figs. 5 and 6a–c).

Species comments

Each new record for the Pacific coast of Colombia (i.e., 23 species) constitutes a range extension or fills a gap in the distribution of a species; hence, it is commented in short below. For pictures of these species, see Figs. 6, 7, 8, 9 and 10. All pictures were taken by the author except when otherwise stated.

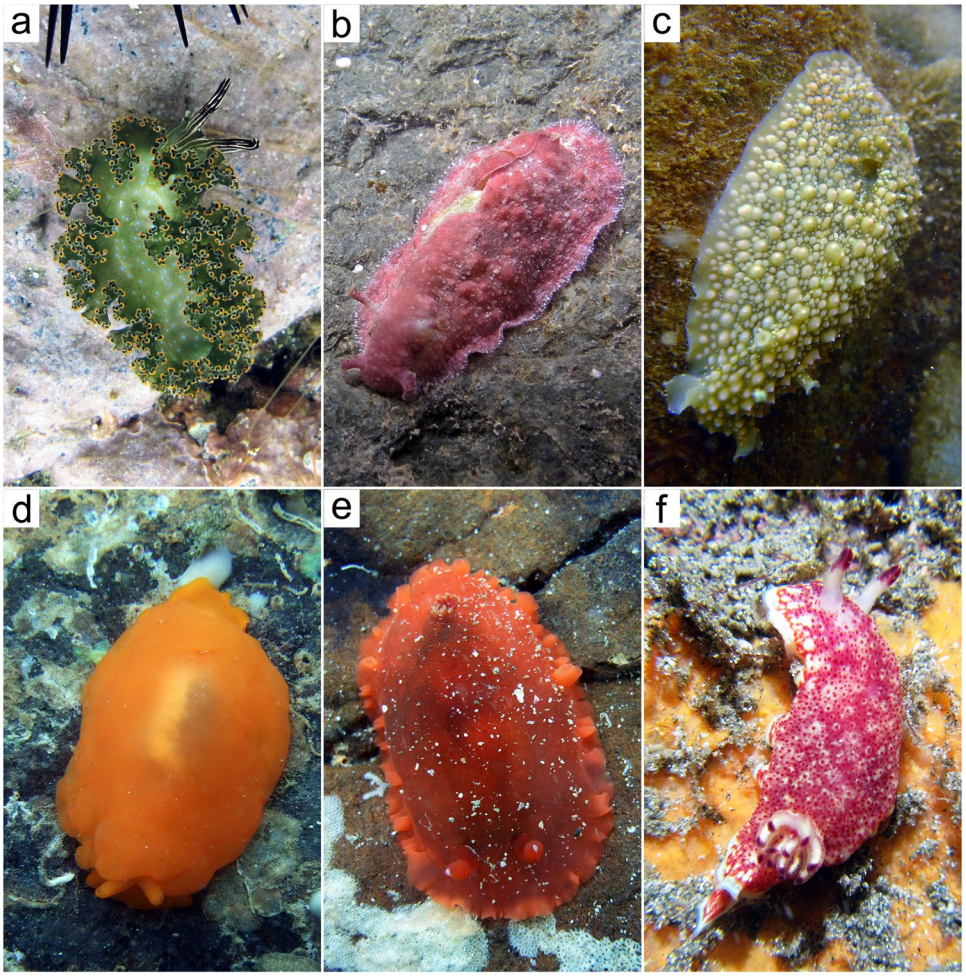

Fig. 5 Some heterobranch sea slugs from the Pacific coast of Colombia: **a** *Elysia diomedea*, **b**,**c** *Dolabrifera nicaraguana*, **d** *Berthellina ilisima*, **e** *Dendrodoris fumata*, **f** *Felimida baumanni*. These species are ranked in descending order of commonness

Nudibranchia

Okenia cf. *academica* Camacho-Garcia & Gosliner, 2004. There are 8 species reported for the TEP (Camacho-García and Gosliner 2004; Behrens and Hermosillo 2005). From these, only *O. angelensis* is distributed from the Gulf of California to Chile, so it could potentially be present in the Colombian Pacific. The southern limit for the remaining 7 species is Costa Rica, with most occurring in the Gulf of California. Camacho-García and Gosliner (2004) described a new species, namely, *O. academica*. The specimen reported here is relatively similar to this species: The body is milky translucent with yellow tips on the dorsal appendages and sides of the gills, and the rhinophores are bright white (Fig. 6d). The specimen was recorded from Málaga; this extends the southern range by more than 800 km.

