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The molluscan fauna (gastropods and bivalves) and notes on environmental conditions of two adjoining protected bays in Puerto Princesa City, Palawan, Philippines

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Abstract
With the rising pressure of urbanization to biodiversity, this study aimed to obtain baseline information on species richness of gastropods and bivalves in two protected bays (Turtle and Binunsalian) in Puerto Princesa City, Philippines before the establishment of the proposed mega resort facilities. A total of 108 species were recorded, (19 bivalves and 89 gastropods). The list includes two rare miters, seven recently described species and first record of *Timoclea imbricata* (Veneridae) in Palawan. Threatened species were not encountered during the survey suggesting that both bays had been overfished. Turtle Bay had very low visibility, low coral cover, substantial signs of ecosystem disturbances and shift from coral to algal communities. Although Binunsalian Bay had clearer waters and relatively high coral cover, associated fish and macrobenthic invertebrates were of low or no commercial values. Upon the establishment and operations of the resort facilities, follow-up species inventories and habitat assessment are suggested to evaluate the importance of private resorts in biodiversity restoration.

Keywords: Binunsalian Bay, bivalves, gastropods, Palawan, species inventory, Turtle Bay

1. Introduction
Gastropods and bivalves are among the most fascinating groups of molluscs that for centuries have attracted hobbyists, businessmen, ecologists and scientists among others from around the globe. Gastropods and bivalves with high economic importance are widely cultivated [1, 2]. Pearl oyster culture and pearl farming is a multi-million dollar industry [3, 4]. Some species (e.g. *Tectus niloticus*) used in the production of pearl buttons had been transplanted outside their natural range of distribution [5, 6], while efforts to restore the populations of overharvested species are widely undertaken [7-10] to satisfy the rapidly increasing demands in the global market.

Ecologically, the importance of molluscs cannot be underestimated. Grazing gastropods can control ephiphytic and macro algal bloom [11-15]. Under laboratory condition, 20,000 juveniles of hatchery produced gastropod *Tectus (Trochus) niloticus* of 4 – 7 mm in diameter can consume sessile diatoms covering an area of 6.5 m^2 within a week [16]. Bivalves as filter feeders can help purify silted marine waters [17].

Although molluscs are of huge importance to the ecosystem and the society, not much is known about the gastropods and bivalves of Turtle and Binunsalian Bays in Puerto Princesa City, Province of Palawan, the Philippines. Both bays were declared as marine sanctuaries by the City Government of Puerto Princesa in 1992 [18], but uncontrolled fishing activities could have heavily impacted its molluscan fauna, a similar case for many paper marine sanctuaries in the country [19].

Both bays are the proposed sites of a world class resort that any disturbance during the construction stage and operational phase may have a long term effect on the composition and abundance of these species. This study which sought to document the species richness of molluscs (gastropods and bivalves) and provide notes on ecological conditions of Turtle and Binunsalian Bays may serve as basis in proposing relevant conservation measures and could be used as baseline in monitoring the impacts of any management interventions.

2. Materials and Methods

The study was conducted in Turtle and Binunsalian Bays, Puerto Princesa City, Palawan, Philippines (Figure 1). There was a reconnaissance survey on 23 June 2014 to have a clear picture of each site in terms of habitat and presence of gastropods and bivalves. Examined areas during the reconnaissance period were limited to shallow habitats with corals and seaweeds. Between 27 June – 1 July 2014, night sampling activities at different sites were conducted by dredging at sandy-rubble and muddy habitats. During sampling, a fish finder was used to avoid dredging over coral reefs and sea grass beds which can both damage the dredge and the reef ecosystems. Total dredging time was 12 h in Turtle Bay and 6 h in Binunsalian Bay. The obtained samples were identified based on various references [20-23]. We sought the opinions of experts in confirming the identities of some tentatively identified species.

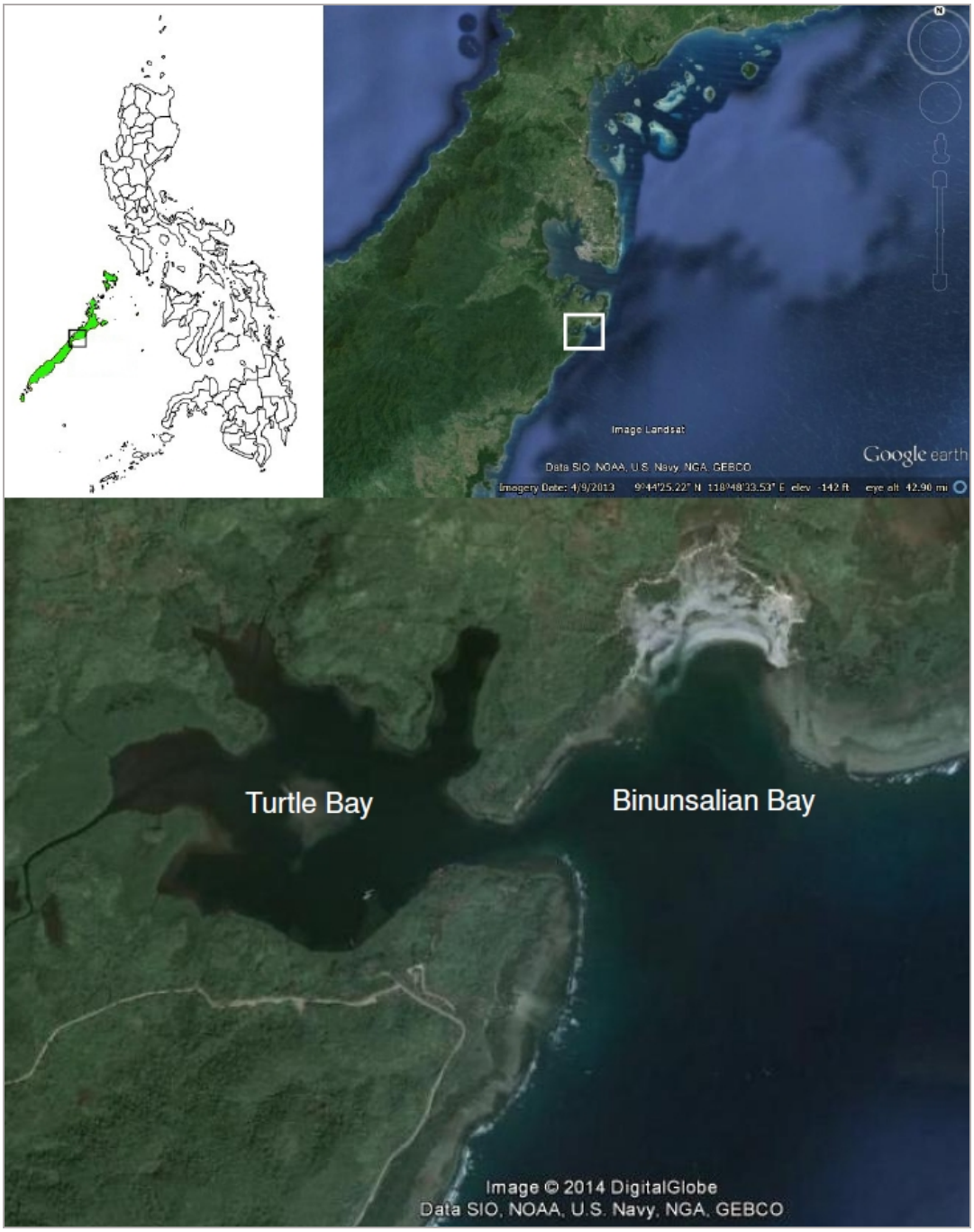

Fig 1: The sampling sites in Turtle and Binunsalian Bays in Palawan, Philippines (source: Google Earth).

3. Results and Discussion

3.1. Species Richness

A total of 108 species of bivalves and gastropods were recorded in Turtle and Binunsalian Bays. Of these, 19 species were bivalves belonging to nine families (Table 1, Figure 2). A total of 89 gastropod species belonging to 24 families were also recorded (Table 2, Figures 3-6).

