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Species Diversity and Assemblage of Mangroves at Setiu Wetland, Terengganu, Malaysia

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ABSTRACT

Mangroves in wetland ecosystems are diverse and play significant role in the adjacent communities on which they are dependent for their livelihoods. It is also important for fishery resources and nutrient inputs in marine and brackish water ecosystems. However, little is known about the tropical wetland lagoon ecosystems, particularly mangrove diversity and assemblages. Therefore, this present study was initiated to observe the mangrove species diversity and assemblages together with the conservation status in an important tropical wetland ecosystem in Setiu, Terengganu, Malaysia. In a variety of landward and small fringe island areas, three zones of square plots were selected (zones 1, 2 and 3) to address the objectives of this study. As a result, a total of 20 true mangrove species belonging to 11 genera from nine families were documented, of which, *Avicennia rumphiana* was listed as vulnerable (VU) by the IUCN. Twelve species of mangrove associates from 11 genera and nine families were also found in the investigated zones at Setiu. One of the mangrove associates, *Intsia bijuga*, was designated as vulnerable (VU) by the IUCN. The Shannon diversity index (*H'*) of mangroves was found to be 1.08 at Setiu Wetland. *Rhizophora mucronata* was found to be well-expanded *(H'* = 1.05) followed by *A. rumphiana, A. officinalis, Heritiera littoralis, A. corniculatum. Excoecaria agallocha, Lumnitzera racemosa,* and *A. ebracteatus (H'* = 0.0) as the lowest. The findings of the present study revealed that mangroves in the Setiu Wetland are diverse and healthy compared to other mangrove ecosystems in the region. To maintain the health and function of the mangrove ecosystem in Setiu Wetland, proper monitoring is required.

Keywords*:* Checklist, index value, Malaysia, threatened species, wetland mangroves

INTRODUCTION

The word "mangrove" is used to refer to both the groups of higher plants and the whole plant community (Djamaluddin, 2018). Woody plants (i.e. trees) or plant communities (i.e. shrubs, palms and ferns) in the tropical and sub-tropical intertidal forest habitats have special physiological adaptations to survive in the harsh marine environment (Tomlinson, 1986; Schmitt & Duke, 2015). However, these adaptations are naturally aided by morphological alterations, reproductions and survival traits that distinguish mangroves from other land plant species (Saenger, 2002). Thus, the world's tropical and subtropical soft-sediment shores are home to true mangroves with physiological advantages (Quadros *et al.*, 2021).

Southeast Asia is well-endowed from a global perspective since it has the largest area of mangroves in the world, encompassing 6.8 million ha and making up 34% – 42% of the total (Giesen *et al*., 2006). Malaysia accounts for a significant portion of the mangroves in Southeast Asia, which is 12% (641,886 ha), while Peninsular Malaysia covers an area of 105,693 ha (Spalding *et al*., 2010; Zhila *et al*., 2014). A total of 84 species of mangrove plant species have been recorded in the world from 16

families (Wang *et al*., 2003). Out of the 84 species, 52 are recorded from South Asia, and 38 are from Malaysian wetlands (Giesen *et al*., 2006). According to Hanum *et al.* (2014), there are 119 species of mangrove plants, including 41 exclusives, 65 non-exclusives and 13 associate mangrove species in Malaysia.

The Setiu Wetland constitutes the largest natural wetland complex on the east coast of Peninsular Malaysia, and the main area of the Setiu Wetland is the coastal lagoon with fringe islands with mangroves, which runs roughly 14 km parallel to the coast (Jamilah *et al*., 2020). Its floral and faunal distribution is influenced by geographic location, environmental conditions, particularly the influence of diverse seawater masses and geomorphological properties. Additionally, the flora of the Setiu Wetland is adapted to its habitat. For instance, the beach ridges interspersed with swales (BRIS) soil vegetation is mostly restricted to the sandy environment of Terengganu's short coastal strip (Jamilah *et al*., 2014; Sathiamurthy, 2015), and such distinctive vegetation is not present on Peninsular Malaysia's west coast (Jamilah *et al*., 2014). Therefore, the habitat and geomorphological features of Setiu Wetlands offer a unique opportunity to study the mangrove species in that area, as has been demonstrated by several earlier research works (Jamilah *et al*., 2014; Jamilah *et al.,* 2020; Islam *et al.,* 2022; Muhammad Nor *et al*., 2022).

Studies on mangrove species diversity assemblage and composition are significant to recognize the condition of the mangrove forest structure, which ultimately helps to understand the function, health and productivity of a forest. However, studies on the diversity of mangroves on the Setiu Wetland, along with the morphological characteristics, conservation status, ethnobotanical uses and local distribution, are not well documented. Few works have been found related to the mangroves on the Setiu Wetland (Zhila *et al*., 2014; Islam *et al*., 2022; Muhammad Nor *et al*., 2022). It has also not been reported comprehensively on the assessment of the potential presence of a few species that have never been accurately recorded but are crucial for biogeographic distribution and biological conservation. The goal of this research is to fill in the gaps in the previously provided material. The results of this investigation will advance our knowledge of the biogeography of true mangroves, their associated species and their diversity, will further enhance the development of management and conservation strategies for the mangroves of Setiu Wetland on the east coast of Peninsular Malaysia.

MATERIALS AND METHODS

Description of the Study Area

Setiu Wetland (often known as Setiu lagoon) is the largest natural wetland in the east coast region of Peninsular Malaysia, covering 23,000 ha and containing freshwater, brackish water (880 ha) and a shallow lagoon (Suratman *et al*., 2005; 2014). It is situated on the east coast of Peninsular Malaysia and is influenced by the tidal activities of the South China Sea. Nine interconnected habitats, including the sea, beach, mudflats, lagoons, estuaries, rivers, fringe islands, coastal forests and mangrove forests, have turned Setiu Wetland into a distinctive area (Nakisah & Fauziah, 2003). Small sandy islands, dense riparian forest inland and vast laying coastal beach forests characterised the wetland. This wetland runs along the coastline of the South China Sea and connects to a small natural inlet (Jamilah *et al.,* 2014). This wetland habitat is characterised by diversified mangrove species and is enriched by freshwater flashes from two connected rivers, Sungai Setiu and Sungai Chalok.

Collection of Samples

The field study was conducted from August 2021 to September 2022 in the Setiu Wetland in three randomly selected zones (zones 1, 2 and 3). Primary data has been collected by conducting a series of surveys. A representative forest area was observed, and randomly selected total of 12 square (10 m x 10 m) study plots and four plots in each zone (between 5°41'43.65" N and 102°42'30.33" E; 5°37'32.94" N and 102°47'02.45" E) within the zones were chosen for this study (Figure 1). Four plots were selected in each zone with a 30 m distance between them based on stand structure characteristics. Twelve study plots were investigated in detail using spot check and quadrat methods (Djamaluddin, 2018). Each plot's mangrove species, along with the number of trees in each species, were documented and identified for the analysis of the diversity index. In the field, morphological traits

have been used for the quick identification of true mangroves and associated species. When accurate identification could not be made, specimens were collected for additional morphological identification in the laboratory.