Limacia janssi (Bertsch & Ferreira, 1974). Uribe et al. (2018) report four species for the eastern Pacific. Only one species (*L. antofagastensis*) is known from the southern hemisphere. The only tropical species is *L. jansii* (Fig. 6e), known to occur from the southern Gulf of California to Panamá, so the record from Gorgona constitutes the southernmost record for this species and extends it for almost 480 km.

Tambja eliora (Er. Marcus & Ev. Marcus, 1967). Camacho-Garcia et al. (2005) report three species of *Tambja*, two (*T. abdere* and *T. eliora*) distributed from the Gulf of California to Costa Rica and one (*T. mullineri*) endemic to the Galápagos Islands. This record (Fig. 6f) from Malpelo extends the distribution of this species almost 550 km southward.

Tyrannodoris leonis (Pola et al., 2005). This species was originally described as *Roboastra leonis* for the Galápagos Islands, but Pola et al. (2005) mention the existence of an illustration of a similar animal from La Paz (Gulf of California). There is also a record from Costa Rica (http://slugsite.us/bow/nudwk517.htm). The specimen (Fig. 7a) recorded at Malpelo confirms its presence in the TEP and fills a gap in its distribution.

Diaulula greeleyi (MacFarland, 1909). This species is known from the Atlantic (Florida, Brazil, and South Carolina) and Pacific (Punta Eugenia, Baja California and Nayarit, Mexico to Panama) coasts of the Americas

