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Biodiversity of natural versus planted mangrove forests across latitudes in Guangdong China with seven new records and potential new species

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Mangrove ecosystems in Guangdong Province, China, are vital for their ecological services and biodiversity, yet comprehensive assessments of their species diversity remain limited. A biodiversity survey conducted during the months of July to August 2024 by random sampling using quadrates to assess biodiversity, species richness, and abundance as well as to evaluate species relationships with reference to the usage of mangroves area and mangrove species in the eight stations Shantou, Huiyang, Zhuhai, Huidong (Planted mangroves at higher latitudes 22–23N of non-pristine areas) Yangjiang, Lianjiang, Leizhou, and Xuwen (natural mangrove forests at lower latitudes 20–21N of pristine areas) of Guangdong's mangrove forests. A total of 87 species (overall diversity) with eight phyla were identified, with Mollusca being the most abundant (41 species, including 28 gastropods), followed by Arthropoda (32 species) and Chordata (4 species). Seven species—*Bakawan rotundata*, *Bakawan puti*, *Haloa wallisii*, *Platytrombidium* sp., *Heterocerus* sp., *Trichoniscus pygmaeus* and SHSY140711—were recorded for the first time in China. Penthalodidae sp., key characters do not fit the diagnosis of any of its genera, represent a potential new genus in the family Penthalodidae. The brief taxonomic description for *Haloa wallisii* and *Bakawan puti* is recorded here to avoid misidentification with related species. Spatial analysis revealed Yangjiang with the highest number of specimens (N = 318), while Shantou had the lowest number of specimens (N = 25). A clear difference in biodiversity gradient was observed between natural (high biodiversity) and planted (low biodiversity) mangrove forests at pristine versus non-pristine areas, respectively. A same trend has been observed for latitudinal gradient from lower 20–21N (high biodiversity) to higher 22–23N (low biodiversity). Cluster and beta-diversity analyses highlighted distinct ecological zones, with Yangjiang, Leizhou, Xuwen, and Lianjiang exhibiting high species turnover. Analysis of species collection relative to mangrove plant species revealed that the highest proportion of organisms (30%) were found in association with *Avicennia marina*, while the lowest (2%) were associated with *Bruguiera gymnorhiza*. Over 60% of species were free-living, underscoring the ecosystem's ecological integrity, while invasive species accounted for only 1%. This research directly aligns with the Sustainable Development Goal (SDG) 14, "Life below water" (Conserve and sustainably use the oceans, seas, and marine resources for sustainable development) and 15 "Life on land". However, this research is also strongly supportive in achieving other SDGs such as (12. Sustainable consumption and production, 13. Climate action, 17. Partnerships for the goal). These findings emphasize the need for targeted conservation strategies,

particularly in high-diversity areas, to mitigate anthropogenic threats and sustain mangrove biodiversity. The results of this study help China's target of protecting 30 percent of the planet's land and oceans by 2030 and provided a critical baseline for future monitoring and management efforts for biodiversity in Guangdong's mangrove ecosystems.

Keywords Tropical mangroves biodiversity, Guangdong Province, New species records, Pristine versus non-pristine areas, Conservation, Spatial heterogeneity, Planted versus natural mangroves, Lower versus higher latitudes

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Mangrove ecosystems are among the most productive and biologically diverse wetlands worldwide, providing critical ecological services such as coastal protection, carbon sequestration, and nursery grounds for marine species[1–3]. These unique tropical and subtropical intertidal forests thrive as a buffer system between terrestrial and marine ecosystems, providing significant ecosystem functions[4]. However, anthropogenic activities including eutrophication, urbanization, aquaculture expansion, physical habitat alteration, non-native species introductions, and climate change severely threatening mangroves ecosystem[3,5–8].

Mangrove ecosystems are characterized by their high efficiency in retaining and recycling nutrients, supporting a high primary microphytobenthos productivity[9]. They are generally rich in biodiversity, including polychaetas, bivalves, various gastropod populations and numerous shorebirds that feed on them[10–12]. The benthic fauna of the mangrove ecosystem plays a crucial role in transferring energy between trophic levels in coastal food webs. During high tide, fish and larger crustaceans feed on sediment-dwelling biota, while during low tide, birds, terrestrial mammals, and reptiles prey on the same food items. Mangrove forests, therefore, influence their benthic communities as a source of nutrients and energy through outwelling with tidal currents, in addition to marine inputs[13–16].

Guangdong Province, situated in southern China, is home to some of the country's most extensive and species-rich mangrove forests[17]. The province's subtropical climate, extensive coastline, and estuarine systems create ideal conditions for diverse mangrove associated biodiversity[18]. Guangdong's mangroves are dominated by species such as *Kandelia obovata*, *Avicennia marina*, and *Aegiceras corniculatum*[19], which form complex habitats supporting numerous invertebrates like crustaceans (e.g., *Uca* spp. and *Scylla paramamosain*) and mollusks, and migratory birds that rely on these ecosystems for feeding and breeding[20,21]. Additionally, these mangroves serve as essential nurseries for fish, contributing to the productivity of adjacent marine environments *i.e.,* fringing or barrier coral reefs[22,23].

However, habitat degradation due to land reclamation and pollution poses a significant threat to this biodiversity[24]. Despite conservation efforts, such as the establishment of protected areas like the Zhanjiang Mangrove National Nature Reserve, our understanding of the full extent of mangrove-associated biodiversity in Guangdong is scarce[25]. This knowledge, however, is essential to expand conservation efforts. The present study thus aims to comprehensively assess biodiversity, species richness, and abundance as well as to evaluate species relationships with reference to the usage of mangroves area and proportion of organisms with reference to mangrove species present at the eight stations Shantou, Huiyang, Zhuhai, Huidong (Planted mangroves at higher latitudes 22–23N of non-pristine areas) Yangjiang, Lianjiang, Leizhou, and Xuwen (natural mangrove forests at lower latitudes 20–21N of pristine areas) of Guangdong's mangrove forests.

Material and methods
Study area
The eight stations; Shantou, Huiyang, Zhuhai, Huidong (Planted mangroves at higher latitudes 22–23N of non-pristine areas), Yangjiang, Lianjiang, Leizhou and Xuwen (natural mangrove forests at lower latitudes 20–21N of pristine areas) situated in Guangdong province, China were selected for this study. The mangrove area in Shantou (23° 32′ 55.00″ N 116° 52′ 56.79″ E) is a wetland area and national park named "Yifengxi Mangrove Reserve" where humans also planted mangroves artificially. There are roads, highways and Yifengxi port. Because of lush mangrove forests, people use this place for walk and picnic. The mangrove forests in Huiyang (22° 44′ 17.85″ N 114° 31′ 55.14″ E) are also a wetland and national park named "Daya Bay Mangrove Park" in the north part of Daya Bay. For the restoration of the mangrove, the most part of this mangroves forest is planted by the government and local community. There is residential area, village and also the Danao River near this site. The Zhuhai (22° 25′ 25.37″ N 113° 37′ 36.07″ E) is a wetland on the Qi'ao island at Housha Bay. This wetland is named "Qi'ao Mangrove Wetland Ecological Park". Mangroves are surrounded by the cultivation zones so the degree of mangroves cover is not high. In the Huidong (22°44′ 1.70″ N 114° 56′ 32.53″ E), the mangroves are mostly planted by the government and under the administration of the "Huizhou Mangrove Municipal Nature Reserve". This area is located on the south-eastern side of the Guangdong province of China and is a relatively developed urbanized region that faces the pressure of anthropogenic pollution. The mangroves at Yangjiang (21° 38′ 27.49″ N 111° 53′ 0.01″ E) are mostly natural mangroves forests on Hailing Island at Hailing Bay. It is a rural

area with less human interaction. The Lianjiang (21°32′ 18.00″ N 109° 46′ 34.69″ E) also have natural mangrove forests in rural areas of Zhanjiang city, where the Guanzhai River is also present. The Xuwen (20° 39′ 35.80″ N 110° 24′ 55.22″ E) has a natural mangrove forest and it's an Island in Zhanjiang city on the southwestern side of Guangdong province of China. The Leizhou (20°49′ 8.26″ N 110° 21′ 54.50″ E) is also a natural mangrove forest named "Guangdong Zhanjiang Mangrove National Reserve" in the Leizhou Bay near the Beijia village, Fucheng town of Zhanjiang. Leizhou is a county located at the extreme southwestern side of Guangdong and lies on the Leizhou Peninsula. It is the third-largest peninsula of China.

Biodiversity surveys

For the sample collection the surveys were conducted during low tide at eight stations of mangrove forests in Guangdong province of China in July to August 2024. The sampling was done randomly, as described by Aslam et al.[26,27], using PVC quadrate (1 m^2) at six points on each station and the number of specimens were recorded. The mobile and unknown specimens were collected by hand while other sessile specimens were removed using forceps and transported to the lab for taxonomic identification. The samples were preserved in 95% ethanol (for molecular analysis) in glass vials and plastic jars after cleaning and washing. The specimens were labelled (name, locality, date, and collection spot regarding mangrove plant species) using paper tape and a permanent marker. The relationship of all the species with mangroves was observed in the field concerning the usage of mangroves at eight stations. Based on field observation, the species richness was categorized into the following three scales: less abundant (+), abundant (++), and most abundant (+++). At the same time, the abundance of species was measured based on the occurrence scale: common, occasional and specific. The relationship of species regarding usage of mangroves was observed and reported: attached, boring, pest, invasive species, bioindicator, predator, competitor, and free-living. The specimens were identified with the help of published literature (see reference source of identification for each species in Table 1) and confirmed by experts (see acknowledgment section). The World Register of Marine Species (WoRMS) was used to update the nomenclature of species. The specimens were collected by the first author and deposited in the collection of the South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou, China.

Morphological and anatomical analyses

The bubble snails (*Bakawan puti* and *Haloa wallisii*) were carefully removed from their shells with using dissection forceps. The male reproductive systems, gizzard and buccal bulb were dissected out with a dorsal incision through the mantle to reveal the organs. The shells were photographed with a mounted digital camera Moticam X5+. The anatomical drawings were produced by close study using a Motic SMZ-171-TLED stereo microscope aided with images from the mounted camera. The height (H) of shell was measured with a Coc raft digital Vernier calliper.

Molecular identification

Morphological determination of species was mainly successful. Yet, in some cases, we additionally performed DNA barcoding for molecular species identification. Briefly, the tissue of the species was homogenized in a 3% cetyltrimethylammonium bromide buffer (CTAB, 3% CTAB, 1.4 M NaCl, 20 mM EDTA (pH 8.0), 100 mM Tris–HCl (pH 8.0), 3% Polyvinylpyrrolidone (PVP), 0.2% β-Mercaptoethanol (VWR, Germany), and 24.8% H_2O) supplemented with 20 µl ProteinaseK (20 mg/l) and incubated at 60 °C for 75 min. Afterward, 10 µl of RNAse A (Roth, Germany) was added, and the samples incubated for 10 min at 70 °C. The samples were then cooled to room temperature, 500 µL of Chloroform: Isoamyl Alcohol (24:1, Sigma) was added, and the mixture was inverted for 2 min. Subsequently, the samples were centrifuged for 5 min at 12,000*g* using a tabletop centrifuge (Eppendorf, Germany). Then, the DNA was precipitated using only the upper liquid phase using 0.1 Vol/Vol of 3 M NaOAc (VWR, Germany) and 1 Vol/Vol ice-cold Isopropanol (Roth, Germany). Samples were then centrifuged for 10 min at 10.000*g* and washed with 96% EtOH, following a wash with 70% EtOH. Afterward, the samples were centrifuged for 10 min at 10,000*g*, the supernatant was discarded, and the samples were dried for 2 h. Then, 20 µL of preheated water (50 °C) was added.

For DNA barcoding, we amplified a part of the cytochrome oxidase 1 (COX1) gene using the LCO and HCO primers (Folmer et al. 1994). PCR was conducted in a total volume of 20 µl containing 10 µl twice-concentrated Green-Tag Master-Mix polymerase (NEB, UK), 1 µl of 100 pmol/µl concentrated forward and reverse primers, 2 µl of DNA, and 6 µl of water. PCR reactions were conducted in an Eppendorf cycler (Eppendorf, Germany) with 15 min of initial denaturation at 95 °C, 30 cycles of 1 min denaturation (94 °C), primer-specific annealing (52 °C for COX1), and 10 min extension (70 °C). Afterward, a final elongation of 10 min (70 °C) was conducted. The PCR product was purified using 0.1 Vol/Vol of 3 M NaOAc and 1 Vol/Vol of ice-cold Isopropanol. The samples were then centrifuged for 10 min at 10,000*g*, and the supernatant was removed. Following the addition of 500 µl 70% EtOH, the samples were centrifuged again for 10 min at 10,000*g*. After removing the supernatant, the tubes were left to dry under a fume hood overnight, 20 µl of 50 °C preheated distilled H_2O added, and the samples stored at − 20 °C until sequencing by Stab Vida (Lisbon, Portugal).

Data analysis

Microsoft Excel (version. 10) and Paleontological Statistics (PAST-version 3.21) were used to analyze diversity indices (Dominance, Simpson, Shannon, Evenness, Brillouin, Menhinick, Margalef, Equitability, Fisher-alpha, Berger-Parker and Chao-1) and perform cluster analysis. Local Ecological Footprinting Tool (LEFT) web-based tool (URL: www.left.ox.ac.uk.) was applied to observe the spatial pattern of biodiversity in the selected area of interest. A standard handheld GPS (Global Positioning System) Garmin device (accuracy ± 0.3 m) instrument was also used to determine site locations and the ArcGIS software (version 10.3) using Landsat satellite imagery from https://www.usgs.gov/landsat for constructing the map (Fig. 1). The sequences were quality trimmed using

Phylum	Class	Family	Species	Common name	Station	Mangrove sp.	Status	Species richness	Abundance scale	References	Figures #
Rodophyta	Florideophyceae	Caulacanthaceae	*Catenella impudica* (Montagne) J.Agardh, 1852	Burmese moss	Huidong, Lianjiang	*Avicennia marina*	Attached	+ + +	Common	Guiry & Guiry[28]	20-3
		Gelidiaceae	*Gelidium pusillum* (Stackhouse) Le Jolis, 1863	Creeping straggle weed		*Rhizophora stylosa*	Free-living	+ + +		Guiry & Guiry[28], Saifullah & Nizamuddin (1977)	20-4
			Total = 2								
Chlorophyta	Ulvophyceae	Ulvaceae	*Ulva clathrata* (Roth) C.Agardh, 1811	Spiky Tendrils	Lianjiang, Shantou	*Rhizophora stylosa*	Competitor	+ + +	Common	Guiry & Guiry[28], Husain & Shameel (1997)	20-1
		Cladophoraceae	*Cladophora* (Kützing, 1843) sp.	blanket weed, reticulated or branching algae	Huidong, Lianjiang	*Rhizophora stylosa*		+ + +		Guiry & Guiry[28]	20-2
		Halimedaceae	*Boodleopsis pusilla (Collins)* W.R.Taylor, A.B.Joly & Bernatowicz, 1953	Green algae/mat	Xuwen, Leizhou	*Avicennia marina*		+ + +		Guiry & Guiry[28]	20-5
			Total = 3								
Cnidaria	Octocorallia	Pennatulidae	*Pteroeides bankanense* (Bleeker, 1859)	Sea Pen	Xuwen	*Avicennia marina*	Free-living	+	Specific	Schram[29]	20-6
			Total = 1								
Arthropoda	Thecostraca	Balanidae	*Megabalanus tintinnabulum* (Linnaeus, 1758)	Titan Acorn Barnacle	Leizhou Lianjiang	*Avicennia marina*	Competitor / Pest	+ + +	Common	Zenetos et al.[30]	13-1
			Fistulobalanus albicostatus (Pilsbry, 1916)	Acorn Barnacle		*Rhizophora stylosa, Kandelia obovata*		+ + +		Katsanevakis et al.[31]	13-2
	Arachnida	Microtrombididae	*Platytrombidium* (Thor, 1936) sp.	Velvet mites	Huidong	*Avicennia marina*	Free-living	+ +	Occasional	Gabrys et al.[32] *	14, 19
		Penthalodidae	Penthalodidae sp.	Mite	Xuwen	*Avicennia marina*		+ +		Khaustov[33]*	14-2
		Tetragnathidae	*Tetragnatha bimaculata* (Li & Liu, 2022)	Orb weaver spider	Huidong	*Avicennia marina*	Attached	+ +	Occasional	Li et al.[34]	14-3
			Tetragnatha sp.	Stretch spider		*Rhizophora stylosa*		+ +		Li et al.[34]	14-4
		Theridiidae	*Episinus* (Walckenaer, 1809) sp.	Cobweb spider		*Rhizophora stylosa*		+ +		Liang et al.[35]	14-5
			Meotipa (Simon, 1894) sp.	Tangle web spider		*Avicennia marina*		+ +		Deng et al.[36]	14-6
		Araneidae	*Nephila pilipes* (Fabricius, 1793)	giant wood spider or giant golden orb-weaving spider	Huidong	*Sonneratia apetala*		+ + +	Common	Kuntner et al. (2017)	14-7
	Hexapoda	Heteroceridae	*Heterocerus* (Fabricius, 1792) sp.	Mud-loving beetle	Yangjiang	*Bruguiera gymnorhiza*	Free-living	+ +	Occasional	King & Lago[37]*	15-1,2
	Malacostraca	Menippidae	*Sphaerozius nitidus* (Stimpson, 1858)	Glowing fan crab	Yangjiang	*Rhizophora stylosa*	Free-living	+ + +	Common	Zenetos et al.[30]	5-3
		Mictyridae	*Mictyris brevidactylus* (Stimpson, 1858)	short-fingered monk crab	Yangjiang, Zhuhai	*Rhizophora stylosa*		+ + +		Poon et al.[38]	15-4
Continued											

