Report on Monitoring of Forest Changes in Pin Supu Sustainable Forest Management Project Area

by

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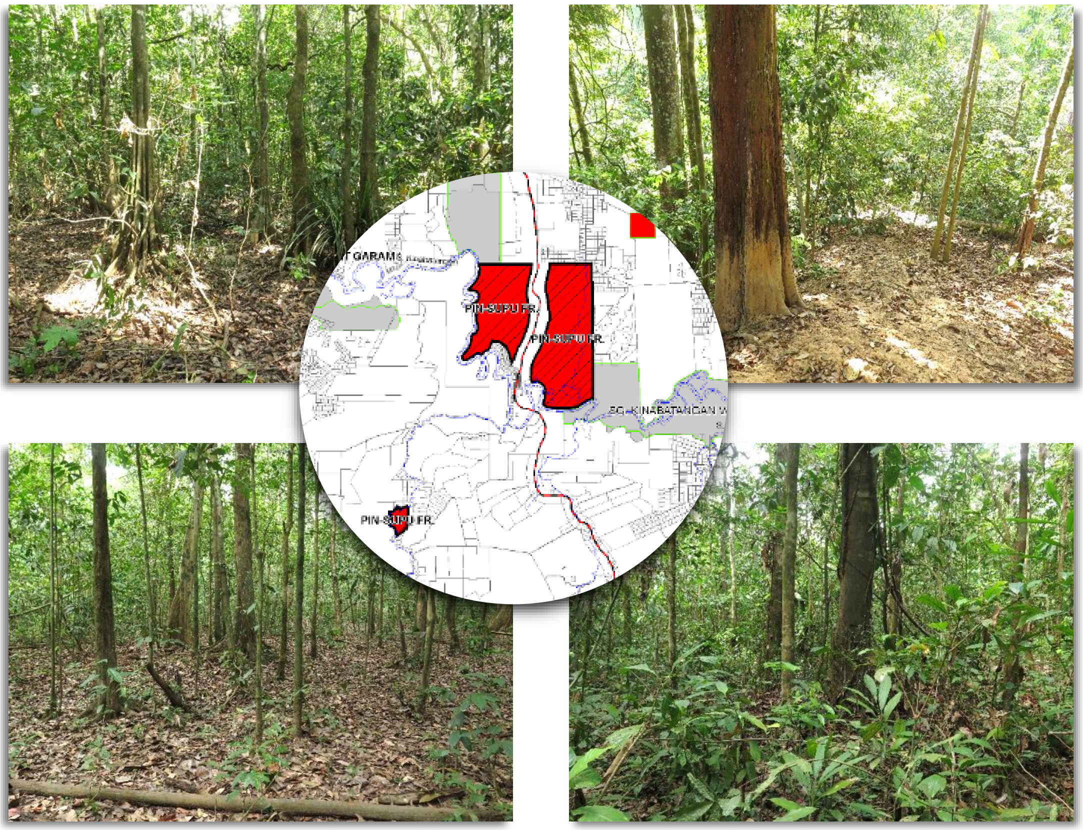

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SABAH FORESTRY DEPARTMENT

1. INTRODUCTION

Pin Supu Forest Reserve (PSFR) is a Class VI Protection Forest with a total area of 4,696 ha. The Kinabatangan District Forestry Office administers the reserve. PSFR consists of three units of land separated by highways and rivers at considerable distances. In the mosaic landscape of the Kinabatangan, Blocks A and B border onto other protected areas, such as Lot 8 in the west and Lot 7 of the Wildlife Sanctuary. However, Block C is entirely isolated and surrounded by oil palm estates (Figure 1).

On a landscape level, the PSFR is part of the Kinabatangan floodplain ecosystems (Nilus *et al.*, 2015). The entire area is below 200 m in elevation and consists of secondary- and advanced-growth of mixed dipterocarp, seasonal freshwater and freshwater swamp forests. Fauna assessment has shown that diverse fauna can be found within the area. The area provides habitats for the fauna and acts as a transient wildlife migratory path between the different forest reserves it borders. On the cultural aspect, the community cooperative initiative (KOPEL) was given the right to harvest bird nests at Supu Caves. Hence, the continuous food source for swiftlet (insects) and the presence of forest surrounding the limestone caves is significant.

Through the Forest Research Centre, the Forestry Department has established 10 (0.13 ha) permanent sample plots and conducted three censuses: September 2014, November 2017 and August 2023 (Figure 2; Table 1). This report evaluates forest change after nine years of monitoring period by the department, and the information will provide forest ecosystem background in the various forest types found in PSFR.

2. OBJECTIVES

The objectives of the monitoring activities are to investigate changes in trees ≥ 10 cm DBH in the following details:

i. Forest cover changes between 2008, 2017 and 2023
ii. Plot similarities in species composition
iii. Mortality and recruitment rates
iv. Growth
v. Above-ground biomass

