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A Baseline Measure of Tree and Gastropod Biodiversity in Replanted and Natural Mangrove Stands in Malaysia: Langkawi Island and Sungai Merbok

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Abstrak: Kepelbagaian pokok bakau dan gastropod yang berkaitan telah dikaji di dua kawasan bakau di pantai barat Semenanjung Malaysia: Pulau Langkawi dan Sungai Merbok. Kawasan bakau yang disampel di Pulau Langkawi baru dibalak dan ditanam semula, manakala kawasan yang disampel di Sungai Merbok adalah sebahagian daripada rizab semula jadi yang dilindungi. Kepelbagaian bakau dan gastropod dinilai dalam empat tapak kajian bersaiz 50 m^2 (10 × 5 m) bagi setiap kawasan. Nilai kekayaan spesies (S), Indeks Shannon (H') dan indeks evenness (J') dikira bagi setiap tapak kajian, dan nilai min S, H' dan J' dikira bagi setiap kawasan. Keputusan menunjukkan nilai S, H' dan J' bagi pokok dan gastropod dari kesemua kawasan kajian dari kedua-dua tapak adalah rendah. Untuk Pulau Langkawi, nilai min S, H' dan J' bagi pokok bakau adalah S = 2.00±0, H = 0.44±0.17 dan J' = 0.44±0.17; nilai min bagi gastropod adalah S = 4.00±1.63, H' = 0.96±0.41 dan J' = 0.49±0.06. Di Sungai Merbok, nilai min S, H' dan J' bagi pokok bakau adalah S = 1.33±0.58, H' = 0.22±0.39 dan J' = 0.22±0.39; nilai min bagi gastropod adalah S = 4.75±2.22, H' = 1.23±0.63 dan J' = 0.55±0.12. Kajian ini menekankan keperluan ukuran kajian asas biodiversiti diadakan untuk ekosistem bakau untuk mengesan impak gangguan antropogenik dan sebagai panduan untuk usaha-usaha pengurusan dan pemulihan ekosistem bakau.

Keywords: Biodiversiti Bakau, Biodiversiti Gastropod, Biodiversiti Pokok, Biologi Pemulihan

Abstract: The diversities of mangrove trees and of their associated gastropods were assessed for two mangrove regions on the west coast of Peninsular Malaysia: Langkawi Island and Sungai Merbok. The mangrove area sampled on Langkawi Island was recently logged and replanted, whereas the area sampled in Sungai Merbok was part of a protected nature reserve. Mangrove and gastropod diversity were assessed in four 50 m^2 (10 × 5 m) sites per region. The species richness (S), Shannon Index (H') and Evenness Index (J') were calculated for each site, and the mean S, H' and J' values were calculated for each region. We report low tree and gastropod S, H' and J' values in all sites from both regions. For Langkawi Island, the mean S, H' and J' values for mangrove trees were S = 2.00±0, H' = 0.44±0.17 and J' = 0.44±0.17; the mean S, H' and J' values for gastropods were S = 4.00±1.63, H' = 0.96±0.41 and J' = 0.49±0.06. In Sungai Merbok, the mean S, H' and J' values for mangrove trees were S = 1.33±0.58, H' = 0.22±0.39 and J' = 0.22±0.39; the mean S, H' and J' values for gastropods were S = 4.75±2.22, H' = 1.23±0.63 and J' = 0.55±0.12. This study emphasises the need for baseline biodiversity measures to be established in mangrove ecosystems to track the impacts of anthropogenic disturbances and to inform management and restoration efforts.

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Keywords: Mangrove Biodiversity, Gastropod Biodiversity, Tree Biodiversity, Restoration Biology

INTRODUCTION

Mangroves are found globally in tropical and subtropical regions at the confluence of marine and terrestrial environments and support a unique ecosystem of considerable importance (FAO 2007; Alongi 2002; Tomlinson 1986). As the net primary production from mangrove flora far exceeds the ecosystem requirements, mangroves can function as both carbon sinks and carbon sources for the surrounding marine ecosystems (Cannicci *et al.* 2009; Duke *et al.* 2007; Duarte & Cebrian 1996). This highly productive ecosystem supports a wide range of animals, including molluscs (e.g. gastropods, bivalves), arthropods (e.g. crustaceans), fish, birds, reptiles (e.g. crocodiles), amphibians and mammals (FAO 2007; Ashton & Macintosh 2002). Mangroves function as breeding and nursery areas for shrimp, crabs and marine fish and have been found to positively influence the biomass of fish (including commercially important species) on neighbouring coral reefs (Mumby *et al.* 2004; Ashton & Macintosh 2002).