Phylum	Class	Family	Species	Common name	Station	Mangrove sp.	Status	Species richness	Abundance scale	References	Figures #
		Macrophthalmidae	*Macrophthalmus* (*Macrophthalmus*) *abbreviatus* (Manning & Holthuis, 1981)	Short-bodied big-eyed crab	Yangjiang, Shantou	Sonneratia apetala		+ + +		Lee[39]	15-5
			Macrophthalmus (*Macrophthalmus*) *convexus* (Stimpson, 1858)	Bigeye Crab	Yangjiang	*Rhizophora stylosa*		+ + +		Schram[29]	15-8
			Macrophthalmus (*Mareotis*) *frequens* (Tai & Song, 1984)	Japanese big-eye crab	Huiyang, Yangjiang	*Avicennia marina*		+ + +		Schram[29]	15-6
		Ocypodidae	*Tubuca arcuata* (De Haan, 1835)	Fiddler Crab		Sonneratia apetala		+ + +		Lee[39]	15-7
			Gelasimus borealis (Crane, 1975)	Northern Calling Fiddler Crab		Sonneratia apetala		+ + +		Shih et al.[40]	15-9
		Sesarmidae	*Chiromantes haematocheir* (De Haan, 1833)	Red-bellied crab	Yangjiang, Zhuhai	*Rhizophora stylosa*		+ + +		Schram[29]	15-10
			Parasesarma plicatum (Latreille, 1803)	Orange-claw marsh crab	Yangjiang	*Kandelia obovata*		+ + +		Proud[41]	16-1
			Orisarma neglectum[42]	Secret Oriental Hand Crab	Leizhou, Lianjiang	*Avicennia marina*		+ + +		De Man[42]	16-2
			Nanosesarma minutum[42]	Small crab	Leizhou, Zhuhai	*Kandelia obovata*		+ + +		Moscoso[43]	16-3
		Ligiidae	*Ligia* (*Megaligia*) *exotica* (Roux, 1828)	Sea roach	Leizhou, Shantou	*Avicennia marina*	Free-living	+ + +		Tsuge[44]	16-4
		Trichoniscidae	*Trichoniscus pygmaeus* (G. O. Sars, 1898)	Pygmy woodlouse	Huiyang, Lianjiang	*Avicennia marina*		+	Specific	Gregory[45]*	16-5
	Collembola	Neanuridae	*Oudemansia* (Schött, 1893) sp.	Springtail	Huidong	*Acanthus ilicifolius*	Free-living	+ +	Occasional	Palacios-Vargas & Bu[46]	16-7
		Entomobryidae	*Entomobrya* (Rondani, 1861) sp.	Slender springtail	Xuwen, Huiyang	*Rhizophora stylosa*		+ +		Zhou & Ma[47]	16-6
	Malacostraca	Alpheidae	*Alpheus inopinatus* (Holthuis & Gottlieb, 1958)	Bigclaw snapping shrimp	Huidong	*Rhizophora stylosa*	Free-living	+	Specific	Schram[29], Zenetos et al.[30]	16-8
	Insecta	Lasiocampidae	*Trabala vishnou* (Lefèbvre, 1827)	rose-myrtle lappet moth	Huidong	*Acanthus ilicifolius*	Predator	+ + +	Common	Kaleka et al.[48]	17-1
			Trabala pallida (Walker, 1855)	Walker moth	Huidong	*Rhizophora stylosa*	Predators	+	Specific	Munn[49]	17-2

Continued

Phylum	Class	Family	Species	Common name	Station	Mangrove sp.	Status	Species richness	Abundance scale	References	Figures #
		Ricaniidae	*Ricania guttata* (Walker, 1851)	Black planthopper	Huidong, Zhuhai, Lianjiang	*Avicennia marina*		+ +	Occasional	Medler[50]	17-5
		Erebidea	*Orvasca subnotata* (Walker, 1865)	Nygmiine tussock moth	Huidong	*Excoecaria agallocha*		+	Specific	Wang et al.[51]	17-4
			Orgyia postica (Walker, 1855)	Cocoa Tussock Moth	Huidong	*Rhizophora stylosa*		+ +	Occasional	Duan & Hu[52]	17-3
		Drosophilidae	SHSY140711	Fly	Xuwen	*Avicennia marina*	Free-living	+		Schoch et al.[53] *	17 and 18
			Total = 32								
Annelida	Polychaeta	Nereididae	*Composetia* (Hartmann-Schröder, 1985) sp.	Sand worm	Yangjiang	*Rhizophora stylosa*	Free-living	+ +	Occasional	Aslam et al.[26,27]	3-1
			Nereis (Linnaeus, 1758) sp.		Xuwen	*Avicennia marina*		+ +		Mustaquim (1997)	3-2
			Total = 2								
Mollusca	Gastropoda	Onchidiidae	*Onchidium reevesii* (Gray, 1850)	Sea slug	Leizhou	*Rhizophora stylosa*	Free-living & attached	+ + +	Common	Dayrat et al.[54]	3-3
		Plakobranchidae	*Elysia leucolegnote* (K. R. Jensen, 1990)	Dark green sacoglossan	Xuwen, Leizhou	*Rhizophora stylosa*	Free-living	+ + +		Swennen[55]	3-4
		Haminoeidae	*Bakawan rotundata*[56]	Mangrove bubble snail	Leizhou	*Rhizophora stylosa*	Free-living	+ + +		Aslam et al.[57] *	3-5
			Bakawan puti[58]	Mangrove snail	Leizhou,	*Avicennia marina*		+ + +		Oskars & Malaquias[58] *	3-6 and 9A–E
			Haloa wallisii (J. E. Gray, 1825)	Wallis bubble snail	Leizhou,	*Avicennia marina*		+ + +		Oskars & Malaquias[59], Naser et al.[60] *	3-7 and 8A–C
		Turritellidae	*Neohaustator fortilirata* (G. B. Sowerby III, 1914)	Tower shell	Yangjiang	*Bruguiera gymnorhiza*	Free-living	+	Specific	Hasegawa[61]	7-4
		Neritidae	*Neripteron violaceum* (Gmelin, 1791)	Violet Nerite	Lianjiang	*Rhizophora stylosa*	Attached	+ + +	Common	Gassies[62]	5-5
		Trochidae	*Monodonta labio* (Linnaeus, 1758)	Toothed Top Shell	Leizhou	*Avicennia marina*		+ + +		Schram[29]	5-4
		Nassariidae	*Nassarius stolatus* (Gmelin, 1791)	Nassa mud snail	Leizhou	*Kandelia obovata*	Free-living and attached	+ +	Occasional	Katsanevakis et al.[31]	5-3
			Nassarius sinarum (R. A. Philippi, 1851)	Dog whelk	Leizhou	*Rhizophora stylosa*		+ + +	Common	Zhang & Yang[63]	5-2

Continued

Phylum	Class	Family	Species	Common name	Station	Mangrove sp.	Status	Species richness	Abundance scale	References	Figures #
		Ellobiidae	*Ellobium chinense* (L. Pfeiffer, 1854)	Land ear shell	Lianjiang	*Laguncularia racemosa*	Free-living	+++		Inoue et al.[64]	5-6
			Melampus (Montfort, 1810) sp.	Marsh snail	Xuwen	*Avicennia marina*		+++		Ramírez et al.[65]	4-5
			Cassidula sowerbyana (L. Pfeiffer, 1853)	Banded ear snail	Lianjiang	*Avicennia marina*	Attached	+++		Raven & Vermeulen[66]	4-4
			Laemodonta punctatostriata (H. Adams & A. Adams, 1854)	Hollow shell snail	Leizhou	Sonneratia apetala	Free-living	+++		Raven & Vermeulen[66]	4-1
		Iravadiidae	*Iravadia (Fairbankia)* Stoliczka, 1868 sp.	Brackish snail	Leizhou	*Rhizophora stylosa*	Free-living	++	Occasional	Brandt[67]	5-1
		Thiaridae	*Sermyla riquetii* (Grateloup, 1840)	Nejihida Kawanina	Lianjiang, Yangjiang	*Laguncularia racemosa*	Free-living and attached	++		Glaubrecht et al.[68]	4-6
		Littorinidae	*Littoraria melanostoma* (Gray, 1839)	Periwinkle snail	Lianjiang, Leizhou	*Kandelia obovata*	Free-living	+++		Reid et al.[69]	4-3
			Littoraria articulata (Philippi, 1846)	Rock periwinkle snail	Lianjiang,	*Rhizophora stylosa*, *Laguncularia racemosa*		+++		Reid et al.[69]	6-1
			Littoraria ardouiniana (Heude, 1885)	Periwinkle snail	Yangjiang	Sonneratia apetala		+++		Reid et al.[69]	6-2
			Mainwaringia leithii (E. A. Smith, 1876)	Winkle sea snail	Lianjiang	*Kandelia obovate*, *Excoecaria agallocha*	Free-living	+++		Reid[70]	4-2
		Cylichnidae	*Truncacteocina* cf. *coarctata*[56]	Rice snail	Yangjiang	*Rhizophora stylosa*	Free-living	++	Occasional	Reid[70]	6-3
		Assimineidae	*Assiminea ovata* (Krauss, 1848)	Micro mollusc	Xuwen	*Kandelia obovata*	Attached	+++	Common	Bartsch[71]	6-4
			Assiminea estuarina (Habe, 1946)	Minute snail	Xuwen, Leizhou	*Avicennia marina*		+++	Common	Fukuda & Hasegawa[72]	6-5
			Assiminea (J. Fleming, 1828) sp.	Mini mollucs	Xuwen	*Kandelia obovata*		++	Occasional	Brandt[67]	6-6
			Optediceros breviculum (L. Pfeiffer, 1855)	Mangrove red snail	Xuwen	*Avicennia marina*		+++	Common	Fukuda & Ponder[73]	7-5

Continued

Phylum	Class	Family	Species	Common name	Station	Mangrove sp.	Status	Species richness	Abundance scale	References	Figures #
		Potamididae	*Pirenella asiatica* (Ozawa & D. Reid, 2016)	Sea snail	Yangjiang	*Kandelia obovata*	Bioindicator	+++	Common	Reid & Ozawa[74]	7-3
			Pirenella incisa (Hombron & Jacquinot, 1848)	Mud snail	Leizhou	Sonneratia apetala		+++		Reid & Ozawa[74]	7-1
			Cerithidea tonkiniana (Mabille, 1887)	Cerithid snail	Yangjiang	Sonneratia apetala		++	Occasional	Reid[75]	7-2
	Bivalvia	Veneridae	*Meretrix lyrata* (G. B. Sowerby II, 1851)	Lyrate hard clam	Leizhou	*Avicennia marina*	Free-living	+	Specific	Schram[29]	11-5
			Cryptonema producta (Kuroda & Habe, 1951)	Asiatic Clam	Yangjiang	*Kandelia obovata*		+		Huber[76]	11-4
		Anomiidae	*Enigmonia aenigmatica* (Holten, 1802)	False Jingle shell	Yangjiang	*Avicennia marina*	Boring	++	Occasional	Schram[29]	12-7
		Arcidae	*Barbatia virescens* (Reeve, 1844)	Blood clam	Yangjiang	*Kandelia obovata*	Free-living	++		Huber[77]	11-6
		Trapezidae	*Neotrapezium sublaevigatum* (Lamarck, 1819)	Arctica clam	Yangjiang	*Kandelia obovata*	Boring	+++		Huber[77]	12-1
		Ostreidae	*Magallana* cf. *bilineata* (Röding, 1798)	Black scar oyster	Leizhou	*Avicennia marina*	Attached	+++	Common	Huber[76]	12-5
		Arcidae	*Anadara sabinae* (Morlet, 1889)	Incongruous Ark Clam	Yangjiang	*Excoecaria agallocha*	Free-living	+	Specific	Huber[77]	23-3
		Modiolidae	*Vignadula mangle* (Ockelmann, 1983)	Sakura clam	Xuwen, Yangjiang	Sonneratia apetala	Free-living and attached	+++	Common	Tan et al.[78]	12-2
		Glauconomidae	*Glauconome angulata* (Reeve, 1844)	Angular shell	Leizhou	Sonneratia apetala	Free-living	+++	Common	Coan & Kabat[79]	11-2
			Glauconome chinensis (J. E. Gray, 1828)	Chinese clam	Leizhou	Sonneratia apetala		+++		Schram[29]	11-1
		Tellinidae	*Tellinides conspicuus* (Hanley, 1846)	Tellens or tellins	Yangjiang	*Avicennia marina*	Free-living	++	Occasional	Coan & Kabat[79]	12-4
		Mytilidae	*Mytella strigata* (Hanley, 1843)	Charru Mussel	Lianjiang, Yangjiang	Sonneratia apetala	Invasive species	+++	Common	Lim et al.[80]	12-3
		Cyrenoididae	*Geloina expansa* (Mousson, 1849)	Mud clam	Yangjiang	*Sonneratia apetala*	Bioindicator	+++		Yahya et al.[81]	12-6
			Total = 41								

Continued

Phylum	Class	Family	Species	Common name	Station	Mangrove sp.	Status	Species richness	Abundance scale	References	Figures #
Ascomycota	Dothideomycetes	Corynesporascaceae	*Corynespora* (Güssow = Freynella O.Kuntze, 1891)	Leaf spot	Xuwen	*Kandelia obovata*	Attached	+++	Common	Xie et al.[82]	10-7
			Total = 1								
Chordata	Teleostei	Gobiidae	*Periophthalmus modestus* (Cantor, 1842)	Shuttles hoppfish or mudskipper	Leizhou	*Sonneratia apetala*	Free-living	+++	Common	Froese & Pauly[83], http://fishbase.de/Country/CountryChecklist.php?	10-1
			Acentrogobius caninus (Valenciennes, 1837)	Green-shouldered goby or tropical sand goby	Xuwen	*Avicennia marina*		+++			10-4
			Mugilogobius abei (Jordan & Snyder, 1901)	Mangrove goby	Xuwen	*Laguncularia racemosa*	Free-living	+++	Common		10-3
		Eleotridae	*Butis koilomatodon* (Bleeker, 1849)	mudsleeper	Leizhou	*Sonneratia apetala*		+++			10-2
			Total = 4								
			Unknown		Xuwen	*Sonneratia apetala*	Free-living	+++	Common		10-5

Table 1. Mangroves biodiversity in Guangdong province of China.