The number of bivalve species in Turtle Bay is higher (17 species) than in Binunsalian Bay (3 species). Such high

number could be associated with the turbid waters of Turtle Bay which supply the required food of bivalves plus an added benefit of concealment from shellfish collectors. However, out of 19 bivalve species, only four (21%) are utilized as food. Notably, a few large (~20 cm) *Atrina vexillum* (Pinnidae), *Chama lazarus* (Spondylidae), *Decatopecten radula* (Pectinidae) and *Maleus maleus* (Isognomonidae) were noted within Turtle Bay. Only the *Timoclea costellifera* (Veneridae) occurred in both bays.

As for gastropods, only 27 species were recorded in Turtle Bay while 65 species in Binunsalian Bay. In spite of such high number, only six (6.7%) of the 89 gastropod species are utilized for local consumption. These commercially exploited species were also low in numbers. Only one or two individuals per commercially exploited species were encountered during the survey. Only three gastropod species: *Canarium urceus* (Strombidae), *Vexillum exasperatum* (Costellariidae) and *Monetaria moneta* (Cypraeidae) occurred in both bays.

Taking into account the total number (108 species) of bivalve and gastropod species, lesser number (42 or 39%) were recorded in Turtle Bay than in Binunsalian Bay (64 or 59%). Such could be related to the wide sandy area in Binunsalian Bay which directly faces the open sea.

Table 1: List of bivalves encountered in Turtle (TB) and Binunsalian (BB) Bays, Puerto Princesa City, Palawan, Philippines.

Bivalves				
Family	**No.**	**Species**	**TB**	**BB**
Arcidae	1	*Anadara uropigimelana* (Bory St. Vincent, 1824)	✓	
Isognomonidae	2	*Isognomon isognomum* (Linnaeus, 1758)	✓	
	3	*Malleus malleus* (Linnaeus, 1758)	✓	
Mytilidae	4	*Septifer excisus* (Weigmann, 1837)	✓	
Pectinidae	5	*Decatopecten radula* (Linnaeus, 1758)	✓	
	6	*Juxtamusium coudeini* (Bavay, 1903)		✓
	7	*Bractechlamys vexillum* (Reeve, 1853)		✓
Pinnidae	8	*Atrina vexillum* (Born, 1778)	✓	
Spondylidae	9	*Chama lazarus* Linnaeus, 1758	✓	
Tellinidae	10	*Tellin* sp1 (white)	✓	
	11	*Tellin* sp2 (red)	✓	
Veneridae	12	*Fulvia subquadrata* Vidal & Kirkendale, 2007	✓	
	13	*Fulvia colorata* Vidal & Kirkendale, 2007	✓	
	14	*Lioconcha fastigiata* (G. B. Sowerby II, 1851)	✓	
	15	*Vasticardium elongatum enode* (G. B. Sowerby II, 1840)	✓	
	16	*Timoclea costellifera* (Adams & Reeve, 1850)	✓	✓
	17	*Paphia textile* (Gmelin, 1791)	✓	
	18	*Timoclea imbricata* (G. B. Sowerby II, 1853)	✓	
Corbulidae	19	*Corbula tunicata* Reeve, 1843	✓	
Subtotal	19		17	3
Percentage			89	16

Table 2: List of gastropods encountered in Turtle (TB) and Binunsalian (BB) Bays, Puerto Princesa City, Palawan, Philippines.

Gastropoda				
Family	**No.**	**Species**	**TB**	**BB**
Acteonidae	20	*Pupa affinis* (A. Adams, 1855)		✓
Buccinidae	21	*Phos vandenberghi* (Fraussen & Poppe, 2005)		✓
	22	*Pollia fumosa* (Dillwyn, 1817)	✓	
Bullidae	23	*Bulla vernicosa* (Gould, 1859)		✓
Cancellariidae	24	*Scalptia articularis* (G. B. Sowerby I, 1832)		✓
Cerithidae	25	*Rhinoclavis aspera* (Linnaeus, 1758)		✓
	26	*Rhinoclavis longicaudata* (A. Adams & Reeve, 1850)	✓	
Columbellidae	27	*Mitrella floccata hanleyi* (Deshayes, 1863)		✓
Conidae	28	*Conus arenatus* Hwass, in Bruguiere, 1792		✓
	29	*Conus magus* Linnaeus, 1758		✓
	30	*Conus thalassiarchus* G. B. Sowerby I, 1834		✓
	31	*Conus quercinus* [Lightfoot], 1786		✓
	32	*Conus eburneus* Hwass in Bruguière, 1792		✓
	33	*Conus tessulatus* Born, 1778		✓
Costellariidae	34	*Vexillum amandum* (Reeve, 1845)	✓	
	35	*Vexillum angustissimum* (E. A. Smith, 1903)		✓
	36	*Vexillum collinsoni* (A. Adams, 1864)		✓
	37	*Vexillum coronatum* (Helbling, 1779)		✓
	38	*Vexillum dilectissimum* (Melvill & Sykes, 1899)		✓
	39	*Vexillum exasperatum* (Gmelin, 1791)	✓	✓
	40	*Vexillum formosense* (G. B. Sowerby III, 1889)	✓	
	41	*Vexillum gruneri* (Reeve, 1844)	✓	
	42	*Vexillum michaui* (Crosse & P. Fischer, 1864)	✓	
	43	*Vexillum pelaezi* Poppe, Tagaro & Salisbury, 2009		✓

	44	*Vexillum perrieri* (Dautzenberg, 1929)		✓
	45	*Vexillum scitulum* (A. Adams, 1853)		✓
	46	*Vexillum spicatum* (Reeve, 1845)		✓
	47	*Vexillum vibex* (A. Adams, 1853)	✓	
	48	*Vexillum virgo* (Linnaeus, 1767)	✓	
	49	*Vexillum xenium* Pilsbry, 1921		✓
Cypraeidae	50	*Erosaria labrolineata* (Gaskoin, 1849)		✓
	51	*Palmadusta contaminata contaminata* (Sowerby I, 1832)		✓
	52	*Palmadusta ziczac* (Linnaeus, 1758)		✓
	53	*Purpuradusta gracilis* (Gaskoin, 1849)	✓	
	54	*Monetaria moneta* (Linnaeus, 1758)	✓	✓
	55	*Cypraea tigris* (Linnaeus, 1758)	✓	
	56	*Lyncina vitellus* (Linnaeus, 1758)	✓	
Epitoniidae	57	*Epitonium alata* (Sowerby II, 1844)	✓	
Haminoeidae	58	*Atys naucum* (Linnaeus, 1758)		✓
	59	*Aliculastrum cylindricum* (Helbling, 1779)		✓
Mitridae	60	*Domiporta carnicolor* (Reeve, 1844)		✓
	61	*Domiporta filaris* (Linnaeus, 1771)		✓
	62	*Imbricaria conularis* (Lamarck, 1811)	✓	
	63	*Imbricaria olivaeformis* (Swainson, 1821)		✓
	64	*Mitra maesta* (Reeve, 1845)		✓
	65	*Scabricola alabaster* (Sowerby, 1900)		✓
	66	*Scabricola ocellata* (Swainson, 1831)		✓
	67	*Ziba bacillum* (Lamarck, 1811)		✓
	68	*Ziba verrucosa foveolata* (Dunker, 1863)		✓
Muricidae	69	*Hexaplex cichoreum* (Gmelin, 1791)	✓	
	70	*Drupella margariticola* (Broderip, in Broderip & Sowerby, 1833)		✓
Nassariidae	71	*Nassarius gemmuliferus* (A. Adams, 1852)	✓	
	72	*Nassarius bicallosus* (E. A. Smith, 1876)	✓	
	73	*Nassarius coronatus* (Bruguière, 1789)	✓	
	74	*Nassarius* sp.	✓	
Naticidae	75	*Natica buriasiensis* Récluz, 1844		✓
	76	*Mammilla melanostoma* (Gmelin, 1791)		✓
	77	*Tectonatica venustula* (Philippi, 1851)	✓	
	78	*Eunaticina papilla* (Gmelin, 1791)	✓	
Olividae	79	*Oliva carneola* (Gmelin, 1791)		✓
	80	*Olivella fulgurata* A. (Adams & Reeve, 1850)		✓
Pyramidellidae	81	*Syrnola fasciata* (Jickeli, 1882)		✓
Ranellidae	82	*Ranularia gutturnia* (Röding, 1798)		✓
Strombidae	84	*Canarium erythrinum* (Dillwyn, 1817)		✓
	85	*Canarium urceus* (Linnaeus, 1758)	✓	✓
	86	*Conomurex luhuanus* (Linnaeus, 1758)		✓
	87	*Dolomena pulchella* (Reeve, 1851)		✓
	88	*Dolomena variabilis* (Swainson, 1820)		✓
	89	*Euprotomus bulla* (Röding, 1798)		✓
	90	*Lambis lambis* (Linnaeus, 1758)	✓	
	91	*Lentigo pipus* (Röding, 1798)		✓
	92	*Terebellum terebellum* (Linnaeus, 1758)		✓
	93	*Terestrombus fragilis* (Röding, 1798)	✓	
	94	*Varicospira crispata* (G. B. Sowerby II, 1842)	✓	
Terebridae	95	*Hastulopsis pertusa* (Born, 1778)		✓
	96	*Hastulopsis suspensa* (E. A. Smith, 1904)		✓
	97	*Myurella kilburni* (R. D. Burch, 1965)		✓
	98	*Strioterebrum arabellum* (Thiele, 1925)		✓
	99	*Terebra funiculata* (Hinds, 1844)		✓
	100	*Terebra subulata* (Linnaeus, 1767)		✓
Trochidae	101	*Rossiteria pseudonucleolus* (Poppe, Tagaro & Dekker, 2006)		✓
	102	*Monilea belcheri* (Philippi, 1849)		✓
	103	*Jujubinus geographicus* Poppe, Tagaro & Dekker, 2006		✓
	104	*Pseudominolia tramieri* Poppe, Tagaro & Dekker, 2006		✓
Turridae	105	*Lophiotoma leucotropis* (A. Adams & Reeve, 1850)		✓
	106	*Lophiotoma acuta* (Perry, 1811)		✓
Vassidae	107	*Vasum tubiferum* (Anton, 1838)	✓	
Xenophoridae	108	*Xenophora cerea* (Reeve, 1845)		✓
Subtotal	89		27	65
			30	73
TOTAL	108		44	68
Percentage			41	63

