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Floral Composition of the Kayan-Sembakung Delta in North Kalimantan (Indonesia) in Different Disturbance Regimes

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ABSTRACT

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This paper presents the results of a preliminary study that identify the floral composition of the Kayan-Sembakung Delta in North Kalimantan under different disturbance regimes. The landforms described in the Regional Physical Planning Project for Transmigration in Indonesia land-system map were evaluated to define the mangrove ecosystem boundary. The mangrove ecosystem disturbance levels distinguished by reclassifying the land-cover map of the mangrove ecosystem into four categories, *i.e*. heavily disturbed mangrove (represented by shrimp ponds abandoned five years ago or less), moderately disturbed mangrove (represented by shrimp ponds abandoned more than five years ago), regrown (secondary) mangrove forest (that may have been logged for wood but did not experience terrain alteration for fishpond development), and relatively undisturbed (primary) mangrove forest. A vegetation survey was conducted in several transects for each of these categories. Basal area, density, species diversity, and abundance of species in each location were calculated to understand the floral composition of the mangrove ecosystem. The study reveals that the mangrove forest in the Simanggaris River has the highest total basal area of 44.50 m^2/ha, as well as the highest tree density of 1635 individual/ha, which indicates the most dense and mature remaining mangrove forest followed by the Sikang River near Liago Village with 85.75% of canopy cover. The heavily degraded mangrove ecosystem in Ibus Island has the highest importance value index of 278.89%, with *Sonneratia sp*. as the dominant species. The Kayan-Sembakung Delta hosts at least six original mangrove species, *i.e. Rhizophora apiculata*, *Osbornia octodonta*, *Lumnitzera littorea*, *Avicennia sp*, *Rhizophora sp*, and *Sonneratia sp*. In addition to the six original mangrove species listed, the inner part of the Kayan Delta also has several forest patches dominated by *Nypa fruticans*, whereas some parts of the Delta host a mixed vegetation composition between freshwater and brackish water ecosystems.

ADDITIONAL INDEX WORDS: *Species diversity, vegetation, mangrove ecosystem.*

INTRODUCTION

Mangrove forests refer to woody stands that grow on the land influenced by fresh and sea water—thus experiencing high salinity, tides, and winds—and that grow on the muddy, anaerobic soils (Kathiresan and Bingham, 2001). The forests provide physical function to protect the land behind from abrasion and protect the front waters from excessive sedimentation (Saenger, 2002). Ecologically, mangrove forests function as nursery grounds for coastal fish, crustaceans, and temporary habitat for various migrant birds, which are the results of complex processes involving sun, wind, and rainfall as energy inputs and main mangrove process that include primary productivity, plant photosynthesis and respiration, aeration, and mineral cycling by the mud as well as organic matter export (Lugo and Snedaker, 1974). Long-term research in Malaysia shows that net primary productivity is about 17.7 t/ha/y, whereas the biomass average was 409 t/ha (Putz and Chan, 1986); the same research also reveals that *Rhizophora apiculata* is the most dominant tree species in mangrove ecosystem.

Mangrove ecosystems in Southeast Asia are highly diverse and threatened at the same time. Between 2000 and 2012, the mangrove forests in Southeast Asia were declining as much as 0.18% per year with the total extent of approximately 100,000 ha (Richards and Friess, 2016). Malaysia has lost about 111,000 ha or 16% out of total extent of its mangrove forests between 1973 and 2000 (Chong, 2006). Indonesia once hosted about 4.25 million ha of mangrove forests, which comprise about 20% of the world's mangrove (Choong, Wirakusumah, and Achmadi, 1990). Indonesia then started to gradually lose its mangrove forest since *ca*. 1800, whereas the rapid mangrove degradation started at the end of 1960. The mangrove degradation in Indonesia continued rapidly around 1970 when mangrove forest was intensively converted into shrimp ponds in the islands outside of Java Island and peaked during the Asian Economic Crisis between 1997 and 1998 (Bourgeois *et al*., 2002; Ilman *et al*., 2016; Setyawan, 2003). This situation is no exception for the Kayan and Sembakung Delta in the North Kalimantan Province.

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Table 1. *Geomorphological and lithological description of landforms that comprise the mangrove ecosystem (RePPProT, 1987).*

Land System	Description	
	Geomorphology	Lithology
Kajapah (KJP)	This land system comprises low and vast coastal plains in which some parts are regularly inundated or permanently form the plain between the high and low tides. Slope is lower than 2%, and relief difference are always less than 2 m.	Rock/mineral dominated by alluvium with a mix of young estuary and marine materials and mostly regosol and alluvial soils; the soil texture on top/bottom is rough/slightly rough and smooth/slightly smooth. This land is suitable for brackish water aquaculture, fishponds, and mangrove planting.
Putting (PTG)	Coastal plain with coastal sand sediment that form a gentle hill. The terrain is flat to gently rolling with slope 0–3% and relief difference between 2 to 10 m.	Rock/mineral dominated by alluvium, coastal sedimentary materials (sand-beach sand, pebbles), and mostly alluvial and regosol soils; the soil texture on the top/bottom is slightly smooth/smooth and rough/slightly rough. This land is suitable for planting coconuts, fast growing woody plants, and many others.
Kahayan (KHY)	Coastal plain with sand sediment that forms lowland as the result of estuary processes. The terrain is gentle to rolling with slope less than 2% and relief difference between 2 to 10 m.	Rock/mineral dominated by alluvium; mix of young estuary and marine materials; alluvium of young river and peat; and mostly alluvial, regosol and organosol soils. The soil texture on top/bottom is smooth/smooth, rough/slightly rough and peat. This land is suitable for farming with inundation regulated watering.