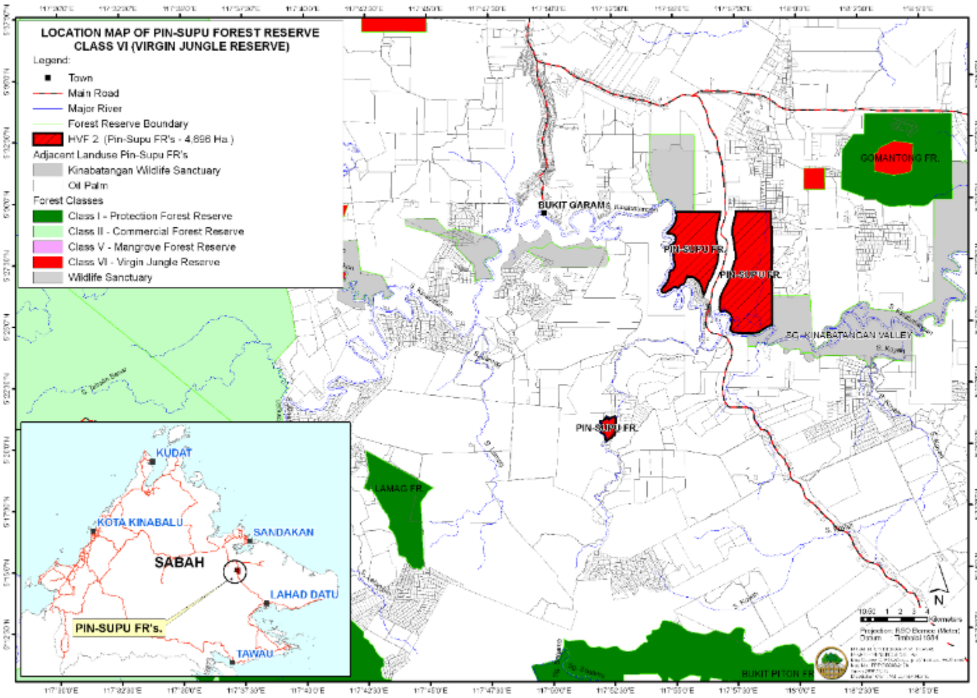

Figure 1. The location map of the Pin-Supu Forest Reserve in Sabah, Malaysia.

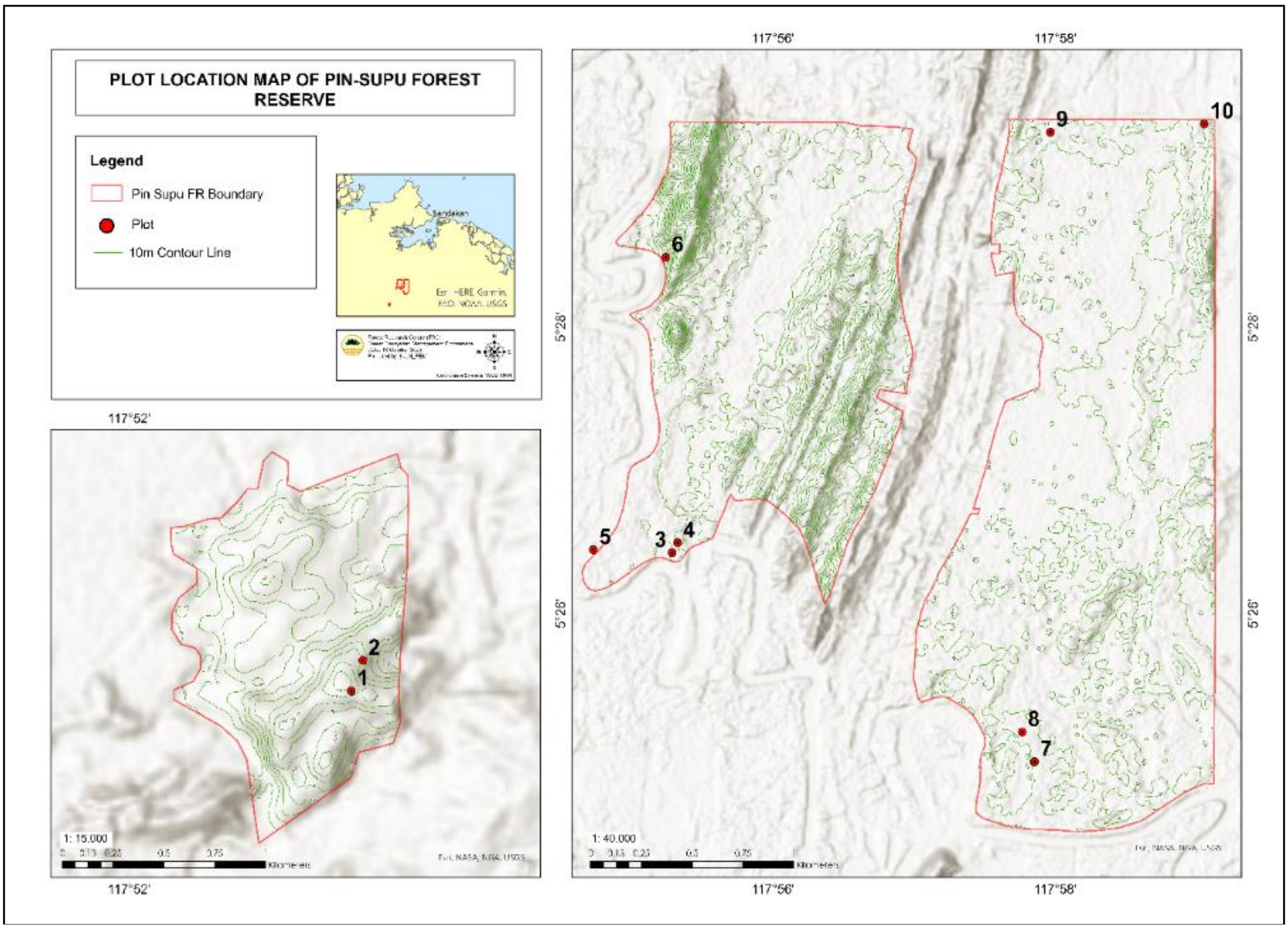

Figure 2. The location of the ten permanent sample plots in Pin-Supu Forest Reserve, Sabah, Malaysia.

Table 1. The location map of the Pin-Supu Forest Reserve in Sabah, Malaysia.