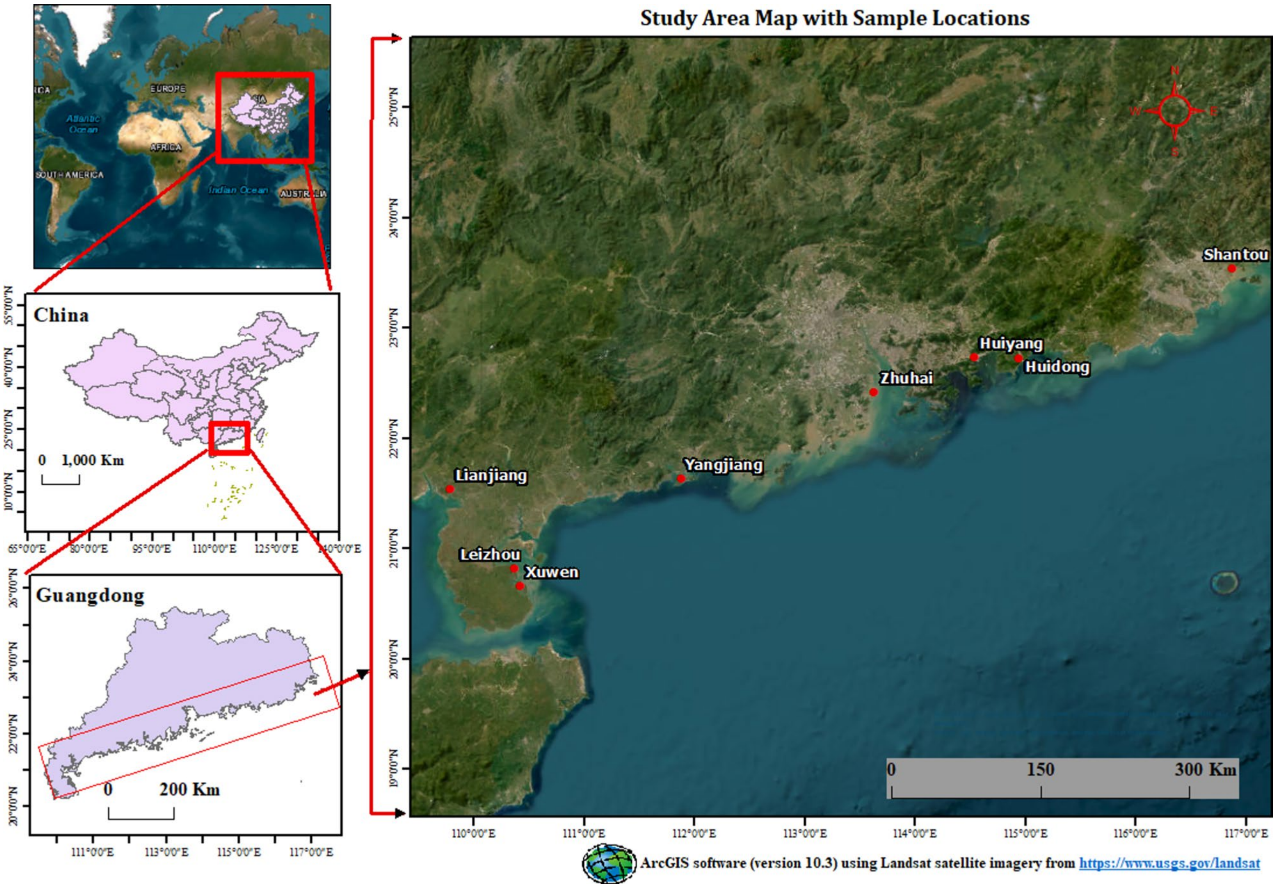


Fig. 1. Map of the eight study stations in Guangdong Province, China, generated using ArcGIS software (version 10.3) through Landsat satellite imagery from https://www.usgs.gov/landsat.

Geneious Prime (version 2025.0.2, Biomatters Ltd.) and deposited at GenBank under Accession No. PV700507 and PV700508. We subjected the sequences to a BLASTn search against the NCBI nucleotide database and downloaded the top 50 hits to confirm the taxonomy. For this, the COX1 sequences were aligned using Clustal Omega 1.2.2[84] in Geneious and a phylogenetic tree was reconstructed using IQ-TREE[85] with automatic model prediction and 1000 bootstrap pseudo replicates to obtain branch support. In all cases, the GTR + F + I + G4 was chosen due to the best-fit model selection based on the Bayesian Information criterion.

Results

The analysis of the data revealed the presence of 87 species (overall species diversity) with eight phyla at different stations in the Guangdong province of China. The mean density of organisms per Phylum from eight stations is shown in Fig. 2. The most abundant phylum was Mollusca represented by 41 species, out of which 28 species were of gastropods: *Onchidium reevesii* (Gray 1850), *Elysia leucolegnote* (Jensen 1990), *Bakawan rotundata*[56], *Bakawan puti*[58], *Haloa wallisii* (Gray 1825), *Neohaustator fortilirata* (Sowerby III 1914), *Neripteron violaceum* (Gmelin 1791), *Monodonta labio* (Linnaeus 1758), *Nassarius stolatus* (Gmelin 1791), *Nassarius sinarum* (Philippi 1851), *Ellobium chinense* (Pfeiffer 1854), *Melampus* (Montfort 1810) sp., *Cassidula sowerbyana* (Pfeiffer 1853), *Laemodonta punctatostriata* (Adams & Adams 1854), *Iravadia* (*Fairbankia*) Stoliczka 1868 sp., *Sermyla riquetii* (Grateloup 1840), *Littoraria melanostoma* (Gray 1839), *Littoraria articulata* (Philippi 1846), *Littoraria ardouiniana* (Heude 1885), *Mainwaringia leithii* (Smith 1876), *Truncacteocina* cf. *coarctata*[56], *Assiminea ovata* (Krauss 1848), *Assiminea estuarina* (Habe 1946), *Assiminea* (Fleming 1828) sp., *Optediceros breviculum* (Pfeiffer 1855), *Pirenella asiatica* (Ozawa & Reid 2016), *Pirenella incisa* (Hombron & Jacquinot 1848) and *Cerithidea tonkiniana* (Mabille 1887). Among gastropods, 14 families were recorded (Onchidiidae, Plakobranchidae, Haminoeidae, Turritellidae, Neritidae, Trochidae, Nassariidae, Ellobiidae, Iravadiidae, Thiaridae, Littorinidae, Cylichnidae, Assimineidae and Potamididae) in which most of the species belong to the family Ellobiidae and Littorinidae as shown in Table 1 (Figs. 3, 4, 5, 6, 7).

Out of the total 28 species of gastropods, three species *Bakawan rotundata*[56], *Bakawan puti*[58], and *Haloa wallisii* (Gray 1825) were first recorded from China (Table 1, Fig. 3). The anatomical nomenclature for *Bakawan rotundata* follows our previous study[57]. The brief taxonomic description for *Haloa wallisii* and *Bakawan puti* is recorded here to avoid misidentification with related species. The anatomical nomenclature for *Haloa wallisii* follows the description of *Haloa* by Oskars and Malaquias[59], see Fig. 8A–C. Shell oval-cylindrical, visible, deep, spiral striae visible. columella slightly concave with a narrow callus, separated from the main shell by a

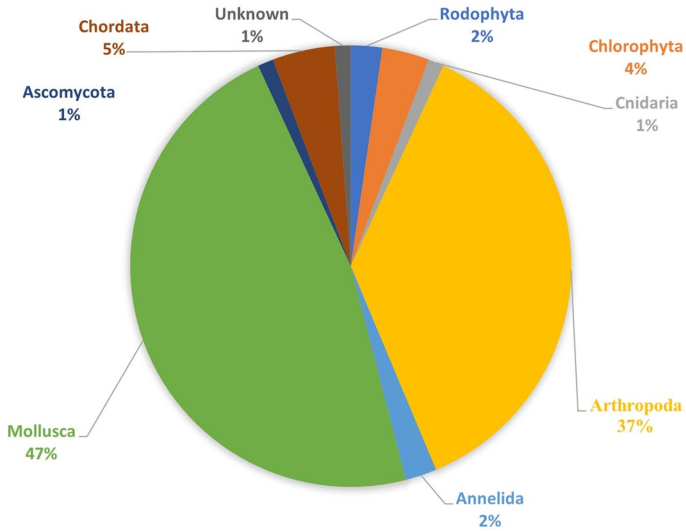


Fig. 2. Pie chart showing mean density of organisms per phylum from sampling stations.

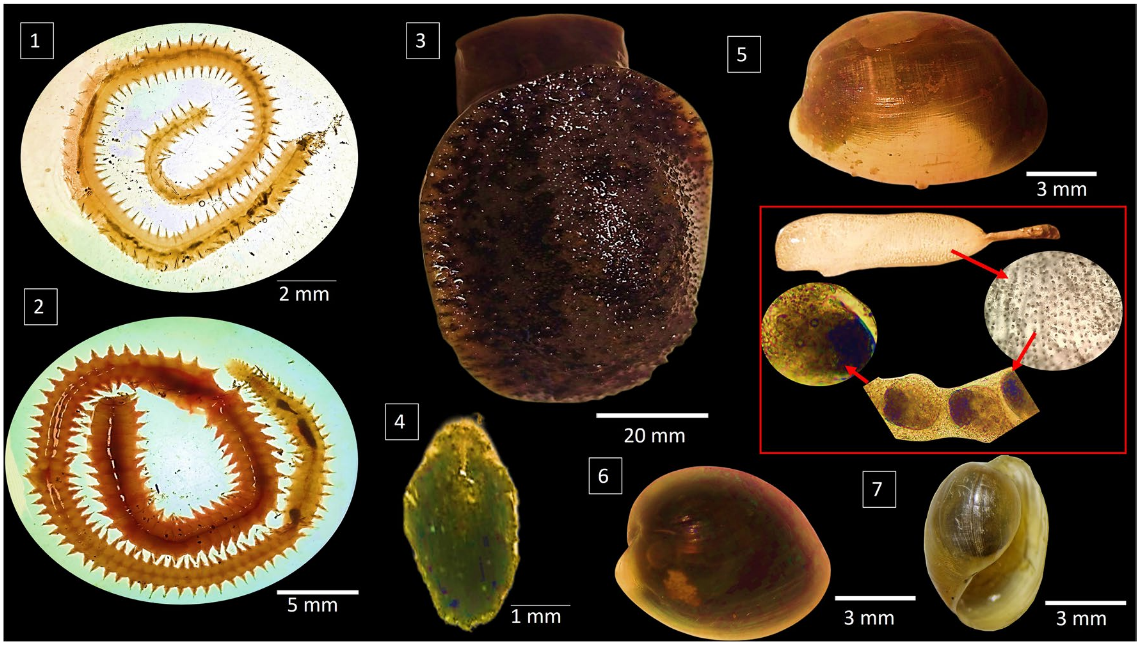


Fig. 3. Polychaetes, sea slug, sacoglossan and bubble snail species found in Mangroves area (1) *Composetia* sp. (2) *Nereis* sp. (3) *Onchidium reevesii* (4) *Elysia leucolegnote* (5) *Bakawan rotundata* (6) *Bakawan puti* (7) *Haloa wallisii*.

furrow. Periostracum of an orange to pale yellow hue. The shell is Whitish–transparent (Fig. 8A). Animal was de-pigmented due to fixation in ethanol and was sampled together with *Bakawan puti*. cephalic shield deeply split forming tow long lobes; eyes are close together and imbedded in a large unpigmented field. Hancock's organ formed by a, thin, long ridge, without branching (Fig. 8B). Prostate bulbously pyriform, smooth. Atrium elongate, thick walled, narrow groove leading up to fundus. Seminal duct short. Fundus, thick walled, walls separated a central groove which opens into the seminal duct inside the fundus. Long retractor muscle runs between seminal duct and lower fundus, a second retractor muscle runs between seminal duct and mantle (Fig. 8C). Based on general outline of the animal and shell it was assumed that this could be *Haloa wallisii*. Closer inspection of the shell and the reproductive system confirm this identification.

The anatomical nomenclature for *Bakawan puti* follows the description of *Bakwan* by Oskars and Malaquias[58], see Fig. 9A–E. Shell whitish-transparent, oval-rounded; surface covered by undulating spiral striae; periostracum whitish-transparent. Columellar callus narrow, columella concave anteriorly. Aperture, tapering slightly posteriorly, broadening towards the anterior. Shoulder rounded; outer lip rounded. Umbilical furrow

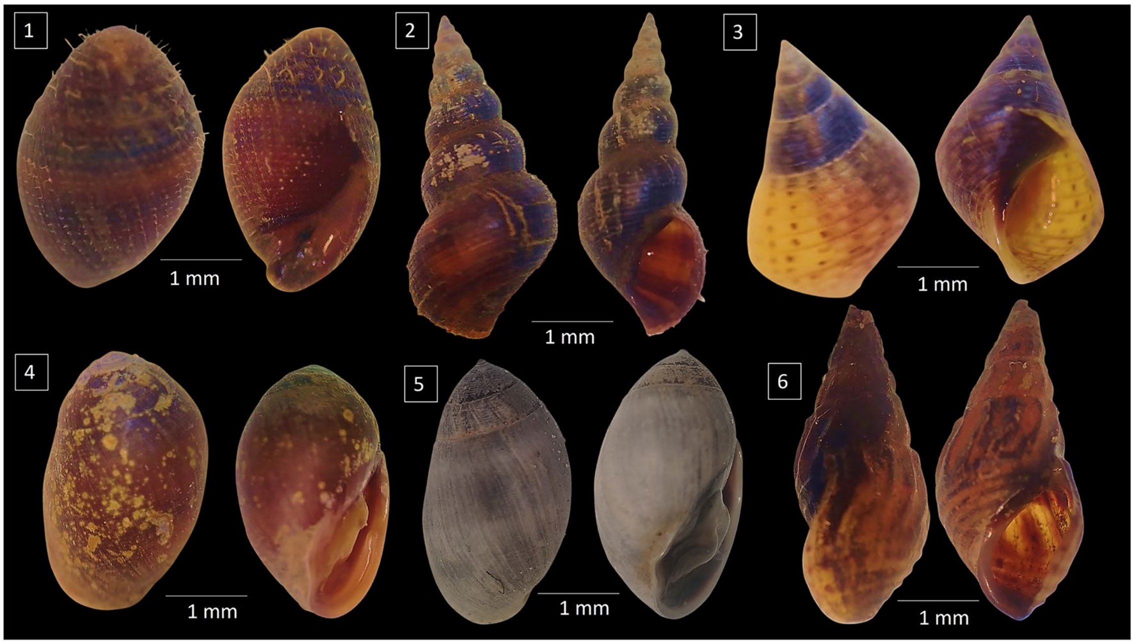


Fig. 4. Gastropod species found in Mangroves area (1) *Laemodonta punctatostriata* (2) *Mainwaringia leithii* (3) *Littoraria melanostoma* (4) *Cassidula sowerbyana* (5) *Melampus* sp. (6) *Sermyla riquetii.*

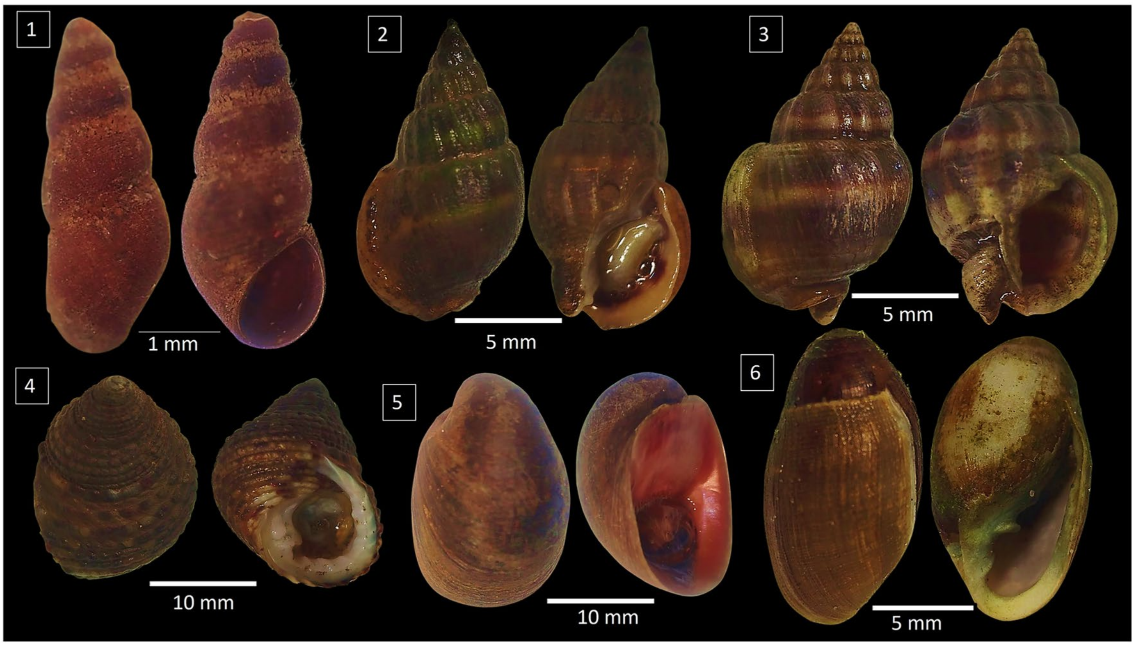


Fig. 5. Gastropod species found in Mangroves area (1) *Iravadia* (*Fairbankia*) sp. (2) *Nassarius sinarum* (3) *Nassarius stolatus* (4) *Monodonta labio* (5) *Neripteron violaceum* (6) *Ellobium chinense.*

runs between lip and main shell (Fig. 9A). Animal pale green to dark green or pale orange to red; mantle semi-transparent. Dark visceral mass apparent trough shell. Cephalic shield square-shaped, broad; slightly indented hind part of cephalic shield covers anterior shell. Eyes set far apart, embedded in a small unpigmented field. Hancock's organ formed by short, thick ridge (Fig. 9B). Elongate oval with short attachment stalk (Fig. 9C, D). Compact, soft warts not apparent. Atrium walled. Fundus with thick walls, pointed triangular bulge on right side, left and right lateral thickened walls easily distinguished internally, meet dorsally, right wall has wider groove than left wall. Seminal groove lies along the atrium wall towards the fundus. Seminal duct opens into fundus apically. One apparent retractor muscle; connecting seminal duct to mantle (Fig. 9E). Based on the colour of the animal it was first assumed that this might be the widespread species *Bakawan rotundata*. However, based on

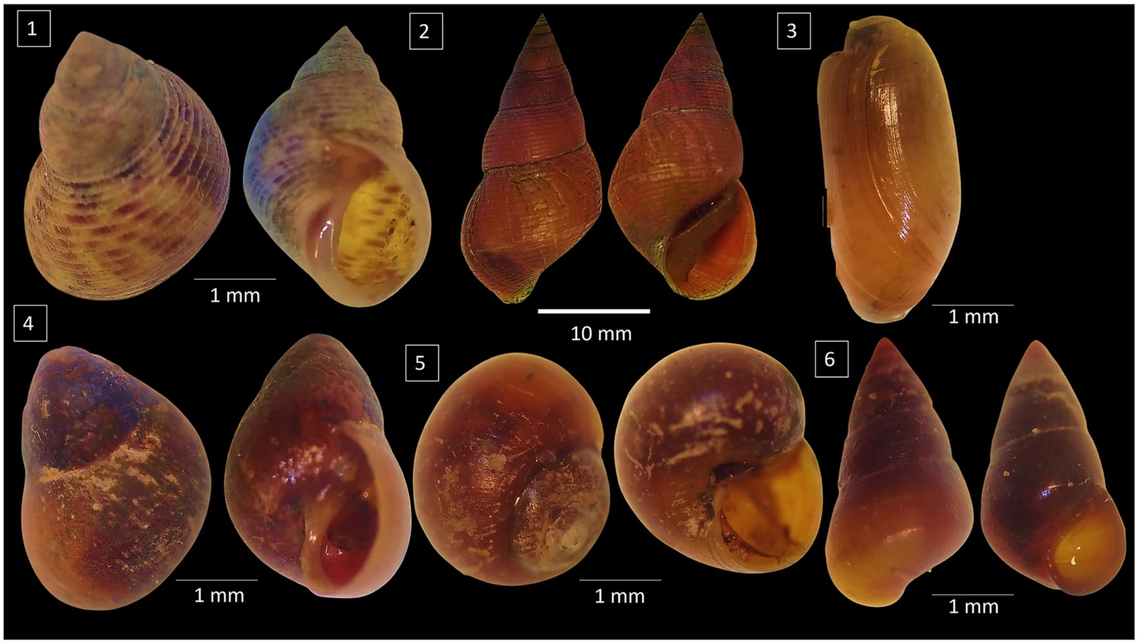


Fig. 6. Gastropod species found in Mangroves area (1) *Littoraria articulata* (2) *Littoraria ardouiniana* (3) *Truncacteocina* cf. *coarctata* (4) *Assiminea ovata* (5) *Assiminea estuarina* (6) *Assiminea* sp.