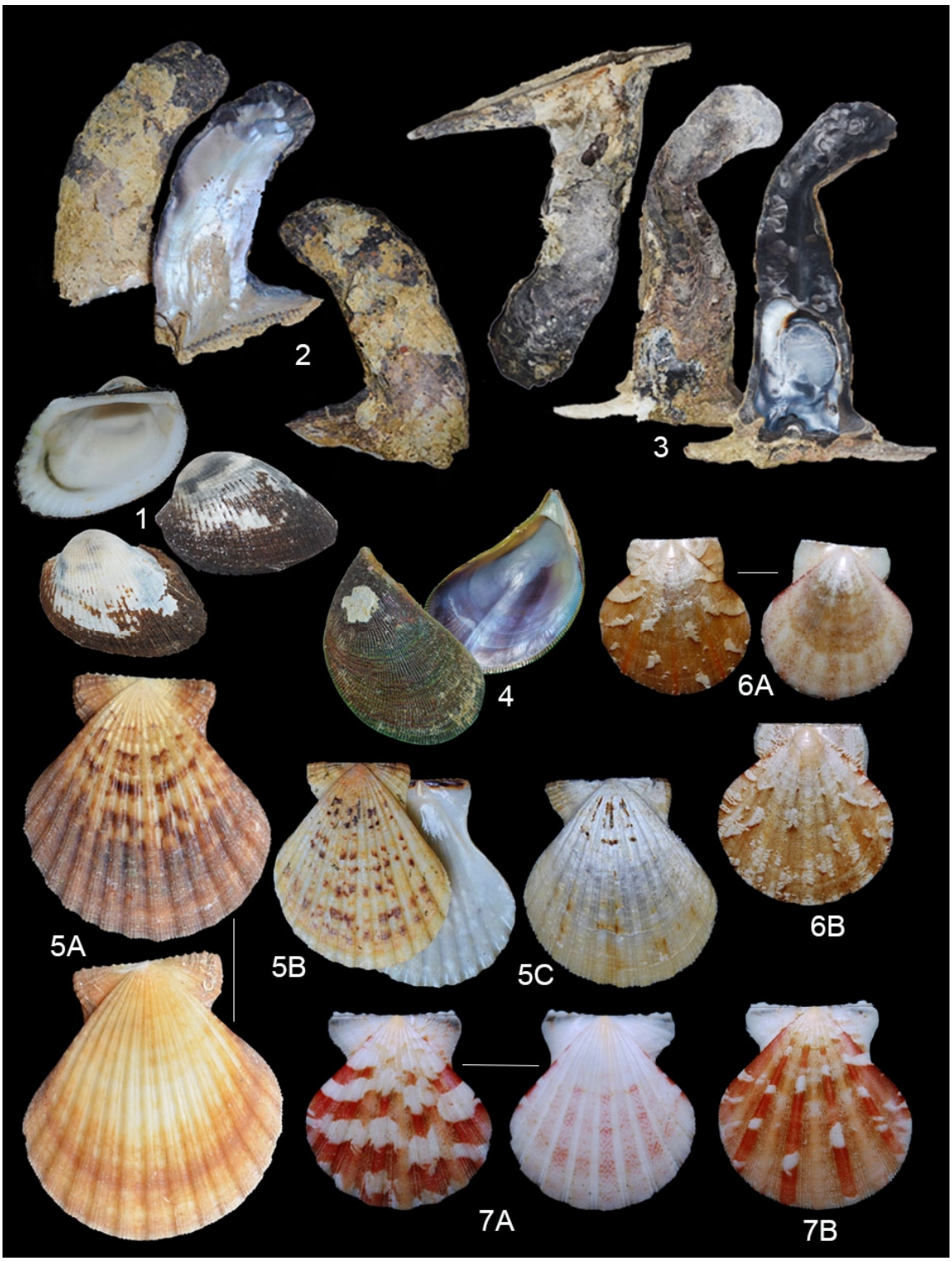

Fig 2: The bivalves of Turtle and Binunsalian Bays. 1. *Anadara uropigimelana,* 2. *Isognomon isognomum,* 3. *Maleus maleus,* 4. *Septifer excisus,* 5. *Decatopecten radula,* 6. *Juxtamusium coudeini,* 7. *Bractechlamys vexillum.*

The finding of the rare species *Timoclea imbricata* (Veneridae) in Turtle Bay, and *Vexillum vibex* and *Scabricola alabaster* (Mitridae) in Binunsalian Bay implies the presence of unique niches in both bays and the potential use of these species as ecological indicators. This is also the first record of *T. imbricata* in Palawan. In addition, the list includes seven species that have been only described between 2005 and 2009: *Fulvia subquadrata, Fulvia colorata* (Veneridae); *Phos vandenberghi* (Buccinidae); *Vexillum pelaezi* (Costellariidae); *Rossiteria pseudonucleolus, Jujubinus geographicus, Psudominolia tramieri* (Trochidae) (Tables 1 and 2). Such continued discovery is suggesting that many species are yet unknown to science. The number of species in the current list is expected to increase with continued exploration and documentation of gastropods and bivalves in both bays.

The combined number of species (108 species) from Turtle and Binunsalian Bays were higher than those recorded from the mangrove and estuarine (65 species) areas of Iwahig River [24] but fewer compared with the more than 200 species in offshore Tubbataha Reefs [25]. Unregulated harvesting can

significantly affect the population of harvested species. For example, poaching in Tubbataha Reefs had significantly reduced the populations of the reef gastropod *Tectus* (*Trochus) niloticus* [26, 27]. In Iwahig River, the abundance of the mangrove clam *Polymesoda erosa* is lower in open accessed areas compared to areas under the jurisdiction of the Iwahig Penal Farm [28]. In Turtle and Binunsalian Bays, the reefs appeared to have been stripped with commercially important macrobenthic invertebrates. Threatened species such as giant clams, topshells, sea cucumbers, tritons and helmet conchs were not encountered, suggesting a relatively low abundance in the area. With such low number of commercially important gastropods and bivalves (10 species or 9.3% of the total species), it is clear that both bays were overfished [29], and shares the same condition of the so many paper marine sanctuaries in the country [19]. This justifies the need to strengthen/revise the conservation schemes employed following the declaration of both bays as marine sanctuary more than two decades ago.