Block	Plot	Radius (m)	Latitude (WGS 84)	Longitude (WGS 84)	Altitude (m)	Forest Ecosystem	1st Census	2nd Census	3rd Census
C	PSP 1	20	05 20 32.0	117 52 35.6	112	Advance-growth of mixed dipterocarp forest	7-Apr-15	6-Apr-18	10-Aug-23
C	PSP 2	20	05 20 36.7	117 52 37.6	89	Advance-growth of mixed dipterocarp forest	7-Apr-15	6-Apr-18	10-Aug-23
B	PSP 3	20	05 26 25.6	117 55 17.5	23	Secondary-growth of Seasonal Freshwater Swamp Forest	8-Apr-15	6-Apr-18	8-Aug-23
B	PSP 4	20	05 26 29.7	117 55 19.5	7	Secondary-growth of Freshwater Swamp Forest	8-Apr-15	6-Apr-18	9-Aug-23
B	PSP 5	20	05 26 26.7	117 54 43.6	15	Riparian Forest--Secondary-growth of previously mixed dipterocarp forest	8-Apr-15	6-Apr-18	8-Aug-23
B	PSP 6	20	05 28 29.7	117 55 14.3	54	Advance-growth of mixed dipterocarp forest & limestone vegetation	9-Apr-15	6-Apr-18	8-Aug-23
A	PSP 7	20	05 24 58.0	117 57 51.2	25	Secondary-growth of Seasonal Freshwater Swamp Forest	9-Apr-15	6-Apr-18	9-Aug-23
A	PSP 8	20	05 25 10.2	117 57 45.9	20	Secondary-growth of Seasonal Freshwater Swamp Forest	9-Apr-15	6-Apr-18	9-Aug-23
A	PSP 9	20	05 29 21.7	117 57 58.1	31	Advance-growth of mixed dipterocarp forest	10-Apr-15	6-Apr-18	11-Aug-23
A	PSP 10	20	05 29 24.9	117 59 03.5	19	Talisai Paya swamp Forest (previously Seasonal Freshwater Swamp Forest)	10-Apr-15	6-Apr-18	11-Aug-23

3. METHODOLOGY

3.1 Forest Cover Changes Pin-Supu Forest Reserve

The assessment of forest cover dynamics within the Pin-Supu Forest Reserve was quantified using remote sensing. Six satellite image scenes were selected based on acquisition years, mainly 2008, 2016, 2020 and 2023 (Table 2).

Table 2. Satellite image acquired for the forest cover change detection.

Satellite	Year	Path/Row	Acquisition Date	Cloud coverage (5%)
Landsat 5 TM	2008	117/56	20 May 2008	Less than 30%
Landsat 8 OLI	2015	117/56	12 August 2015	Less than 30%
	2016	117/56	13 July 2016	Less than 30%
	2020	117/56	26 September 2020	Less than 30%
	2023	117/56	17 July 2023	Less than 30%

Data Acquisition and Pre-Processing

All satellite images were acquired and downloaded from the USGS (glovis.usgs.gov). The images were radiometrically pre-processed in QGIS (Quantum GIS) to convert the DN values into reflectance values.

Each scene was further processed in ArcGIS Pro for classification. Six land covers were identified: water bodies, dryland forest, swamp vegetation, shrubland, oil palm and bare land. A composite image comprising band 5, band 4 and band 3 for Landsat 5 was used in the classification. A composite of Band 6, Band 5 and Band 2 was used for Landsat 8 OLI. At least 15 training samples were collected for each land cover. Training sample selection was based on ancillary data such as elevation data, natural vegetation maps, soil maps and observation from high-resolution imagery on Google Earth. The image was classified using pixel-based supervised classification and support vector machine (SVM) as the classifier.

The classification for the forested area was divided into three sub-classes based on the spectral variation of the tree crowns that can be observed, such as light green, medium and dark green-coloured tree crowns. These sub-classes were then merged into one class and classified as dryland forests. Based on the soil map, natural vegetation map and soil wetness index, forested areas located below 30 m (a.s.l) are classified as swamp vegetation. The swamp vegetation was also divided into three sub-classes based on the spectral variation of vegetation: bright, medium and brown. These sub-classes were subsequently merged into a single "swamp vegetation" class to represent a broader characterisation of vegetation in swampy areas. The classified image was then post-processed using a 3 x 3 majority filtering to reduce the 'salt and paper’ effect. Any misclassified pixels of swamps in areas where the elevation is more than 30 m (a.s.l) were reclassified as dryland forests, given the normality of peat swamps to be on flat sites. The classified raster was then converted to vector data. Dryland and swamp vegetation were delineated by identifying wet areas using MNDWI (Modified Normalized Difference Water Index).

3.2 Re-measurement of recorded trees

All previously labelled trees ≥ 10 cm diameter at breast height (DBH) were re-measured, and their species identity was re-confirmed. Newly recruited trees ≥ 10 cm diameter at breast height were labelled, measured and identified to species level.

3.3 Data manipulation and analysis

The data set within each sample plot was checked for anomalies such as abrupt changes in an individual’s size or irreconcilable changes in species identities (different families or genera). All anomalies were rectified to avoid excluding data from the sample.

All tree data were subject to Bray-Curtis Ordination using the R statistical package to investigate plot differences based on dissimilarity in species composition and their abundance.

Mean annual mortality rates (m) were estimated using the equation provided by Sheil *et al*. (1995):

$$m = 1 - (N_1 / N_0)^{1/t}$$

N_0 is the number of trees at the beginning of a census interval, and N_1 is the number of trees surviving at the end of the census interval t (years).

Mean annual recruitment rates (r) were calculated using the equation provided in Sheil (1996):

$r = 1 - (1 - n_r / N_t)^{1/t}$

n_r is the number of recruits, and N_t is the number of trees at the end of the census interval t (years).

Turnover rates were estimated as the mean of mortality and recruitment rates.

Annual diameter increment (AGR) and relative growth rate of diameter (RGR) were calculated using the following equations:

$AGR = (x_t - x_0) / t$

$RGR = (x_t - x_0 / x_0) / t \times 100\ \%$

x_0 and x_t are DBH at the beginning and end of census interval t (years).

Potentially erroneous tree growth data were identified using the criteria adopted by Condit *et al.* (1993b). Trees that shrank by more than 5% of their initial diameter per year or exceeded a mean annual diameter increment of 75 mm per year were discarded from the analysis. These minimum and maximum thresholds for growth rates have successfully avoided growth anomalies and provided estimates close to the median of each group of growth data in other studies (Condit *et al*. 1993a). Fortunately, no trees were omitted from the growth analysis.

The aboveground carbon estimation of individual trees can be estimated from the measured diameter using the aboveground biomass allometric regression equation by Chave *et. al* (2014) that is suited and widely used by the Sabah Forestry Department:

$AGB= [\exp(-1.803 - 0.976E + 0.976 \ln(\rho) + 2.673 \ln(DBH_i) - 0.0299 [\ln(DBH_i)]^2]$

E= climate variable (http://chave.upstlse.fr/pantropicalallometry.htm)

The individual tree biomass value that derives from the equation will be summed to produce the biomass of the sample plot, which is then multiplied by a standard value of carbon concentration to produce an estimate of carbon stock. An assumption value of 47% of the dry biomass is carbon.