Little is known about the dynamic of the mangrove species, *i.e*. population status, life history, and regeneration patterns throughout the world; therefore, it is important to identify the present species composition in the remaining patches of the mangrove ecosystem, especially considering that 16% of all known mangrove species are under the high threat of extinction (Polidoro *et al*., 2010). The mangrove ecosystems in Indonesia also contain an average of 1083 $\pm$ 378 t/ha of carbon (Murdiyarso *et al*., 2015). This preliminary study aims to provide the current state of the mangrove species diversity (SD) of different disturbance regimes in Kayan-Sembakung Delta in North Kalimantan Province of Indonesian Borneo. Although the conversion and recovery of mangrove ecosystem has occurred massively in Kayan-Sembakung Delta, the knowledge about dominant species and other species composition in the remaining mangrove forests will help any further studies and ecosystem restoration efforts targeting this threatened ecosystem.

METHODS

This study started by developing a hypothesis, followed by spatial analysis to identify the natural boundary of the mangrove ecosystem. Field samples were then developed based on the different disturbance regimes of the ecosystem. The field data collection was then performed to identify the floristic composition of the mangrove ecosystem. This study also carefully identifies the land-use history of each sampling location to understand the current regeneration phase of the mangrove ecosystem. Finally, a standard set of vegetation analysis technique was used to understand the floristic composition in this delta.

Hypothesis

The hypothesis to prove is that mature, primary, or completely regrown mangrove forest shall contain a high number of original mangrove species compared to the mangrove forest that recently converted into shrimp ponds or abandoned shrimp ponds that are gradually recovering back to mangrove forest.

To prove this hypothesis, the study distinguished the mangrove ecosystem in Kayan-Sembakung Delta based on its different disturbance regimes and then combines geospatial and field-collected data to understand the floristic composition of the mangrove ecosystem.

Study Area

This study was performed in a mangrove ecosystem that actively produces export-quality shrimp of Kayan-Sembakung Delta in the North Kalimantan Province of Indonesian Borneo. Kayan-Sembakung Delta is geographically located in the west of the Sulawesi Sea; south of Sabah, Malaysia; north of the Berau District in East Kalimantan Province; and east of the Nunukan, Tana Tidung, and Bulungan Districts of the North Kalimantan Province of Indonesia. The study location comprises a large area stretching north-south along the coastline of the North Kalimantan Province, between 117°3′35″ E and 117°55′36″ E and 2°38′22″ N and 4°13′27″ N. The study area and the location of the vegetation sample plots are presented in Figure 1.

Mangrove Ecosystem

Because this study focuses only on the mangrove ecosystem, the ecological boundary of the mangrove ecosystem was preliminarily determined through the landform information from the land-system map produced by the Regional Physical Planning Programme for Transmigration project (RePPProT) in 1987. The landform classification has been determined by RePPProT project by considering the physiographic setup of the area, soil physical characteristics, and general vegetation type (Nurwadjedi, 2000). This study considered the Kajapah (KJP), Putting (PTG), and Kahayan (KHY) land systems comprising the mangrove ecosystems in the Kayan-Sembakung Delta because these three land systems comprise the tidal swamp landform. The geomorphological and lithological characteristics of these land systems are described in Table 1, whereas the indicative boundary of the mangrove ecosystem is shown in Figure 2a.

The mangrove ecosystem in the Kayan-Sembakung Delta comprises a continuous tidal mudflat along the coastline with a total extent of 581,529.14 ha. This boundary includes four inhabited islands of Bunyu, Nunukan, Tarakan, and Sebatik, which also host small patches of mangrove forest along their coastlines; however, these islands also comprise plains, alluvial