Mangroves also provide ecosystem services with substantial economic value with respect to waste treatment (e.g. pollution control, detoxification), disturbance regulation (e.g. storm protection, flood control), and, to a lesser extent, food production, habitat (e.g. nurseries for commercially important species) and raw materials (Costanza *et al.* 1997). Globally, the estimated worth of mangrove services is US$ 180,895,923,000 (Alongi 2002 based on values in Costanza *et al.* 1997). Nevertheless, current practices suggest that the consequences of mangrove loss are not well appreciated (Duke *et al.* 2007). Mangroves are being rapidly destroyed worldwide due to urban and industrial coastal development, overexploitation of mangrove resources, aquaculture (especially shrimp ponds) and agriculture (Amin *et al.* 2009; Duke *et al.* 2007; Ashton *et al.* 2003; Alongi 2002; Ashton & Macintosh 2002).

The Indo-West Pacific has the largest combined mangrove area in the world and boasts the highest biodiversity, particularly in South East Asia (Sandilyan & Kathiresan 2012). Malaysia is second only to Indonesia in the size and biodiversity of its mangrove areas (FAO 2007). During the past 25 years, extensive mangrove loss has occurred in Malaysia (≈109000 ha), and significant replanting programmes are required to remedy this loss (FAO 2007). The current sustainably managed mangroves or replanted mangroves are often monoculture stands of economically valuable species, e.g. *Rhizophora* spp. (Walton *et al.* 2007; Bosire *et al.* 2006; Alongi 2002; Ashton & Macintosh 2002; Ellison 2000). The possible deleterious effects of monoculture stands on the associated faunal communities have not been properly addressed in restoration projects (Bosire *et al.* 2008). A measure of success for replanting programmes is mangrove biodiversity, i.e., the replanted stands should ideally resemble natural stands.

The aim of this study was to provide an initial, baseline measure of tree and gastropod biodiversity in two Malaysian mangrove areas: Langkawi Island

and Sungai Merbok. The sites sampled on Langkawi Island were actively logged and replanted, whereas the sites sampled in Sungai Merbok represented a natural stand. The species richness, diversity and evenness of tree species were assessed for both regions to determine if the replanted stands maintained the same level of diversity found in the natural stands. Furthermore, the species richness, diversity and evenness of gastropods were assessed in both regions to determine if faunal communities could become re-established in replanted stands and if the community of gastropods would resemble the communities found in natural stands.

MATERIALS AND METHODS

Description of Regions and Study Sites

Region 1: Langkawi Island

The Langkawi Archipelago lies west of Peninsular Malaysia in the Andaman Sea near the Malaysian-Thai border. The archipelago consists of 99 islands at high tide and 104 islands at low tide; sampling was conducted on Langkawi Island, the largest and most densely populated of the islands (Jahal *et al.* 2009). Langkawi Island is one of Malaysia's principal tourist attractions and is, therefore, developing rapidly. Coastal development has converted much of the original mangrove area to agricultural lands, aquaculture ponds, mariculture, commercial and residential areas, and jetties that support the increase in boating activity. Furthermore, in areas not designated as Permanent Forest Areas, the local communities on Langkawi Island actively use mangroves for timber. Private use of mangroves for timber is prevalent even in areas designated as Forest Reserves or Permanent Forest Reserves (Shahbudin *et al.* 2012).

Langkawi Island sites

Four sites were sampled on Langkawi Island (L1–L4; Fig. 1A–C). The mangrove areas sampled on Langkawi Island, Tanjung Rhu and Kilim, were both exposed to heavy boat traffic associated with tourist activities and were actively logged and replanted. Perhaps the most striking feature of the Langkawi Island sites was the density of the *Rhizophora* sp. stands. The tight spacing of trees indicates that they had been actively planted, as mature stands are less dense due to self-thinning (Alongi 2002). The trees were logged in all sites visited and then replanted on a continuing basis. The age of the trees, based on trunk diameter and tree height, was estimated to be approximately 5–10 years (Benoit Dayrat pers. comm.). In this study, the sites from Langkawi Island represented replanted stands.