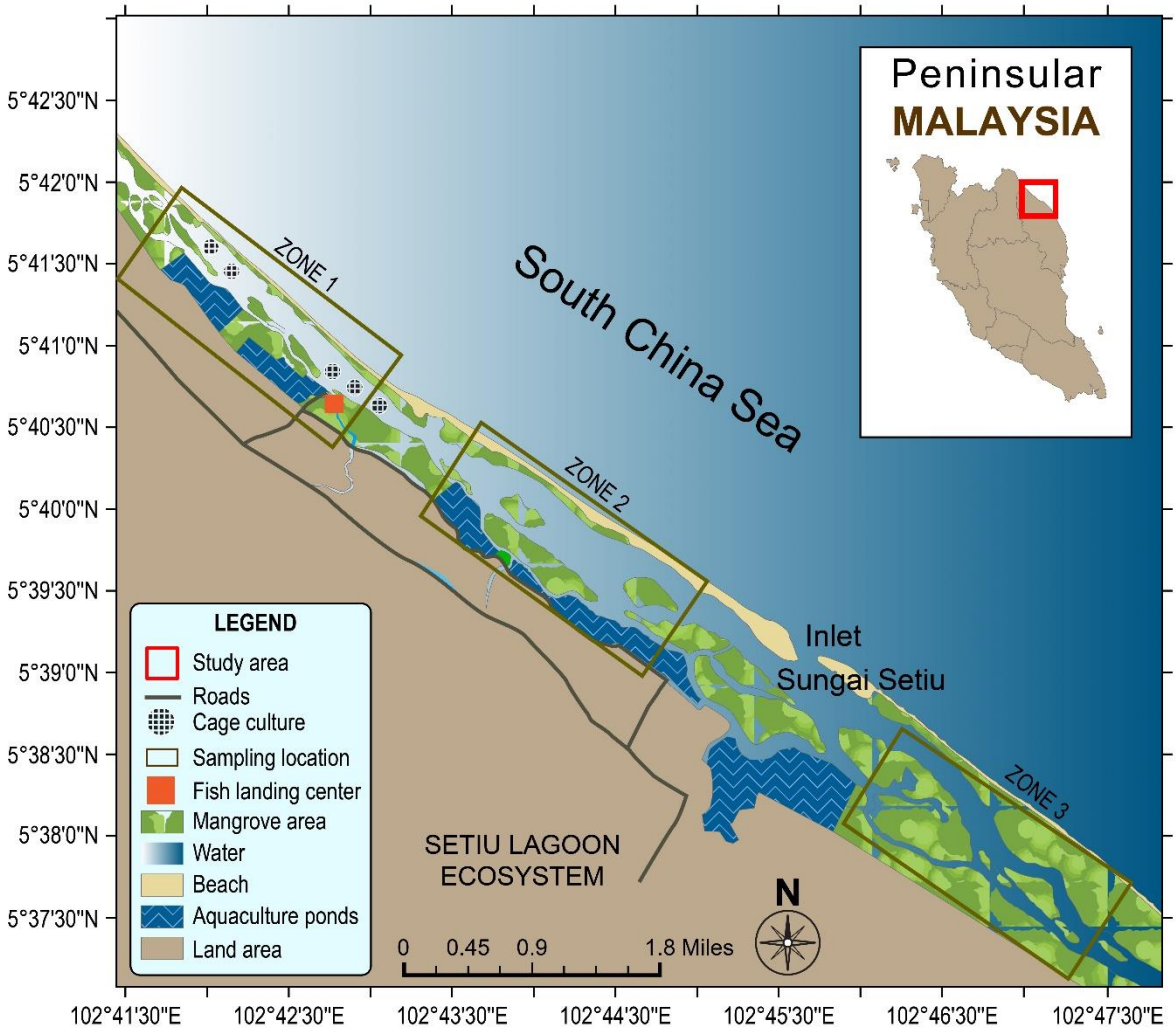

Figure 1. Map of the study area showing the positions of three zones at Setiu Wetland, Terengganu, Malaysia

Identification of Mangrove Species

Species identification was done *in situ* using a field guidebook of Shin *et al.* (2015). For confusing species, plant samples with flowers and fruits were collected and brought into the laboratory for identification, where species identification was done following the Handbook of Mangroves in the Philippines-Panay (Tomlinson, 1986; Primavera, 2004; Giesen *et al.*, 2006; Shin *et al.*, 2015). The International Plant Naming Index (IPNI, 2022) was also used to confirm the taxonomic categorisation.

Analysis of Diversity Indices

The Shanon diversity index (*H*') was calculated using Paleontological Statistical Software (PAST) ver. 4.07 (Hammer *et al*., 2013). The Shannon-Wiener information function was used to determine the diversity indices. The diversity index, Eq. (1) developed by Shannon and Weaver (1963) considers both the number of species and the distribution of individuals within each species,

$$H' = -\sum[(pi) \times \log_{\epsilon}(pi)] \quad \text{Eq. (1)}$$

where H' = Shannon diversity index, p = the proportion of individuals in the i species, p_i = proportion of individuals of i^{th} species in a whole community, and $\log_e$ (pi) = proportion of individuals based on a natural log.

RESULTS AND DISCUSSION

Species Composition of Mangroves

A total of 20 species of true mangroves from 11 genera belonging to nine families (Table 1, Figure 2) were recorded from three studied zones at Setiu Wetland. These findings were significantly greater than other recent research on mangrove-dominated Malaysian coasts. As compared to the studies of Shah *et al.* (2016) at Sarawak and Zakaria *et al.* (2018) at Kalang Island, Malaysia, the present findings at Setiu Wetland recorded more diverse mangrove species than the aforementioned research. The higher number of mangrove species in this wetland might be due to the ecological variations where different species have different eco-biological responses toward growth and adaptation. Generally, mangroves in wetland ecosystems like Setiu are very rich in diversity due to low energy forces and actions, good nutrient deposition and a confined area protected from wave action, which helps to grow and adapt more mangroves during tidal dispersal and anchorage of seed (Jamilah *et al*., 2014; Poh *et al*., 2018).

However, Muhammad Nor *et al*. (2022) listed 23 exclusive mangrove species (listing data only) from the Setiu Wetland with a limitation on the coverage of morphology and diversity of mangroves. The higher number of listings was due to the inclusion of a few mangrove hybrids, *Intsia bijuga* and *Finlaysonia obovata*, as exclusive mangroves, and these were reported as mangrove associates by Giesen *et al*. (2006) and Tomlinson (1986). Mangrove associates are mostly found in terrestrial or aquatic habitats but are also commonly found in mangrove ecosystems (Tomlinson, 1986; Wang *et al*., 2011).

Several studies reported that the mangrove *Rhizophora apiculata* was widely dispersed on Malaysian coasts (Wan Juliana *et al*., 2014; Hoque *et al*., 2015; Mahmud & Viez, 2015), and this was also applicable to Setiu Wetlands. In terms of abundance, the family Rhizophoraceae (*R. apiculata, R. mucronata, Bruguiera gymnorrhiza, B. parviflora, B. sexangular*, and *B. cylindrica*) was recorded highest in Setiu (Wan Juliana *et al.*, 2014; Mahmud & Viez 2015), followed by Acanthaceae (*Avicennia alba, A. officinalis*, and *A. rumphiana*) and Lythraceae (*Sonneratia caseolaris* and *S. alba*). Tomlinson (1986) mentioned that Rhizophoraceae species had a significant physiological ability to adapt to harsh environmental conditions. Three species of *Rhizophora*, namely *R. mucronata, R. stylosa,* and *R. apiculata*, as well as two putative hybrids, *R.* x *lamarckii* (*R. apiculata* x *R. stylosa*), and *R.* x *annamalayana* (*R. apiculata* x *R. mucronata*), were found in the Indo-Malaya region (Duke, 2006). However, one mangrove hybrid (*R.* x *annamalayana)* was reported previously in the Setiu Wetland (Muhammad Nor *et al*., 2022; Figure 3). The present study did not observe any mangrove hybrids in the three studied zones, and this could probably be due to having traits in common with the parent species.