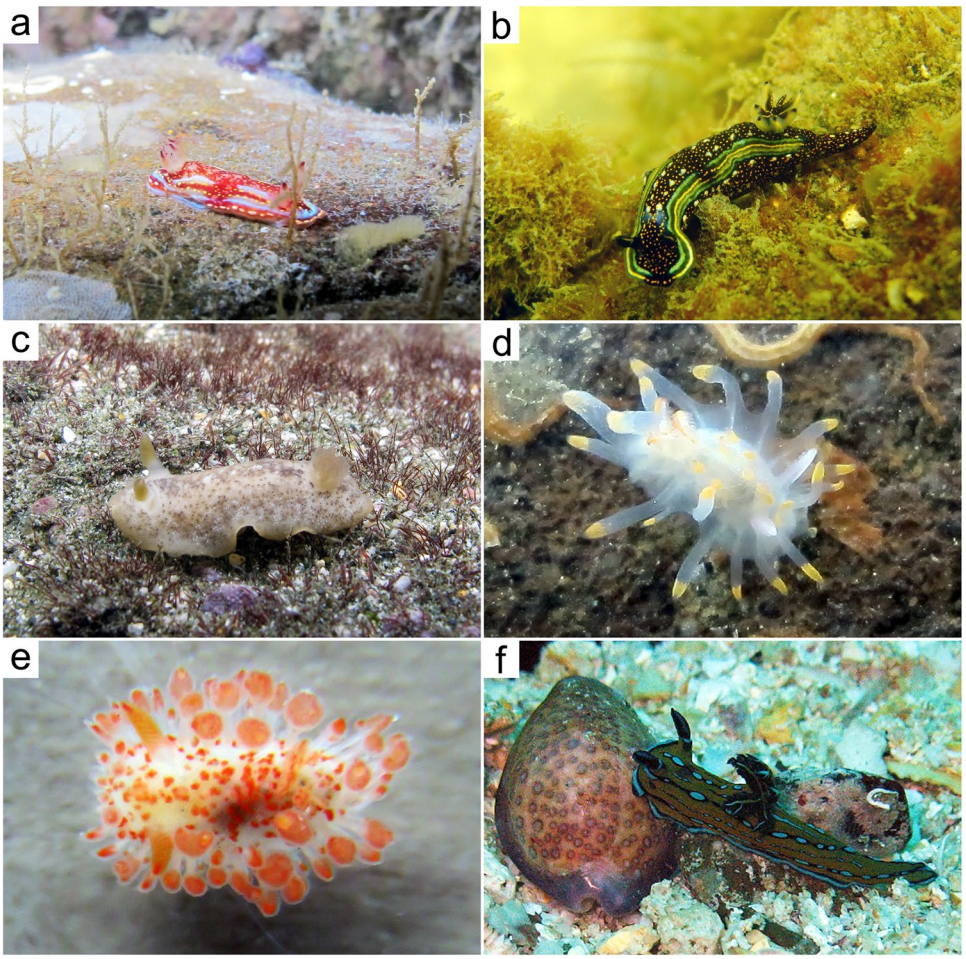

Fig. 6 Heterobranch sea slugs from the Pacific coast of Colombia: **a** *Felimida sphoni*, **b** *Felimare agassizii*, **c** *Tayuva lilacina*, **d** *Okenia* cf. *academica*, **e** *Limacia janssi*, **f** *Tambja eliora*. Species (**d**) to (**f**) are new records in this coast. Picture 6f credit to J.F. Lazarus-Agudelo

(Camacho-Garcia et al. 2005). This record (Fig. 7b) from Gorgona is the southernmost on the eastern Pacific for this species, increasing its geographic range by almost 480 km southward.

Geitodoris mavis (Marcus & Marcus, 1967). Camacho-García et al. (2005) report this species from Mexico, Costa Rica, and the Galapagos Islands. The specimens from Gorgona, Málaga, and Buenaventura are lighter in color than the one depicted in the Field guide to the sea slugs of the tropical eastern Pacific; however, the white line on the gill sheath (Fig. 7c) leaves no doubt on the identification. This record fills a gap in the distribution of the species along the TEP.

Doris pickensi Marcus & Marcus, 1967. Behrens and Hermosillo (2005) report 5 Dorid species for the TEP. In a redescription of the species, Camacho-Garcia and Gosliner (2008) confirm the presence of this species from the Gulf of California to Costa Rica. The specimens from Malpelo and Málaga reported here were small (ca. 4 mm) and almost uniform lemon-yellow (Fig. 7d). These records are the southernmost for this species and extend its geographic range to 700–800 km to the southeast of the Pacific ocean.

Chromolaichma dalli (Bergh, 1879). Bertsch (1978) reports this species from Baja California and Costa Rica. It is also known from Panamá and the Galápagos Islands (Behrens and Hermosillo 2005; Camacho-Garcia et al. 2005). This record (Fig. 7e) from Gorgona fills a gap in the distribution range of this species in the TEP.

Mexichromis antonii (Bertsch, 1976). Bertsch (1978) reports this species from Baja California, the Gulf of California, Colima (México), and Costa Rica. Behrens and Hermosillo (2005) and Camacho-Garcia et al. (2005) also include Panamá. This record (Fig. 7f) from Gorgona extends the geographic range by almost 480 km southward.

Mexichromis tura (Marcus & Marcus, 1967). Bertsch (1978) reports this species from La Paz, Nayarit (México) and Panamá. This record (Fig. 8a) from Málaga extends the geographic range of this species by almost 400 km southward.

Doriopsilla janaina Er. Marcus & Ev. Marcus, 1967. This species is known from the Gulf of California down to Panamá and in the Galápagos (Behrens and Hermosillo 2005). Hence, the record (Fig. 8b) from Gorgona fills a gap in its distribution along the TEP.