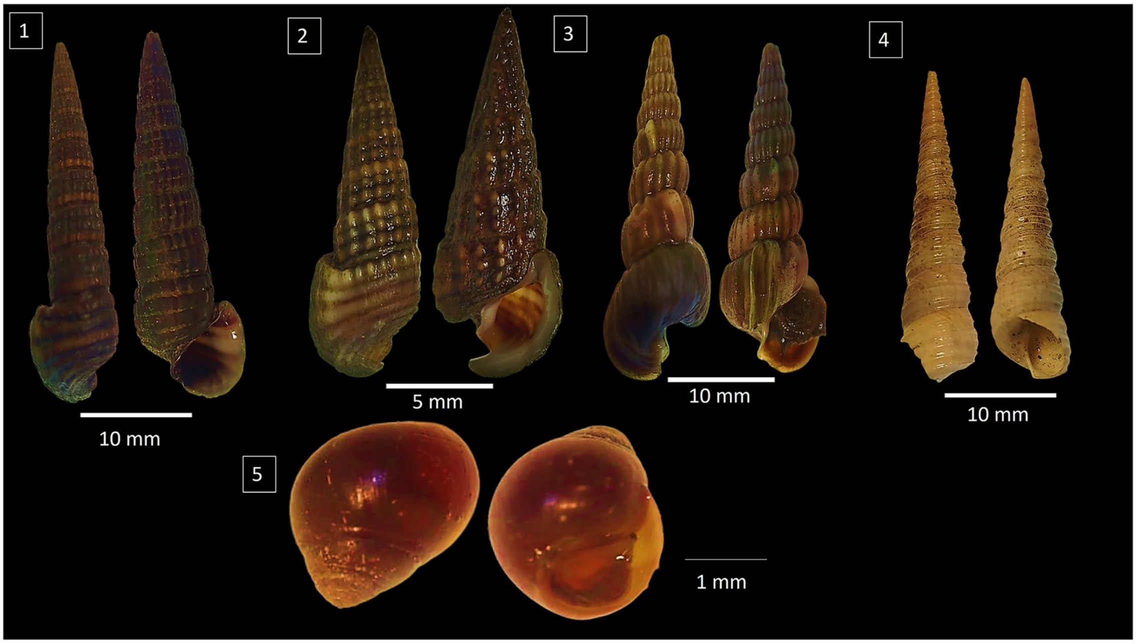


Fig. 7. Gastropod species found in Mangroves area (1) *Pirenella incisa* (2) *Cerithidea tonkiniana* (3) *Pirenella asiatica* (4) *Neohaustator fortilirata* (5) *Optediceros breviculum.*

the unique characteristics of the reproductive system combined with the features of the shell these specimens are identified as to belonging to *B. puti*. The egg masses of gastropod species were also observed (Fig. 10).

Among bivalves, there were 11 families (Veneridae, Anomiidae, Arcidae, Trapezidae, Ostreidae, Arcidae, Modiolidae, Glauconomidae, Tellinidae, Mytilidae and Cyrenoididae) in which most of species recorded from the family Glauconomidae and Veneridae (Table 1). A total of 13 bivalve species; *Meretrix lyrata* (Sowerby II 1851), *Cryptonema producta* (Kuroda & Habe 1951), *Enigmonia aenigmatica* (Holten 1802), *Barbatia virescens* (Reeve 1844), *Neotrapezium sublaevigatum* (Lamarck 1819), *Magallana* cf. *bilineata* (Röding 1798), *Anadara sabinae* (Morlet 1889), *Vignadula mangle* (Ockelmann 1983), *Glauconome angulata* (Reeve 1844), *Glauconome*

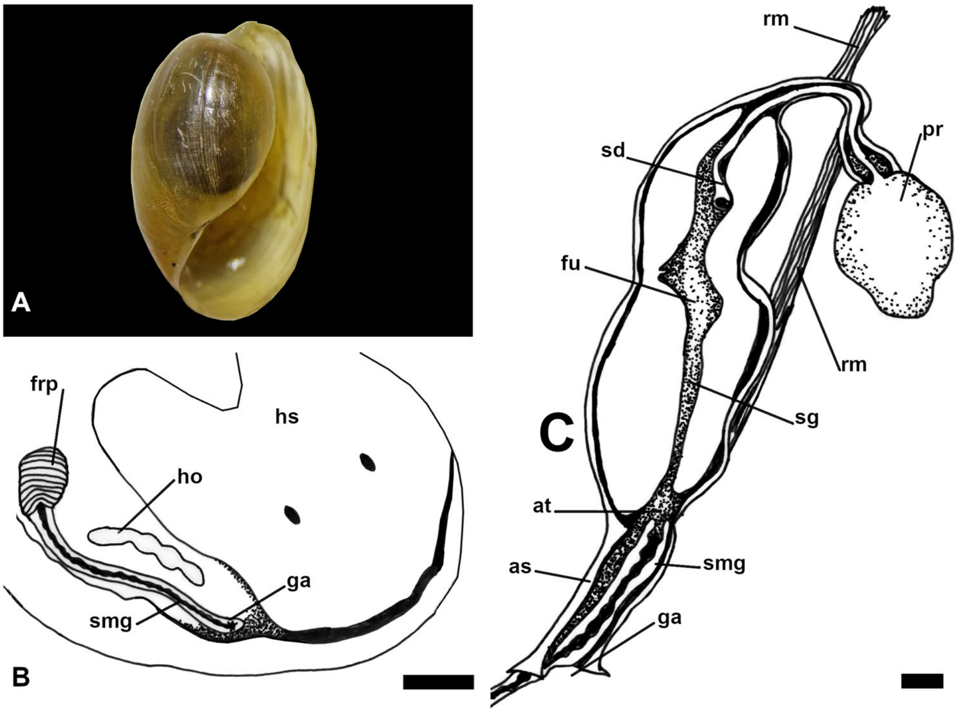


Fig. 8. (**A–C**). Anatomy of *Haloa wallisi,* H = 11.83 mm. (**A**) apertural view of shell. (**B**) Cephalic region of snail. (**C**) External view of male reproductive system. Abbreviations: as, atrium sheath; at, atrium; frp, female reproductive system. fu, fundus; ga, genital aperture; ho, Hancock's organ; pr, prostate; sd, seminal duct; smg, seminal groove; rm, retractor muscles. Scale bars: (b) 1 mm; (c) 0.25 mm.

chinensis (Gray 1828), *Tellinides conspicuus* (Hanley 1846), *Mytella strigata* (Hanley 1843) and *Geloina expansa* (Mousson 1849) (Table 1, Figs. 11, 12).

The phylum Arthropoda was represented by following 32 species: *Megabalanus tintinnabulum* (Linnaeus 1758), *Fistulobalanus albicostatus* (Pilsbry 1916), *Platytrombidium* (Thor 1936) sp., Penthalodidae sp., (the specimens belong to a potentially new genus because the key characters do not fit the diagnosis of any of its genera and resemble the most representatives of the genus Protopenthalodes Jesionowska 1989), *Tetragnatha bimaculata* (Li & Liu 2022), *Tetragnatha* sp., *Episinus* (Walckenaer 1809) sp., *Meotipa* (Simon 1894) sp., *Nephila pilipes* (Fabricius 1793), *Heterocerus* (Fabricius 1792) sp., *Sphaerozius nitidus* (Stimpson 1858), *Mictyris brevidactylus* (Stimpson 1858), *Macrophthalmus* (*Macrophthalmus*) *abbreviatus* (Manning & Holthuis 1981), *Macrophthalmus* (*Macrophthalmus*) *convexus* (Stimpson 1858), *Macrophthalmus* (*Mareotis*) *frequens* (Tai & Song 1984), *Tubuca arcuata* (De Haan 1835), *Gelasimus borealis* (Crane 1975), *Chiromantes haematocheir* (De Haan 1833), *Parasesarma plicatum* (Latreille 1803), *Orisarma neglectum*[42], *Nanosesarma minutum*[42], *Ligia* (*Megaligia*) *exotica* (Roux 1828), *Trichoniscus pygmaeus* (G. O. Sars 1898), *Oudemansia* (Schött 1893) sp., *Entomobrya* (Rondani 1861) sp., *Alpheus inopinatus* (Holthuis & Gottlieb 1958), *Trabala vishnou* (Lefèbvre 1827), *Trabala pallida* (Walker 1855), *Ricania guttata* (Walker 1851), and *Orvasca subnotata* (Walker 1865), and *Orgyia postica* (Walker 1855) (Table 1, Figs. 13, 14, 15, 16, 17).

A molecular analysis revealed, a distinct clade that was made out of "cf. Drosophilidae" and "Canacidae sp." was identified, suggesting unique lineages within these species. The data revealed important insights into genetic divergence and species evolution (Fig. 18), SHSY140711. The second tree focuses on mitochondrial COX1 genes and showcases genetic relationships within the Microtrombididae family and a sequence labeled "cf. Microtrombididae" (Fig. 19). The morphological identification revealed the genus *Platytrombidium* Thor 1936. However, this sequence clusters separately, indicating it was genetically distinct from others and a sequence labeled "cf. Microtrombididae." The strong bootstrap support for this clade suggested a robust evolutionary relationship.

The representatives of phylum Chordata in mangrove forests were *Periophthalmus modestus* (Cantor 1842), *Acentrogobius caninus* (Valenciennes 1837), *Mugilogobius abei* (Jordan & Snyder 1901) and *Butis koilomatodon* (Bleeker 1849), see Table 1, Fig. 10.

Ony two genera of phylum Annelida were found: *Composetia* (Hartmann-Schröder 1985) sp. and *Nereis* (Linnaeus 1758) sp. (Table 1, Fig. 3). The members of other phyla identified were *Pteroeides bankanense* (Bleeker 1859[86]) of Cnidaria and *Corynespora* (Güssow = Freynella O.Kuntze 1891) of Ascomycota.

Species of macroalgae belonged to Chlorophyta (*Ulva clathrata* (Roth) C. Agardh 1811, *Cladophora* (Kützing 1843) sp. and *Boodleopsis pusilla (Collins)* W.R.Taylor, Joly & Bernatowicz 1953) and Rodophyta (*Catenella impudica* (Montagne) (Agardh 1852) and *Gelidium pusillum* (Stackhouse) (Le Jolis 1863) were also found (Table 1, Fig. 20).

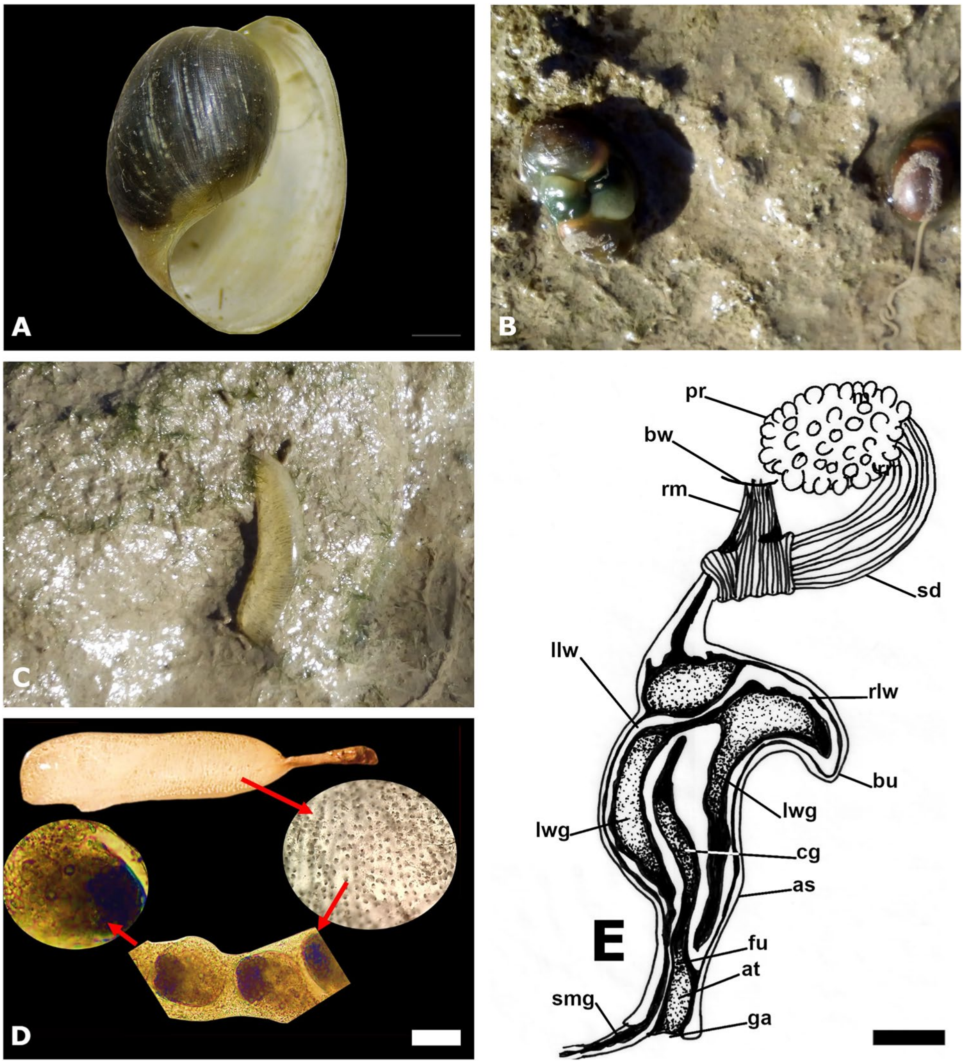


Fig. 9. (**A–E**). Anatomy of *Bakawan puti*, H = 8.95 mm. (**A**) Apertural view of shell. (**B**) Live specimens in the field. (**C**) Eggmasses embedded in mangrove mud. (**D**) Eggmass with 40×, 100× and 400× magnifications of eggs with larvae. (**E**) Dorsal view of external surface of male reproductive system, showing exposed atrium and fundus. Abbreviations: as, atrium sheath; at, atrium; bw, body wall; bu, bulge; cg, central groove; fu, fundus; ga, genital aperture; llw, left lateral wall; lwg, grooves of lateral walls; pr, prostate; sd, seminal duct; rlw, right lateral wall; smg, seminal groove; rm, retractor muscles. Scale bars: (D) 1,5 mm (for unmagnified eggmass); (c) 0.5 mm.