The species from families Acanthaceae and Lythraceae were found growing scattered as single stands at zone 1 and fringe islands in this wetland ecosystem. In mangrove associates, the Fabaceae family was largely prevalent in all studied zones at Setiu Wetland. One uncommon species, *Ceriops zippeliana* (Blume) previously described as *C. decandra (*Ding Hou) has been revised (Sheue *et al*., 2009), and was found only in this wetland at zone 2. This species was also listed by Muhammad Nor *et al*. (2022) from Setiu, especially in the fringe islands. Moreover, Islam *et al*. (2022) recorded *C. tagal* from the Setiu wetland. Both species are widespread in the world. The higher density of *C. zippeliana* patches was found in zone 2 of this wetland ecosystem, assuming that this species naturally grows and reproduces in that area. In all analysed zones, the soil of the Setiu Wetland was primarily sandy (Islam *et al*., 2022). On the periphery island in zone 2, the salinity was greater at 21.63 ± 0.20 psu (Islam *et al.*, 2022). The *Ceriops* genus typically has the potential to thrive in deep saline clay soils, which can also be hypersaline (Connolly *et al*., 2006). This could be the reason why zone 2 has a higher *C. zippeliana* density. This information could be associated with the flexibility of ecological gradients, and this species has different responses to this situation (Cornwell *et al*., 2019).

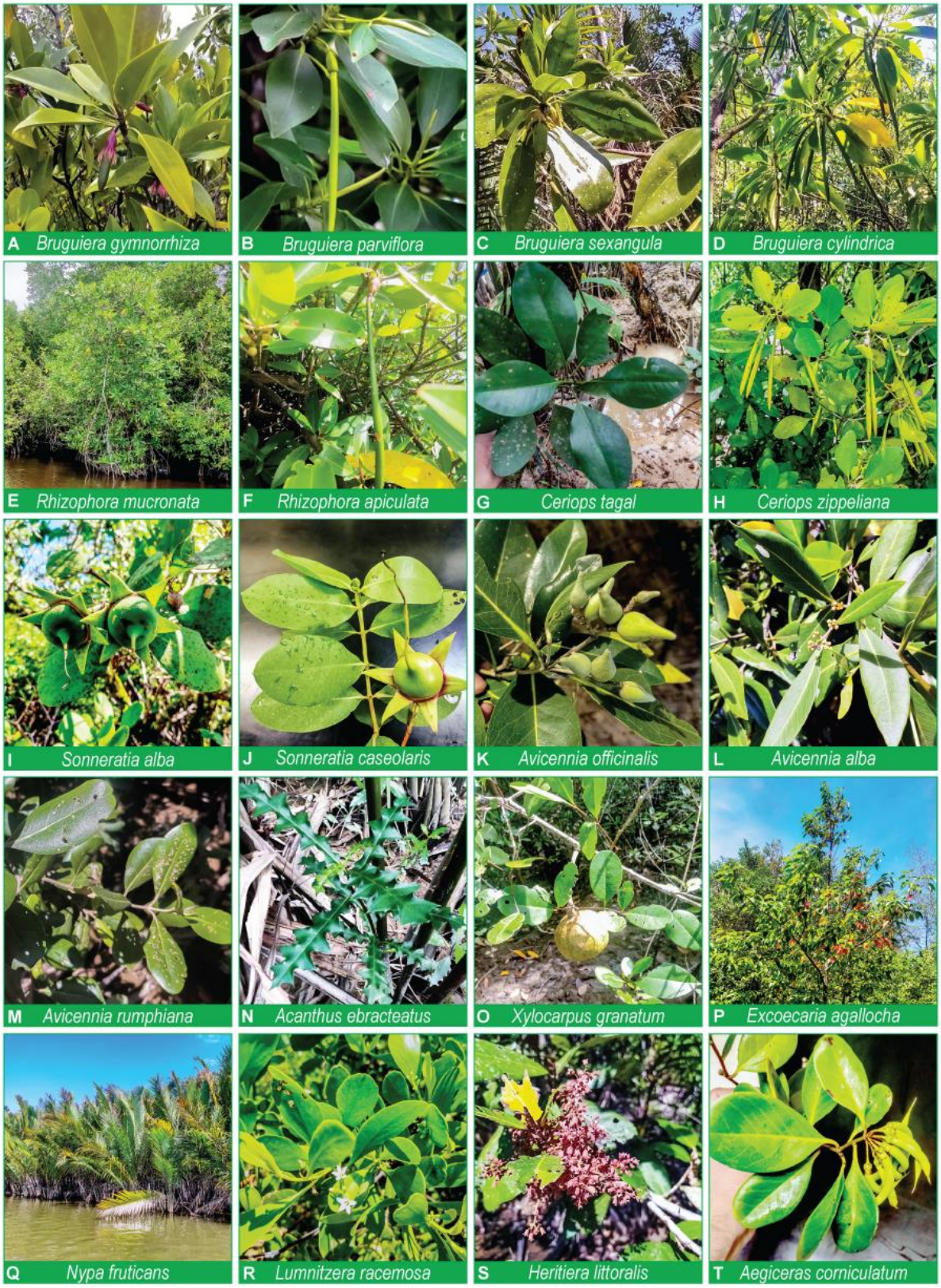

Figure 2. Mangrove species recorded at Setiu Wetland; (**A**) *Bruguiera gymnorrhiza*, (**B**) *Bruguiera parviflora*, (**C**) *Bruguiera sexangular*, (**D**) *Bruguiera cylindrica*, (**E**) *Rhizophora mucronate*, (**F**) *Rhizophora apiculate*, (**G**) *Ceriops tagal*, (**H**) *Ceriops zippeliana*, (**I**) *Sonneratia alba*, (**J**) *Sonneratia caseolaris*, (**K**) *Avicennia officinalis*, (**L**) *Avicennia alba*, (**M**) *Avicennia rumphiana*, (**N**) *Acanthus ebracteatus*, (**O**) *Xylocarpus granatum*, (**P**) *Excoecaria agallocha*, (**Q**) *Nypa fruticans*, (**R**) *Lumnitzera racemose*, (**S**) *Heritiera littoralis*, and (**T**) *Aegiceras corniculatum*

Figure 3. Mangrove hybrid *Rhizophora* x *annamalayana* (*Rhizophora apiculata* x *Rhizophora mucronata*) identified in the Setiu Wetland previously on the east coast of Peninsular Malaysia (Photo credit and source: Dr. Muhammad Nor)

Table 1. Lists of mangrove species identified in three studied zones from Setiu Wetland, Terengganu, Malaysia (VU = Vulnerable, LC = Least Concern)