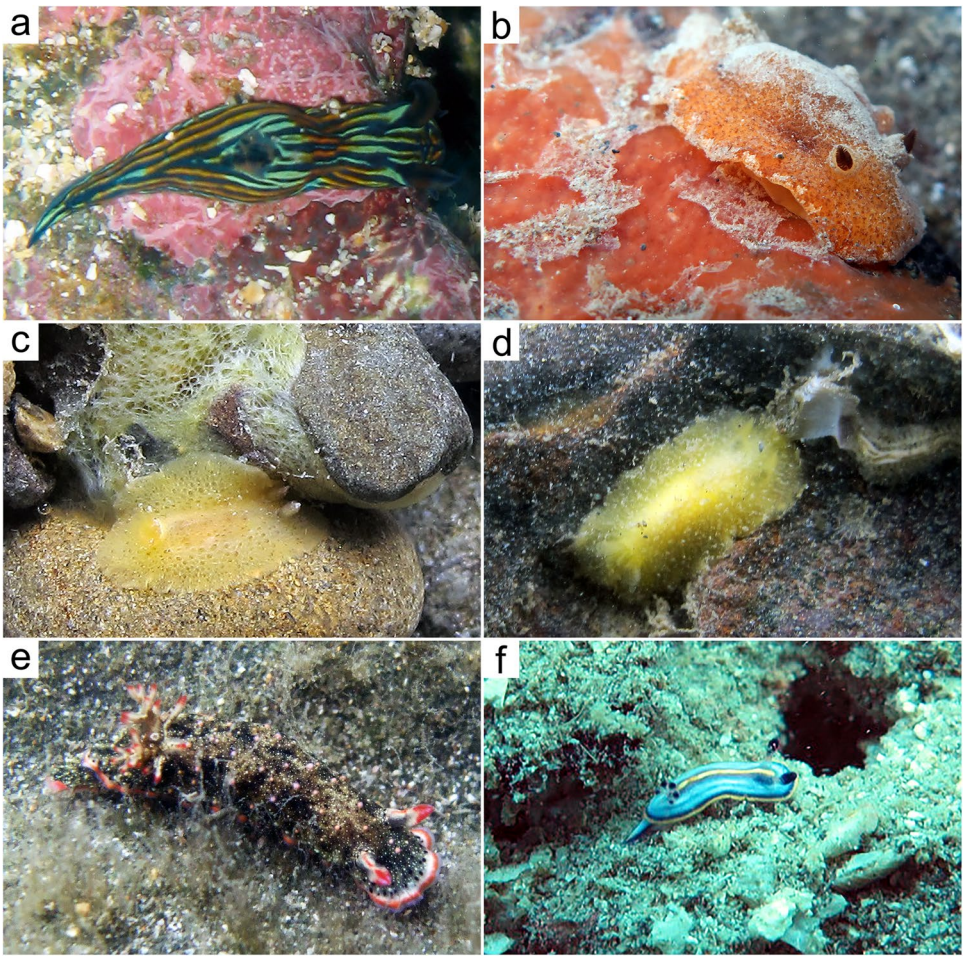

Fig. 7 New records of heterobranch sea slugs from the Pacific coast of Colombia: **a** *Tyrannodoris leonis*, **b** *Diaulula greeleyi*, **c** *Geitodoris mavis*, **d** *Doris pickensi*, **e** *Chromolaichma dalli*, **f** *Mexichromis antonii*. Picture 7a credit to J.F. Lazarus-Agudelo

Dendronotida

Marionia cf. *kinoi* Angulo-Campillo & Bertsch, 2013. Angulo-Campillo and Bertsch (2013) report only two species of *Marionia* in the eastern Pacific: *M. kinoi* and *Marionia* sp. *M. kinoi* has been reported throughout the Mexican Pacific, Costa Rica, Panamá, and the Galápagos Islands (Angulo-Campillo and Bertsch 2013). The unnamed species is known only from Isla Isabel (México) (Behrens and Hermosillo 2005). According to Bertsch (pers. comm.), the photographed specimens from Gorgona and Malpelo (Fig. 8c) do not resemble *M. kinoi* or *Marionia* sp.; hence, this could be a third species from the TEP, but more studies need to be done.

Arminida

Armina sp. Rafinesque, 1814. In a revision of the genus *Armina*, Báez et al. (2011) report three species for the eastern Pacific, one unnamed. From these, *A. californica* is distributed from Alaska to Panamá and Perú, *A. cordellensis* from central California, and *Armina* sp. from Baja California. The specimen recorded at Gorgona is unlike any of the preceding species (Fig. 8d). It was very small (ca. 2–3 mm) with a white-yellowish background with longitudinal reddish stripes.

Aeolidida

Bulbaeolidia sulphurea Caballer & Ortea, 2015. Carmona et al. (2017) report this species from the Galápagos Islands and the Pacific coast of Panama, Costa Rica, and El Salvador. This record (Fig. 8e) from Gorgona fills a gap in the distribution of this species along the TEP.

Anteaeolidiella chromosoma (Cockerell & Eliot, 1905). Carmona et al. (2013) report this species from México. With these records from Málaga and Buenaventura, there is a considerable extension (ca. 4800 km southeast) in range distribution along the eastern Pacific for this species (Fig. 8f).