Fig 3: The bivalves of Turtle and Binunsalian Bays. 8. *Atrina vexillum*, 9. *Chama lazarus*, 10. *Tellin* sp. 1 (white), 11. *Tellin* sp. 2 (red) 12. *Fulvia subquadrata*, 13. *Fulvia colorata*.

3.2. Notes on Environmental Conditions

The water in Turtle Bay was generally turbid (~1-3 m visibility) making it difficult to find the molluscs during the reconnaissance survey. Dredging was difficult at the inner shallow areas having deep muddy substrate. Such could be due to soil erosion from the surrounding agricultural sloping fields and inadequate water exchange because of small bay opening. Hard coral cover at the reef crest was generally low (~10%). There were lots of broken coral colonies and patches of rubble. This condition could have been caused by anchors of fishing boats that seek shelter during the day and in times of bad weather. There appears a high nutrient load as manifested by many coral colonies being gradually overtaken by green algae such as *Halimeda* spp. and *Caulerpa* spp. There were also some bleached corals. By contrast, Binunsalian Bay had clearer (~5-8 m visibility) water possibly because of its rocky-sandy coastline and wide opening which directly flushes the silted water towards the Sulu Sea. Live coral cover was high (~50%) yet devoid of commercially important fishes, gastropods, bivalves and echinoderms. Not a single rock boring giant clams were noted suggesting high level of exploitation. Giant clams, topshells and other macrobenthic reef invertebrates can be very visible in successfully managed protected areas [9, 30, 31].

Measures to rehabilitate the damaged reefs [32] to restore the lost ecological and economic values [33] must be set in place. To hasten the recovery of lost species, reintroduction maybe considered as the first option [5, 6, 10, 34, 35]. The restoration of biodiversity through effective partnership among the local government units, private entities and academe [9, 36-38] can benefit the adjacent open accessed areas through spill-over effects [39-41].

Fig 4: The bivalves of Turtle and Binunsalian Bays. 14. *Lioconcha fastigiata,* 15. *Vasticardium elongatum enode,* 16. *Timoclea costellifera*.

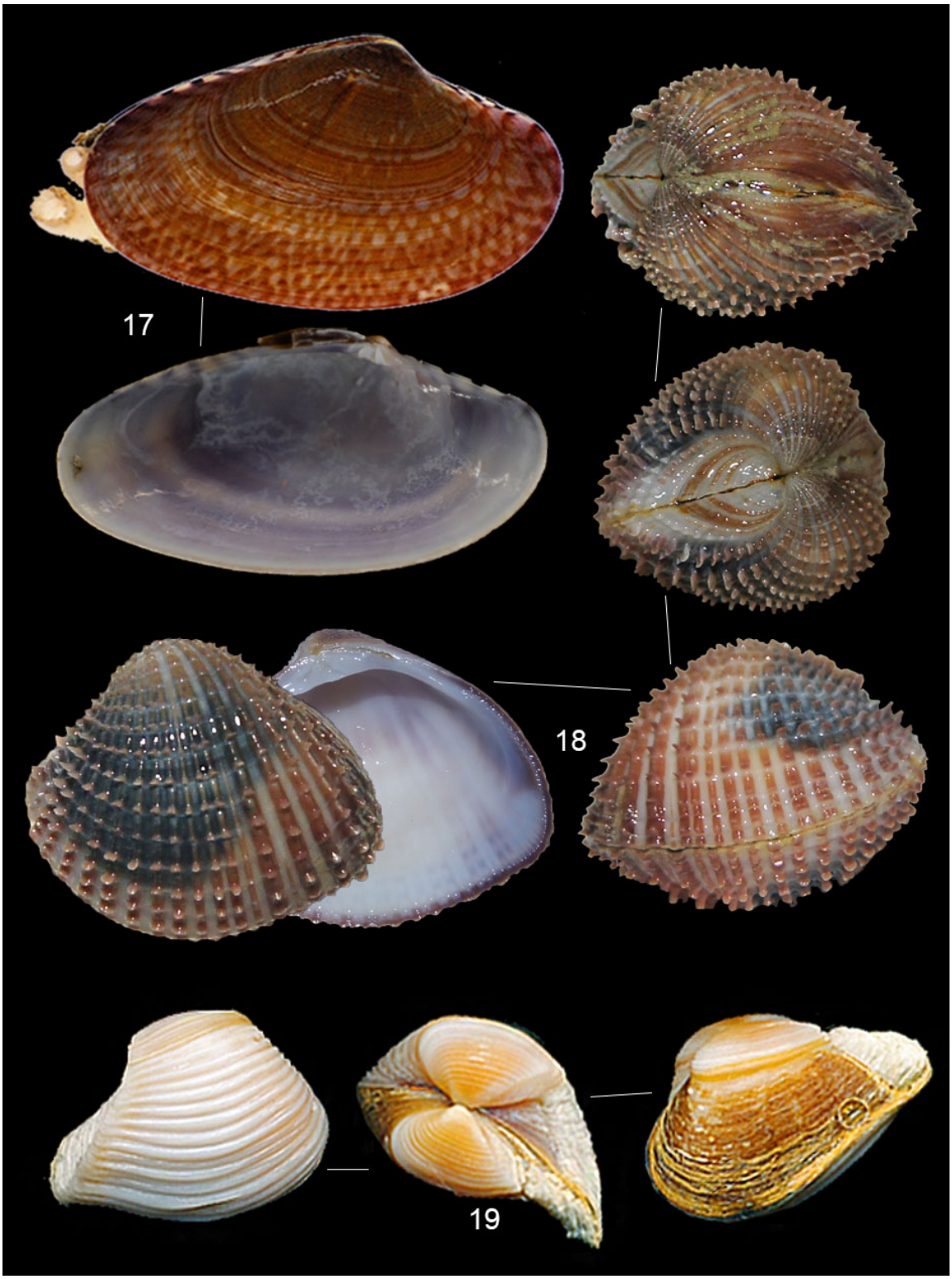

Fig 5: The bivalves of Turtle and Binunsalian Bays. 17. *Paphia textile*, 18. *Timoclea imbricata*, 19. *Corbula tunicata*.