AGB Carbon = 0.47 x AGB (kg/ha)

4. RESULTS

4.1 Forest Cover Changes

The dynamic changes in forest cover within the Pin-Supu Forest Reserve were evaluated through image processes of six satellite image scenes, specifically in 2008, 2016, 2020, and 2023. The area for each land cover was calculated and depicted in Table 3. However, cloud cover was inevitable in the 2008 satellite image. Appendix I details the land cover distribution for four observed years (Figures 3–6). Over the past 15 years, forest expansion has shown an apparent upward trend in dryland (30 ha) and swampland (267 ha), as listed in Table 3. Correspondingly, there is a notable decline in the extent of marshland and shrub cover within dry areas. Water bodies exhibit an upward trend in land cover, while bare land is on a decreasing trajectory. However, the oil palm cover displays irregularities.

Table 3. The area and percentage (in parentheses) of vegetation and other land cover of Pin Supu Forest Reserve in 2008, 2016, 2020 and 2023.

Vegetation Cover		2008 Area (ha)		2016 Area (ha)		2020 Area (ha)		2023 Area (ha)	
Dry Land	Forest	2,510.3	(53.7)	2,525.9	(54.1)	2,488.6	(53.3)	2,540.1	(54.4)
	Shrubland	95.0	(2.0)	85.5	(1.8)	104.7	(2.2)	65.4	(1.4)
Swamp Vegetation	Swamp Forest	686.9	(14.7)	769.8	(16.5)	648.0	(13.9)	953.8	(20.4)
	Marsh	1,192.0	(25.5)	1,135.0	(24.3)	1,239.0	(26.5)	969.8	(20.8)
	Shrubland	14.7	(0.3)	52.4	(1.1)	58.7	(1.3)	15.5	(0.3)
Waterbodies		49.2	(1.1)	45.4	(1.0)	64.3	(1.4)	64.6	(1.4)
Bare Land		78.5	(1.7)	26.2	(0.6)	55.1	(1.2)	41.5	(0.9)
Oil Palm		24.1	(0.5)	32.4	(0.7)	14.1	(0.3)	22.1	(0.5)
Cloud Cover		**21.8**	**(0.5)**						
Total (ha)		**4,672.6**							

4.2 Plot similarities in relation to species composition

The dendrogram reveals two distinct groupings based on the water table and soil drainage characteristics of the site, namely, inland and swamp ecosystems (Figure 2; Table 4). In regions with a moderately high-water table, the floristic composition of disturbed lowland seasonal freshwater swamp forests is evident in PSP 3, 7, and 8. In contrast, the highest water table, characteristic of freshwater swamp forests, is represented in PSP 4. PSP 1, 2, 6, and 9 are established in drier sites, featuring various regenerative lowland mixed dipterocarp forests. However, according to the soil association map, PSP 10 is situated in an area marked by a high-water table or formerly a swamp forest, currently dominated by Talisai paya trees.

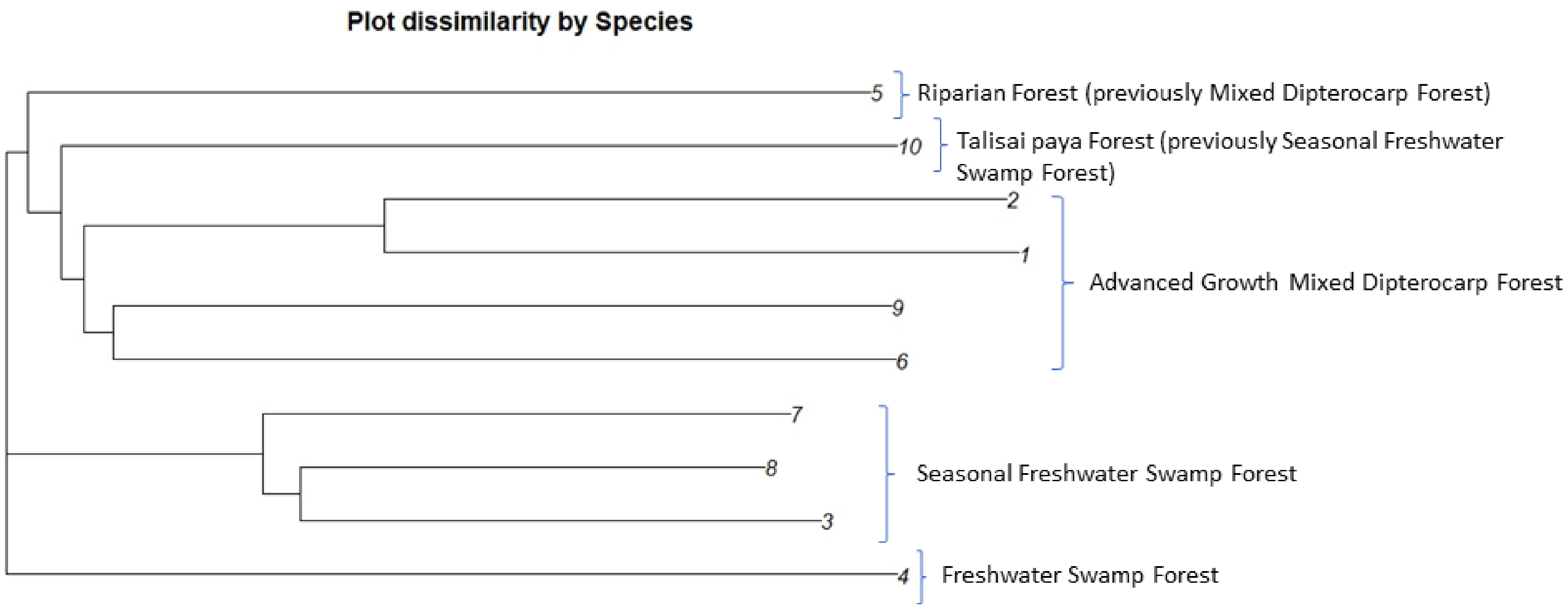

Figure 2 A dendrogram of all 10 permanent sample plots (PSPs) are clustered according to water-table condition in the Pin Supu Sustainable Forest Management project area, Sabah.