Limenandra confusa Carmona, Pola, Gosliner & Cervera, 2014. This species is known in the eastern Pacific from the Midway Islands, Hawaii, Mexico, Gulf of California, and Costa Rica (Bertsch 1972; Carmona et al. 2014b). This

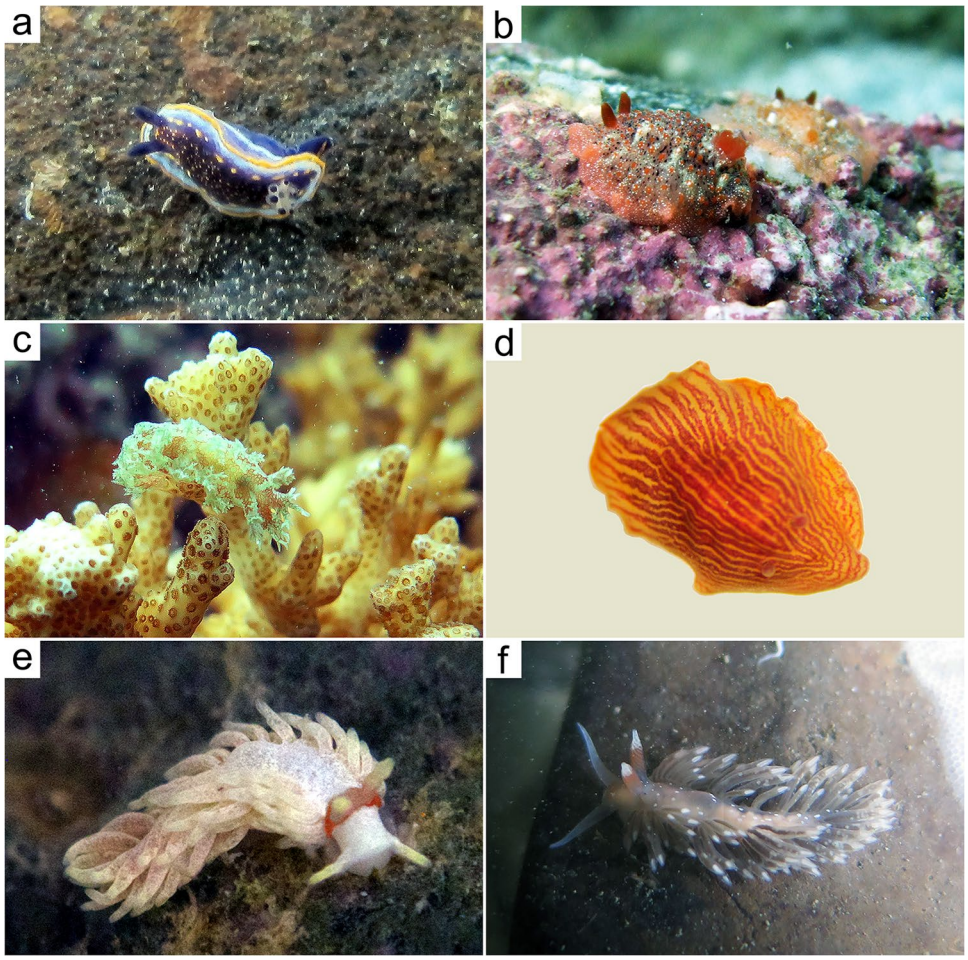

Fig. 8 New records of heterobranch sea slugs from the Pacific coast of Colombia: **a** *Mexichromis tura*, **b** *Doriopsilla janaina*, **c** *Marionia* cf. *kinoi*, **d** *Armina* sp., **e** *Bulbaeolidia sulphurea*, **f** *Anteaeolidiella chromosoma*