Region 2: Sungai Merbok

The mangrove area surrounding the Sungai Merbok estuary is located in the state of Kedah in the Northwestern region of Peninsular Malaysia (Somerfield *et al.* 1998). This mangrove area consists primarily of *Rhizophora apiculata* and *Bruguiera parviflora* and is managed only in certain regions (Somerfield *et al.*

1998; Ong 1982). Approximately 5000 ha of the Sungai Merbok mangroves has been set aside as a nature reserve and 1500 ha is used for rice paddies (Chong 2006; Somerfield *et al.* 1998). The remainder consists of pond aquaculture, roads, industry and residential areas (Somerfield *et al.* 1998).

Sungai Merbok sites

Four sites were sampled in Sungai Merbok (M1–M4; Fig. 1D–F). Samples were collected in a section of the reserve next to a road that had rice paddies on the opposite side. Despite nearby agriculture, the sampling sites were located in sections of mangrove that were relatively undisturbed. In all of the Sungai Merbok sites, the trees were estimated to be 20 m tall and perhaps 30 years old (Benoit Dayrat pers. comm.). Several trees were most likely older, as this region had never been logged. Although these mangroves may experience agricultural run-off, the sites in Sungai Merbok represented natural stands in this study.

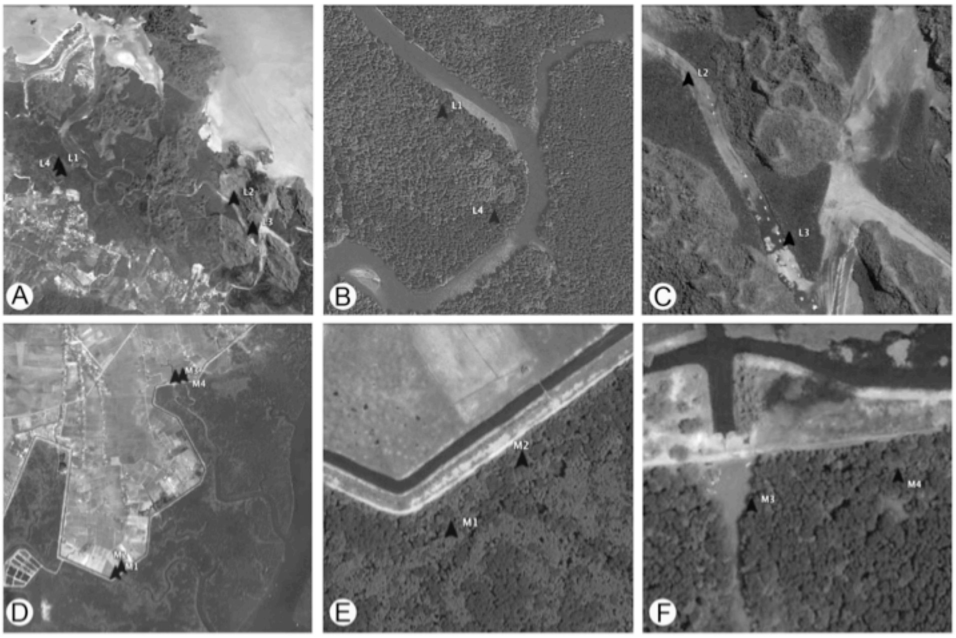

Figure 1: Aerial images of study sites in Langkawi Island and Sungai Merbok acquired from Google Earth™ mapping program (©2012 GeoEye, ©2012 DigitalGlobe, Data SIO, NOAA, US Navy, NGA, GEBCO): (A) Langkawi Island study sites L1–L4; (B) study sites L1 and L4; (C) study sites L2 and L3; (D) Sungai Merbok study sites M1–M4; (E) study sites M1 and M2; (F) study sites M3 and M4.

Experimental Design

Within each region, four sites were sampled (L1–L4 and M1–M4), for a total of eight sites. At each site, a transect was placed 2–10 m from a water source, perpendicular to the water, and in an area with lower tree density and firmer sediments to permit access. All sampling was performed approximately one hour before the lowest tide. Each study site included the area 2.5 m to the right and left of the transect tape. The total sampling area per site was thus 50 m^2 (10 × 5 m).