As shown in Fig. 21, the highest number of specimens (N) was observed at station Yangjiang, with 318 species (24%) and the lowest was recorded at station Shantou with 25 species (3%), (see Table 2 for the stations' variation in biodiversity of mangroves areas concerning the total number of specimens). The percentages of the mean density of species regarding usage of mangroves show the highest (60%) values for free-living organisms and the lowest (1%) value for invasive species, as shown in Fig. 22. The percentages of species collection spots regarding the mangrove plant species showed the highest collection of organisms besides the *A. marina* (30%) and the lowest collection from the *B. gymnorhiza* (2%) as shown in Fig. 23.

The diversity indices showed the highest number of specimens (N = 318) at Yangjiang (natural mangrove forests at lower latitudes 20–21N of pristine areas) and the lowest (N = 25) at Shantou (Planted mangroves at higher latitudes 22–23N of non-pristine areas). In the present study the Dominance (0.05–0.38) and Simpson (0.62–0.95) indices were limited to zero levels, indicating that all taxa were equally present in all stations. The Shanon index, with values ranging from 1.01 to 3.13, indicates that many taxa were present. The evenness index in the present study was 0.77–0.96, with a few/single species dominated in specific stations. While the Brillouin (0.84–2.93), Menhinick (0.60–1.52), Margalef (0.62–4.51), Fisher-alpha (0.89–7.05), and Chao-1 (3.00–27.50) indices were directly proportional to the abundance rate, they represented higher abundance rates at Yangjiang station. Equitability (0.91–1.01) index showed that members of all taxa were evenly distributed in all stations. However, the Berger-Parker index was inversely proportional to the abundance and showed the lowest value (0.09) in Yangjiang station. The details of all indices are given in Table 3 and Fig. 24.

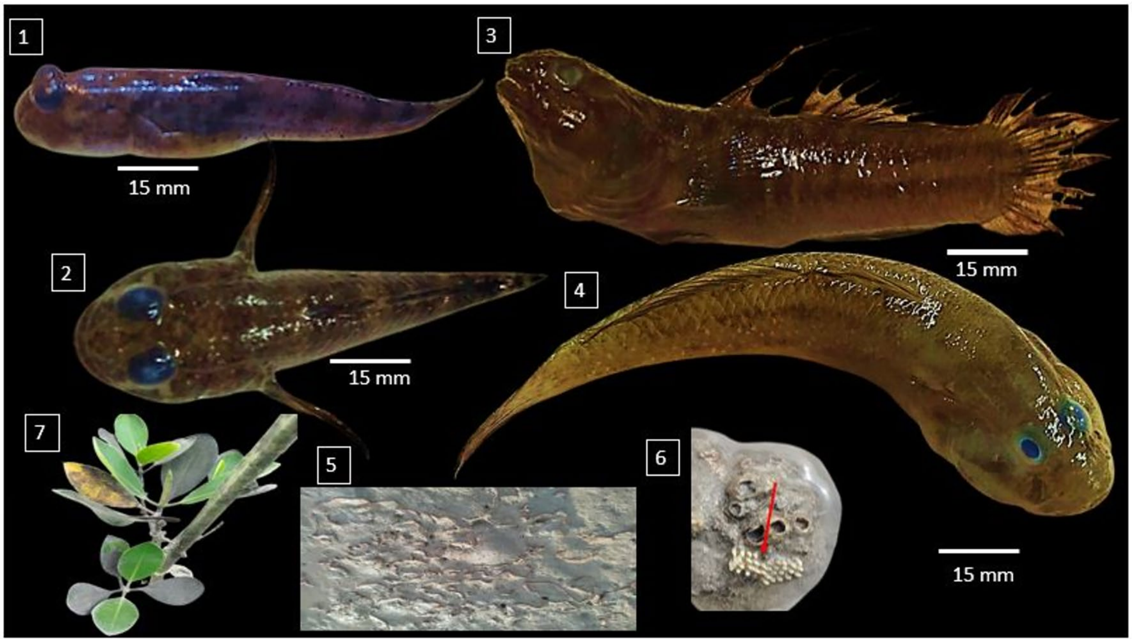


Fig. 10. Fishes, leaf spot, gastropod eggs and an unknown species found in Mangroves area (1) *Periophthalmus modestus* (2) *Butis koilomatodon* (3) *Mugilogobius abei* (4) *Acentrogobius caninus* (5) *Unknown* (6) Gastropod eggs.

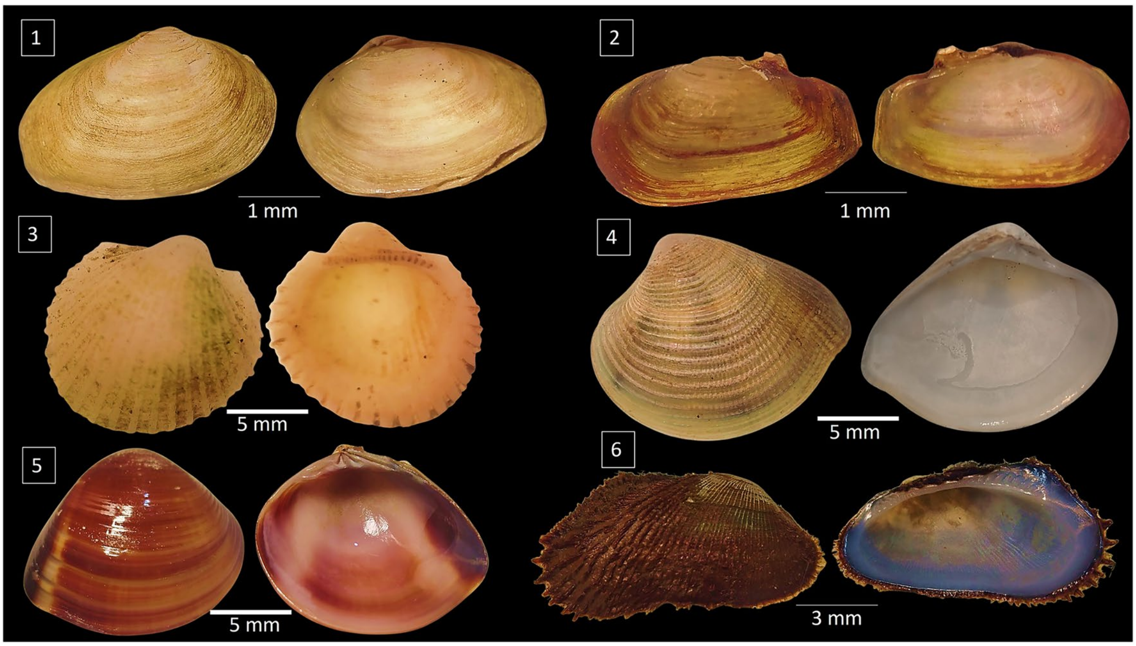


Fig. 11. Bivalve species found in Mangroves area (1) *Glauconome chinensis* (2) *Glauconome angulata* (3) *Anadara sabinae* (4) *Cryptonema producta* (5) *Meretrix lyrata* (6) *Barbatia virescens.*

The cluster analysis among eight stations revealed a distance between Yangjiang and Leizhou and Lianjiang and Huidong (Fig. 25A). In contrast, Zhuhai, Shantou, and Huiyang showed neighbor clustering (Fig. 25B.) with a distance index ranging from 21.52 to 73.58. The values of the Cophenetic coefficient among stations were 0.95. The map of spatial pattern of biodiversity shows high values (yellow) of beta biodiversity and greater heterogeneity at stations Yangjiang, Leizhou, Xuwen and Liangjiang. Low values (blue) of beta-diversity at stations Shantou, Zhuhai, Huiyang and Huidong indicated a homogeneous set of species. The spatial resolution was 30 m and the overall mean biodiversity value was 7056.572 ± 28.94 in our area of interest, with minimum and maximum values was 6977 and 7161, respectively (Fig. 26).

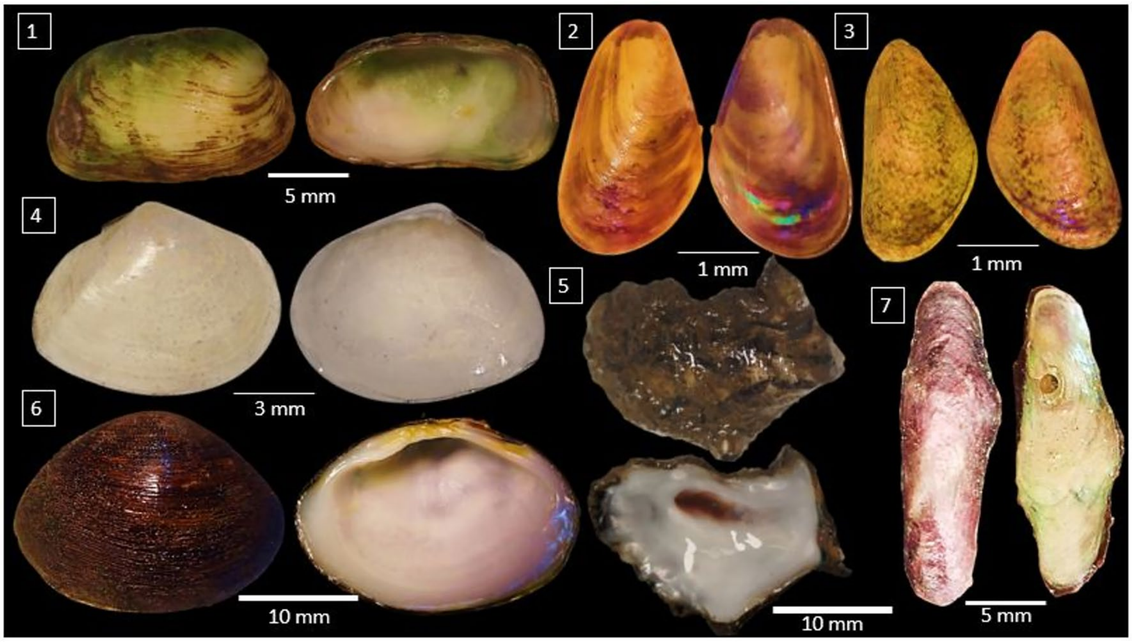


Fig. 12. Bivalve species found in Mangroves area (1) *Neotrapezium sublaevigatum* (2) *Vignadula mangle* (3) *Mytella strigata* (4) *Tellinides conspicuus* (5) *Magallana* cf. *bilineata* (6) *Geloina expansa.*

Fig. 13. Barnacle species found in Mangroves area (1) *Megabalanus tintinnabulum* (2) *Fistulobalanus albicostatus.*

Discussion

This study was conducted to assess the biodiversity of the eight mangrove forests sites of Guangdong Province, China. The results showed that there were eight representative major phyla, with significant spatial variation in species richness and community structure. The phylum Mollusca emerged as the most dominant taxonomic group, comprising 41 species, of which 28 were gastropods distributed across 14 families. The high representation of families such as Ellobiidae and Littorinidae underscores the ecological specialization and adaptation of mollusks to intertidal environments. These findings are consistent with molluscan diversity patterns reported in the Philippines and western Hainan Island, where mollusks serve key ecological roles in detritus processing, biofilm grazing, and nutrient recycling[87,88]. Remarkably, three gastropod species—*Bakawan rotundata*, *Bakawan*

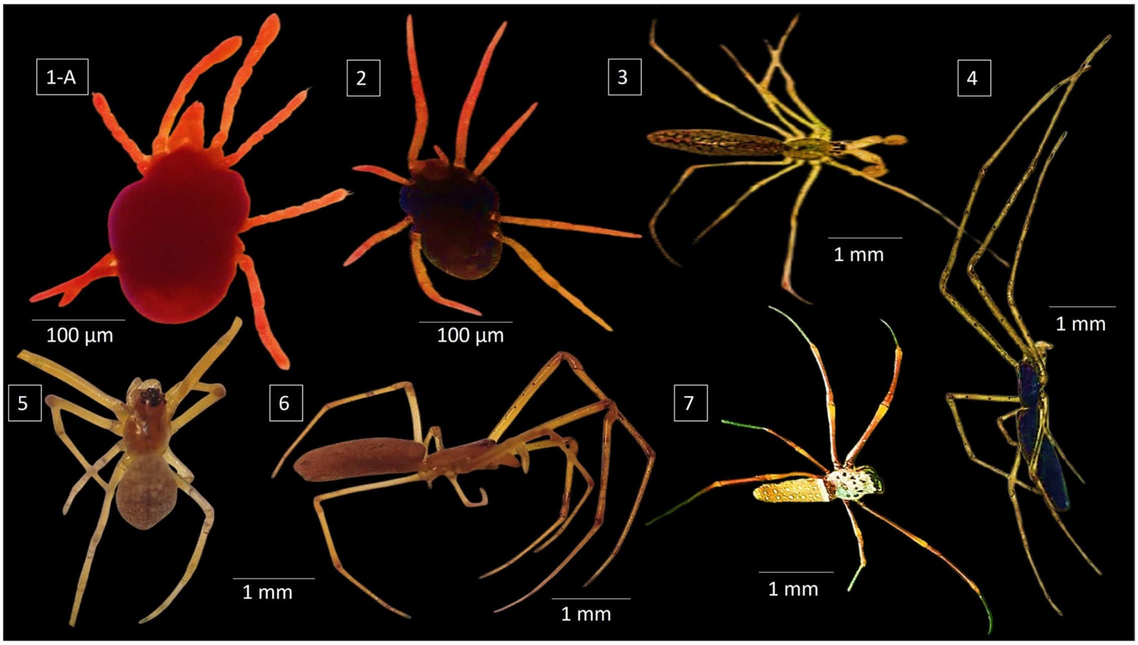


Fig. 14. Mite and spider species found in Mangroves area (1-A) *Platytrombidium* sp. (2) *Eupodidae* sp. (3) *Tetragnatha bimaculate* (4) *Tetragnatha* sp. (5) *Episinus* sp. (6) *Meotipa* sp. (7) *Nephila pilipes.*

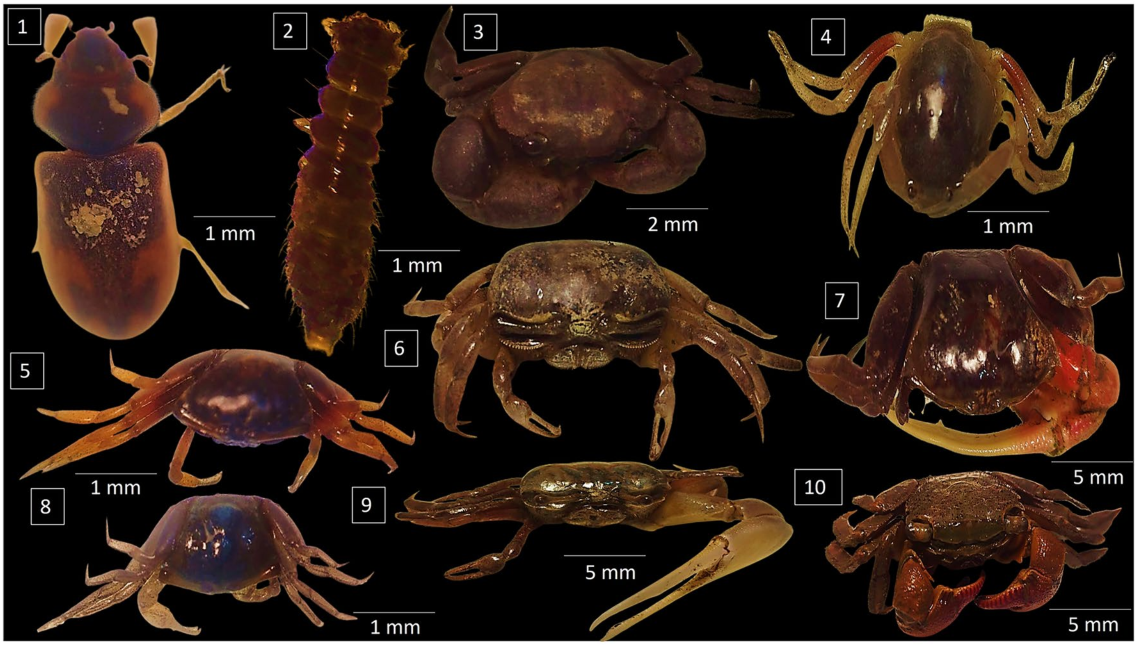


Fig. 15. Crab species found in Mangroves area (1) *Heterocerus* sp. (2) *Heterocerus* sp. larvae (3) *Sphaerozius nitidus* (4) *Mictyris brevidactylus* (5) *Macrophthalmus (Macrophthalmus) abbreviatus* (6) *Macrophthalmus* (*Mareotis*) *frequens* (7) *Tubuca arcuate* (8) *Macrophthalmus* (*Macrophthalmus*) *convexus* (9) *Gelasimus borealis* (10) *Chiromantes haematocheir.*

puti, and *Haloa wallisii*—were recorded for the first time in China, expanding their known biogeographic range and reflecting the connectivity between the South China Sea and adjacent tropical waters[59]. The genus *Haloa* Pilsbry 1921 consists of dull-coloured snails found in sub-tropical and tropical climates of the Indo West Pacific region. According to the Oskars and Malaquias[59], there are 13 valid species in the genus *Haloa*. *Haloa wallisii*, was previously more well known as, but misidentified, under the name *Haminoea natialensis* as well as several other taxa now regarded as synonyms. The species has a wide distribution from the Indian Ocean (South Africa, Mozambique, United Arab Emirates, India) to the west and Southwest- Pacific (Thailand, Hong Kong and