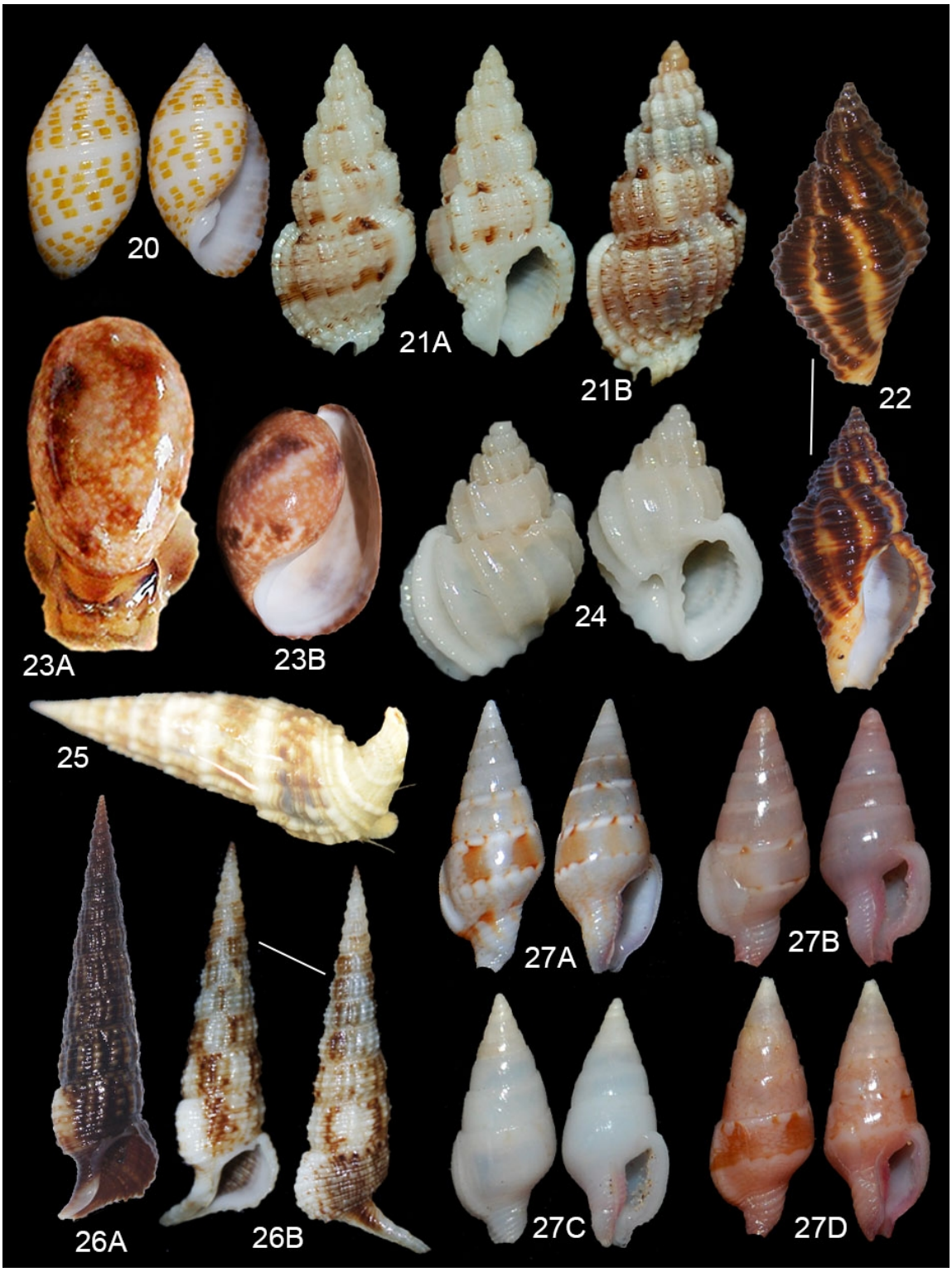

Fig 6: The gastropods of Turtle and Binunsalian Bays. 20. *Pupa affinis*, 21. *Phos vandenberghi*, 22. *Pollia fumosa*, 23. *Bulla vernicosa*, 24. *Scalptia articularis*, 25. *Rhinoclavis aspera*, 26. *Rhinoclavis longicaudata*, 27. *Mitrella floccata hanleyi.*

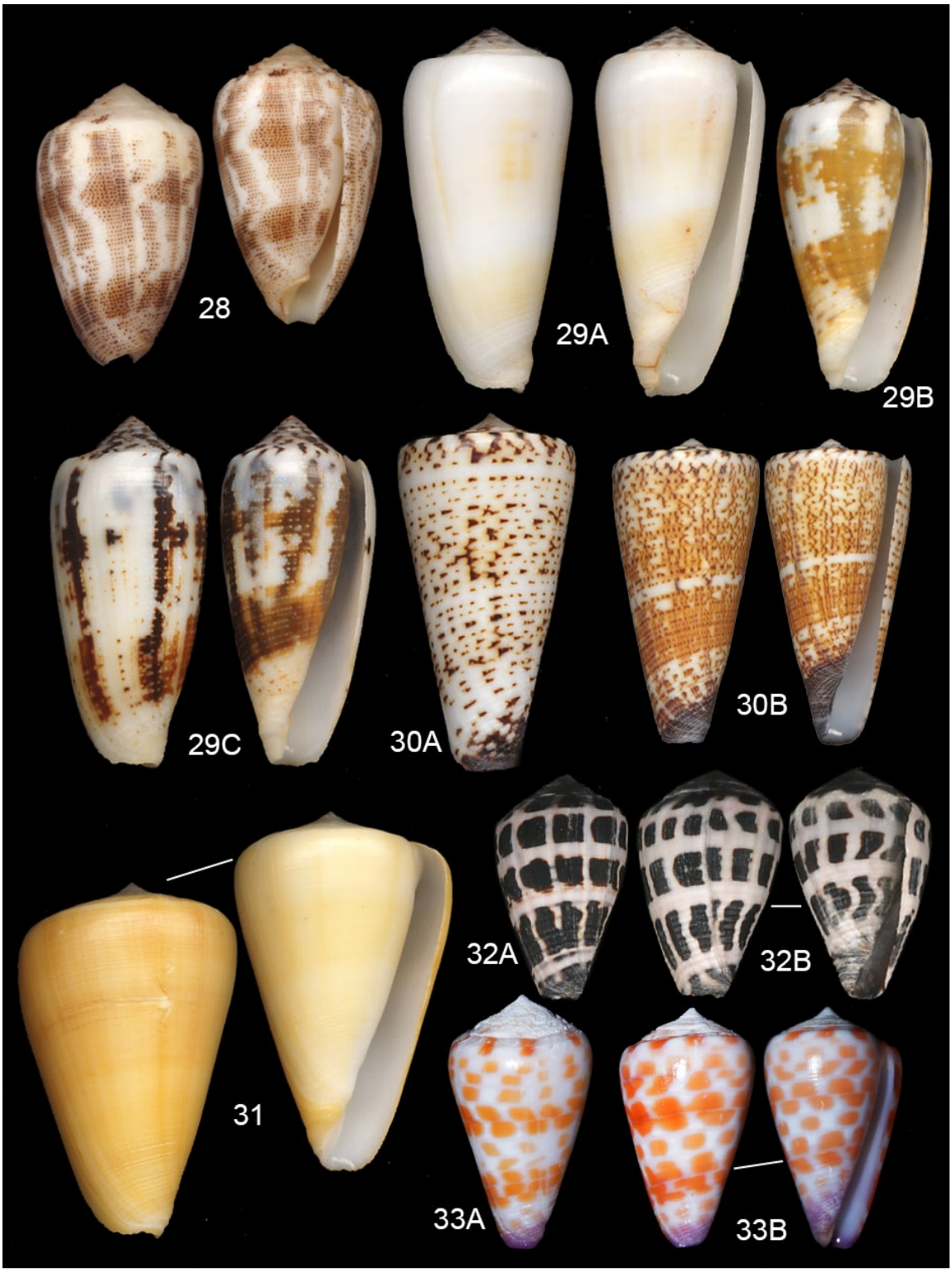

Fig 7: The gastropods of Turtle and Binunsalian Bays. 28. *Conus arenatus*, 29. *Conus magus*, 30. *Conus thalassiarchus*, 31. *Conus quercinus*, 32. *Conus eburneus*, 33. *Conus tessulatus*.