The vegetation of the study sites was identified to genus, whereas the gastropods were identified to species if possible. The tree abundance was recorded within each 50 m^2 site. Mangrove seedlings and saplings were not included in the count because they would not necessarily be recruited into the adult stand (Bosire *et al.* 2006). The gastropod species were not recorded for the entire 50 m^2 site. Instead, 10 random positions within the 50 m^2 area were selected using a random number generator, and a 0.5 × 0.5 m quadrat was placed at each of these 10 positions. All gastropod species found within each quadrat were recorded. Gastropods were counted on the muddy substratum; additionally, on the roots of the mangrove trees and on quadrats that encompassed a tree, they were sampled directly beside the trunk. The gastropod abundances from the 10 quadrats were combined to represent the site. The four sites sampled per region were considered the replicates (i.e. n = 4 for each region). The tree and gastropod abundance data were used to calculate species density (individuals/m^2) and diversity indices.

Data Analysis

The tree and gastropod species richness (S), Shannon Index (H') and Evenness Index (J') values were calculated for each site (Pielou 1966; Shannon & Weaver 1949). The species richness was recorded as the total number of species found in each site. The Shannon Index was calculated as $H' = -\sum[pi \bullet \ln(pi)]$; the Evenness Index was calculated as $J' = H'/(\log_2 S)$. Lastly, the mean tree and gastropod S, H' and J' values were calculated for each region.

RESULTS

The tree diversity was low at both sites assessed. The only trees reported were *Rhizophora* sp. and *Bruguiera* sp. *Rhizophora* sp. was more dense across the study sites. At the Sungai Merbok sites M3 and M4, it was the only species present (Table 1). Of the gastropod species recorded, *Sphaerassiminea miniata* had the highest density across sites, whereas others, such as *Cassidula nucleus, Cerithidea obtusa, Littoraria* spp. and *Paraonchidium* sp. were rarer (Table 2).

At all of the Langkawi Island sites (L1–L4), the S, H' and J' values were very low. At Sungai Merbok, the sites (M1–M4) showed even lower measures of tree S, H' and J' (Table 3). Additionally, with only one tree species found at sites M3 and M4, the diversity index was zero, and the J' value was therefore meaningless. The gastropod S, H' and J' values were higher than those calculated for the trees (Tables 3 and 4). Nevertheless, the values for gastropods were still quite low compared to those found in other studies (e.g. Amin *et al.* 2009).

The tree S, H' and J' values were higher at the Langkawi Island sites. However, the difference is negligible in view of the low values found in all sites from both regions. In contrast, the gastropod S, H' and J' values were higher at the Sungai Merbok sites. Again, however, the difference between regions was not high, although it was evident from inspection of the data (Table 5).

Table 1: Density (individuals/m^2) of tree species in sites from Langkawi Island and Sungai Merbok. Each site was 50 m^2 (10 × 5 m).

Tree species	Langkawi Island				Sungai Merbok			
	L1	L2	L3	L4	M1	M2	M3	M4
	Density							
Rhizophora sp.	0.62	0.2	0.28	0.38	*	0.04	0.24	0.12
Bruguiera sp.	0.12	0.02	0.2	0.04	*	0.06	0	0
Total	0.74	0.22	0.48	0.42	*	0.1	0.24	0.12

Note: *Data missing

Table 2: Density (individuals/m^2) of gastropod species in sites from Langkawi Island and Sungai Merbok. A 0.5 × 0.5 m quadrat was sampled at 10 random positions/site. The data from the 10 positions were combined.

Gastropod species	Langkawi Island				Sungai Merbok			
	L1	L2	L3	L4	M1	M2	M3	M4
	Density							
Sphaerassiminea miniata	14	4	0	4.8	8.4	2	3.2	0.4
Nerita lineata	0.8	2	2.4	0	0	0	0	0
Cassidula aurisfelis	0	0	0	0	2.4	1.2	0	2.8
Cassidula nucleus	0	0	0	0	0	1.2	0	0
Terebralia sulcata	7.2	0	0	1.6	2.8	0.8	1.6	0
Cerithidea obtusa	0	0	0	0.4	0	0	0	0
Littoraria sp.	0	0	0.4	0	0	0	0	0
Littoraria carinifera	0	0	0	0.4	0	0	0	0
Assiminea brevicula	1.2	0.4	0	4.8	0.4	0.4	0	0
Laemodonta sp.	0	0.8	0	0.8	3.6	1.2	1.2	0
Platyvindex sp.	0	0	0	0	1.6	0	0.4	0
Paraonchidium sp.	0	0	0	0	0	0.8	0	0
Total	23.2	7.2	2.8	12.8	19.2	7.6	6.4	3.2

Table 3: Species richness (S), Shannon Index (H') and Evenness Index (J') of tree species in Langkawi Island and Sungai Merbok.