Family	Species	IUCN status	Type	Ethnobotanical Uses
Rhizophoraceae	*Bruguiera gymnorrhiza* (L.) Lamk.	LC	Tree	Bark and leaves have medicinal properties.
	Bruguiera cylindrica (L.) Bl.	LC	Tree	Edible fruits, young roots and hypocoty. Wood serves as charcoal and firewood.
	Bruguiera parviflora (Roxb.) W. & A.ex Griff	LC	Tree	The mature trees are used for firewood and charcoal production.
	Bruguiera sexangular (Lour.) Poir.	LC	Tree	Edible plant parts, and wood serve as charcoal and firewood.
	Rhizophora apiculata Blume	LC	Tree	The timber is used for firewood, construction work and fish traps.
	Rhizophora mucronata Lamk.	LC	Tree	Stem is used for charcoal and firewood. The bark is used for tannin production.
	Ceriops tagal (Perr.) C.B. Rob.	LC	Tree	Medicinal properties and dye production.
	Ceriops zippeliana (Blume)	LC	Tree	Tree parts have medicinal properties.
Lythraceae	*Sonneratia alba* J.E. Smith	LC	Tree	Fruits are edible, and wood is used for household and commercial products.
	Sonneratia caseolaris (L.) Engler	LC	Tree	Edible tree parts (fruits, leaves and flowers).
Acanthaceae	*Avicennia officinalis* L.	LC	Tree	Fruits used as food. Bark has medicinal value.
	Avicennia alba Blume	LC	Tree	Plant parts have food value and mature trees are used as timber and wood.
	Avicennia rumphiana Hall. F.	VU	Tree	Fruits are edible. The wood is used as firewood and for smoking.
	Acanthus ebracteatus Vahl.	LC	Shrub	Tree parts have medicinal properties.
Meliaceae	*Xylocarpus granatum* Koen.	LC	Tree	The tree has medicinal properties. Used as timber and wood and tannin products.
Euphorbiaceae	*Excoecaria agallocha* L.	LC	Tree	Leaves have medicinal value and stems are used as firewood and charcoal.
Arecaceae	*Nypa fruticans* Wurmb.	LC	Palm	The leaves are used for handicraft purposes and young shoots are therapeutic.
Combretaceae	*Lumnitzera racemosa* Willd.	LC	Tree	The bark is used in tanning. Ornamental value.
Malvaceae	*Heritiera littoralis* Dryand.	LC	Tree	The root is therapeutic, the seeds are edible, and the stem is used as timber.
Myrsinaceae	*Aegiceras corniculatum* (L.) Blanco	LC	Tree	Leaves have food value. Mature stem used as firewood.

Species Diversity

The Shannon diversity index (*H'*) showed that *R. mucronata* had a higher value of *H'* = 1.05 and was followed by *B. gymnorrhiza* (*H'* = 0.9) and *Nypa fruticans* (*H'* = 0.89) as a single species (Table 2). The lowest diversity index was observed in *A. rumphiana, A. officinalis, H. littoralis, A. corniculatum. E. agallocha, L. racemosa,* and *A. ebracteatus,* respectively (*H'* = 0), which might be because *C. zippeliana* was observed to be confined to a specific area (zones 1 and 2). The highest diversity index (*H'*) value was observed in zone 1 (*H'* = 2.26) followed by zone 3 (*H'* = 1.73) and zone 2 (*H'* = 1.51). The diversity index (*H'*) for mangroves from the studied zones at Setiu Wetland was 1.08 and represented a higher level of species diversity. This value is comparable with the value obtained in Pulau Ketam, Selangor, Malaysia (Rozainah *et al*., 2018; Table 3) and Sandwip Island (*H* = 1.81) Chittagong, Bangladesh (Sajib *et al*., 2016). The most abundant species was *C. zippeliana* which was confined to zone 2.

Table 2. Shannon Diversity Index (*H'*) of true mangrove species found in the Setiu Wetland area

Species	*H'* index	Total abundance (Plants/hactor)
Rhizophora apiculata	0.85	500
Rhizophora mucronata	1.05	1033
Bruguiera gymnorrhiza	0.9	267
Bruguiera parviflora	0.69	67
Bruguiera sexangula	0.69	67
Bruguiera cylindrica	0.41	233
Ceriops zippeliana	0.11	1533
Ceriops tagal	0.41	233
Avicennia alba	0.73	267
Avicennia officinalis	0	33
Avicennia rumphiana	0	33
Sonneratia caseolaris	0.69	67
Sonneratia alba	0.69	67
Nypa fruticans	0.89	333
Xylocarpus granatum	0.69	67
Heritiera littoralis	0	33
Acanthus ebracteatus	0	33
Aegiceras corniculatum	0	33
Excoecaria agallocha	0	33
Lumnitzera racemosa	0	33

Table 3. Comparison of Shannon Diversity Index (*H'*) with multiple Southeast Asian studies sites

Location	Plot area (ha)	*H'*	References
Pulau Ketam, Selangor, Malaysia	0.02	1.81	Rozainah *et al*., 2018
Gaya Island, Sabah, Malaysia	0.15	0.72	Mojiol *et al*., 2019
Pulau Kukup, Johor, Malaysia	0.2	1.54	Tan *et al*., 2012
Tanjung Piai, Johor, Malaysia	0.2	1.44	Tan *et al*., 2012
Sungai Balok FR, Pahang, Malaysia	0.16	1.82	Rozainah and Mohamad, 2006
Trang province, Southern Thailand	0.88	1.11-1.99	Sudtongkong and Webb, 2008
Tanjung Puting National Park, Indonesia	-	3.29	Murdiyarso *et al.,* 2009
Setiu wetland, Malaysia	0.01	1.08	Present study

Note: '-' indicates data not available.

True Mangrove Species

Rhizophoraceae

From the genus *Bruguiera*, a higher number of species was recorded from the Setiu Wetland. (Figure 2A-D). *Bruguiera gymnorrhiza* (Figure 2A) is commonly found in the mid-zone of the mangrove belt and is accompanied by *Rhizophora* spp. (Djamaluddin, 2018). This species is locally known as Bakau or Berus Merah. The natural diversity of the species is vast. It is spread from Africa through South Asia, Southeast Asia, the Philippines, Papua New Guinea, Australia, Polynesia and Samoa. Mature *B. gymnorrhiza* is a medium-sized tree with tough, dark gray to brown bark with lenticels. This species is easily identified by its kneed root, pointed flower and ridged hypocotyl seedlings (Tomlinson, 1986).

Bruguiera parviflora (Figure 2B) was found in zone 2. According to Djamaluddin (2018), *B. parviflora* grows well in estuarine habitats of medium height. This species has similar morphological characteristics to the other two members of the genus *Bruguiera.* A mature tree is characterised by flanged gray and cracked bark. It has lateral roots that extend slightly below the surface and a portion that protrudes "bent knee". The flower grows in a cluster, calyx lobes are straight and uncured and the calyx tubes are ridged. Narrow and spiral-rolled fruits. The hypocotyl is cylindrical, smooth and curved. *Bruguiera parviflora* is widely distributed in the coastal regions of South Asia (Giesen *et al.,*

2006), the Solomon Islands, Vanuatu and Australia (Tomlinson, 1986).

The species *B. sexangula* (Figure 2C) grows up to 30 m tall. Small clusters of reddish calyxes can be seen all over the tree when it is in bloom. The grayish trunk features cracks and many lenticels in its bark. Its “fin-like” buttresses emerge above the substrate occasionally with stilt roots and frequently with kneed roots. The fruit grows inside the calyx and enlarges as it ripens. This species is distributed from South Asia, through Peninsular Malaysia, Singapore and Indonesia to Papua New Guinea and the Solomon Islands, and then south to northern Australia and New Caledonia (Tomlinson, 1986).

Bruguiera cylindrica (Figure 2D) has been found in zones 1 and 2 of this wetland ecosystem. Like *B. gymnorrhiza*, *B. cylindrica* has the same occurrence in the mid-zone of the mangrove belt fringe and estuarine habitat (Djamaluddin, 2018; Islam *et al*., 2022). This species is characterised by the pendulous flowers produced in a little cluster of three or fewer stalks at the leaf axils, and each flower is comparatively short in size and light green in colour. Fruits with purplish-green colouration at the end of cylindrical hypocotyls that is green at the base. *Bruguiera cylindrica* is distributed from South Asia to Southeast Asia and is also found in the Philippines, Papua New Guinea, the Solomon Islands, and Australia (Giesen *et al*., 2006). It has similar characteristics to *B. gymnorrhiza* species. All three species of the genus *Bruguiera*, rank as the least concerning (LC) species on the IUCN list.