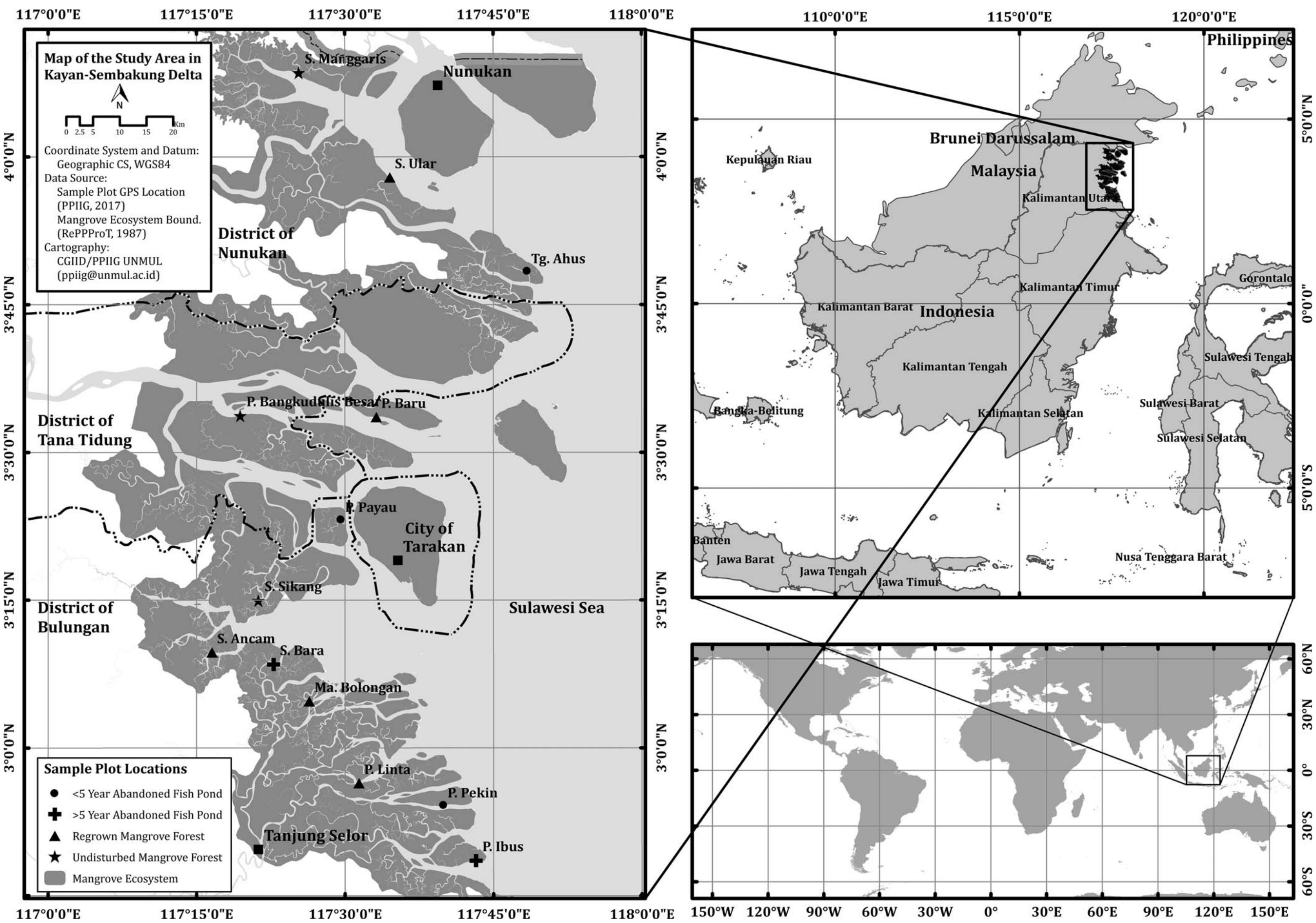

Figure 1. (Left) Study area in Kayan-Sembakung Delta, North Kalimantan, Indonesia, along with the locations of sampling plots in the vegetation transects that are shown with different symbols and abbreviations. P: Island, S: River, Ma: Estuary, Tg: Peninsula. (Top right) Location of the Kayan-Sembakung Delta relative to Borneo Island; (bottom right) location of Borneo Island relative to the world.

plains, valleys, and low-elevation hills. Figure 2b presents the land-cover map that was used to stratify the mangrove ecosystem based on the level of the disturbance prior to plotting the sample locations for vegetation survey.

Sampling

It is well known that most parts of the Kayan-Sembakung Delta have been converted into shrimp ponds. To cover all different structures of the mangrove ecosystem, this study distributed the sampling plots for SD based on the disturbance regimes of the mangrove ecosystem. To achieve this, the land-cover map of the mangrove ecosystem developed by another study was reclassified into four categories, *i.e*. a heavily disturbed mangrove (represented by shrimp ponds abandoned for five years or less), a moderately disturbed mangrove (represented by shrimp ponds abandoned for more than five years), a regrown (secondary) mangrove forest (that may have been logged for wood but did not experience terrain alteration for fishpond development), and relatively undisturbed (primary) mangrove forest. The details for the reclassification scheme are presented in Table 2. Vegetation sample plots were developed for each mangrove forest disturbance regime and distributed purposively, as shown in Figure 2b.

Vegetation Survey

Within each sampling location, transects 125 m long perpendicular to the shoreline contain six subplots (*i.e*. one for the starting point and another five for each 25 m forward) that contain multiple quadrants for different growing phases that were established following the protocol for mangrove ecosystem biophysical assessment developed by the Center for International Forestry Research (Kauffman and Donato, 2012). This approach was chosen to ensure that the SD as well as biophysical characteristics for all growing phases (seedling, sapling, pole, and tree) are well covered.

The schematic of the transect, plot, and subplot is shown in Figure 3, whereas the data collection object, criteria, and procedure for each transect, plot, and subplot to study the vegetation composition and describe general land-cover status are listed in Table 3.

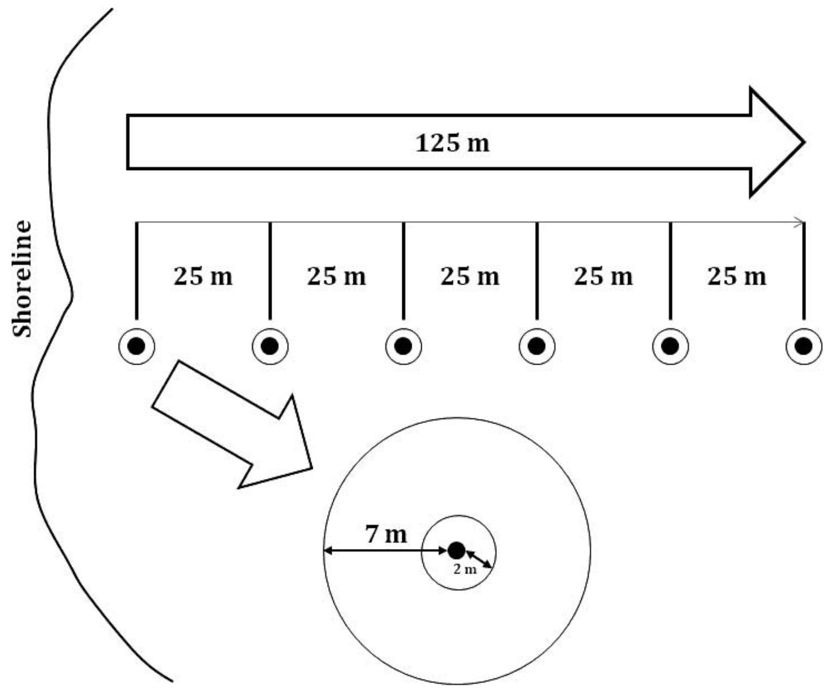

Figure 2. Sketch showing the configuration of the transect relative to the shoreline, subplot intervals (25 m), and different inventory radius for trees and saplings.

Land-Use History

To complete the information, especially that related with the land-use history of each of the sampling locations, brief interviews with the local people were conducted at the sampling locations. The following key questions were asked.