Table 4. The dissimilarity index values among 10 plots established in the Pin Supu Sustainable Forest Management project area, Sabah.

	PSP 1	PSP 2	PSP 3	PSP 4	PSP 5	PSP 6	PSP 7	PSP 8	PSP 9	PSP 10
PSP 1	0	0.672	0.968	0.990	0.984	0.940	0.985	0.957	0.917	0.973
PSP 2	0.672	0	0.968	0.981	0.968	0.940	0.955	0.957	0.917	0.973
PSP 3	0.968	0.968	0	0.898	0.897	0.904	0.577	0.527	0.926	0.927
PSP 4	0.990	0.981	0.898	0	0.939	0.961	0.892	0.896	0.963	0.954
PSP 5	0.984	0.968	0.897	0.939	0	0.920	0.870	0.878	0.911	0.912
PSP 6	0.940	0.940	0.904	0.961	0.920	0	0.909	0.857	0.833	0.863
PSP 7	0.985	0.955	0.577	0.892	0.870	0.909	0	0.551	0.887	0.889
PSP 8	0.957	0.957	0.527	0.896	0.878	0.857	0.551	0	0.880	0.868
PSP 9	0.917	0.917	0.926	0.963	0.911	0.833	0.887	0.880	0	0.885
PSP 10	0.973	0.973	0.927	0.954	0.912	0.863	0.889	0.868	0.885	0

4.1 Comparison of population dynamics for trees ≥10 cm DBH among plots

4.1.1 Mortality, recruitment and turnover

A comparative analysis of tree mortality and recruitment across all sample plots spanning the two monitoring periods, 2015–2018 and 2018–2023, in the Pin Supu SFM project area is detailed in Table 5. Throughout the eight-year monitoring period, an average mortality rate of 3% (equivalent to 144 trees) and a recruitment rate of 2% (70 trees) were documented, resulting in twice as many recorded deaths as recruitments. Notably, Plot 4 and Plot 10 exhibited the highest number of tree fatalities, with mortality rates ranging from 2.03% to 7.76% per year and 4.38% to 6.55% per year, respectively.

Table 5. Summary of mortality, recruitment and turnover of trees ≥ 10 cm DBH in all 10 permanent sample plots (PSPs) between 2015–2018 and 2018–2023 in Pin Supu Sustainable Forest Management project area, Sabah, Malaysia.

Plot No	**No of trees 2015**	**No of trees 2018**	**No of trees 2023**	**No of dead trees 2018**	**No of dead trees 2023**	**No of recruits 2018**	**No of recruits 2023**	**2015-2018**			**2018-2023**		
								Mort-ality (% yr^{-1})	**Recruit-ment (% yr^{-1})**	**Turn-over (% yr^{-1})**	**Mort-ality (% yr^{-1})**	**Recruit-ment (% yr^{-1})**	**Turn-over (% yr^{-1})**
1	55	54	55	5	6	5	7	3.13	3.19	3.16	2.18	2.51	2.35
2	53	52	52	3	10	2	10	1.93	1.30	1.61	3.92	3.92	3.92
3	54	54	54		1		1				0.35	0.35	
4	134	127	82	8	45	1		2.03	0.26	1.15	7.86		3.93
5	48	44	43	4	6		5	2.86			2.71	2.29	
6	58	58	57	2	2	2	1	1.16	1.16	1.16	0.65	0.33	0.49
7	56	52	50	3	5		3	1.82			1.87	1.15	
8	61	59	56	3	6	1	3	1.67	0.57	1.12	1.99	1.02	1.51
9	59	56	52	7	9	4	5	4.13	2.44	3.28	3.22	1.87	2.55
10	49	47	50	9	10	7	13	6.55	5.24	5.89	4.38	5.48	4.93
Total/ Average	**627**	**603**	**551**	**44**	**100**	**22**	**48**	**2.8**	**2.0**	**2.5**	**2.9**	**2.1**	**2.8**

4.1.2 Growth

Table 6 illustrates a comparison of tree growth across all sample plots. On average, trees with a diameter at breast height (DBH) ≥ 10 cm in Plot 2, 5, and 10 have consistently shown positive growth, maintaining elevated Average Growth Rates (AGR) and Relative Growth Rates (RGR) in both monitoring periods. In contrast, trees in Plot 7 exhibited the lowest growth.

Table 6 Growth of trees ≥ 10 cm DBH in all 10 permanent sample plots (PSPs) between 2015–2018 and 2018–2023 in Pin Supu Sustainable Forest Management project area, Sabah, Malaysia. (Annual Growth Rate, AGR; Relative Growth Rate, RGR)

Plot No.	Mean of AGR 2015–2018 (cm/yr)	Mean of AGR 2018–2023 (%)	Mean of RGR 2015–2018 (cm/yr)	Mean of RGR 2018–2023 (%)
1	0.08 ± 0.11	0.25 ± 0.05	1.13 ± 0.20	1.25 ± 0.25
2	0.47 ± 0.15	0.37 ± 0.05	1.64 ± 0.30	1.83 ± 0.29
3	0.07 ± 0.06	0.22 ± 0.04	0.69 ± 0.22	1.12 ± 0.17
4	0.19 ± 0.05	0.36 ± 0.05	1.04 ± 0.28	1.38 ± 0.17
5	0.50 ± 0.15	0.47 ± 0.08	2.18 ± 0.52	1.66 ± 0.25
6	0.21 ± 0.05	0.14 ± 0.03	0.97 ± 0.20	0.56 ± 0.12
7	0.02 ± 0.03	0.13 ± 0.03	-0.03 ± 0.18	0.62 ± 0.10
8	0.12 ± 0.03	0.25 ± 0.05	0.73 ± 0.20	1.01 ± 0.17
9	0.33 ± 0.05	0.27 ± 0.05	1.50 ± 0.22	1.12 ± 0.19
10	0.49 ± 0.09	0.51 ± 0.08	2.80 ± 0.42	2.55 ± 0.48
Grand Total	**0.23 ± 0.03**	**0.30 ± 0.02**	**1.20 ± 0.10**	**1.29 ± 0.07**