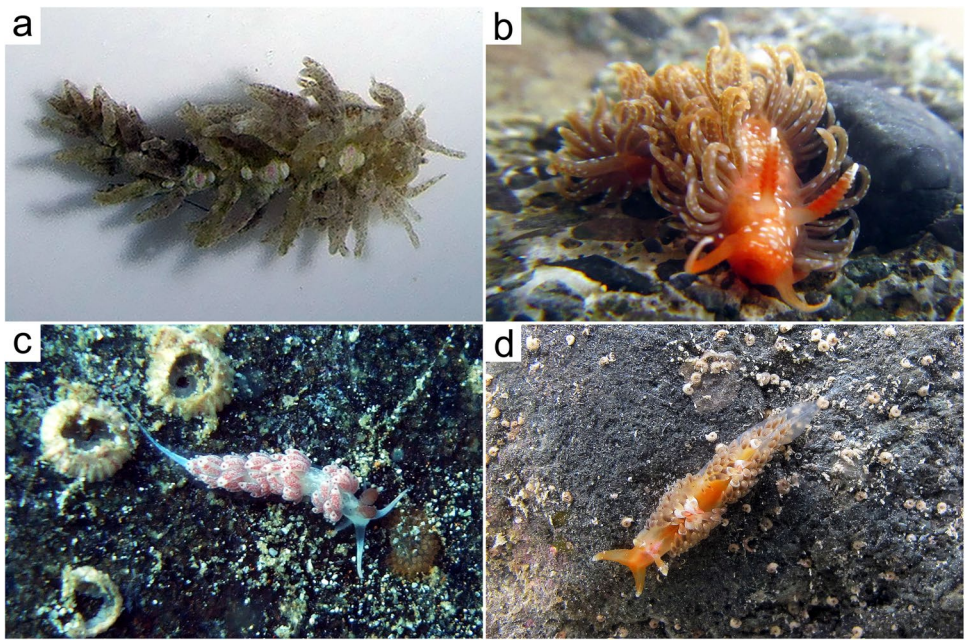

Fig. 9 New records of heterobranch sea slugs from the Pacific coast of Colombia: **a** *Limenandra confusa*, **b** *Spurilla braziliana*, **c** *Favorinus elenalexiae*, **d** *Phidiana lascrucensis*

Fig. 10 New records of heterobranch sea slugs from the Pacific coast of Colombia: **a** *Fiona pinnata*, **b** *Dolabella auricularia*, **c** *Stylocheilus rickettsi*, **d** *Polybranchia mexicana*

record (Fig. 9a) from Gorgona extends the distribution of the species by almost 480 km southward in the TEP.

Spurilla braziliana MacFarland, 1909. Carmona et al. (2014a) mention that in the eastern Pacific, this species has been reported from Costa Rica and Peru. This record (Fig. 9b) from Gorgona fills a gap in the distribution range of this species. The previous authors also report this species from the Colombian Caribbean, so this record confirms its presence on both coasts of Colombia.

Favorinus elenalexiae Garcia F. & Troncoso, 2001. Garcia and Troncoso (2001) report this species from the Gulf of California, Costa Rica, Panamá, and the Galápagos Islands. This record (Fig. 9c) from Gorgona fills a gap in the distribution of this species in the TEP.

Phidiana lascrucensis Bertsch & Ferreira, 1974. Bertsch and Ferreira (1974) report this species from Baja California to Costa Rica, Behrens, and Hermosillo (2005), and Camacho-García et al. (2005) add Panamá to its distribution range. The records (Fig. 9d) from Gorgona, Malaga, and Buenaventura, apart from showing the relative commonness of the species, extend its distribution range 400 km southward.

Fiona pinnata (Eschscholtz, 1831). This species is widely distributed, perhaps due to its natural history: drifting on floating objects. According to Behrens and Hermosillo (2005), it is cosmopolitan in northern seas. However, this Gogona record is, perhaps, the southernmost record for the species on the TEP (Fig. 10a).

Aplysiomorpha

Dolabella auricularia (Lightfoot, 1786). The records of this species are unclear, Camacho-García et al. (2005) report it for the tropical Pacific, while Behrens and Hermosillo (2005) consider it circumtropical. This species (Fig. 10b) is common (at night) on the Gorgona coral reef's backreef and reef slope; during daylight, they have been found hiding in coral rubble.

Stylocheilus rickettsi (MacFarland, 1966). Behrens and Hermosillo (2005) and Camacho-García et al. (2005) report *S. striatus* for the TEP. However, Bazzicalupo et al. (2020) resurrect *S. rickettsi* as the species for the eastern Pacific. They examined specimens from southern Baja California (México), Costa Rica, and Panamá. Although there are no records from other localities (e.g. the Galápagos Islands), they propose a distributional range from Baja California to the Galápagos Islands. Hence, the records (Fig. 10c) from Gorgona could either be the southernmost record or fill a gap in its distribution along the TEP.