Two species of *Rhizophora*, namely, *R. apiculata* and *R. mucronata*, were recorded from the three studied zones of the Setiu Wetland (Figures 2, E and F). *Rhizophora apiculata* and *R. mucronata* were observed as dominant species in the different areas of the Setiu wetland (Table 2). The middle and lower zones of this wetland, both on the landward and fringe islands, were grouped by *R. mucronata* and *R. apiculata*. On the other hand, *R. apiculata* was not found in zone 3, while *R. mucronata* was recorded in all three observed zones. Mature trees grow over 30 m tall and are characterised by conspicuous, arching stilt roots. Tree bark is dark gray. The leaves are thick, elliptic, and feel leathery. Flowers are bisexual and yellowish, and they contain four brownish-yellow to reddish sepals. The club-shaped, cylindrical hypocotyl, which is sometimes mistaken for a "fruit," is green with purple. The tough, brown, oblong to pear-shaped fruits have one viable seed inside. *Rhizophora apiculata*, locally known as Bakau Minyak or Bakau Tenduk. This species is famous for its use in firewood and charcoal production by the local people.

Rhizophora mucronata is locally known as Bakau Belukap, Bakau Gelukap, Bakau Jamkaror, and Bakau Hitam. This species is only found near the tidal creek and on the lower zone margins. *R. mucronata* has been found habituated in the lower zone of both the landward and fringe islands in three studied zones at Setiu Wetland. The morphological traits include tap and stilt roots structure, darkish bark, elliptic, simple and opposite leaves with speckled undersides, bisexual flowers with white hairy petals, oval-shaped, long, or round fruits with one seed and rough and cylindrical hypocotyls (Djamaluddin, 2018). *Rhizophora mucronata* habitat is widely spreaded in the South Asian region (Giesen *et al*., 2006), Africa, Australial and Solomon Islands (Tomlinson, 2016). Two species of *Rhizophora* rank as the least concerning (LC) species on the IUCN list.

One of the Rhizophoraceae genera, *Ceriops*, has a vast geographic range that extends from eastern Africa to tropical Asia, northern Australia, through Melanesia, Micronesia and Southern China (Sheue *et al*., 2009). At the time of the present observation, two species of *Ceriops* were identified, namely, *C. tagal* and *C. zippeliana*, from Setiu Wetland. *Ceriops tagal* (Figure 2G) was easily identified by its knee root structure during the inflorescence and maturation of propagules (Primavera, 2004; Sheue *et al*., 2009). This species was relatively larger than its predecessors, *C. decandra* and *C. zippeliana*. Unlike, other related species, *C. tagal* is one of the least diversified mangrove species in the studied area and is locally known as Tengar or Tengar Samak. It is a small-sized tree or shrub. The tree has brown and smooth bark. *Ceriops tagal* is characterised by small, stilt roots and rounded, glossy-green leaves. The white flowers turn brown while maturing. The calyx tube has shrunk, and the ovoid fruits, which can be up to 3 cm long, are dangling from it. Fruits start brown, but as they mature and the hypocotyl emerges, they change colour. The

hypocotyls are long and slender. Its distributional range starts from Africa to the Western Pacific, Australia and Southeast Asia, and New Caledonia (Giesen *et al*., 2006).

Ceriops zippeliana (Figure 2H) is widespread and common in most of the *Ceriops* habitat (Sheue *et al*., 2009). This species, was found in the Setiu Wetland in both the fringe islands and landward regions (Jamilah *et al*., 2020). Locally known as Tengar, *C. zippeliana* has many similar features to its predecessors, but it can be distinguished from them by the colour of their mature propagules, which are red as opposed to yellow for *C. decandra* and *C. tagal* (Primavera *et al*., 2004). It was observed that *C. zippeliana* and *C. decandra* are generally smaller in size compared to *C. tagal* specimens found in the Setiu Wetland. These species have been used as firewood and material for houses by the coastal fishermen community in the Setiu area. *Ceriops zippeliana* has a wider distribution range in the Indo-West regions (Giesen *et al*., 2006). According to the IUCN list, both *Ceriops* species are the least concern (LC) category.

Lythraceae

Sonneratia alba (Figure 2I) is another highly diverse true mangrove species observed in the three studied zones located at Setiu Wetland. This species is generally distributed along seaward edges or the lower zone in Setiu (Islam *et al*., 2022) in single-stand form or sometimes in cluster form on fringe islands. Large-sized tree with spreading canopy characterized by brown bark, blunt pneumatophores and elliptic to ovate or obovate-shape leaves. Large, round-shaped flowers have a powder-puff like appearance due to their numerous white stamens. Mature fruits are like fleshy berries, round and flattened in shape (Djamaluddin, 2018). This species has wider native distribution ranges, found in Southwest Oceania, Australia, Southeast Asia, New Caledonia, the West Pacific islands and Seychelles to Africa (Giesen *et al.*, 2006).

Sonneratia caseolaris (Figure 2J) is a rare member of the family Lythraceae and was observed only in zone 2. It has similar characteristics to other members of its family. In its natural habitat, *S. caseolaris* is a small to medium-sized tree that rarely reaches a height of 20 m and has numerous, extremely strong vertical pneumatophores. Leaves are simple, opposing and of varying sizes. At the terminals of stems, flowers are seen in clusters. The broad, oval flower buds are less than twice as long as they are wide. Green on the outside and greenish or yellowish white on the inside, the calyx lobes are typically noticeably longer than the tube. The slender, dark crimson petals have this hue. Numerous and quickly shed, the stamens have filaments that are carmine below and white above. They have a crimson lower portion and a white upper portion (Tomlinson, 2016). The distributional range is the western islands of the Pacific Ocean, via tropical Southeast Asia, the west coast of India, southern China, New Guinea and northern Australia (Giesen *et al*., 2006). Both (*S. alba* and *S. caseolaris)* species ranks as the least concerning species on the IUCN list least concerning (LC).

Acanthaceae

Two genera, namely *Avicennia* and *Acanthus*, belong to the family Acanthaceae. The genus *Avicennia* includes three species (*A. officinalis*, *A. alba*, and *A. rumphiana*). These three species were observed in the three different zones, where *A. officinalis* had the highest diversity among the *Avicennia* genus in the recorded zones (Table 1).

Avicennia officinalis (Figure 2K) habitat is located in the lower intertidal and estuarine zone. *Avicennia officinalis* habitat was recorded in the middle zone of the fringe islands of Setiu Wetland (Islam *et al.*, 2022). It produces huge, rancid-smelling orange-yellow blooms. The oblong-shaped leaves have a striking golden-green underside. It possesses lenticular-covered, slender, pencil-like pneumatophores. Root respiration in the anaerobic, muddy soil is made possible by pneumatophores that protrude from the soil. Roots of aerial stilts may also form. This species is widely distributed in Bangladesh, India, Southeast Asia, Sri Lanka, East Pakistan, New Guinea, and Southern Australia (Mehta e*t al*., 2021).

Avicennia alba (Figure 2L) is a tropical mangrove species belonging to the Acanthaceae family. It is widely distributed in India, Southeast Asia, Australia and Oceania. It grows along the coast and estuaries. In the current investigation, *A. alba* was found to be one of the most diverse species in all three zones of the Setiu Wetland. Its habitat spread in both

landward and seaward areas in all three zones studied. In both positions, *A. alba* has been found in the lower intertidal zone (approximately 40 to 50 m, away from the shoreline). *Avicennia alba* develops a low, bushy crown that is dense and often branches near the trunk's base. This species doesn't grow more than 20 m (66 feet) in length. The roots are shallow and produce a huge number of pneumatophores in the form of pencils. Morphological characteristics include silvery gray or white-coloured leaves with a silvery underside; up to 4 cm long, grayish-green fruit with an elongated beak; and grayish bark with lenticels (Giesen *et al*., 2006).