4.2 Comparison of population dynamics for trees ≥10 cm DBH among forest ecosystems

4.2.1 Mortality, recruitment and turnover

A comparison of tree dynamics in three distinct forest ecosystems between the 2015 – 2018 and 2018 – 2023 periods is presented in Table 7 and 8. The Talisai Paya swamp forest demonstrated the highest turnover rate for both census periods (Table 6). The riparian forest, SFWSF, and FWSF exhibit an increasing trend in turnover rate, while the Talisai Paya swamp shows a decreasing trend throughout the monitoring period. The MDF indicates no changes in turnover rate during the census. The Talisai Paya swamp exhibits the highest mortality rates in the first monitoring period, while FWSF shows the highest mortality rates in the second monitoring period. The Talisai Paya swamp demonstrates the highest recruitment rates in both monitoring periods (Table 7). Throughout the observed ecosystems, approximately 50% and 70% of all tree deaths were represented by the lowest diameter size class (10.0 to 19.9 cm) in the first and second monitoring periods, respectively (Table 8).

Table 7 Summary of mortality, recruitment and turnover of trees ≥ 10 cm DBH observed within mixed dipterocarp forest (MDF), riparian forest, Talisai Paya swamp forest, seasonal freshwater swamp forest (SFWSF) and freshwater swamp forest (FWSF) between 2014–2023 in Pin Supu Sustainable Forest Management project area, Sabah, Malaysia.

Plot No	No of trees 2015	No of trees 2018	No of trees 2023	No of dead trees 2018	No of dead trees 2023	No recr-uits 2018	No of recr-uits 2023	2015-2018			2018-2023		
								Mort-ality (% yr^{-1})	Recruit-ment (% yr^{-1})	Turn-over (% yr^{-1})	Mort-ality (% yr^{-1})	Recruit-ment (% yr^{-1})	Turn-over (% yr^{-1})
MDF	225	220	216	17	27	13	23	2.6	2.0	2.3	2.4	2.1	2.3
Riparian	48	44	43	4	6	0	5	2.9	0.0	1.4	2.7	2.3	2.5
Talisai Paya swamp	49	47	50	9	10	7	13	6.6	5.2	5.9	4.9	5.5	4.9
SFWSF	171	165	160	6	12	1	7	1.2	0.2	0.7	1.4	0.8	1.1
FWSF	134	127	82	8	45	1	0	2.0	0.3	1.2	7.9	0.0	3.9
Grand Total	**627**	**603**	**551**	**44**	**100**	**22**	**48**	**2.4**	**1.2**	**1.8**	**3.3**	**1.7**	**2.5**

Table 8 Tree dead of trees ≥ 10 cm DBH based diameter classes within mixed dipterocarp forest (MDF), riparian forest, Talisai Paya swamp forest, seasonal freshwater swamp forest (SFWSF) and freshwater swamp forest (FWSF) between 2015–2023 in Pin Supu Sustainable Forest Management project area, Sabah, Malaysia.

Year of assessment	Forest	10.0–19.9	20.0–29.9	20.0–39.9	30.0–49.9	40.0–59.9	> 60	Grand Total
2015 – 2018	MDF	8		8		1		17
	Riparian	3				1		4
	Talisai Paya swamp	3	5		1			9
	SFWSF	3	1		2			6
	FWSF	6	2					8
	Grand Total	**23**	**8**	**8**	**3**	**2**		**44**
2018 – 2023	MDF	13		8		3	3	27
	Riparian	3		2		1		6
	Talisai Paya swamp	7	2		1			10
	SFWSF	8	3		1			12
	FWSF	39	6					45
	Grand Total	**70**	**11**	**10**	**2**	**4**	**3**	**100**

4.2.2 Growth

A comparison of tree growth on three distinct forest ecosystems in two monitoring periods is presented in Table 9. The Talisai Paya swamp and riparian forests demonstrated high annual growth and relative growth rates in both monitoring periods. The SFWSF and FWSF exhibited an increasing trend of AGR. However, only the former demonstrated an increasing trend of RGR. Only MDF showed consistent AGR and RGR in both monitoring periods.

Table 9 Growth of trees ≥ 10 cm DBH within mixed dipterocarp forest (MDF), riparian forest, Talisai Paya swamp forest, seasonal freshwater swamp forest (SFWSF) and freshwater swamp forest (FWSF) between 2015–2023 in Pin Supu Sustainable Forest Management project area, Sabah, Malaysia.

Forest Condition	Mean of AGR 2015–2018 (cm/yr)	Mean of AGR 2018–2023 (cm/yr)	Mean of RGR 2015–2018 (%)	Mean of RGR 2018–2023 (%)
MDF	0.27 ± 0.05	0.26 ± 0.02	1.30 ± 0.12	1.17 ± 0.11
Riparian	0.50 ± 0.15	0.47 ± 0.08	2.18 ± 0.52	1.66 ± 0.25
Talisai Paya swamp	0.49 ± 0.09	0.51 ± 0.08	2.80 ± 0.42	2.55 ± 0.48
SFWSF	0.07 ± 0.03	0.20 ± 0.02	0.47 ± 0.12	0.92 ± 0.09
FWSF	0.19 ± 0.05	0.36 ± 0.05	1.04 ± 0.28	1.38 ± 0.17
Grand Total	0.23 ± 0.03	0.30 ± 0.02	1.20 ± 0.10	1.29 ± 0.07

4.2.3 Species compositional changes

The MDF has the highest number of species recorded in PSFR, while FWSF and Talisai Paya swamp forests have the lowest (Table 10; Appendix II). Throughout the monitoring period, the reduction in the total number of species is negligible. MDF depicts the highest number of species recorded as dead and recruited in both monitoring periods (Table 11). The composition of dead and recruited trees varies among successional groups, including mixed climax and pioneer species, as well as mixed structural canopy layers such as the main canopy, middle storey, and understorey species.