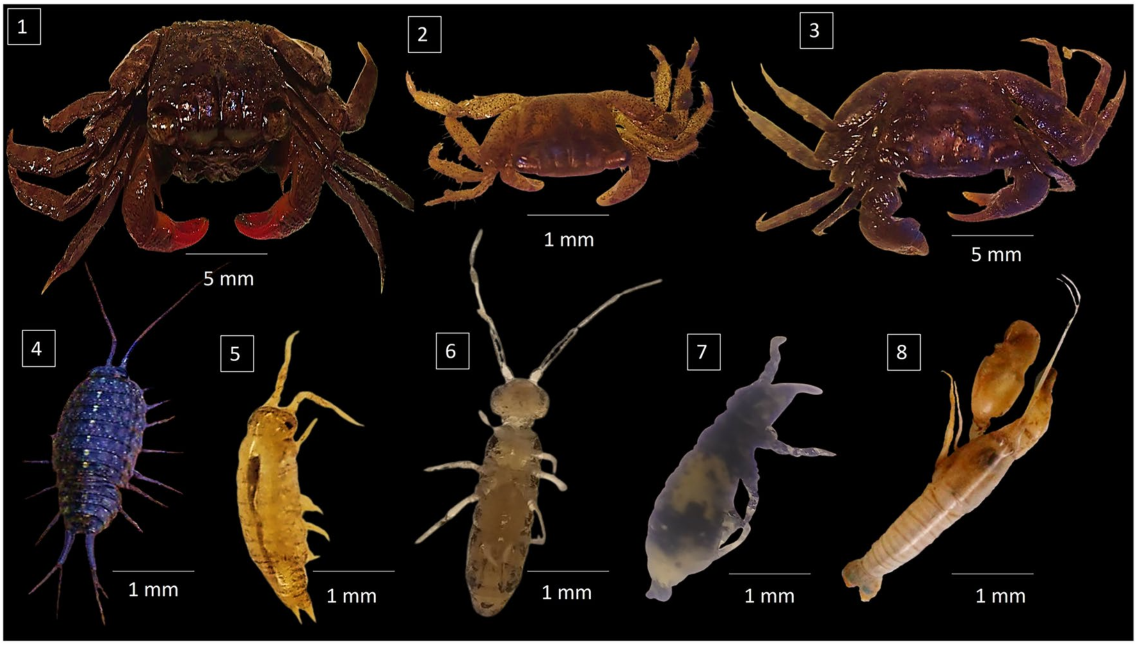


Fig. 16. Crab, sea roach, woodlouse, springtails and shrimp species found in Mangroves area (1) *Parasesarma plicatum* (2) *Orisarma neglectum* (3) *Nanosesarma minutum* (4) *Ligia (Megaligia) exotica* (5) *Trichoniscus pygmaeus* (6) *Entomobrya* sp. (7) *Oudemansia* sp. (8) *Alpheus inopinatus*.

Fig. 17. Moths and fly species found in Mangroves area (1) *Trabala vishnou* (2) *Trabala pallida* (3) *Orgyia postica* (4) *Orvasca subnotata* (5) *Ricania guttata* (6-A) SHSY140711.

Australia)[59,89]. Recently it was also reported from the coast of Iraq in the northwestern Persian Gulf[60]. With our results the range of this species is further increased and will likely further increase as the species becomes more well known and reconcilable to naturalists.

The genus *Bakawan* comprises typically brightly coloured snails linked with intertidal mangrove environments and mudflats. Previously the genus was associated with the widespread species *Haminoea fusca*[56,57], which later turned out to be four distinct species. The most widespread and recognized species was in reality *Bakawan rotundata*[56], whereas *B. fusca* is only known from museum lots collected in the Philippines[58].

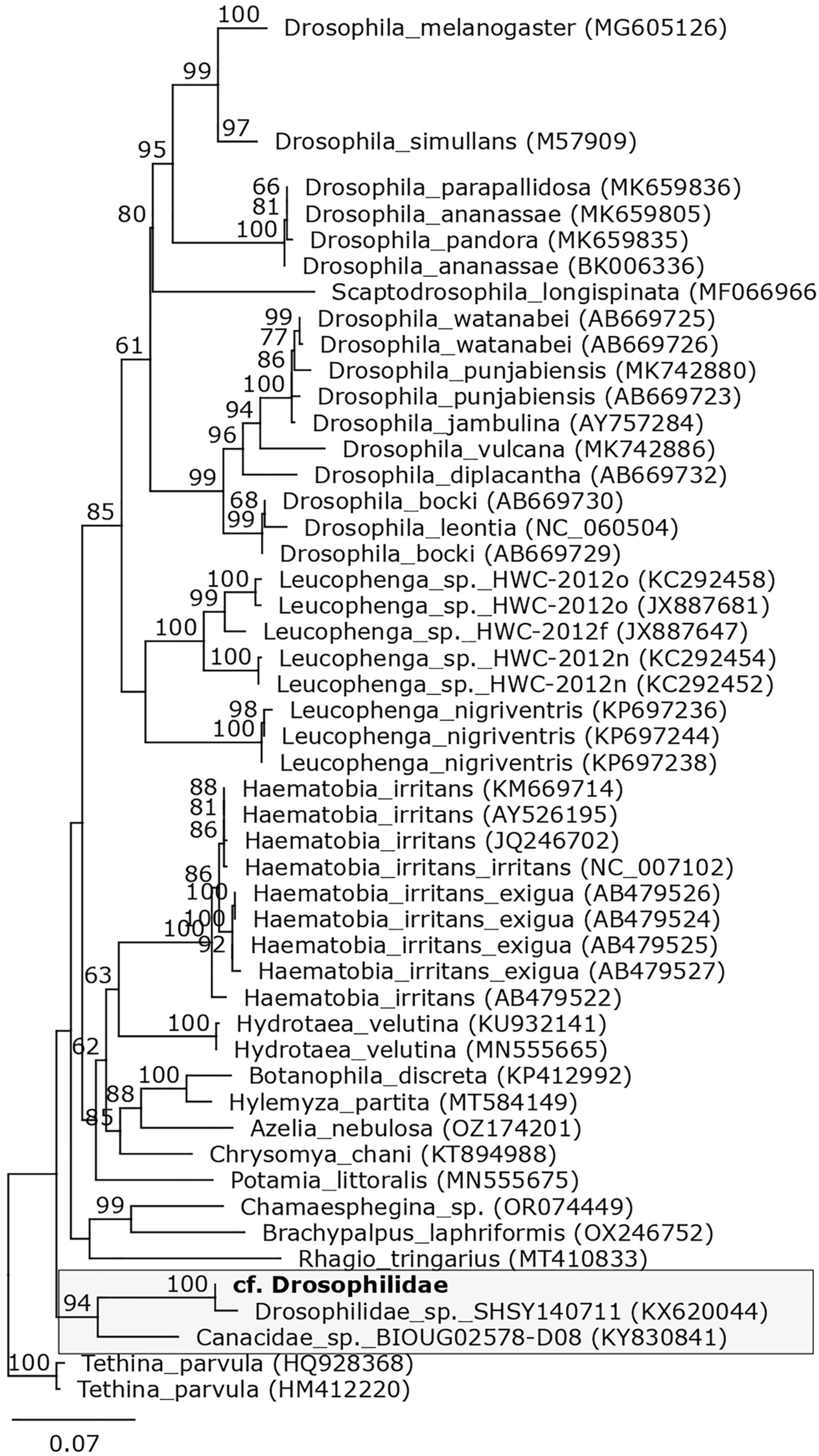


Fig. 18. Phylogenetic consensus tree inferred from mitochondrial COI (cytochrome c oxidase subunit I) gene sequences showing the evolutionary relationships among various species within the family Drosophilidae and related dipteran taxa. Bootstrap values (> 50%) from 1000 replicates are indicated at the corresponding nodes. Specimen labels include species names and associated GenBank accession numbers. The clade encompassing Drosophilidae, including *Drosophila melanogaster*, *D. simulans*, and *Leucophenga* species, is clearly resolved with high support values. Additional families such as Muscidae (*Haematobia irritans*, *Hydrotaea velutina*), Calliphoridae (*Chrysomya chani*), and Syrphidae (*Brachypalpus laphriformis*) are included as outgroups to root the tree. The scale bar indicates the number of nucleotide substitutions per site.

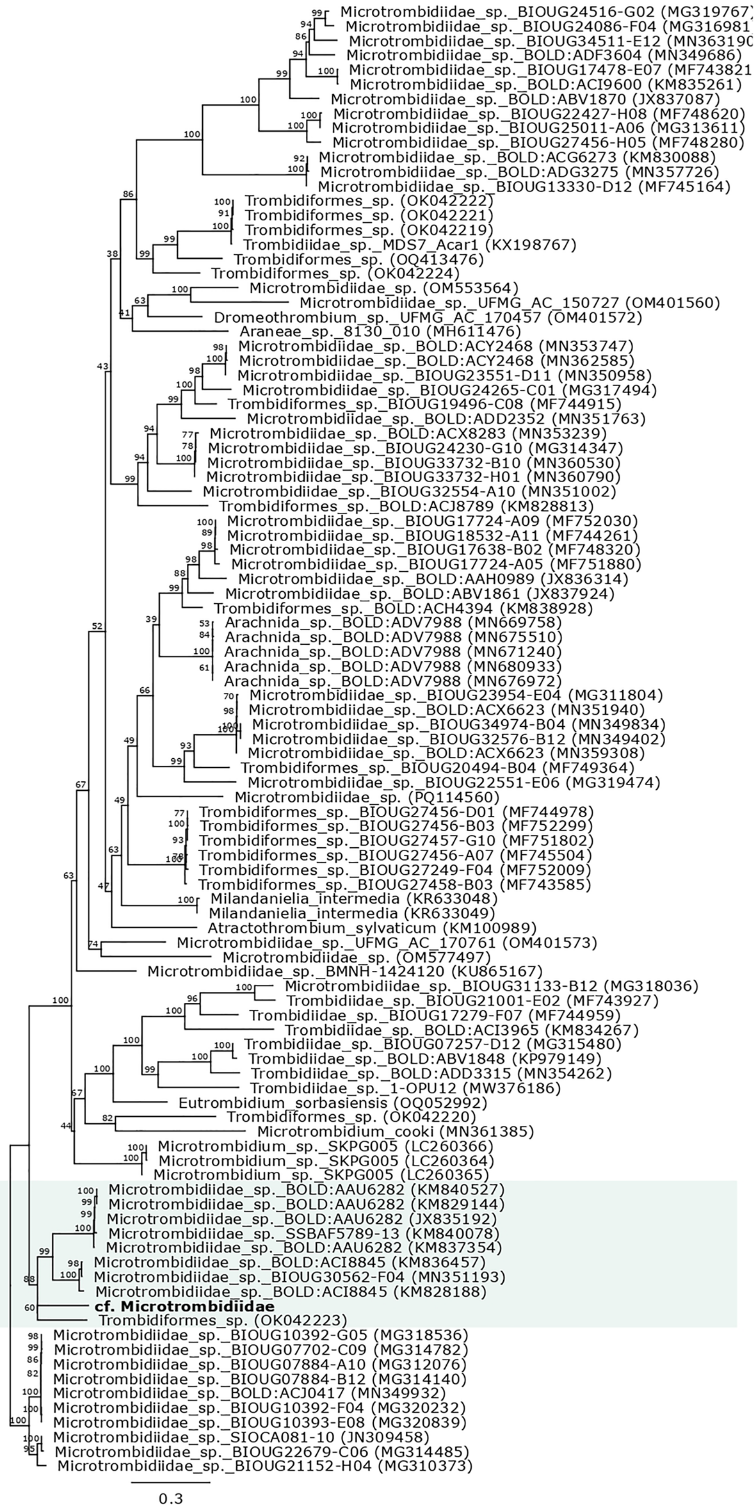


Fig. 19. Phylogenetic consensus tree based on COI (cytochrome c oxidase subunit I) gene sequences depicting the evolutionary relationships among selected species and unidentified taxa of the order Trombidiformes, including members of the family Microtrombidiidae. Bootstrap support values (> 50%) from 1000 replicates are shown at the nodes. Specimen identifiers are labeled with their respective BOLD process IDs, GenBank accession numbers, and collection codes. A distinct clade representing *Microtrombidium* sp. is highlighted in blue, indicating a monophyletic grouping with strong bootstrap support. Scale bar represents the number of nucleotide substitutions per site.

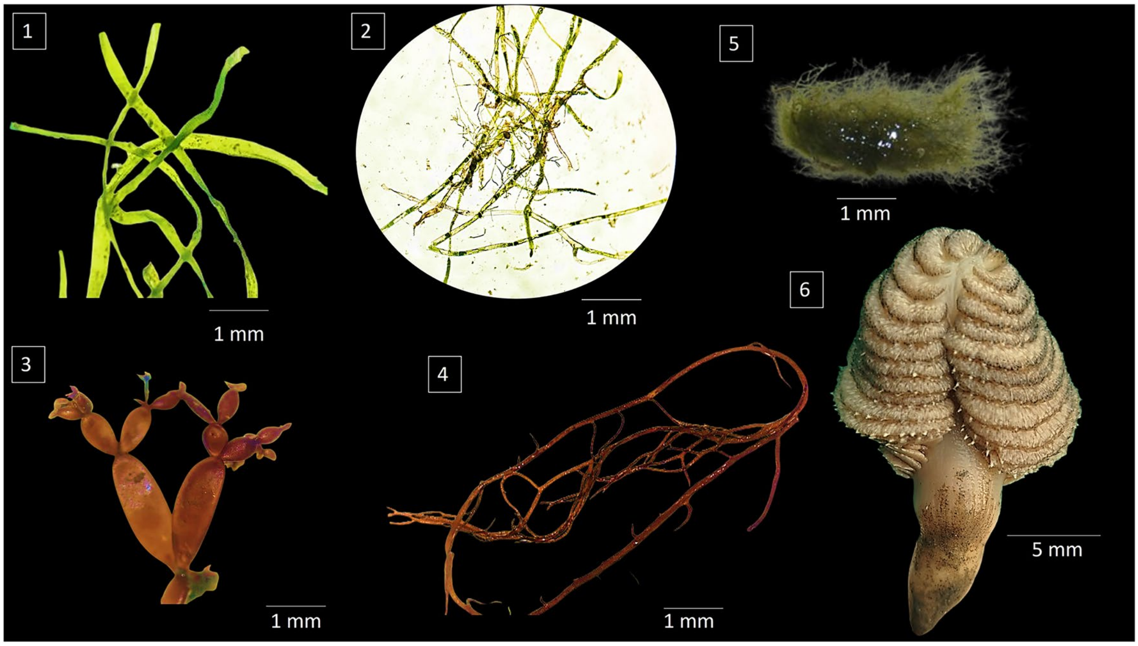


Fig. 20. Algae species found in Mangroves area (1) *Ulva Clathrata* (2) *Cladophora* sp. (3) *Catenella impudica* (4) *Gelidium pusillium* (5) *Boodleopsis pusilla* (6) *Pteroeides bankanense.*

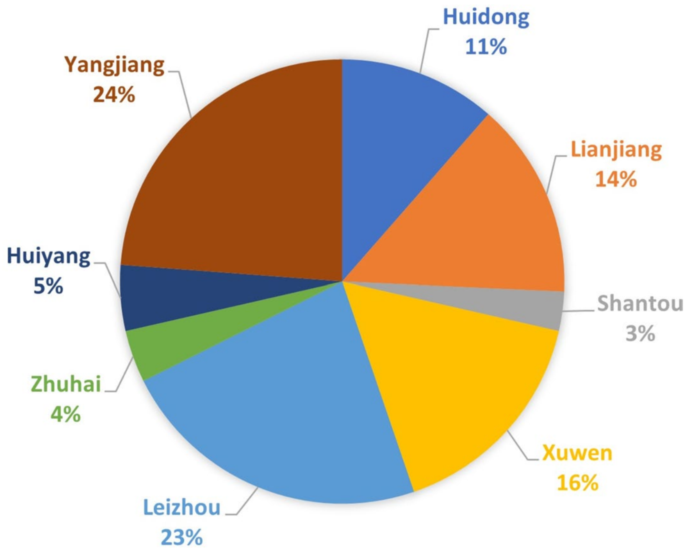


Fig. 21. Pie chart showing percentages of species collected in eight stations.