Site	S	H'	J'
Langkawi Island			
L1	2	0.44	0.44
L2	2	0.30	0.30
L3	2	0.68	0.68
L4	2	0.31	0.31
Sungai Merbok			
M1	*	*	*
M2	2	0.67	0.67
M3	1	0	**
M4	1	0	**

Note: *Data missing; **undefined number (J' = H'/0)

Table 4: Species richness (S), Shannon Index (H') and Evenness Index (J') of gastropod species in Langkawi Island and Sungai Merbok. Quadrats were combined, and the values (S, H' and J') were calculated from the combined data for the site as a whole.

Site	S	H'	J'
Langkawi Island			
L1	4	0.94	0.47
L2	4	1.09	0.54
L3	2	0.41	0.41
L4	6	1.39	0.54
Sungai Merbok			
M1	6	1.50	0.58
M2	7	1.85	0.66
M3	4	1.18	0.59
M4	2	0.38	0.38

Table 5: Mean species richness (S), Shannon Index (H') and Evenness Index (J') values of tree and gastropod species in Langkawi Island and Sungai Merbok.

	S	H'	J'
Tree			
Langkawi Island	2.00±0	0.44±0.17	0.44±0.17
Sungai Merbok	1.33±0.58	0.22±0.39	0.22±0.39
Gastropod			
Langkawi Island	4.00±1.63	0.96±0.41	0.49±0.06
Sungai Merbok	4.75±2.22	1.23±0.63	0.55±0.12

DISCUSSION

Low Abundance, S, H' and J' Values

We found low tree and gastropod density, S, H' and J' values at all sites from both regions. This result may indicate that the mangroves in Peninsular Malaysia either have a low natural species density and diversity or that both regions investigated were equally disturbed.

At all of the sampling sites, the only tree species present were *Rhizophora* sp. and *Bruguiera* sp. The dominant species at all sites (except site M2) was *Rhizophora* sp. This observation was not particularly surprising, as mangrove tree species are often found in distinct ranges and grouped in distinct forest communities (Ellison *et al.* 1999; Duke *et al.* 1998). The sites were all within the range of the *Rhizophora* sp. and *Bruguiera* sp. stands.

The tree richness showed no difference between sites. The tree H' value also did not differ greatly between sites and ranged from 0.30 to 0.68. These H' values were all quite low and the difference between an H' value of 0.30 and 0.68 remains unclear. The evenness values were also low, ranging from 0.30–0.68. The low values of S, H' and J' most likely reflect the small sampling sites, which did not fully encompass all of the mangrove tree species found along the tidal gradient. Under these conditions, the diversity of mangrove tree species is naturally low within zones of distinct communities. Additionally, the low values may partially reflect a bias towards less dense sites.

The gastropod density and species richness reported for each site was low in comparison to the number of species that could be found in a casual search of the area. For instance, the gastropod species that were most abundant at the sampling sites were *S. miniata, Terebralia sulcata, Assiminea brevicula* and *Laemodonta* sp. All of these species can be found on the surface of muddy sediments. The gastropod species that were rarer at the sampling sites were *C. nucleus, C. obtusa, Littoraria* sp., *Littoraria carinifera* and *Paraonchidium* sp., all of which were found on tree trunks and fallen wood and were commonly observed in a casual search. This finding could suggest that the transect sampling technique showed a bias towards those species found on the sediments and in the leaf litter because less dense areas were chosen for study. Time-based collections (e.g. Ashton *et al.* 2003) of gastropods may yield a more representative sample of the gastropod species present at a given site but introduce the potential for sampling bias.

Although the sampling technique employed in this study may not have encompassed the full gastropod diversity present, the H' and J' values calculated were similar to H' and J' values calculated for gastropods in Matang, Malaysia (Sasekumar & Chong 1998). The range of H' and J' values for the sites across both regions in the present study fell within the range of H' and J' values calculated in a 2-year-old, 15-year-old and mature mangrove stand in Matang. For instance, the values calculated for sites L3 (H' = 0.41, J' = 0.41) and M4 (H' = 0.38, J' = 0.38) were very similar to the values calculated in a 2-year-old stand in Matang (H' = 0.3944, J' = 0.3590); the values calculated for sites M1 (H' = 1.5, J' = 0.58) and M2 (H' = 1.85, J' = 0.66) were comparable to the values calculated in a mature stand in Matang (H' = 1.5663, J' = 0.6532). In the present study, the effect of replanting and mangrove age on gastropod diversity is unclear, as low H' and J' values were reported for site M4 in Sungai Merbok, which was part of an unlogged nature reserve, whereas relatively high H' and J' values were reported for site L4 (H' = 1.39, J' = 0.54) in Langkawi. Furthermore, other natural and anthropogenic disturbances will affect the diversity of gastropods at a given site.