Avicennia rumphiana (Figure 2M) is the only species found in zone 1 of Setiu with the least diversity index and is considered vulnerable by the IUCN Red List of Threatened Species (IUCN, 2022). Generally, medium- to large-sized trees have a smooth, dark grayish colouration on the bark. It has a close stand and grows straight. Pneumatophores (roots) with a pencil-like appearance arise above ground to form long, shallow belowground roots. Leaves are ovate or elliptic, simple, opposite, thick and have an entire margin with non-curved edges. Leaf colouration is dark greenish above, and beneath it is covered with dense powdery hairs. The leaf's middle rib is covered with hairs; and the leaf stalk is about 18 – 20 mm long (Mariano *et al*., 2019). In the past, *A. rumphiana* was known as *A. lanata*, and its distribution ranged from Peninsular Malaysia, the Philippines to New Guinea (Giesen *et al*., 2006).

The genus *Acanthus* has only one representative, *Acanthus ebracteatus* (Figure 2N), which was found in zone 3 during the study period. It was recorded that *A. ebracteatus* habitat is confined to the landward zone (within 10 m of shorelines). Native distribution of the species is Tropical Asia, Tropical Australia and the Pacific region. It is a decumbent-stemmed shrub that can be upright or sprawling. It can grow as tall as 2 m. Its tap root system remains at the soil's surface. A flowering stem (spike) that is 8 to 15 cm long contains the plant's flowers. With time, the white petals of its blossoms turn brown. It occurs in the mangroves' interior and is a significant component of the undergrowth. Additionally, they were discovered along riverbanks close to the seaside, where they frequently encounter seawater (Giesen *et al*., 2006). All members of the family Acanthaceae were ranked as the least concerning species on the IUCN list (LC) except for *A. rumphiana*.

Meliaceae

Xylocarpus granatum (Figure 2O) is another true mangrove species found in the two different zones (1 and 3) of the Setiu Wetland. This species was found in the intertidal middle part of zones 1 and 2. The mature tree trunk surface is smooth, and colouration is greenish to yellowish. *Xylocarpus granatum* is characterised by a well-developed buttress root system that resembles a narrow ribbon-like appearance. Large fruits with hard upper surfaces resemble melon structures. Inflorescences are comparatively long and forked, and they develop from leaf axils (Tomlinson, 1986). Its original geographic range extends from east Africa and the Bay of Bengal to Australia and Polynesia. It ranks as the least concerning species on the IUCN list (LC).

Euphorbiaceae

Excoecaria agallocha (Figure 2P) is only found in zones 1 and 2. This species was recorded from the upper part of the intertidal area in both landward and fringe island zones (Islam *et al*., 2022). Characteristics of this species include creeping roots, grayish bark and dark greenish leaves. The flower has a grain shape, is axillary, spread out along the bunch, fragrant, male or female-only (male flowers lack peduncles and are smaller than female flowers), has green and white petals, a yellowish-green sepal and a yellow filament (Giesen *et al*., 2006; Djamaluddin, 2018). This species is commonly found in Southeast Asia (Giesen *et al*., 2006). *E. agallocha* is distributed in the Pacific, along with the Solomon Islands, Vanuatu, Fiji and Tonga (Shcmitt & Duke, 2015; Tomlinson, 1986). It is reported that the natural distributional range is in Eastern Africa, Sri Lanka, Hainan, Ryuku Island and tropical Australia. It is listed among the IUCN's least concern species (LC).

Arecaceae

Nypa fruticans (Figure 2Q) was the only palm species recorded in zones 1 and 3. It was observed in the lower zone of the intertidal area of both the landward and fringe islands in Setiu. Especially, zone 3 was dominated by the *N. fruticans* due to the freshwater supply from the

connected two rivers. The species is locally known as Nipah Palm, with underground, strong forking branches that root from the lower surface, which form clumps and have no stems. The leaves are upright with a modest curvature. The thick leaf stalk has a shiny-green upper surface and a slightly powdery lower surface. The bisexual flower clusters emerge from the base of the stem (the female flower is characterised by a circular head and the male by a bright yellowish colour). The body of the fruit is spherical. Each brown fruit has one white, egg-shaped seed that is 4 – 5 cm long and is obovate, angular, and fibrous (Giesen *et al*., 2006). *Nypa fruticansis* is widely distributed in Southeast Asia (Giesen *et al*., 2006). It was reported that this species was found in the Solomon Islands (Schmitt & Duke, 2015). Tomlinson (1986) reported that the species' distribution range was between Japan and Australia. It is also a native mangrove species in the Bengal delta region, including Bangladesh and West Bengal, India (Djamaluddin, 2018). It is listed among the IUCN's least concern species (LC).

Combretaceae

Lumnitzera racemose (Figure 2R) was found to be least diversified in the Setiu Wetland (Table 2) but only found in zones 1 and 2. The specimen was found in the upper zone of the fringe island in Setiu Wetland (Islam *et al*., 2022). Generally, this species prefers estuarine habitats. Morphologically, this species is smaller in size, an evergreen tree or shrub lacking pneumatophores that have a rough, reddish-brown fissured bark. Young branchlets are reddish or grayish, initially a little bit hairy, then smooth. The narrowly obovate leaves are slightly leathery. Leaves are clustered together and have a leaf stalk. Bisexual, without a pedicel, nectar-filled flowers with five white petals and five green sepals are found at the base of the plant. Fruit has an ellipse-shaped, yellowish-green, fibrous and dense structure (Giesen *et al*., 2006). Its geographical distribution range extends from Eastern Africa to Australia, the Pacific Islands and Southeast Asia. It ranks as the least concerning species on the IUCN list (LC).

Malvaceae

Heritiera littoralis (Figure 2S) was only observed in zone 3. According to Islam *et al.* (2022), this species occupied the upper portion of the intertidal zone at Setiu and was found in both seaward and landward parts. It is an evergreen tree with a buttressed trunk, fissures and dark or gray bark. Near the ends of the branches, the leathery, stiff leaves are grouped. Leaves are characterised by being ovate-elliptic or oblong. The colouration of the leaves is dark greenish in the upper portion and grayish-white in the lower portion. Unisexual, small, conspicuous flowers typically grow in dense, hairy clusters in the axils of leaves near the tips of branches. Compared to female flowers, male flowers are more numerous but smaller. Green to brown-coloured fruit characterised by a single seed (Giesen *et al*., 2006). This species has been widely found in the South Asian region. It can be found in the Pacific and the Solomon Islands (Schmitt & Duke, 2015). Tomlinson (1986) described the distributional range of *H. littoralis* in Africa, Madagascar, Hong Kong and Australia. In the IUCN list, it is ranked as the species that causes the least concern (LC).

Myrsinaceae

Aegiceras corniculatum (Figure 2T) was only restricted to zone 1. However, *A. corniculatum* was reported to be found in the middle part of the intertidal zone of the fringe island (Islam *et al*., 2022). These are smaller trees or shrubs that can grow to a height of 6 m and have roots that run parallel to the ground. The outer bark is fissured, lenticular and varies in colour from gray to brown to practically black. The spirally organised and round–notched leaves are leathery. They have a glossy, brilliant green upper portion and a lighter, typically somewhat reddish, lower portion. The tenacious calyx is white to green. Fruit is pointy, sharply curled, and ranges in colour from green to red, like two small bananas (Giesen *et al*., 2006). Southeast Asia is the native range of distribution for this species. It can be found in the Solomon Islands, South China, India, Sri Lanka and tropical Australia (Tomlinson, 1986; Schmitt & Duke, 2015).

Mangrove Associates

Twelve species of mangrove associates from 11 genera of nine families were also recorded from the studied zones at Setiu Wetland (Table 4 and Figure 4). To distinguish between real mangroves and mangrove allies, Tomlinson's criteria provided a very clear benchmark, which has been widely accepted (Parani *et al*., 1998; Kathiresan & Bingham, 2001; Lacerda *et al*., 2002; Saenger, 2002; Wang *et al*., 2003; Duke, 2006).