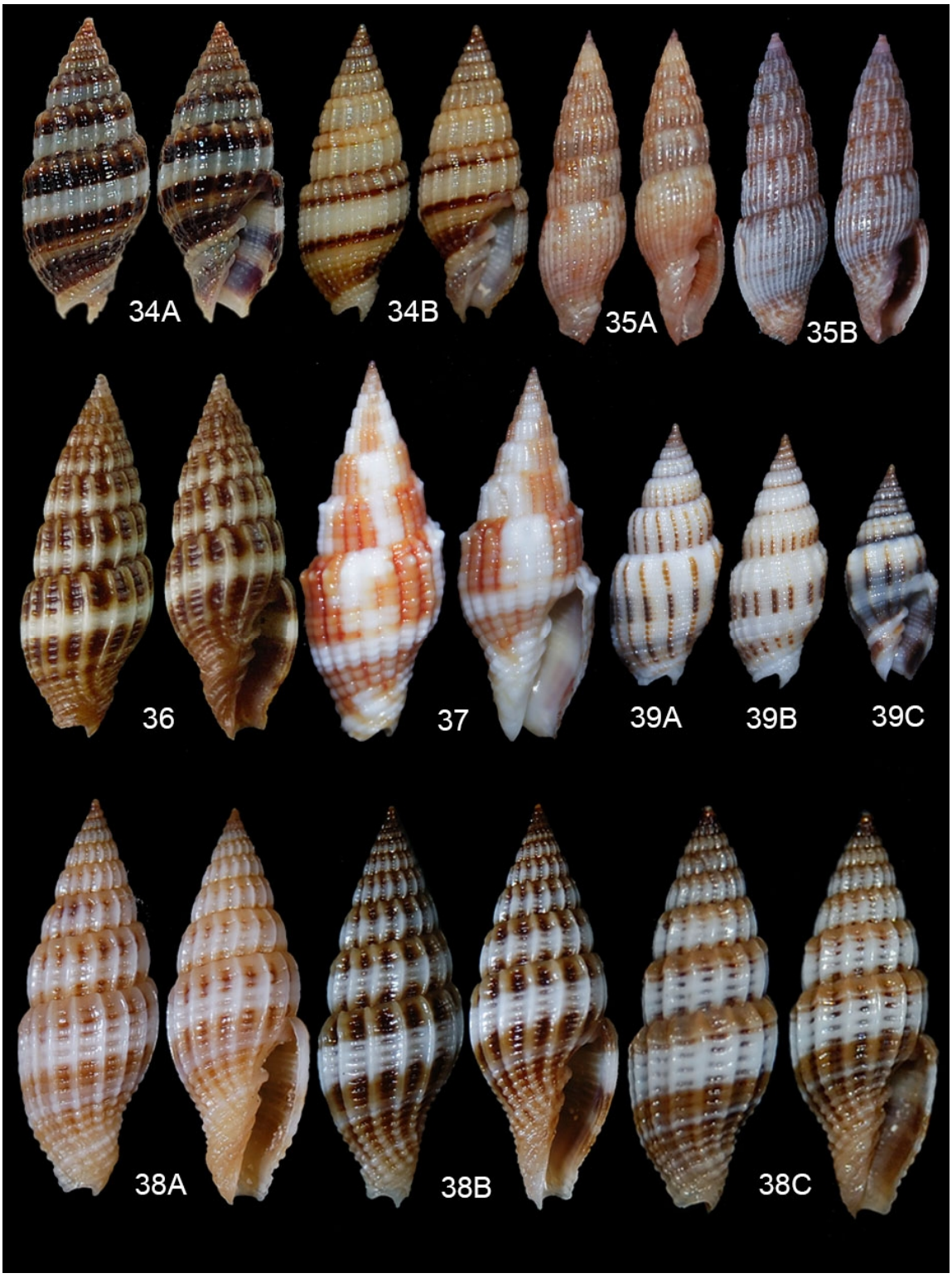

Fig 8: The gastropods of Turtle and Binunsalian Bays. 34. *Vexillum amandum*, 35. *Vexillum angustissimum*, 36. *Vexillum collinsoni*, 37. *Vexillum coronatum*, 38. *Vexillum dilectissimum*, 39. *Vexillum exasperatum.*

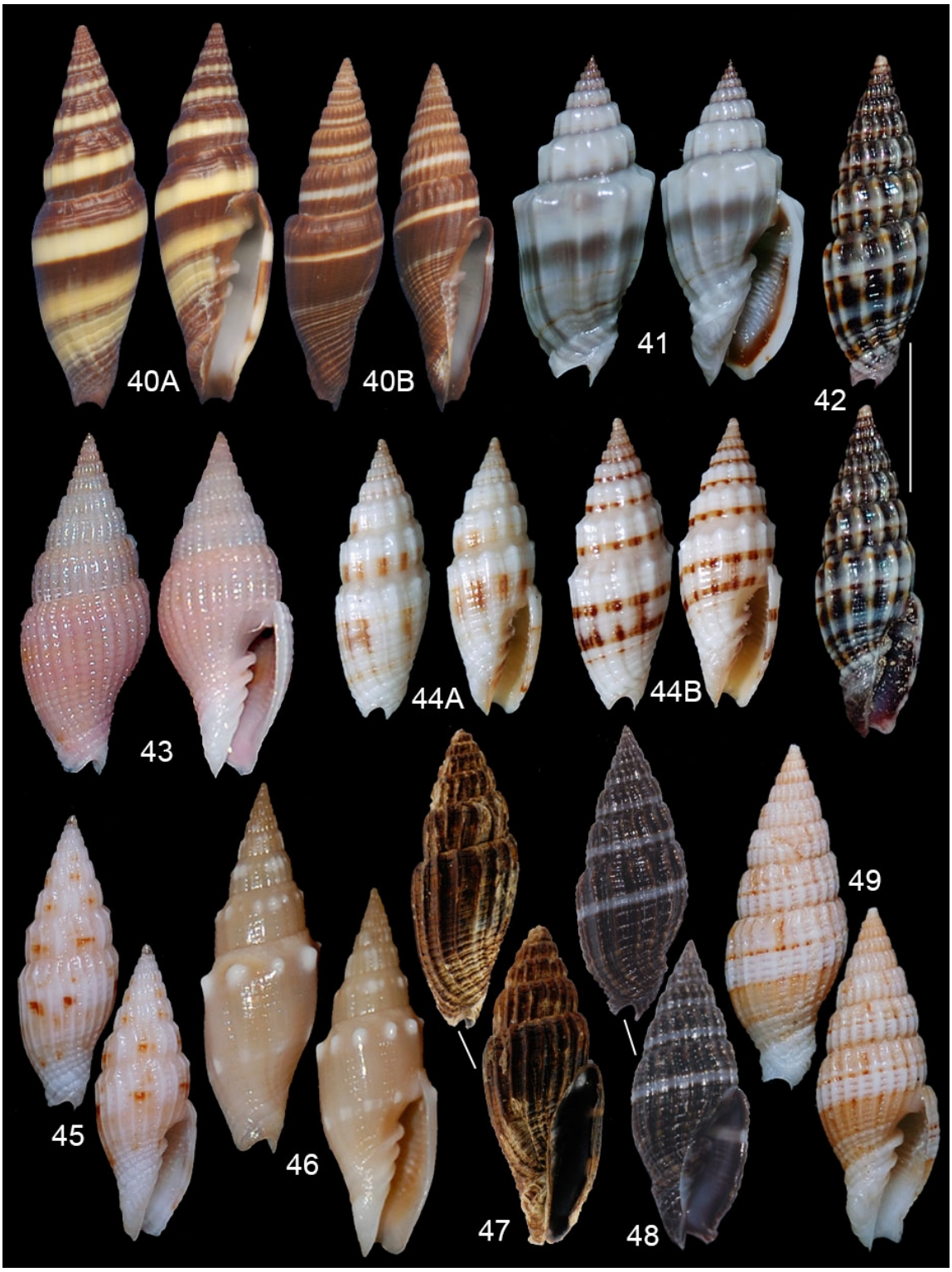

Fig 9: The gastropods of Turtle and Binunsalian Bays. 40. *Vexillum formosense,* 41. *Vexillum gruneri,* 42. *Vexillum michaui,* 43. *Vexillum pelaezi,* 44.*Vexillum perrieri,* 45. *Vexillum scitulum,* 46. *Vexillum spicatum* 47. *Vexillum vibex,* 48. *Vexillum virgo,* 49. *Vexillum xenium.*