Bakawan puti[58] is one of these recently described species, previously only recorded from two islands of the Philippines[58] and more recently from Lantau Island in Hong Kong[90]. The species name (pale in Tagalog) refers to the pale orange colour and pale periostracum of the few known specimens from Philippines. Oskars and Malaquias[58] forwarded that the orange coloration of the animal could be diagnostic but would not with the study of additional specimens. This apprehension was based on that both *B. rotundata* and *B. hedleyi*[58] from Australia shows a striking colour variation from white, to bright green, red and black. The result of our current study strongly suggests that the coloration of these snails is likely caused by its local environment, likely the algae it feeds on, but this will have to be confirmed in future research. The species of the genus can be distinguished by shell shape and the colour of the periostracum. However, *B. routndata* and *B. puti can* only readily be distinguished externally by the periostracum, which may be hard to distinguish due to the colour of the animal and visceral mass. As both species can display an array of colours, and apparently has a partially overlapping range, the two species may have been confused in species records. It can also conclude that *B. puti*

Yangjiang	N	Leizhou	N	Xuwen	N	Lianjiang	N	Huidong	N	Huiyang	N	Zhuhai	N	Shantou	N
Heterocerus sp.	9	*B. pusilla*	20	*B. pusilla*	15	*C. impudica*	10	*C. impudica*	15	*M. (Mareotis) frequens*	6	*M. brevidactylus*	10	*U. clathrata*	12
S. nitidus	11	*M. tintinnabulum*	15	*P. bankanense*	2	*G. pusillum*	15	*G. pusillum*	13	*T. arcuata*	8	*C. haematocheir*	7	*M. (Macrophthalmus) abbreviatus*	3
M.brevidactylus	25	*F. albicostatus*	10	Penthalodidae	20	*U. clathrata*	13	*Cladophora* sp.	11	*G. borealis*	10	*N. minutum*	6	*L. (Megaligia) exotica*	10
M. (Macrophthalmus) abbreviatus	10	*O. neglectum*	13	*Entomobrya* sp.	15	*Cladophora* sp.	13	*Platytrombidium* sp.	25	*T. pygmaeus*	2	*R. guttata*	5		
M. (Macrophthalmus) convexus	13	*N. minutum*	10	SHSY140711	8	*M. tintinnabulum*	15	*T. bimaculata*	6	*Entomobrya* sp.	10				
M. (Mareotis) frequens	10	*L. (Megaligia) exotica*	8	*C. marmorata*	3	*F. albicostatus*	9	*Tetragnatha* sp.	3						
T. arcuata	30	*O. reevesii*	8	*E. leucolegnote*	14	*O. neglectum*	13	Theridiidae 1	3						
G. borealis	25	*E. leucolegnote*	25	*Melampus* sp.	13	*T. pygmaeus*	7	Theridiidae 2	2						
C. haematocheir	10	*B. rotundata*	15	*A.ovata*	9	*R. guttata*	5	*N. pilipes*	3						
P. plicatum	20	*B. puti*	12	*A. estuarina*	6	*N. violaceum*	10	*Oudemansia* sp.	10						
Composetia sp.	5	*H. wallisii*	10					*A. inopinatus*	2						
Nereis sp.	1	*M. labio*	5	*Assiminea* sp.	3	*E. chinense*	6	*T. vishnou*	2						
N. fortilirata	3	*N. stolatus*	9	*V. mangle*	10	*C. sowerbyana*	4	*T. pallida*	14						
S. riquetii	9	*N. sinarum*	5	*Corynespora* Güssow = Freynella	5	*S. riquetii*	3	*R. guttata*	5						
L. ardouiniana	12	*L*	7	*A. caninus*	3	*L. melanostoma*	9	*O. subnotata*	3						
T. cf. *coarctata*	9	*Iravadia (Fairbankia)* sp.	5	*M. abei*	2	*L. articulata*	7	*O. postica*	3						
P. asiatica	25	*L. melanostoma*	11	Unknown	9	*M. leithii*	6								
C. tonkiniana	18	*A. estuarina*	8	*O. breviculum* (L. Pfeiffer 1855)	15	*M. strigata*	4								
C. producta	3	*P. incisa*	25												
E. aenigmatica	7	*M. lyrata*	8												
B. virescens	17	*M.* cf. *bilineata*	20												
N. sublaevigatum	8	*G. angulata*	10												
A. sabinae	2	*G. chinensis*	6												
V. mangle	11	*P. modestus*	5												
T. conspicuus	5	*B. koilomatodon*	2												
M. strigata	7														
G. expansa	13														
Total	318		272		152		149		120		36		28		25

Table 2. Stations variation in biodiversity of Mangroves areas (N = Total Number of specimens).

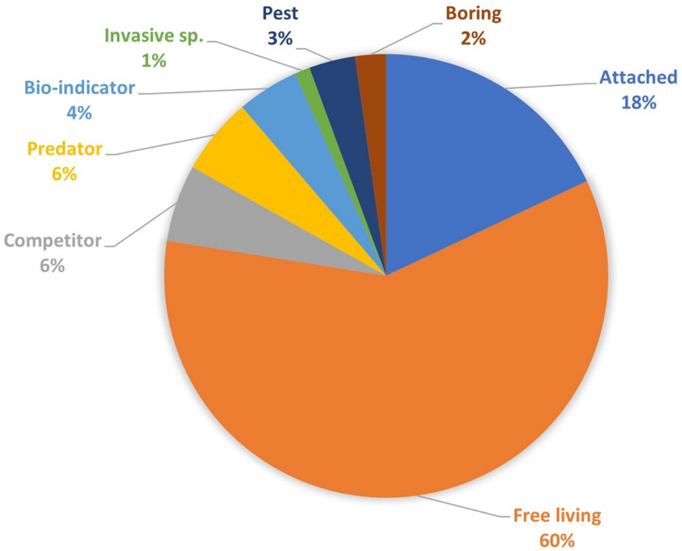


Fig. 22. Percentages of mean density of species with reference to usage of mangroves.

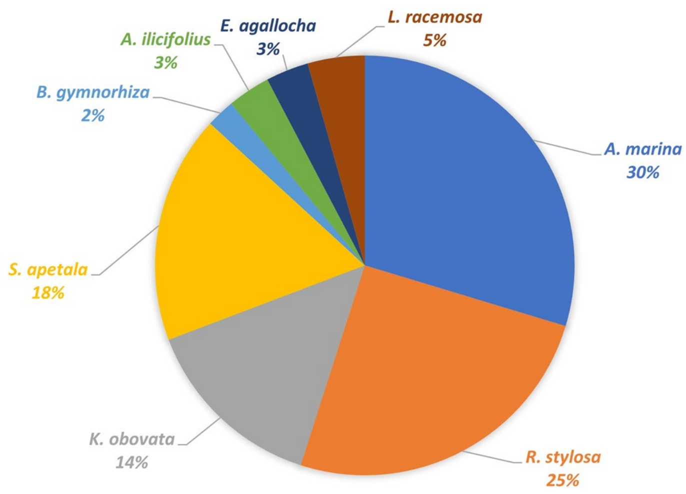


Fig. 23. Percentages of species collection from different mangrove plants at study areas.

	Yangjiang	Leizhou	Xuwen	Lianjiang	Huidong	Huiyang	Zhuhai	Shantou
Taxa_S	27.00	25.00	17.00	17.00	16.00	5.00	4.00	3.00
Individuals	318.00	272.00	152.00	149.00	120.00	36.00	28.00	25.00
Dominance_D	0.05	0.05	0.07	0.06	0.10	0.21	0.24	0.38
Simpson_1-D	0.95	0.95	0.93	0.94	0.90	0.79	0.76	0.62
Shannon_H	3.13	3.12	2.69	2.79	2.52	1.56	1.41	1.01
Evenness_e^H/S	0.85	0.91	0.87	0.96	0.77	0.95	1.02	0.92
Brillouin	2.93	2.90	2.45	2.53	2.24	1.32	1.18	0.84
Menhinick	1.51	1.52	1.38	1.39	1.46	0.83	0.76	0.60
Margalef	4.51	4.28	3.19	3.20	3.13	1.12	0.90	0.62
Equitability_J	0.95	0.97	0.95	0.98	0.91	0.97	1.01	0.92
Fisher_alpha	7.05	6.71	4.91	4.94	4.96	1.58	1.28	0.89
Berger-Parker	0.09	0.09	0.13	0.10	0.21	0.28	0.36	0.48
Chao-1	27.50	25.00	17.00	17.00	16.00	5.00	4.00	3.00

Table 3. Diversity indices in all stations.

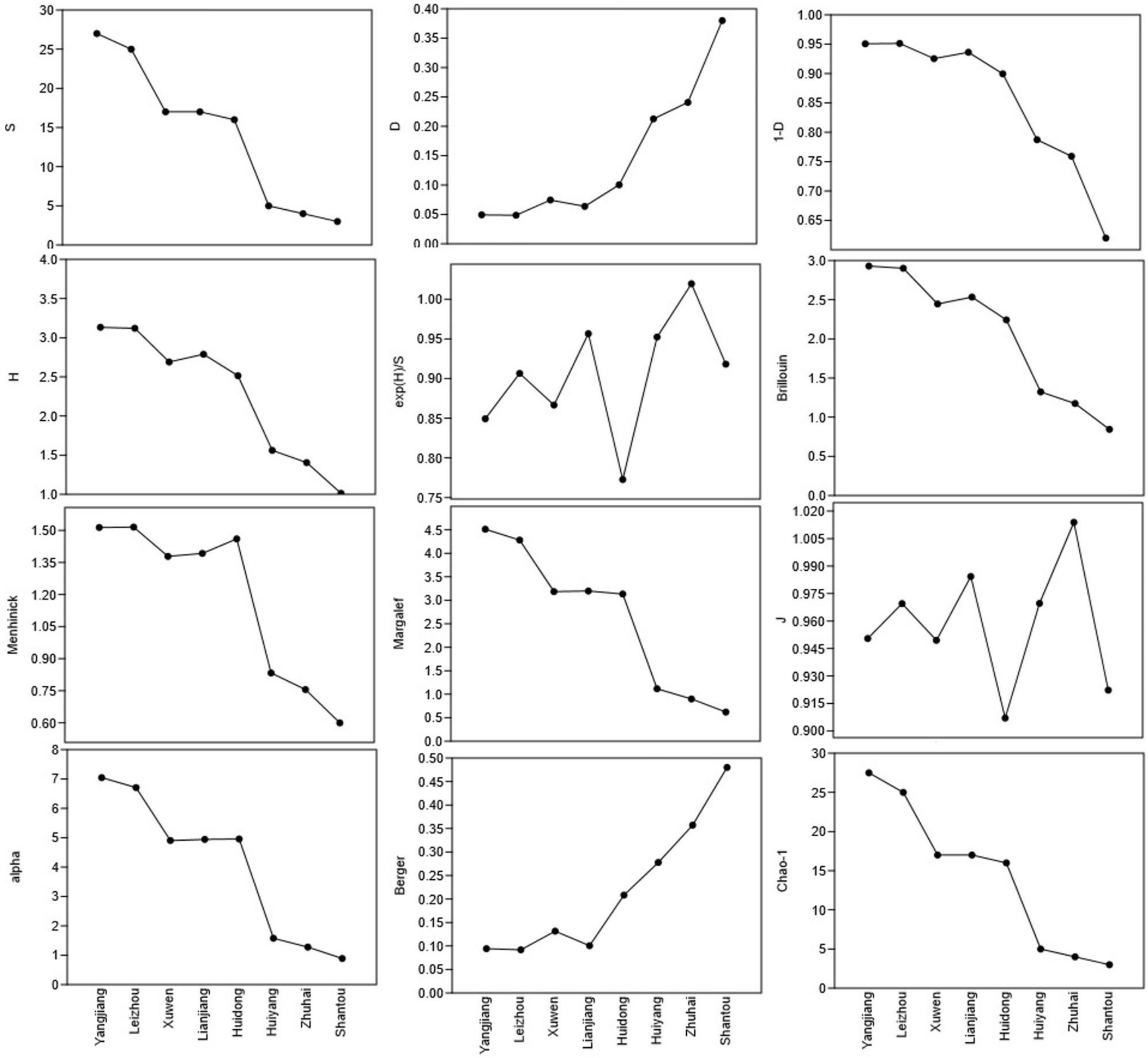
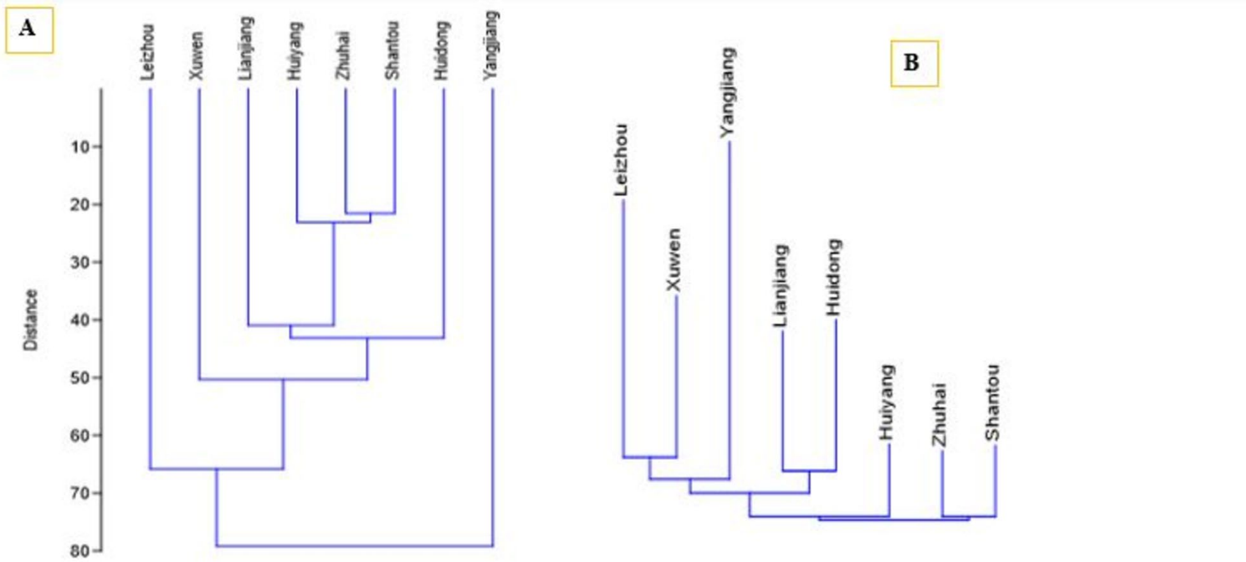


Fig. 24. Graphs showing diversity indices at eight stations of mangrove areas.

may have a much broader range than previously anticipated. Consequently, the identification in the field should be done with caution and ideally be tested by molecular or anatomical means.

Complementing molluscan richness, the phylum Arthropoda accounted for 32 species, encompassing crustaceans, arachnids, mites, and insects. Species such as *Tubuca arcuata*, *Chiromantes haematocheir*, and *Macrophthalmus convexus* were prominent, known for their roles in sediment aeration and mangrove litter decomposition. The diversity of terrestrial arthropods,—including spiders like *Tetragnatha bimaculata* and insects such as *Ricania guttata,* —highlights the ecological complexity of canopy and understory zones within mangroves. Comparable faunal structures have been documented in the Matang Mangrove Forest of Malaysia and mangroves in Thailand, where macro-arthropods not only contribute to the trophic web but serve as bioindicators of environmental quality[91,92]. We discovered three new records of families cf. Microtrombididae, Penthalodidae and cf. Drosophilidae from China with a potential new species based on molecular analyses and morphological identification. Within insects associated with *Avicennia marina*, we found a fly that could only be determined at the family level. The obtained sequence clustered within the Drosophilidae (SHSY140711), along with an unidentified "Canacidae sp.", suggesting the presence of a molecularly unidentified cluster within these species. Additionally, we found two mites also associated with *Avicennia marina*, that could only be identified to the Microtrombididae and Penthalodidae families. The mite belong to the family Penthalodidae is a potential new genus based on morphological identification. The key characters do not fit the diagnosis of any of its genera and resemble the most representatives of the genus Protopenthalodes Jesionowska 1989[33]. While, the morphological identification of Microtrombididae family revealed the genus *Platytrombidium* Thor 1936[32]. However, the sequence clusters separately from other known members of *Platytrombidium* with high bootstrap



	Yangjiang	Leizhou	Xuwen	Lianjiang	Huidong	Huiyang	Zhuhai	Shantou
Yangjiang	0.00	95.66	83.08	82.07	82.73	67.04	69.71	74.05
Leizhou		0.00	65.77	65.18	73.58	64.53	62.85	62.87
Xuwen			0.00	58.46	58.45	43.20	45.52	45.99
Lianjiang				0.00	45.64	42.79	41.41	38.68
Huidong					0.00	43.10	41.40	42.51
Huiyang						0.00	22.67	23.60
Zhuhai							0.00	21.52
Shantou								0.00

Fig. 25. Dendrograms based on UPGMA Hierarchical Cluster analysis (**A**) and (**B**) Neighbor clustering among eight stations, using paired group Euclidean for distance index measure, Cophenetic coefficient indicate the value 0.95 among eight stations. Next tables showing the correlation of distance index among eight stations.

support, potentially representing a new genus. Yet, to confirm this, additional taxonomic analysis, including morphological comparisons, ecological data, and further genetic testing, is required. The aim of the COI analysis was not to provide an integrative taxonomic framework or to formally describe new taxa, but solely to check whether reference sequences already exist for the morphologically distinct taxon we report as a potential new species. The barcoding data therefore served as a presence/absence test in sequence databases rather than as the primary evidence for species delimitation. Our COI results show that there are currently no matching reference sequences available and that our specimens cluster apart from described lineages, which is consistent with the interpretation of a yet undescribed taxon but does not by itself constitute a formal species description. The taxonomic hypothesis is based on morphology, whereas COI was only used to document the lack of existing references and the distinct clustering pattern. A comprehensive integrative taxonomic treatment, including multi locus phylogenies, detailed genetic distance analyses, and a formal species description, clearly lies beyond the scope of this biodiversity survey. Such work will require dedicated future studies focusing on this lineage, and we have toned down the wording in the text to refer to it as a “putative” or “potential” new species supported by morphology and the absence of COI reference sequences, rather than as a formally delimited new species.