Lecythidaceae

Barringtonia racemosa (powder-puff tree) (Figure 4A) is a shrub or small tree in the family Lecythidaceae. It is found in coastal swamp forests and on the edges of estuaries in the Indian Ocean, and according to IUCN lists, it is of least concern (LC). The identifying characteristics are that the leaf edge is toothed and clustered at the ends of branches, and the flowers are large and arranged in a spear-like arrangement. It occurs only in tidal rivers and areas with regular seawater input. They are also found in beaches, freshwater swamps in edges of peat swamp forests. Young leaves and fruits are eaten as salad or vegetables. The seeds and barks of this tree are also used in native medicine (Shin *et al*., 2015).

Fabaceae

Cynometra ramiflora (Figure 4B) is found in mangroves and flooded forests in Australia, New Guinea, Island Southeast Asia and Tropical Asia as far west as India (Giesen *et al*., 2006), and according to the IUCN list, it is of least concern (LC). The tree grows up to 10 – 20 m tall. The trunk's diameter at breast height (DBH) is up to 60 cm. Leaves are compounded with one, rarely two, pairs of leaflets. The new leaves are pink. Lateral veins form loops well inside the blade margin. Fruit is an asymmetrical, roughly globose nut, roughly 45 × 39 × 34 mm, rust brown and woody, with a solitary seed. Flowering while in cultivation has been recorded in August and October. They grows on both rocky and sandy seashores, besides tidal rivers, on the landward side of mangrove forests, often on heavy, firm soil. Its wood is used for construction and fuel, and parts of the plant are ascribed to medicinal use.

Intsia bijuga (Figure 4C) is commonly known as a species of flowering tree in the family Fabaceae, native to the Indo-Pacific but vulnerable on the IUCN list. It is a deciduous tree with a slightly buttressed trunk and a spreading crown. Leaves are almost round and have a hairy lower midrib. This species is found in mangrove areas and sandy beaches. It is also occasionally found in dried parts of swampy areas. The barks and leaves are used in traditional medicines. The tree's timber is very durable and termite-resistant, making it a highly valued material for flooring and other uses. The wood can also be used to extract a dye (Shin *et al*., 2015).

Derris trifoliata (Figure 4D) is a rambling climber locally named Tuba Laut. It is 3 – 5 m long. Its leaves are alternate, pinnate, 12 – 20 cm; leaflets 5, ovate, 6 –10 cm, acuminate, and rounded at the base. Flowers are white or pale pink in colour and occur in drooping clusters. Fruits have round and flat, coin-like pods. It grows on muddy and sandy substrates on the landward mangrove edge. Its tuberous roots are well known to be used for stupefying fish (Shin *et al*., 2015). The IUCN conservation status of this species has not been evaluated (NE).

Rubiaceae

Oxyceros longiflorus (Figure 4E) is a semi-woody shrub in the gardenia family (Rubiaceae) found in rainforests of northern South America and Asia. It is most noteworthy for its tubular flowers and inverted hook-like thorns on stems. The stands of this species were generally less than 3 m in height. Morphological characteristics of this species include a semi-woody climber with inverted hook-like thorns on the stems, wrinkled leaves, flowers that are first white and then turn yellow, and fruits that are small, round, hard, and green in colour. Plant parts have been used as medical products. Roots are used as insecticides and insect repellents (Giesen *et al*., 2006). Its conservation status has not been evaluated (NE), according to IUCN listings.

Table 4. Lists of mangroves associates species identified from the studied zones at Setiu Wetland (IUCN Red List Threatened categories: VU = Vulnerable, LC = Least Concern, NE = Not Evaluated)

Family	Genus	Species	IUCN status	Type	Ethnobotanical Uses
Lecythidaceae	*Barringtonia* J.R. Forst. & G. Forst.	*Barringtonia racemosa* (L.) Spreng	LC	Shrub to medium-sized tree	Plant extracts were used as tanning agents, insecticides, and fish poison.
Fabaceae	*Cynometra* L.	*Cynometra ramiflora* L.	LC	Tree	Timber and wood are used for construction. Ornamental tree.
	Intsia Thouars	*Intsia bijuga* (Colebr.) Kuntze	VU	Tree	Edible fruits and seeds. Ornamental plant.
	Derris Lour	*Derris trifoliata* Lour.	NE	Shrub	The plant has medicinal and poisonous potential.
Rubiaceae	*Oxyceros* Lour	*Oxyceros longiflorus* (Lam.) T Yamazaki	NE	Shrub	Roots have insecticidal properties. Seed and bark have medicinal value.
Pandanaceae	*Pandanus* Parkinson	*Pandanus tectorius* Sol.	LC	Woody shrub or a small tree	Edible fruits and leaves. Leaves are used as handicraft items.
Sapotaceae	*Planchonella* Pierre	*Planchonella obovata* (R.Br.) Pierre	NE	Tree	The wood used for timber.
Malvaceae	*Taliparitii* Fryxell	*Hibiscus tiliaceus* L.	LC	Shrub or small tree	Fruits, leaves, and flowers are edible and therapeutic.
		Thespesia populnea (L) Soland. Ex Correa	LC	Shrub or small tree	Light timber uses for fiber, medicinal and ornamental values.
Sapindaceae	*Allophylus* L	*Allophylus cobbe* L. (Reausch)	LC	Shrub	The barks and leaves have medicinal and fruits have poisonous properties.
Apocynaceae	*Cerbera* L	*Cerbera odollam* Gaerth.	LC	Tree	Medicinal properties.
Arecacea	*Calamus* L	*Calamus erinaceus* (Becc.) J. Dransf.	LC	palm	Little commercial uses. Stems are used for weaving into baskets.