Sacoglossa

Polybranchia mexicana Medrano, Krug, Gosliner, Biju Kumar & Valdés, 2018. Medrano et al. (2019) noted that this species had been recorded from southern Baja California to the Galápagos Islands in the eastern Pacific, as *P. viridis*. In their revision of the genus, they propose *P. mexicana* as new species restricted to the eastern Pacific. This record (Fig. 10d) from Gorgona fills a distributional gap for the species in the TEP.

Discussion

Knowing how many species occur in any given region, ecosystem, or community is a monumental task, which can be challenging and elusive (Pimm 2012). But understanding

such local patterns of biodiversity is essential to any management and conservation priorities. Human welfare depends upon the biodiversity of healthy ecosystems (Duarte 2000; Naeem et al. 2002; Benedetti-Cecchi 2006; Loreau and de Mazancourt 2013). On a global scale, across all phyla, figures regarding the number of species are even more difficult to obtain and compare (Bouchet et al. 2006; Mora et al. 2011; Appeltans et al. 2012). Different techniques and attempts (Gotelli and Colwell 2001; Foggo et al. 2003; Smith 2005; Fisher et al. 2015) have been implemented. There are several components to deal with. First, geographical: how many species occur within a given locality. Second, taxonomic: correctly identifying the species and describing new taxa. Third, functional: determine the roles played by each species, and their abundances and relative contributions. There is still a lot of work that needs to be done, both regionally and globally. The results of this investigation confirm that conclusion.

There is a relatively long history of Heterobranch research in certain regions of the eastern Pacific (Bertsch 2020); consequently, the diversity of this group is well known; however, this is not the case for the Colombian coast. Our knowledge of the marine fauna of the Colombian Pacific has a complex history. The area has endured a long period of isolation and accessibility restrictions (including security issues). Any inventories of the fauna and flora are still incomplete. Even the records of some species must be taken with caution, as the correct identification of species and distributional records can be inaccurate. Hopefully, this report, although far from complete, provides reliable data based on previous reports of peer-reviewed papers and information de novo.

The Chocó department shoreline is almost half of the entire Colombian Pacific coast. It runs for 3.1711° in latitude (more than 352 km). In this paper, there is only one new record from the Chocó northern littoral, *Chromolaichma sedna* at Cabo Marzo. The shoreline of Chocó is mostly rocky, an ecosystem ideal for many species of sea slugs. More research efforts in this region should increase the number of known species. Gorgona and Málaga are perhaps the most studied localities along the Pacific coast of Colombia, but heterobranch sea slugs, as inferred from the literature, have been overlooked. Malpelo is a very remote island, and logistic (and economic) restrictions hinder research in that locality. Although Buenaventura (where the major western port of Colombia is located) is the most accessible locality, the ecosystems there are mostly muddy flats, mangroves, and limestone cliffs, and the water has very low visibility and salinity. These are not the preferred habitats for most heterobranchs, especially the nudibranchs.

Most heterobranch species are small (less than 1 cm) and sometimes cryptic animals and can be overlooked in sampling efforts. More rigorous investigations will likely yield many more species.

The information in classical faunal compendia that encompass broad geographical regions (e.g., Keen 1971) suggests that more species are present in the Colombian Pacific. Many species have been reported both north and south of Colombia; their presumed presence here should be documented with further studies. Species reported only from Panamá or Ecuador may also be expected to occur in the Colombian littoral. Hence, one can expect a list of species longer than the one presented here. Colombian TEP marine biodiversity is not as huge as other regions in the world, but it certainly is much larger than currently known as demonstrated in this paper with this group of mollusks and warrants our continued investigation.

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Declarations

Conflict of interest The author declares no competing interests.

Ethical approval No animal testing was performed during this study.

Sampling and field studies All necessary permits for sampling and observational field studies were obtained by the author from the competent authorities and are mentioned in the acknowledgements, if applicable. The study is compliant with CBD and Nagoya protocols.

Data availability All available data, including pictures, is included in the manuscript.

Author contribution Identification of samples, treatment of results, preparation, and writing of the whole paper were performed by the author.

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