Less abundant yet ecologically meaningful were members of the phylum Chordata, represented by amphibious fish such as *Periophthalmus modestus* and *Butis koilomatodon*. These species exemplify physiological adaptations to hypoxic, brackish environments typical of mangrove swamps. The presence of gobioid fish, widely observed across Asian mangrove systems, supports the notion of mangroves as vital nursery and foraging grounds for estuarine fish communities[93]. Similarly, the annelid genera *Nereis* and *Composetia*, observed in mangrove sediments, play a crucial role in bioturbation; contributing to oxygenation and organic matter breakdown—functions critical for maintaining sediment health and microbial interactions[94].

The diversity extended to sessile organisms such as *Pteroeides bankanense* (Cnidaria) and fungal taxa like *Corynespora* (Ascomycota), highlighting the breadth of trophic and decomposer guilds within the system. Macroalgal taxa from Chlorophyta and Rhodophyta, including *Ulva clathrata* and *Gelidium pusillum*, were found primarily in intertidal zones, reflecting tolerance to fluctuating salinity and temperature. These algae contribute to primary productivity and provide refuge for small invertebrates. The prevalence of *Ulva*, a known eutrophication indicator, suggested as a local nutrient enrichment species which could be reproduced abundantly by the anthropogenic runoff, which was entering from the urbanized area and deposited in the mangrove sediments. In the sediments, this anthropogenic runoff becomes the cause of highest growth of *Ulva*sp[95,96]..

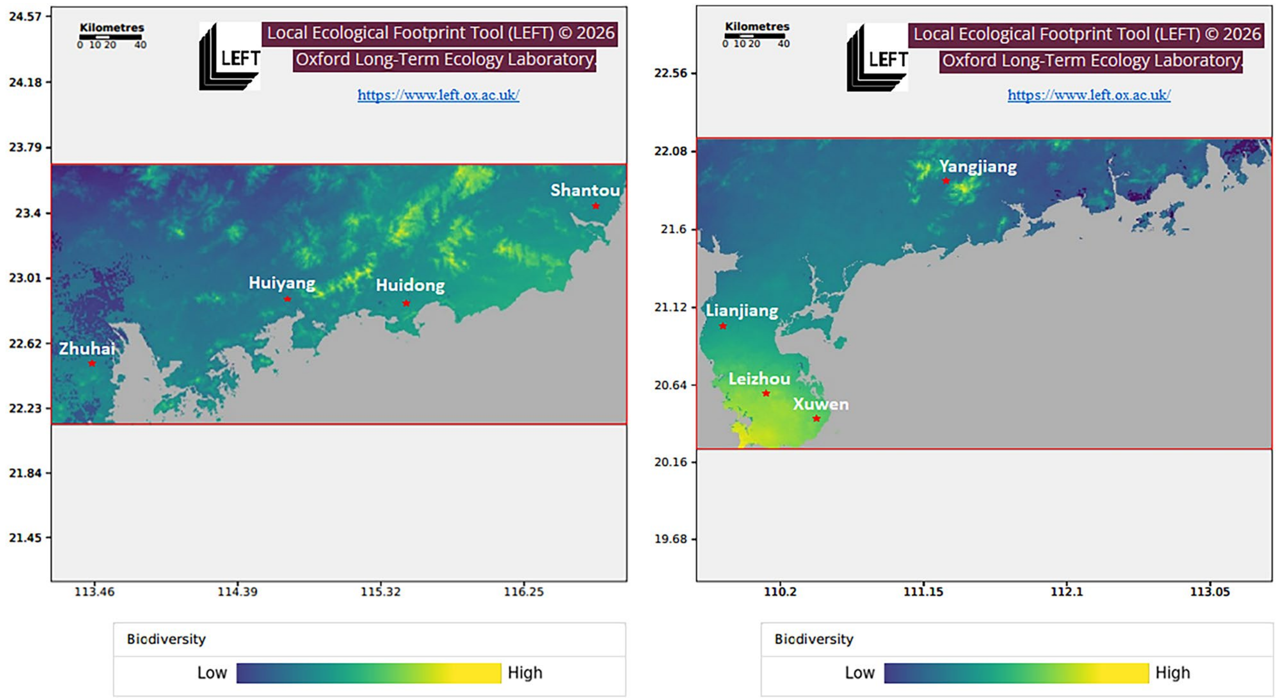


Fig. 26. Spatial biodiversity pattern across eight mangrove stations in Guangdong Province, China, generated using the Local Ecological Footprinting Tool (LEFT) from the https://www.left.ox.ac.uk/

Yangjiang (natural mangrove forests of pristine area) consistently exhibited the highest values across Shannon (3.13), Fisher-alpha (7.05), and Margalef (4.51) indices. At the same time, Shantou (planted mangroves of non-pristine area) showed the lowest diversity across metrics, suggesting that environmental disturbances or human intervention, salinity shifts, or sediment flushing may reduce species presence and detectability, during specific season of the year *e.g.*, monsoon. A same trend was also reported in the mangrove ecosystems of eastern India and the Mekong Delta[97,98]. These values reflected habitat integrity at Yangjiang, Lianjiang, Leizhou, and Xuwen where natural mangrove forests in pristine areas supported the species and identified as a biodiversity hotspot. Shantou, Huiyang, Zhuhai and Huidong stations are planted mangrove forests in non-pristine areas and are recorded as low biodiversity spots. These results are in agreement with the findings of Ghahramani et al.[99] and Carugati et al.[100], reported high biodiversity in natural and undisturbed mangrove forests, respectively. A same trend has been observed in comparison of latitudinal gradient among eight stations. Shantou, Huiyang, Zhuhai, Huidong are at higher latitudes 22–23N and showed lower biodiversity spots, while Yangjiang, Lianjiang, Leizhou, and Xuwen are at lower latitudes 20–21N) and showed higher biodiversity spots. These results of latitudinal gradient are in agreement with the findings of Bracewell et al.[101], well documented the environmental conditions (warmer climate, habitat stability, higher primary productivity and energy availability) at lower latitudes, suitable for the abundance of marine life. A similar study showed the same trend in marine benthic communities peaking at low latitudes and decreasing toward high latitudes[102]. Tropical coastal benthic communities can change in relative dominance and species composition due to mentioned environmental conditions[103]. The temperature is the overriding factor in distinguishing estuarine benthic community composition on a latitudinal gradient[104]. However, in response to environmental changes related to the climate change, many benthic species are shifting their ranges to colder regions[105]. Rapid alterations in the marine climate are forcing these species to adapt to anthropogenic changes[106]. There is a negative relationship between biodiversity and anthropogenic influences[107,108], confirming the evidence of higher biodiversity to lower biodiversity from pristine (non-polluted) versus non-pristine (polluted) areas, respectively.

Shannon and Simpson indices indicated balanced community structures across stations, while the evenness values (0.77–0.96) suggested relative uniformity in species distribution with minor site-specific dominance. Notably, the Berger-Parker index, lowest at Yangjiang (0.09), affirmed the absence of dominant species and further implied ecological equilibrium. These patterns of diversity trends observed in the Sundarbans and Mekong Delta, where primary productivity and canopy complexity were strong predictors of species richness[97,98]. The Dominance Index values (0.05–0.38) and Simpson Index (0.62–0.95) indicate low dominance and high diversity across most stations. These low dominance values suggest a relatively even community structure, where no single species overwhelmingly dominates the habitat—a key characteristic of ecologically stable systems[109,110]. The Shannon- Wiener Index, with values ranging from 1.01 to 3.13, showed that there was high species diversity at Yangjiang. This affirms the integrity of Yangjiang's mangroves and supports the earlier biodiversity observations based on taxonomic enumeration.

Evenness Index (0.77–0.96) values further corroborate that species were relatively well- distributed across stations, although some locations exhibited slight skewness due to a few dominant species. This is commonly observed in transitional or edge habitats within mangroves, were microhabitat features influence species distribution. The Brillouin Index (0.84–2.93), often used in cases of complete population data, also indicated higher certainty and species richness in more biodiverse stations like Yangjiang, mirroring the findings from Brunei Bay mangrove studies where similar index values were used to differentiate pristine and anthropogenically influenced zones[111]. Other richness-based indices such as the Menhinick (0.60–1.52), Margalef (0.62–4.51), and Fisher-alpha (0.89–7.05) revealed patterns directly proportional to species abundance, further affirming that Yangjiang hosted a wider array of taxa compared to other stations. In particular, Fisher's alpha, known for its sensitivity to rare species, suggests that rare or low-frequency species were more common in Yangjiang, a trait often indicative of habitat complexity and minimal disturbance[112]. Overall, the use of multiple diversity indices in this study provides a robust and nuanced depiction of mangrove biodiversity across Guangdong Province, China. The consistency of Yangjiang's high diversity across all indices highlights it as a key site for future monitoring and conservation. Conversely, stations like Shantou, with consistently low index values, may warrant ecological restoration and impact assessments. These results align with global mangrove biodiversity assessments and underscore the importance of multi-metric approaches for evaluating ecosystem health and species distribution.

The spatial dimension of biodiversity, elucidated through cluster and beta-diversity analyses, unveiled distinct ecological zones. Cluster analysis revealed species dissimilarities between Yangjiang–Leizhou and Lianjiang–Huidong, while Zhuhai, Shantou, and Huiyang clustered closely due to shared taxa and similar habitat conditions. The cophenetic coefficient of 0.95 affirmed the dendrogram's fidelity. Spatial mapping of beta-diversity with 30-m resolution highlighted pristine (non-polluted) areas Yangjiang, Leizhou, Xuwen, and Lianjiang as centers of high species turnover and microhabitat heterogeneity, depicted by high beta-diversity (yellow zones). These areas likely possess diverse mangrove species, variable hydrology, and broader ecological niches, which promote community differentiation. In contrast, non-pristine (polluted) areas Shantou and Huiyang exhibited lower beta-diversity, reflecting environmental homogeneity, simplified vegetation, and possibly greater anthropogenic influence[113,114]. A recent study from the Huidong mangrove areas provided an important insight into mangroves biomass production through nutrient availability and revealed that there was a problem of eutrophication in the mangrove sites due to the potential anthropogenic input[5]. Overall, the clustering and beta-diversity patterns underscore both ecological richness and vulnerability within the mangrove systems of Guangdong. The heterogeneity at Yangjiang, Leizhou, and Xuwen positions them as potential biodiversity reservoirs, while the homogeneity at Shantou and Huiyang calls for focused ecological restoration. These results complement previous diversity index analyses and reinforce the need for spatially explicit conservation approaches in tropical and subtropical mangrove regions, aligned with both global conservation goals and China's national ecological protection frameworks.

In terms of relationship of species with the usage of mangroves, the majority of recorded species (60%) were free-living, including gastropods, crabs, and fish that are not obligate symbionts or epiphytes. This dominance of free-living forms suggested a well-structured and dynamic trophic web with extensive ecological interactions. However, invasive species represented just 1% of the overall diversity, suggesting limited penetration of non-native species into these mangrove ecosystems. Comparable findings were observed in studies from Indonesian and Indian mangrove zones, where free-living macrofauna were reported as indicators of sediment and water quality and their abundance declined sharply in degraded or heavily disturbed sites[115,116]. The minimal invasive presence is promising, but continued monitoring is essential, as mangrove zones worldwide are increasingly vulnerable to bioinvasions, especially via ballast water discharge and aquaculture runoff (Lee et al. 2008[117]). Analysis of species collection relative to mangrove plant species revealed that the highest proportion of organisms (30%) were found in association with *Avicennia marina*, while the lowest (2%) were associated with *Bruguiera gymnorhiza*. This pattern aligns with ecological literature identifying *A. marina* as a pioneer and highly tolerant mangrove species that thrives in exposed intertidal zones, offering a structurally complex and oxygen-rich habitat that supports rich faunal communities[118–122]. In contrast, *B. gymnorhiza* typically inhabits more stabilized and shaded inland mangrove areas with reduced tidal flushing and aeration, potentially leading to lower faunal diversity. Manson et al.[123] has well documented in Australian mangroves that *A. marina* stands supported significantly greater mollusk and arthropod abundance compared to denser, less aerated forest interiors dominated by *Rhizophora* and *Bruguiera*. Furthermore, the pneumatophores of *A. marina* provide essential refuge and surface area for epifaunal organisms such as gastropods and barnacles, thus explaining the high density and diversity of collections near *A. marina*. These findings not only highlight the ecological variability among mangrove sites in Guangdong but also echo broader global patterns of mangrove biodiversity linked to plant species composition, structural habitat complexity, and anthropogenic impact. A clear dominance of free-living and native organisms suggests a resilient ecological framework, yet the disparity between stations, particularly the low diversity at Shantou warrants targeted conservation action. Present patterns emphasize the importance of preserving diverse mangrove tree species, maintaining habitat integrity, and monitoring invasive species threats to ensure the long-term sustainability of mangrove biodiversity in China and similar coastal zones globally.

The mangrove forests of Guangdong Province host a taxonomically and functionally diverse assemblage of organisms, with significant spatial heterogeneity in species richness and community structure. High diversity stations such as Yangjiang and Leizhou warrant prioritization for conservation, while areas like Shantou and Huiyang require further assessment and potential habitat restoration. The integration of taxonomic, functional, and spatial diversity metrics in this study offers a robust baseline for long-term biodiversity monitoring, management zoning, and sustainable utilization of mangrove resources in southern China.

Limitations

1. Temporal constraints: Sampling was limited to the post-monsoon months (July–August 2024), which may have missed seasonal biodiversity variations.
2. Taxonomic ambiguity: Despite DNA barcoding, some species were only identified to the genus or family level, necessitating further taxonomic validation.
3. Sampling intensity: The number of quadrats per site (6) and absence of long-term monitoring may not fully capture microhabitat-specific or cryptic species.
4. Functional ecology gap: While diversity metrics were assessed, functional roles and ecosystem services of identified taxa were not deeply explored.

Future prospects

Year-round sampling will help uncover seasonal trends and cryptic biodiversity. A multi-locus molecular approach, combining COX1 with nuclear markers, is needed to confirm taxonomic novelty and evolutionary lineage of ambiguous species. Future studies should integrate ecosystem service evaluation, such as nutrient cycling roles, trophic interactions, and bioindicator potential. High-diversity areas like Yangjiang and Leizhou should be prioritized for long-term biodiversity monitoring and ecological restoration pilot projects. Broader application of the spatial mapping approach can aid conservation zoning across South China's mangrove belt.

Conclusion

This study underscores the high biodiversity of mangrove ecosystems in Guangdong, China with Yangjiang emerging as a key hotspot. The presence of newly recorded species and varied diversity indices across stations emphasize the need for localized conservation strategies. This study also highlights the necessity of integrative taxonomic approaches to avoid misidentification and underestimation of species diversity. Phylogenetic trees provide valuable insights into genetic relationships, with the mite and fly tree, while Penthalodidae sp. characters specifically raising the possibility of discovering a new genus/species. However, a comprehensive taxonomic approach is required to formally classify any newly identified species. When compared with similar studies globally, the Guangdong mangroves hold ecological significance not only for their species richness but also for their function as buffer zones supporting marine life. Long-term monitoring, habitat restoration, and sustainable management are imperative to preserve this critical coastal biome.

Data availability

"Sequence data that support the findings of this study have been deposited at GenBank under Accession No. PV700507 and PV700508 and raw sequence data is provided in the supplementary files".

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Author contributions
S.A. wrote the original manuscript, undertook laboratory work, field sampling and designed the research. **M.W.H.C.** carried out the conceptualization & visualization. **T. R. O.** contributed to the taxonomic identification for bubble snails, writing and proofreading. **G.C.** and **J.D.** contributed to the molecular work,

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Declarations

Competing interests
The authors declare no competing interests.

Ethical approval
In this study no live animal has been used. All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities. The study is compliant with CBD and Nagoya protocols.

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