Table 10 Number of tree species with ≥ 10 cm DBH within mixed dipterocarp forest (MDF), riparian forest, Talisai Paya swamp forest, seasonal freshwater swamp forest (SFWSF) and freshwater swamp forest (FWSF) between 2015–2023 in Pin Supu Sustainable Forest Management project area, Sabah, Malaysia.

Forest type	**Number of species in 2018**	**Number of species in 2023**
MDF	99	96
Riparian	15	15
Talisai Paya swamp	8	6
SFWSF	35	38
FWSF	6	6
Total	163	161

Table 11 List of species recruited and tree death ≥ 10 cm DBH within mixed dipterocarp forest (MDF), riparian forest, Talisai Paya swamp forest, seasonal freshwater swamp forest (SFWSF) and freshwater swamp forest (FWSF) between 2015–2023 in Pin Supu Sustainable Forest Management project area, Sabah, Malaysia.

Turnover	FOREST ECOSYSTEMS				
	MDF	**Riparian**	**Talisai Paya swamp**	**SFWSF**	**FWSF**
Tree death 2018	Annonaceae 2	*Colona serrata*	*Terminalia copelandii*	*Antidesma thwaitesianum*	*Lagerstroemia sp.*
	Gironniera nervosa	*Dillenia excelsa*		*Baccaurea tetrandra*	*Mallotus muticus*
	Glochidion rubrum	*Ficus nota*		*Dillenia excelsa*	*Nauclea orientalis*
	Gluta wallichii			*Memecylon sp.*	
	Guioa sp.			*Vitex pinnata*	
	Macaranga sp.				
	Macaranga gigantea				
	Mallotus sp.				
	Melicope confusa				
	Pentace laxiflora				
	Shorea acuminatissima				
	Shorea multiflora				
	Spathiostemon javensis				
	Vernonia arborea				
Tree death 2023	*Artocarpus nitidus*	*Ficus nota*	*Alstonia cf spatulata*	*Antidesma thwaitesianum*	*Mallotus muticus*
	Barringtonia macrophylla	*Pterospermum sp.*	*Crateva sp.*	*Baccaurea tetrandra*	
	Canarium sp.	*Pterospermum elongatum*	*Dillenia excelsa*	*Beilschmiedia sp.*	
	Crypteronia griffithii		*Diospyros sp.*	*Cratoxylum cochinchinense*	
	Ctenolophon parvifolius		*Terminalia copelandii*	*Dillenia excelsa*	
	Cynometra sp.		*Vitex elata*	*Memecylon sp.*	
	Diospyros sp.			*Syzygium sp.*	
	Fordia splendidissima				
	Glochidion rubrum				
	Hopea sp.				
	Hydnocarpus sumatrana				
	Lithocarpus sp.				
	Litsea lucida				
	Macaranga sp.				
	Macaranga hypoleuca				
	Madhuca sp.				
	Melicope cf confusa				
	Pleiocarpidia paniculata				
	Pternandra coerulescens				
	Shorea argentifolia				
	Shorea multiflora				
	Syzygium caudatilimbum				
Recuits 2018	Annonaceae 1		*Diospyros sp.*	*Dillenia excelsa*	*Mallotus muticus*
	Artocarpus nitidus		*Vitex elata*		
	Crypteronia griffithii				
	Dillenia excelsa				
	Fordia splendidissima				
	Gluta wallichii				

	Gonystylus sp.			
	Pternandra coerulescens			
	Saraca declinata			
	Shorea laevis			
	Vatica chartacea			
Recruits 2023	*Alangium sp.*	*Alseodaphne*	*Alstonia cf spatulata*	*Antidesma thwaitesianum*
	Fordia splendidissima	*Kleinhovia hospita*	*Diospyros sp.*	*Beilschmiedia sp.*
	Gardenia sp.	*Planchonia valida*		*Chionanthus sp.*
	Gluta sp.	*Pterospermum elongatum*		*Diospyros elliptifolia*
	Knema sp.	*Rauvolfia sumatrana*		*Diospyros wallichii*
	Macaranga sp.			*Garcinia sp.*
	Mallotus sp.			*Leea indica*
	Pentace borneensis			
	Pleiocarpidia paniculata			
	Pternandra coerulescens			
	Syzygium caudatilimbum			
	Vatica chartacea			
	Xanthophyllum sp.			

4.2.4 Above-ground Carbon changes

In the 2023 census, the overall average above-ground biomass (AGB) values in all plots indicate a 9% increase from the initial values in 2015 (Table 12). The recorded overall averages of AGB in all plots are approximately 349 C t/ha in 2015 and 378 C t/ha in 2023.

Two plots, PSP 3 (SFWSF) and PSP 10 (Talisai Paya forest), demonstrate an overall increase in forest structure values and also show 9% and 29% increases in initial above-ground carbon (AGC), respectively (Table 11).

The riparian forest represented by PSP 5 shows the highest increase in AGC from the initial values (36%), despite a 10% decrease in initial tree density (Table 11). Similarly, Plot 4 (FWSF), Plot 6 (MDF), and Plot 8 (SFWSF) indicate reductions in tree densities but show increasing AGC values of 23%, 13%, and 6% from the initial AGC, respectively. Only PSP 7 (SFWSF) depicts a decrease in structural values, but AGC remains consistent.

In the MDF, PSP 1 and PSP 2 demonstrate a reduction in forest structural values and a loss of 3% and 8% of their initially estimated above-ground carbon, respectively (Table 11). However, other MDF plots, specifically PSP 9, exhibit a 3% increase in initial above-ground carbon, despite a reduction in forest structural values.

Table 12 Summary of forest structure and estimated above-ground Carbon (AGC) per hectare of lived standing trees with ≥ 10 cm DBH within mixed dipterocarp forest (MDF), riparian forest, Talisai Paya swamp forest, seasonal freshwater swamp forest (SFWSF) and freshwater swamp forest (FWSF) between 2015–2023 in Pin Supu Sustainable Forest Management project area, Sabah, Malaysia.