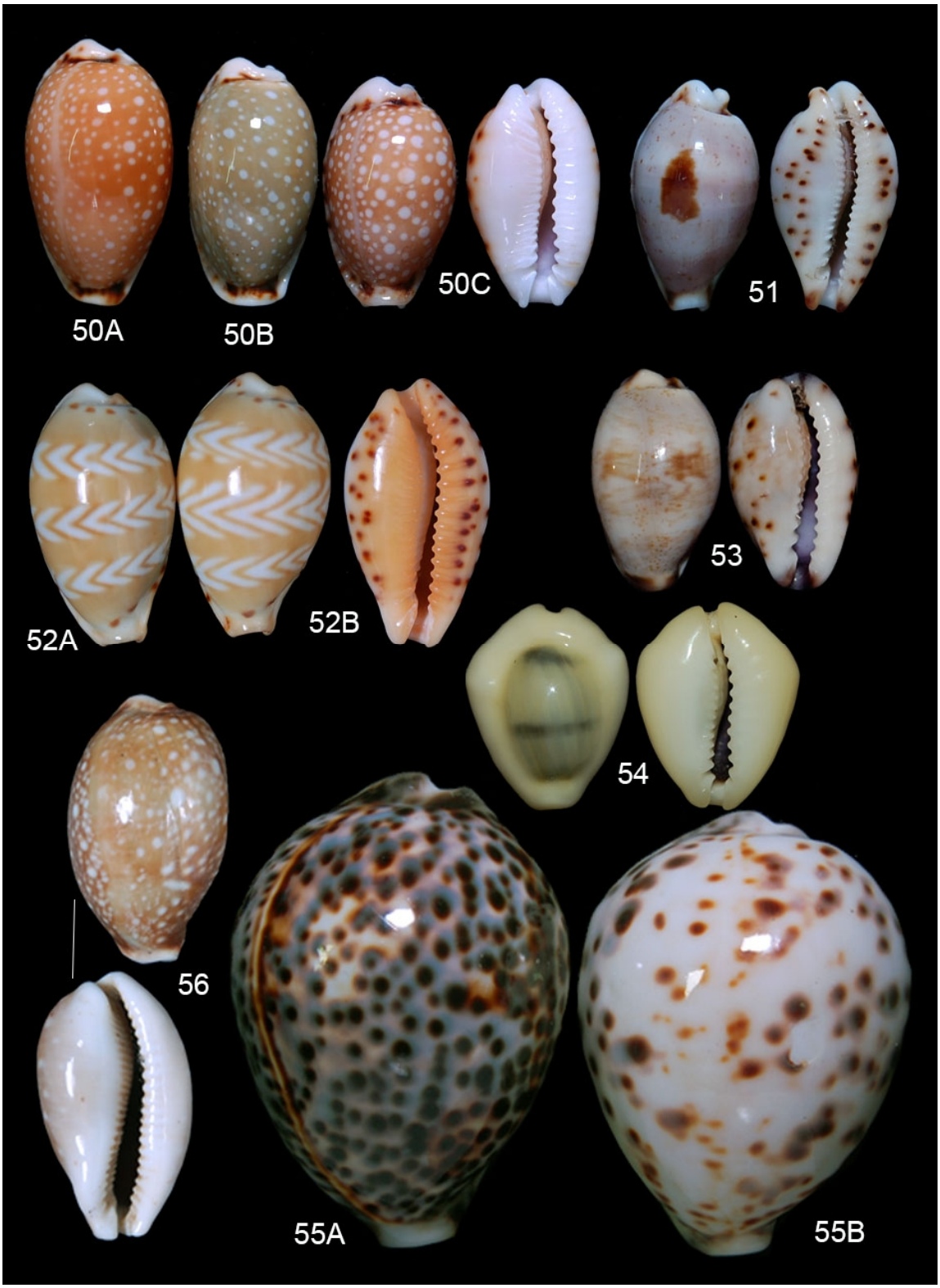

Fig 10: The gastropods of Turtle and Binunsalian Bays. 50. *Erosaria labrolineata*, 51. *Palmadusta contaminata contaminata*, 53. *Purpuradusta gracilis*, 54. *Monetaria moneta*, 55. *Cypraea tigris*, 56. *Lyncina vitellus*.

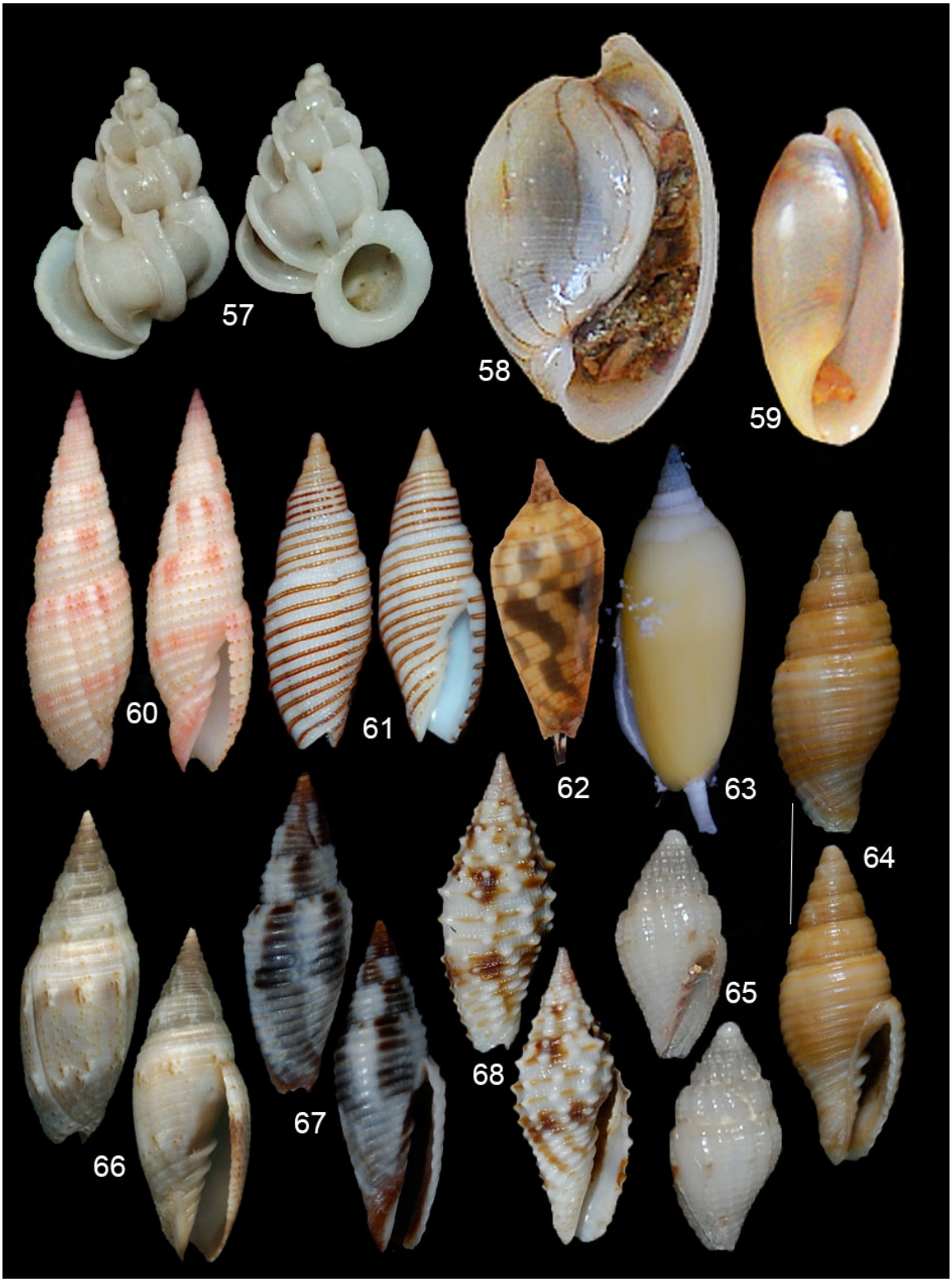

Fig 11: The gastropods of Turtle and Binunsalian Bays. 57. *Epitonium alata*, 58. *Atys naucum*, 59. *Aliculastrum cylindricum*, 60. *Domiporta carnicolor*, 61. *Domiporta filaris*, 62. *Imbricaria conularis*, 63. *Imbricaria olivaeformis*, 64. *Mitra maesta*, 65. *Scabricola alabaster*, 66. *Scabricola ocellata*, 67. *Ziba bacillum*, 68. *Ziba verrucosa foveolata*.

Fig 12: The gastropods of Turtle and Binunsalian Bays. 69. *Hexaplex cichoreum*, 70. *Drupella margariticola*, 71. *Nassarius gemmuliferus*, 72. *Nassarius bicallosus*, 73. *Nassarius coronatus*, 74. *Nassarius* sp., 75. *Natica buriasiensis*, 76. *Mammilla melanostoma*, 77. *Tectonatica venustula*, 78. *Eunaticina papilla.*