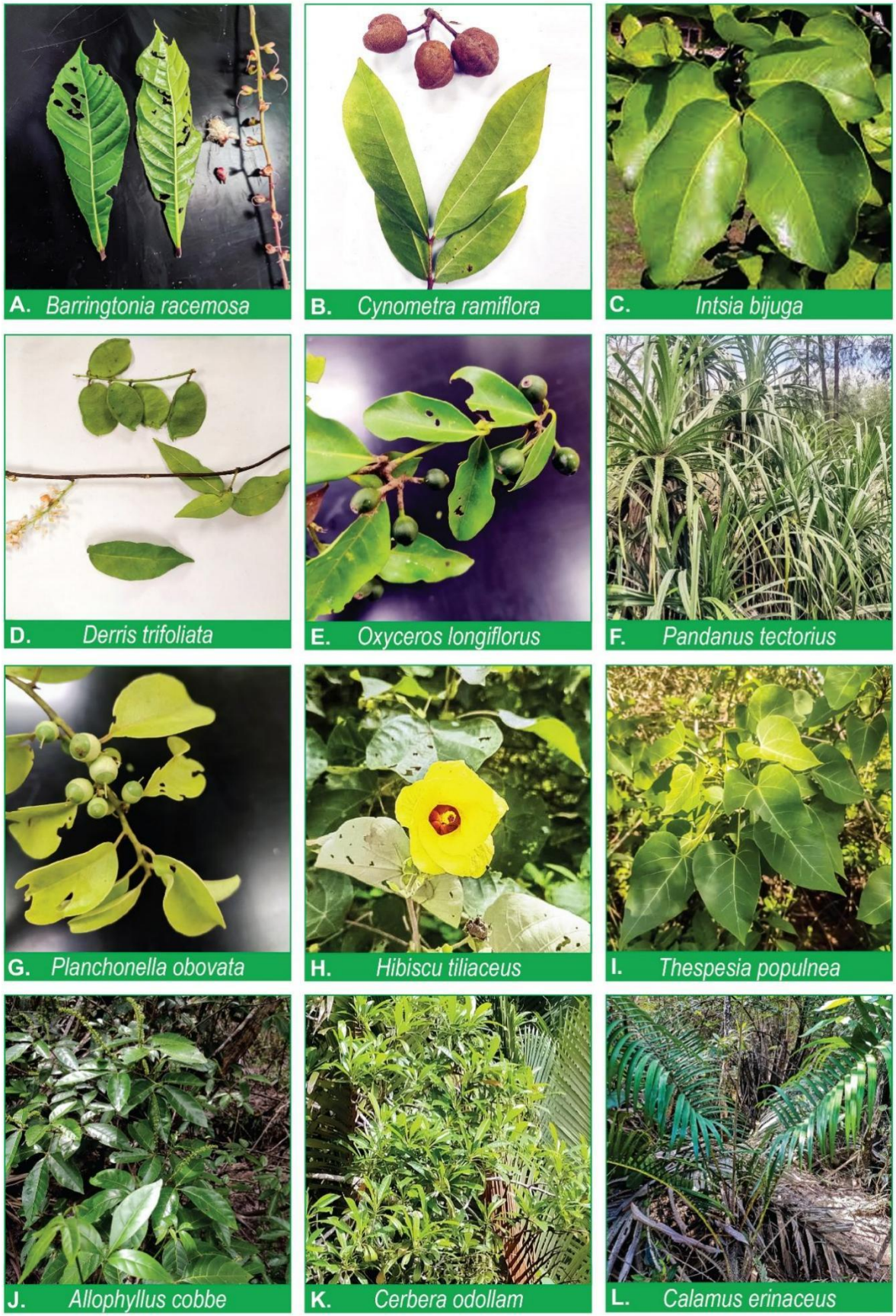

Figure 4. Lists of mangroves associates recorded from Setiu Wetland; (**A**) *Barringtonia racemose*, (**B**) *Cynomet raramiflora*, (**C**) *Intsia bijuga*, (**D**) *Derris trifoliate*, (**E**) *Oxyceros longiflorus*, (**F**) *Pandanus tectorius*, (**G**) *Planchonella obovate*, (**H**) *Hibiscus tiliaceus*, (**I**) *Thespesia populnea*, (**J**) *Allophylus cobbe*, (**K**) *Cerbera odollam*, and (**L**) *Calamus erinaceus*

Pandanaceae

Pandanus tectorius (Figure 4F) is a species of *Pandanus* that is locally named Pandan Laut. They are evergreen and coarsely branched palm-like tree. The fruit's distinctive characteristics are its orange or red colour and pineapple-like structure with many separable prism-like sections. It is supported by aerial roots (prop roots) that firmly anchor the tree to the ground. It grows in the coastal lowlands on sandy substrates typically near the edge of the ocean. Its fruits and young leaves are edible, and the local community uses the leaf for weaving baskets, mats, hats, and rope (Shin *et al*., 2015). The IUCN list rates it as of least concern (LC).

Sapotaceae

Planchonella obovata (Figure 4G) is a tree in the family Sapotaceae. The local name in Malaysia is Menasi. It occurs in many parts of Southeast Asia, Micronesia, and on islands in the Indian Ocean. The identifying feature is its crown-coppery appearance. It grows as a bushy-crowned tree, reaching a maximum height of 10 to 20 m. The leaves are hairy when young, with the upper surfaces becoming smooth and shiny. Leaves are roughly oval to spear-shaped and measure 6 – 24 cm long and 1.5 – 15 cm wide. The flowers are small and greenish-white and are said to smell like pandan. Fruits resemble small berries that appear from August to October. Commonly found at rocky and sandy seacoasts, inland sandy heaths, limestone hills, and mangrove edges. Sometimes wood is used as timber (Shin *et al*., 2015). Its conservation status has not been evaluated (NE), according to IUCN listings.

Malvaceae

Hibiscus tiliaceus (Figure 4H), commonly known as the sea hibiscus or coast cottonwood, has a pantropical distribution along coastlines. It has a worldwide distribution but is commonly found on the sandy and rocky shores of southeast Asia. *Hibiscus tiliaceus* reaches a height of 4 – 10 m with a trunk up to 15 cm in diameter. The flowers are bright yellow with a deep red center upon opening. The branches of the tree often curve over time, and the leaves are heart-shaped and deep red. It has been used in a variety of applications, such as seacraft construction, firewood and wood carvings. *Hibiscus tiliaceus* is widely used in Asian countries as a subject for the art of bonsai, especially in Taiwan (Giesen *et al*., 2006). The IUCN list rates it as of least concern (LC). *Thespesia populnea* (Figure 4I) has papery bark and is a woody climber. It has shiny heart-shaped green leaves. The bell-shaped yellow flower has a purple calyx in the middle. Its distributional range spread from the Bay of Bengal to the Moluccas, Myanmar, Cambodia, Thailand, Vietnam, Malaysia, Singapore, Brunei and Indonesia. (Shin *et al*., 2015). The IUCN list rates it as of least concern (LC).

Sapindaceae

Allophylus cobbe (Figure 4J), commonly known as teaberry, is an erect or scrambling shrub. It grows on seashores, in secondary forests, in brushwood, and in hedges. Leaves are always in groups of three have a sharp, and deeply indented leaf edge. Flowers are tiny and white, arranged in a short spear-like arrangement. The resulting fruit is a glabrous red drupe measuring from 4 to 16 mm in diameter and containing a single large seed. The timber has been used for roofing and firewood, and for making bows, rafts and fish traps. The fruits are edible and can also be used as fish poison (Shin *et al*., 2015). The IUCN list rates it as of least concern (LC).

Apocynaceae

Cerbera odollam (Figure 4K) is a dicotyledonous angiosperm, a plant species in the family Apocynaceae and commonly known as Pong-pong. It bears a fruit known as 'Othalangathat' and yields a potent poison that has been used for the treatment of intestinal worms. It is a species native to India and other parts of southern Asia, growing preferentially in coastal salt swamps and marshy areas but also used as a hedge plant between home compounds (Giesen *et al*., 2006). It receives the least concern (LC) rating on the IUCN list.

Arecaceae

Calamus erinaceus (Figure 4L) is a genus of flowering plants in the palm family Arecaceae that is among several genera known as rattan palms. There are thought to be 400 species in this genus, all native to tropical and subtropical Asia, Africa and Australia. They are dioecious, mostly leaf climbing lianas with

slender, reedy stems. Flowers and fruits are in long clusters. Fruits are round and covered vertically with straw-coloured scales. Generally found at the landward edge of mangroves or the landward margin of coastal sandbars. It has little commercial use as household furniture because its cans are too stiff and hard (Giesen *et al*., 2006). The IUCN list rates it as of least concern (LC).

CONCLUSION

Mangroves are considered the world's most productive ecological system. Hence, the overall, mangrove species diversity in the Setiu Wetland was more diverse and floristically enriched compared to other mangrove forests in Southeast Asia. It makes up around 41.42% of all Malaysia's mangrove species. A total of 20 true mangrove species were identified and recorded from this wetland, and *Rhizophora mucronata* was well-distributed. One species of mangrove, *Avivennia rumphiana*, and its mangrove associate, *Intsia bijuga*, were listed as vulnerable (VU) by the IUCN in this wetland habitat. Geographical, biological and physicochemical factors predominated and influenced the zonation pattern of mangroves in the Setiu Wetland. The results of this study may serve as a preliminary source of data and baseline information for future research on the ecology and conservation of this wetland ecosystem in tropical climates. Thus, this study is anticipated to encourage additional research, particularly for long-term monitoring.

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