(1) When was the shrimp pond built for the first time?
(2) When was the shrimp pond rebuilt or renovated
(3) Was this shrimp pond abandoned?
(4) What was the reason for abandoning the shrimp pond?

The answers to these questions were used to determine how long ago a sampling location that was once a shrimp pond abandoned in order to indicate the phase of recovery process of the mangrove ecosystem.

Data Analysis

Vegetation data were then analyzed with the standard quantitative plant ecology measures, *i.e*. species important value, richness, diversity, dominance, and evenness indices. Species importance value index (IVI) is determined by calculating the species density (D), relative density (RD), frequency (F), dominance, and relative dominance (RDm) according to the following equations (Odum and Barrett, 2005).

For trees:

$$IVI = RDs + RF + RDm \quad (1)$$

Table 2. *Reclassification of land-cover class into mangrove ecosystem disturbance regimes.*

Class Code	Land Cover Class Classification	Mangrove Ecosystem Disturbance Regime	Justification (Land-Use History)
1	Shrimp ponds, abandoned shrimp ponds	Heavily disturbed mangrove forest	• The mangrove was converted into shrimp ponds less than five years ago • No recovery process
2	Shrub, swampy shrub, bush, swampy bush	Moderately disturbed mangrove forest	• The mangrove was converted into shrimp ponds more than five years ago • Recovery process recently started
3	Secondary mangrove forest, secondary swamp forest	Regrown (secondary) mangrove forest	• The mangrove is gradually recovering into forest
4	Primary mangrove forest, primary swamp forest	Relatively undisturbed mangrove/swamp forest	• No conversion or wood harvesting occurred • The mangrove has been successfully recovered

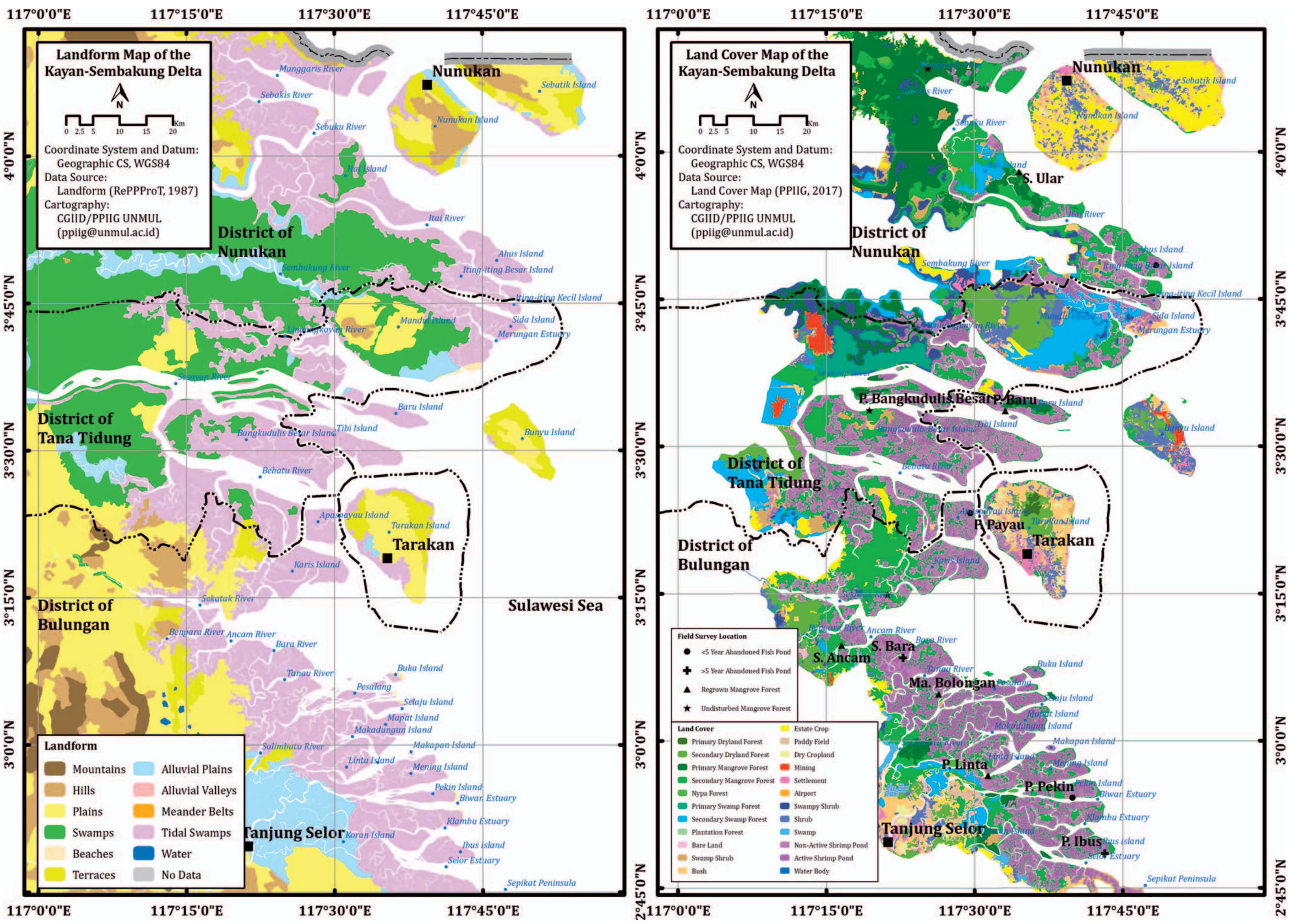

Figure 3. (Left) Indicative boundary of the Kayan-Sembakung Delta based on the geomorphological and lithological (landform) characteristics derived from the RePPProT. The tidal swamps comprise the mangrove ecosystem. (Right) Land-cover map of 2017 of the Kayan-Sembakung Delta. The sampling plots were distributed in different disturbance regimes of the remaining mangrove ecosystem.