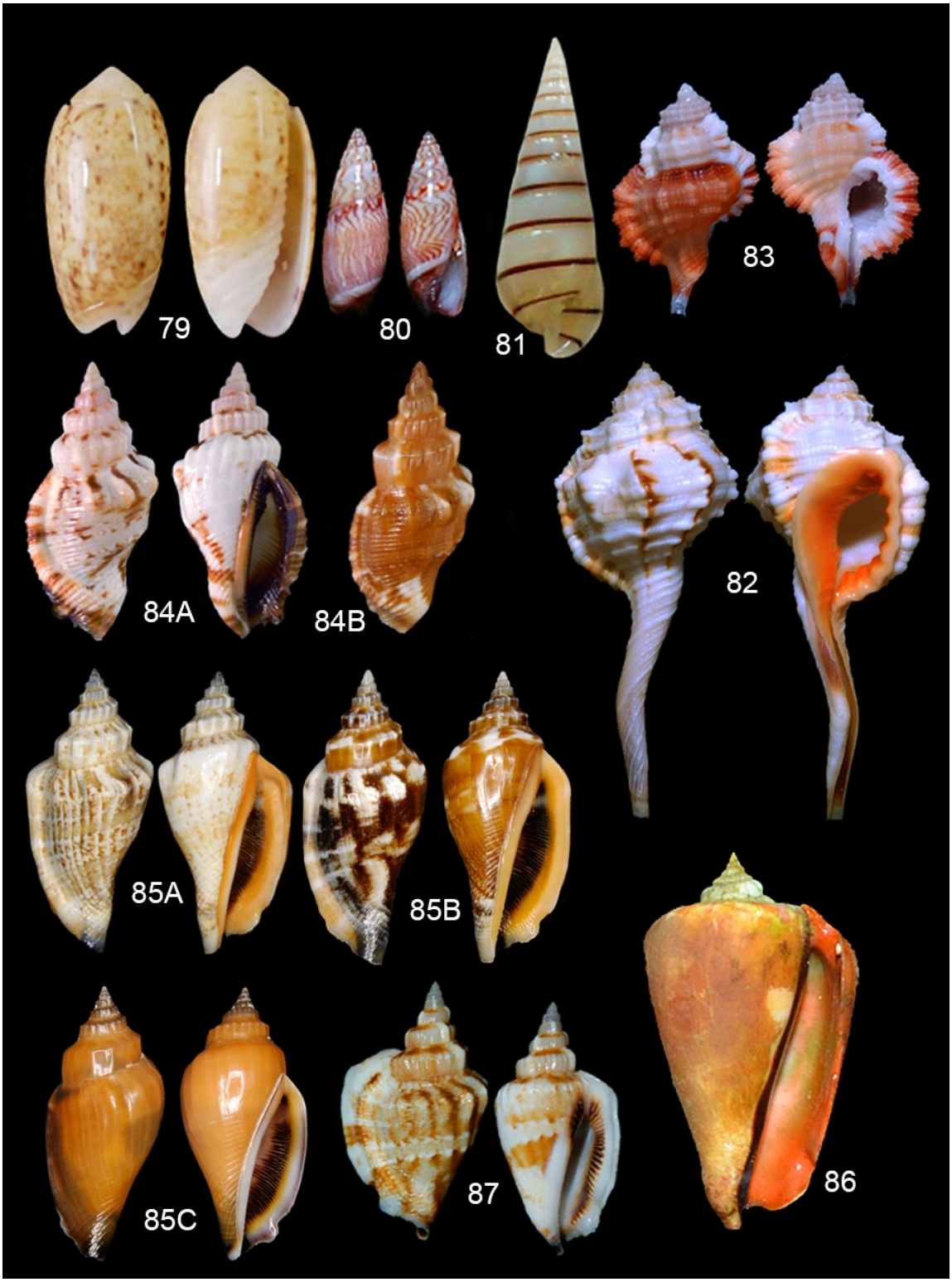

Fig 13: The gastropods of Turtle and Binunsalian Bays. 79. *Oliva carneola*, 80. *Olivella fulgurata*, 81. *Syrnola fasciata*, 82. *Ranularia gutturnia*, 83. *Turritriton labiosus*, 84. *Canarium erythrinum*, 85. *Canarium urceus*, 86. *Conomurex luhuanus*, 87. *Dolomena pulchella*.

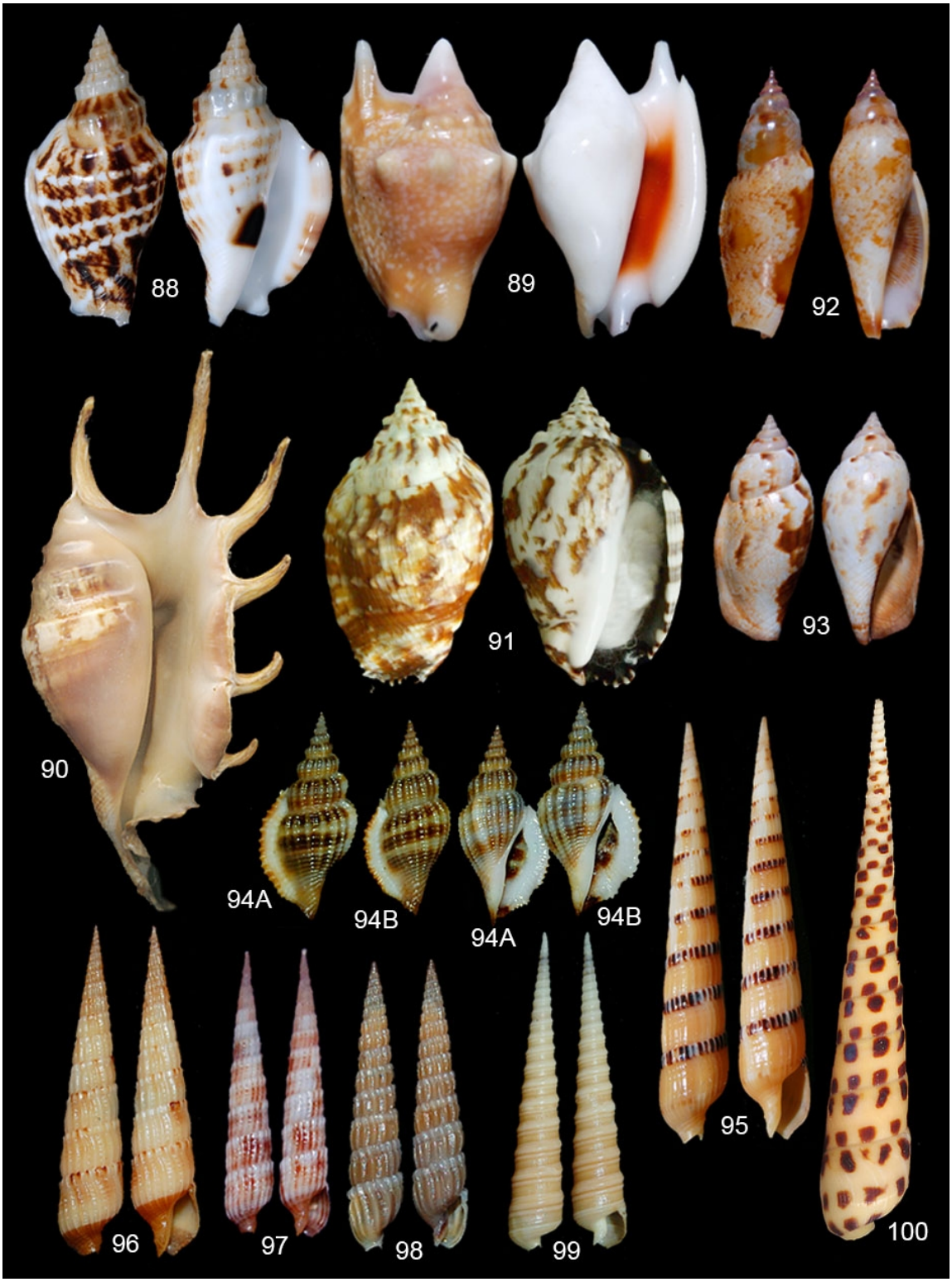

Fig 14: The gastropods of Turtle and Binunsalian Bays. 88. *Dolomena variabilis,* 89. *Euprotomus bulla*, 90. *Lambis lambis*, 91. *Lentigo pipus,* 92. *Terebellum terebellum,* 93. *Terestrombus fragilis,* 94. *Varicospira crispata,* 95. *Hastulopsis pertusa,* 96. *Hastulopsis suspense,* 97. *Myurella kilburni,* 98. *Strioterebrum arabellum,* 99. *Terebra funiculata,* 100. *Terebra subulata.*

Fig 15: The gastropods of Turtle and Binunsalian Bays. 101. *Rossiteria pseudonucleolus,* 102. *Monilea belcheri,* 103. *Jujubinus geographicus,* 104. *Pseudominolia tramieri*, 105. *Lophiotoma leucotropis*, 106. *Lophiotoma acuta,* 107. *Vasum tubiferum,* 108. *Xenophora cerea.*

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