The gastropod S, H' and J' values were also comparable to the S, H' and J' values calculated by Amin and collegues (2009) based on an investigation of gastropod diversity in mangroves with various levels of anthropogenic disturbance in Indonesia. On average, the S, H' and J' values in this study were similar to those found by those authors in Pelintung and Sg. Dumai, the stations with poorer water quality, more anthropogenic disturbance, higher metal concentrations and a generally lower quality of physicochemical parameters (Amin *et al.* 2009). The lower H' values reported, 0.38, 0.41 and 0.94 at sites M4, L3 and L1, respectively, may suggest some type of disturbance; in the case of L1 and L3, these lower values may simply reflect the recent logging and replanting in that region.

Langkawi Island vs. Sungai Merbok

In this preliminary study, no differences were found between a replanted region, Langkawi Island and a natural stand, Sungai Merbok. Although the mean tree S value did not differ greatly between the sites, the mean H' and J' values at the Langkawi Island sites were twice the corresponding values at the Sungai Merbok sites. Although the difference may appear striking, it is actually due only to the influence of sites M3 and M4, which had only one tree species (vs. two at the other sites), resulting in a H' value of zero and a meaningless J' value. Another possible explanation of this finding is that the trees at the Langkawi Island sites were closely spaced as a result of active planting, which augmented the abundances of certain tree species. Only by sampling from the low to the high tide line could differences in tree S, H' and J' values (if any exist) be determined. In addition, due to the naturally low tree diversity in the mangroves, another measure, such as diameter at breast height (DBH), may yield a better method for distinguishing a natural, healthy mangrove stand from a disturbed site.

Additionally, the gastropod distributions did not differ strikingly between the two regions. The gastropod species richness, diversity, and evenness were, on average, relatively similar for Langkawi Island and Sungai Merbok. This result was unexpected and surprising. It was expected that the recent logging of the Langkawi Island sites would be reflected in a reduction of the community of gastropods. This finding may suggest that gastropod species are not greatly affected by periodic tree removal, as they are able to recolonise a disturbed area rapidly (Bosire *et al.* 2008). Alternatively, it is possible that more sites need to be sampled in each region. Overall, of the faunal communities present in the mangroves, gastropods are ideal bioindicators, as they are found globally, are easily identified and sampled year round (unlike crabs) and are tolerant of environmental fluctuations but also have limited mobility and are thus susceptible to human disturbances (Amin *et al.* 2009; Nordhaus *et al.* 2009).

Recommendations for Future Studies

This study emphasises the need for more baseline biodiversity measures to be established for mangroves. In Malaysia and in many other countries, the diversity of the mangrove flora and fauna remains largely unstudied. Ideally, sampling would run from the low tide to the high tide mark, and sampling sites would be much larger. Nevertheless, note that the mangrove ecosystem presents formidable sampling problems, e.g. difficult/hazardous site accessibility via boat or car, extremely soft sediments, areas with dangerous animals, dense mangrove stands that cannot be penetrated and tidal restrictions. More importantly, sampling was consistent between sites. Diversity indices provide a powerful tool for comparisons between regions; however, more sites need to be sampled across several regions, and any differences should be identified using statistical analyses.

It is important to determine the effect of creating monoculture stands on faunal assemblages. If the richness and diversity of tree species does influence faunal richness, then the loss of tree species could be detrimental to ecosystem functioning. At the same time, it may be possible to maintain the tree richness and diversity through a replanting program, making the periodic logging of a site relatively sustainable. Mangrove ecosystems may be resilient to occasional logging, but studies on a larger scale over a longer time period are required to confirm this hypothesis. Data of this type are necessary to support informed management decisions. With our present knowledge, the replanting of logged areas should aim to maintain the tree diversity and should consider the associated fauna. At a minimum, mangroves should be re-established through the planting of monocultures or by leaving these areas to become fallow. Both scenarios are certainly preferable to the development of the reclaimed lands for other purposes.

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