For seedlings:

$$IVI = RDs + RF \tag{2}$$

where, D, $D = \frac{\sum Species\ count}{Plot\ Extent}$; RD, $RDs = \frac{D\ Species\ i}{D\ All\ Species} x100\%$; relative frequency (RF), $RF = \frac{F\ Species\ i}{F\ All\ Species}\ x\ 100\%$; frequency ($F$), $F = \frac{\sum Subplot\ of\ species\ encountered}{\sum All\ Subplots}$; species dominance (SDm) (for trees only), $Dm = \frac{Basal\ Area\ of\ Species\ i}{Plot\ Extent}$; and RDm, $RDm = \frac{D\ Species\ i}{D\ All\ Species} x100\%$.

The SD is measured through the distribution pattern of different species, using the equation as follows:

$$H' = -\sum_{i=1}^{S} (Pi \times ln(Pi)) \tag{3}$$

Table 3. *Data collection object, criteria, and procedure for each transect and subplot.*

No	Object	Criteria	Data Collection Procedure
1	Seedling	Any plants under 1-m tall	Individual count, species identification, and description within the small subplot (2-m radius)
2	Pole and tree	Any plants with diameter >5 cm	Individual count, diameter at breast height (dbh) and tree height measurement, species identification and description within the large subplot (7-m radius)
3	Canopy cover	Percentage of tree canopy covering the plot	Measure the tree canopy cover using Canopy Cover application in android smartphones for each subplot, then average the six results
4	General condition	Land-use history of the area	Short interview with local people to gather more information about the land-use history

Table 4. *Result of quantitative analysis of tree in Kayan-Sembakung Delta.*

No	Sample Location	Local Coordinates (UTM 50N WGS84) Latitude	Longitude	Class Code	Basal Area (m^2/ha)	Density (n/ha)	Canopy Cover (%)	Dominant Species Species Name	IVI (%)
District of Nunukan									
1	S. Simanggaris	457788	546860	4	44.50	1635	82.43	*Rhizophora apiculata*	184.67
2	S. Ular	438376	563897	3	26.18	574	67.39	*Rhizophora apiculata*	108.70
3	Tg. Ahus	420889	589604	1	4.50	217	44.00	*Osbornia octodonta*	111.01
District of Tana Tidung									
4	P. Bangkudulis Besar	393660	535921	4	15.36	1445	82.87	*Lumnitzera littorea*	100.76
5	P. Baru	393552	561374	3	16.13	1245	82.25	*Rhizophora apiculata*	109.58
6	P. Paspayau	374375	554791	1	0.16	22	9.97	*Avicennia sp.*	No Data
District of Bulungan									
7	Ma. Ancam	349537	530663	3	13.42	754	77.53	*Rhizophora apiculata*	121.47
8	Ma. Bolongan	340397	548855	2	4.29	97	71.08	*Sonneratia sp.*	192.07
9	S. Bara	347184	542190	1	4.31	336	72.08	*Rhizophora apiculata*	200.97
10	P. Linta	325065	558166	3	34.85	487	75.50	*Sonneratia sp.*	No Data
11	P. Pekin	320982	573982	1	16.43	769	67.50	*Sonneratia sp.*	249.83
12	P. Ibus	310502	580051	2	2.66	162	72.32	*Sonneratia sp.*	278.89
13	S. Sikang	359080	539314	4	15.05	801	85.75	*Rhizophora sp.*	199.37

Note: Class Code1: Recently (<5 years) abandoned fishpond; 2: long (>5 years) abandoned fishpond; 3: regrown mangrove forest; 4: undisturbed mangrove forest; IVI: importance value index (quantitative ecology term).
Note: Indonesian topographic terms: S.: Sungai*, river; Tg.:* Tanjun*, peninsula; P.:* Pulau*, island; Ma.:* Muara*, estuary*.

where, H' is the SD index, S is the number of species in the population, and P_i is the ratio between the number of species i (n_i) compared with the number of individual species count. High SD is >3, medium is 2–3, and low is 0–2.

Species richness (SR) depends on species count and natural logarithm of sample plot extent, thus calculated as follows:

$$R1 = \frac{S-1}{ln(N)} \tag{4}$$

where, $R1$ is the SR index, S is the species count, and N is the species individual count. Good SR is >4.0, medium is 2.5–4.0, and poor is <2.5.

The SDm shows how a species is dominating the population in each growing phase, defined as follows:

$$C = \sum_{i=1}^{S} Pi^2 \tag{5}$$

where, C is SR, S is species count, n_i is species i individual count, N is total individuals in total n, and P_i is n_i/N (the proportion of species i). Values toward 0 are dominated by one species, whereas values toward 1 are dominated by two or more species.

Species distribution (SDt) defines whether individual trees are distributed evenly into species on site, defined as follows:

$$e = \frac{H'}{ln(S)} \tag{6}$$

where, e is the SDt index, S is the species count, and H' is the SD index. Values from 0.00–0.25 are not evenly distributed, from 0.26–0.50 are less evenly distributed, from 0.51–0.75 are medium, from 0.76–0.95 are almost even, and from 0.96–1.00 are evenly distributed.

RESULTS

Field data collection and analysis reveal that the mangrove SD in Kayan-Sembakung Delta is relatively low (Table 4). Quantitative analysis of trees in all sampling locations shows that the number of species encountered in most sampling locations ranges only from 2–5 species except in a few locations such as Simanggaris River in the Nunukan District and Sikang River near the Liago Village in the Bulungan District. Out of 13 sampling locations, only three locations were considered as undisturbed mangrove forest stands (Figure 1). The other sampling locations comprise slightly disturbed mangrove and regrown mangrove forest on abandoned fishponds. In terms of basal area, the sampling location in Linta Island has the highest basal area of 3.22 m^2/ha, whereas the Ibus Island has the lowest basal area of 0.16 m^2/ha. The Simanggaris River has the highest vegetation density of 1635 individual/ha, whereas Paspayau Island has the lowest vegetation density with only 22 individual/ha. The Sikang River has the highest canopy cover of 85.75, whereas the Tanjung Ahus has the lowest canopy cover of 9.97%. *Rhizophora sp*. and *R. apiculata* dominates the sampling locations with high canopy cover and relatively undisturbed mangrove ecosystem (*i.e*. Simanggaris RiverRiver, Bangkudulis Besar Island, and Sungai Sikang). The regrown mangrove forest and long abandoned fishponds are dominated by *Sonneratia sp*., whereas the recently abandoned fishponds were dominated by *Osbornia octodonta*, *Lumnitzera littorea*, and *Avicennia sp*. Table 2 lists basic parameters from the quantitative analysis of vegetation in Kayan-Sembakung Delta in tree-growing phase.

The quantitative tree species analysis coincidently describes the general characteristics of every level of mangrove ecosystem recovery with some exceptions in a few sample locations. In general, the abandoned fishponds (class codes 1 and 2) have low basal area density and canopy cover (0.16 to 16.43 m^2/ha, 22 to 769 individual trees/ha, respectively), whereas the regrown and undisturbed mangrove forests (class codes 3 and 4) have higher basal area and density (13.42 to 44.50 m^2/ha and 487 to 1635 individual trees/ha, respectively). In line with this finding, the recently abandoned fishponds show very low basal area and vegetation density because of the clear cut of the mangrove forest.

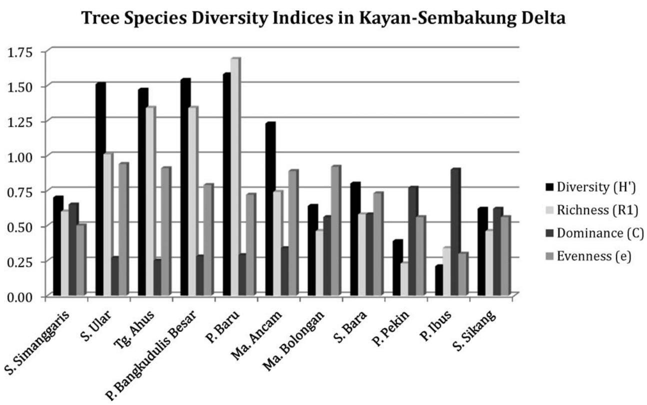

Figure 4. Tree species diversity indices of the Kayan-Sembakung Delta. The highest diversity and richness indices occurred in various disturbance regimes, *e.g.,* highly disturbed (Tg. Ahus), regrown mangrove forest (Ma. Ancam, P. Baru, and S. Ular), and the undisturbed mangrove forest (P. Bangkudulis Besar). The existence of the pioneer tree species in the heavily disturbed mangrove forest might explains the high indices.

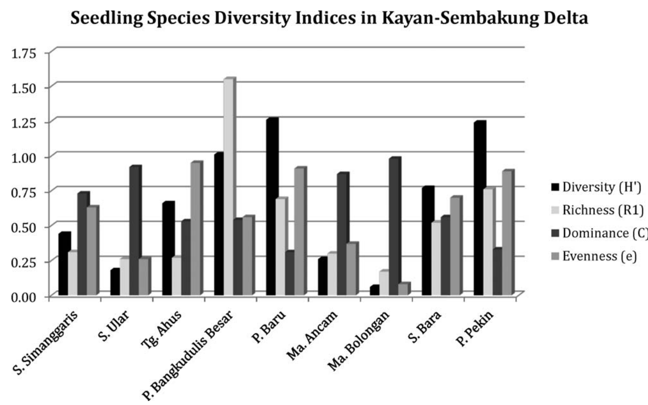

Figure 6. Seedling species diversity indices of the Kayan-Sembakung Delta. The highest diversity and richness indices occurred in various disturbance regimes, *e.g.,* highly disturbed (P. Pekin), regrown mangrove forest (P. Baru), and the undisturbed mangrove forest (P. Bangkudulis Besar). The existence of seedlings of the pioneer species in the heavily disturbed mangrove forest might explains the high indices.

Quantitative analysis on the tree SD shows that the tree species in Kayan-Sembakung Delta is low in diversity ($H' < 2$), poor in SR ($R1 < 2.5$), variable in SDm (C ranges from 0.25 to 0.90), and highly variable in species evenness (e ranges from 0.30 to 0.94), as shown in Figure 4.

Along with the tree SD indices previously presented, Table 1 describes the IVI for each dominant tree species in each sample locations.

Quantitative analysis on the sapling SD shows that the sapling species in Kayan-Sembakung Delta is low in diversity ($H' < 2$) except for the one in Ular River, which is poor in SR ($R1 < 2.5$), variable in SDm (C ranges from 0.23 to 0.80), and highly variable in species evenness (e ranges from 0.37 to 1.00), as shown in Figure 5.

Quantitative analysis on the seedling SD shows that the seedling species in Kayan-Sembakung Delta is low in diversity ($H' < 2$), poor in SR ($R1 < 2.5$), variable in SDm (C ranges from 0.08 to 0.95), and highly variable in species evenness (e ranges from 0.37 to 1.00), as shown in Figure 6.

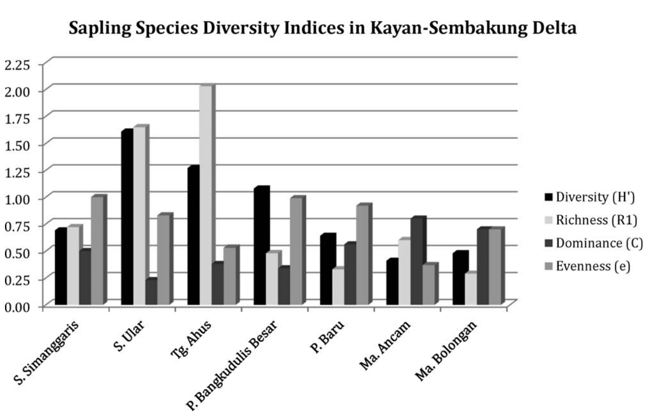

Figure 5. Sapling species diversity indices of the Kayan-Sembakung Delta. Similar to the tree species diversity, the highest indices of diversity and richness also occurred in the regrown mangrove forest and the heavily disturbed mangrove forest.

In general, vegetation quantitative analysis confirms that Kayan-Sembakung Delta is relatively poor in floral SD, even in the sampling locations that are heavily vegetated and relatively undisturbed, such as the Simanggaris River, the Bangkudulis Besar Island, and the Sikang River. This applies for all sampling locations and growing phases, *i.e.* tree, sapling, and seedling.

DISCUSSION

The results of this research confirm general concern on the degradation of the mangrove ecosystem (Polidoro *et al*., 2010) because originally the mangrove forest in the Indo-Malesia region in which this study area is located hosts the highest SD represented by more than 49 taxa, as compared to any other biogeography regions in the world (Duke, 1992). Table 5 presents a nonexhaustive list of previous research on mangrove SD in Indonesia.

From the previous list, it is clear that the genus of *Rhizophora* is currently dominating major mangrove species in different locations in Indonesia, followed by *Sonneratia*, *Avicennia*, and *Bruguiera*. The number of major mangrove species found in each location also varies greatly, and this most probably occurred because of the intensity of the mangrove utilization, succession phase, and the SD replanted for the purpose of mangrove forest rehabilitation efforts. Specific to this research, this work intentionally excluded the part of the mangrove ecosystem in the upstream part of the Kayan-Sembakung Delta that is mostly influenced by freshwater and dominated by *Nypa fruticans*. This mangrove zone hosts more variable species because of mixing with freshwater swamp forest species than those of intertidal zones that are influenced more by saltwater.

Table 5. *Summary of previous research on mangrove species diversity in various locations in Indonesia.*

No	Author (Year)	Location	Methods	Results
1	Puasa, Wantasen, and Mandagi (2018)	Tongkaina, Manado, North Sulawesi	100-m transects and subplots with different size for each growing phase	Dominant and high-frequency species: *Sonneratia alba* and *Rhizophora apiculata*
2	Afriyani (2018)	Pulau Sungsang Banyuasin, South Sumatera	Quadrant transects with different size for each growing phase	Four mangrove species dominated by *Bruguiera gymnorhiza*
3	Hidayat (2018)	Gampong Pande, Kutaraja, Nanggroe Aceh Darussalam	Five separated plots with quadrant subplots	15 mangrove species dominated by *Rhizhopora apiculata* and *R. stylosa*
4	Setiawan and Mursidin (2018)	Pulau Tanakeke, South Sulawesi	Quadrant plots with different size for each growing phase that distributed randomly	Seven mangrove species dominated by *Rhizhopora stylosa*
5	Rahayu, Syuhriatin, and Wiryanto (2018)	Gendangan, Purwodadi, Purworejo, Central Java	Quadrant transects with different size for each growing phase	Seven mangrove species dominated by *Rhizhopora mucronata*
6	Idris, Markum, and Sofian (2018)	Eyat Mayang, Lembar, W. Lombok, West Nusa Tenggara	Unknown	10 mangrove species
7	Kirauhe, Siahaan, and Pelealu (2017)	Kapeta and Tanaki, Siau Barat Selatan, South Sulawesi	Six transects separated by 300-m distance with quadrant subplots	Five mangrove species dominated by *Bruguiera gymnorrhiza*
8	Mernisa and Oktamarsetyani (2017)	Sebong Lagoi, Bintan, Bangka Belitung	Unknown	Dominant species: *Xylocarpus granatum, Avicennia alba* and *Rhizophora mucronata*
9	Hutasoit, Melki, and Sarno (2017)	Sembilang National Park, Banyuasin, South Sumatera	Quadrant transects with different size for each growing phase	12 mangrove species dominated by *Rhizophora apiculata*
10	Winata *et al*. (2017)	Pulau Rimau Protection Forest	Quadrant transects with different size for each growing phase	15 mangrove species dominated by *Nypa fruticans* and *Sonneratia caseolaris*
11	Parmadi, Dewiyanti, and Karina (2016)	Kuala Idi, Aceh Timur, Nanggroe Aceh Darussalam	Quadrant transects with different size for each growing phase	Six mangrove species dominated by *Rhizhopora apiculata* and *R. mucronata*
12	Juwita, Soewardi, and Yonvitner (2015)	Simpang Pesak, Belitung Timur, Bangka Belitung	Quadrant transects with different size for each growing phase	Five mangrove species dominated by *Rhizophora apiculata*
13	Fahmi (2015)	Sungai Tallo, Makassar, South Sulawesi	Quadrant transects with different size for each growing phase	Five mangrove species, *i.e. Rhizophora apiculata*, *R. mucronata*, *Sonneratia caseolaris*, and *Avicennia marina*
14	Ghufrona, Kusmana, and Rusdiana (2015)	Pulau Sebuku, South Kalimantan	Quadrant transects with different size for each growing phase	10 mangrove species dominated by *Rhizhopora mucronata*
15	Suwardi (2014)	Pulau Panikiang, Barru, South Sulawesi	Quadrant transects with different size for each growing phase	17 mangrove species dominated by *Rhizhopora stylosa*, *R. apiculata, Bruguiera gymnorrhiza*, and *Sonneratia alba*
16	Suhardjono (2014)	Yenanas, Pulau Batanta, Raja Ampat, West Papua	Quadrant transects with different size for each growing phase	10 mangrove species dominated by *Rhizophora apiculata* and *Bruguiera gymnorrhiza*
17	Nurrahman, Djunaedi, and Rostika (2012)	Sungai Raya, Bengkayang, West Kalimantan	Quadrant transects with different size for each growing phase	Eight mangrove species dominated by *Avicennia marina* and *A. alba*
18	Arinasa (2012)	West Bali National Park, Bali	Purposive transect	28 mangrove species dominated by *Avicennia marina* and *Lumnitzera racemosa*
19	Darmadi, Lewaru, and Khan (2012)	Muara Harmin, Cantigi, Indramayu, West Java	Stratified sampling based on mangrove zone	Five mangrove species dominated by *Rhizophora apiculata*
20	Matan, Marsono, and Ritohardoyo (2016)	Andai, Manokwari, West Papua	Quadrant plots with different size for each growing phase	20 mangrove species dominated by *Rhizhopora apiculata*
21	Indriani, Marisa, and Zaaria (2009)	Pulau Rimau Protection Forest	Quadrant transects with different size for each growing phase	Two mangrove species dominated by *Rhizophora apiculata* and *Nypa fruticans*
22	Ningsih (2008)	Deli Serdang, North Sumatera	Quadrant plots with different size for each growing phase	Eight mangrove species dominated by *Avicennia marina*
23	Romadhon (2008)	Pabiyan, Kepulauan Kangean, East Java	Unknown	Two mangrove species, *i.e. Rhizhopora apiculata* and *Avicennia alba*
24	Suhardjono and Rugayah (2007)	Pulau Sepanjang, East Java	Quadrant plots with different size for each growing phase	32 mangrove species dominated by *Rhizophora apiculata*
25	Yani (2006)	Cikiperan, Cilacap, Central Java	Quadrant plots with different size for each growing phase	32 mangrove species dominated by *Rhizophora mucronata*
26	Setyawan *et al*. (2005)	Coast of Central Java	Belt transect method crossing the mangrove zone	Eight mangrove species dominated by *Rhizophora spp*., *Avicennia spp*, and *Sonneratia spp*.
27	Sudarmadji (2004)	Baluran National Park, East Java	Quadrant plots with different size for each growing phase	Nine mangrove species of Rhizhoporaceae family
28	This research	Kayan-Sembakung Delta, North Kalimantan	Quadrant transects with different size for each growing phase	Nine mangrove species dominated by *Rhizophora apiculata* and *Sonneratia sp*.

Figure 7. (A) Typical dryland tree species of *Dillenia suffruticosa* and (B) the tall freshwater palm of *Oncosperma tigillarium* found in P. Baru (Baru Island) showing the existence of the freshwater swamp ecosystem at the transition zone with the mangrove ecosystem.

Variable mangrove forest floristic composition in Kayan-Sembakung Delta is highly influenced by the aquaculture phases and utilization intensity. As inferred from facts gathered in the field work, as soon as the fishponds abandoned, the dry part of the ponds (*e.g.,* fishpond dikes) would be invaded by fast growing shrub species while the inundated part of the pond gradually regenerates and grows back into mangrove forest in less than five years. The authors found that sample locations that have been recovered from fishponds for less than five years (*i.e*. Ahus Peninsula, Paspayau Island, Bara River, and Pekin Island) and those that have been recovered from fishponds for more than five years (*i.e*. Bolongan Estuary and Ibus Island) shared a relatively high basal area and dominance of major mangrove species in opposite of the combination of mangrove major and minor species, as well as shrub species.

In view of geomorphological process, a delta is a relatively flat area at the mouth of a river or a river system in which sediment load is deposited and distributed (Kolb, 1984). However, several pieces of evidence confirmed that not all of the islands within the ecological boundary of the Kayan-Sembakung Delta formed by sedimentation process. A number of islands such as Tarakan, Bunyu, Nunukan, and Baru Islands (one of the sample plot locations) seem to be separated with the Borneo Mainland since the Miocene era, thus they do not represent islands that formed through sedimentation process. An evaluation of the digital elevation model shows that not all of the islands experience sedimentation at their interface to the sea. Especially for Baru Island, the elevation was relatively higher than other islands that were formed by sedimentation process. Field observation of the terrain also showed that even the forest floor was wet, but regular tidal influence was not observed during the day. To confirm this field observation, the vegetation analysis shows that Baru Island is dominated by *R. apiculata*; however, the island hosts many different freshwater tree species such as the tall freshwater palm of *Oncosperma tigillarium* (Figure 7b), spiky liana such as *Calamus sp.*, and trees such as *Dillenia suffruticosa* (Figure 7a). The low intensity of tides causes less mud substrate forming the forest floor than assumed to significantly reduce the domination of the major mangrove species in this area.

CONCLUSIONS

The Kayan-Sembakung Delta hosts at least six dominant mangrove original species, *i.e. R. apiculata*, *O. octodonta*, *L. littorea*, *Avicennia sp.*, *Rhizophora sp.*, and *Sonneratia sp*. The Simanggaris River has the highest total basal area (including tree and sapling) of 44.50 m^2/ha as well as the highest tree density of 1635 individual/ha, which indicates that this area has the greatest mangrove ecosystem with the most dense and mature mangrove forest cover, followed by Sikang River near Liago Village with 85.75% of canopy cover. In contrast, the heavily degraded mangrove ecosystem in Ibus Island has the highest IVI of 278.89%, with *Sonneratia sp*. as the most dominant species. As a reflection of this research, a wider vegetation analysis should be completed to cover areas that have not been studied in this research. The most important mangrove ecosystem complex to study further includes the Kayan River tributaries that host *Nypa fruticans* mixed with other low-salinity adaptable mangrove species, Mandul Island, the Sembakung Estuary, and the northern part of Sesayap River that combines the mangrove and freshwater swamp ecosystems.

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