Forest condition	Plot	Forest structure details	2015	2018	2023
Advance-growth of mixed dipterocarp forest	1	Density/ha (Stem/ha)	436.5	428.6	436.5
		BA/ha (m^2/ha)	30.2	28.9	28.7
		Volume (m^3/ha)	370.9	355.4	353.6
		AGC (C t/ha)	389.9	377.9	378.4
Advance-growth of mixed dipterocarp forest	2	Density/ha (Stem/ha)	420.6	412.7	412.7
		BA/ha (m^2/ha)	31.0	35.2	27.5
		Volume (m^3/ha)	382.1	427.1	335.9
		AGC (C t/ha)	392.3	461.1	359.8
Secondary-growth of Seasonal Freshwater Swamp Forest	3	Density/ha (Stem/ha)	428.6	428.6	428.6
		BA/ha (m^2/ha)	23.1	23.3	25.1
		Volume (m^3/ha)	293.2	296.8	317.6
		AGC (C t/ha)	296.9	300.1	323.8
Secondary-growth of Freshwater Swamp Forest	4	Density/ha (Stem/ha)	1063.5	1007.9	650.8
		BA/ha (m^2/ha)	39.7	40.7	43.0
		Volume (m^3/ha)	521.1	531.8	545.9
		AGC (C t/ha)	417.1	434.8	515.5
Secondary-growth of previously mixed dipterocarp forest (Riparian Forest)	5	Density/ha (Stem/ha)	381.0	349.2	341.3
		BA/ha (m^2/ha)	23.4	27.3	28.9
		Volume (m^3/ha)	295.3	338.6	356.6
		AGC (C t/ha)	224.0	279.6	305.3
Advance-growth of mixed dipterocarp forest & limestone vegetation	6	Density/ha (Stem/ha)	460.3	460.3	452.4
		BA/ha (m^2/ha)	32.6	34.1	35.9
		Volume (m^3/ha)	400.4	417.5	437.9
		AGC (C t/ha)	437.3	462.2	494.4
Secondary-growth of Seasonal Freshwater Swamp Forest	7	Density/ha (Stem/ha)	444.4	412.7	396.8
		BA/ha (m^2/ha)	24.2	23.3	24.1
		Volume (m^3/ha)	304.5	293.2	301.0
		AGC (C t/ha)	281.6	273.1	283.9
Secondary-growth of Seasonal Freshwater Swamp Forest	8	Density/ha (Stem/ha)	484.1	468.3	444.4
		BA/ha (m^2/ha)	33.2	32.2	34.2
		Volume (m^3/ha)	413.2	400.2	422.3
		AGC (C t/ha)	474.8	459.8	501.4
Advance-growth of mixed dipterocarp forest	9	Density/ha (Stem/ha)	468.3	444.4	412.7
		BA/ha (m^2/ha)	33.8	32.3	32.6
		Volume (m^3/ha)	416.1	395.6	394.9
		AGC (C t/ha)	390.4	391.1	401.6
Talisai Paya Swamp Forest (formerly Seasonal Freshwater Swamp Forest)	10	Density/ha (Stem/ha)	404.8	388.9	412.7
		BA/ha (m^2/ha)	20.5	20.4	23.8
		Volume (m^3/ha)	262.0	259.2	298.2
		AGC (C t/ha)	181.1	189.3	234.2

5. DISCUSSION

5.1 Limitation of findings

In this report, data on above-ground carbon, tree growth, mortality, and recruitment rates have been collected from three censuses conducted at 8-year intervals. The monitoring results for various forest types in both the floodplain and dryland are highly dynamic, and caution should be exercised in interpreting the findings. Further long-term assessments are required to gain a comprehensive understanding of the latest monitoring results.

5.2 Changes in forest cover

Floodplain forests are dynamic ecosystems found along riverbanks that experience periodic flooding. The expansion and contraction of their extend are shaped by the interplay of water flow, sediment deposition, and vegetation dynamics. Historically, extreme natural events like floods and droughts exert selective pressure on populations, and variations in water flow patterns can influence the relative success of different species and regulate ecosystem process rates (Resh et al., 1988; Hart & Finelli, 1999).

The expansion of the forest from 687 ha to 954 ha in 15 years on wetlands is noteworthy (Table 3). The swamp trees, known for their rapid growth and turnover, likely accelerated the succession process, as indicated in the earlier findings. Additionally, some degraded swampland has been treated and rehabilitated, aiding in the regeneration process.

Approximately 96% of the dryland identified in 2008 was categorised as forest cover, while the remaining portion had shrub vegetation (Table 3). The slow progression of the dryland forest may be attributed to unfavourable soil productivity, such as skid trails, stumping points, or former campsites on the site. Additionally, the forest edge effect may have limited any succession processes.

It is envisaged that as forests grow and expand, contribution towards biodiversity conservation, and providing habitats for numerous plant and animal species could be significant. Moreover, the expanding forests could enhance its supporting services in primary production, nutrient cycling and water cycling. These high-growth and dynamic forests could act as vital carbon sinks, helping mitigate climate change by absorbing and storing carbon dioxide (MEA 2005). Moreover, these forests also play a crucial role in maintaining water quality, regulating local climates, and preventing soil erosion. Forest expansion promotes ecosystem resilience and is of paramount importance for ecological balance and human well-being.

5.3 Changes in forest dynamics and growth over time

Regeneration of residual stand forest in Pin Supu after human-induced disturbance, such as timber extraction and forest fire influenced by the level of degradation of the site, availability of regenerative seedlings or saplings, and undergrowth competition such as herbaceous climbers and sedges. The loss of large trees that were extracted during logging activities in advance-growth forests in the past creates canopy gaps that stimulate the growth of many neighbouring species of various sizes, e.g. understorey seedlings, saplings and pole-size trees (Phillips *et al.* 1994). Thus, the findings of low recruitment over mortality rate and yet complimented with positive tree growth and incremental trend of above-ground biomass may indicate that these natural forests are recuperating, hence demonstrating that the forests are on a successional trajectory towards diverse composition and structural forests.

5.4 Variation in forest dynamics growth among forest communities

The findings have delivered some evidence of differences in forest communities in their assemblages, growth and dynamics of trees ≥ 10.0 cm DBH are significantly related to the edaphic conditions that are likely to be associated with the gradient of resource availability that distinguished forest communities in terms of their floristics, structure and diversity. Further monitoring is required to rationalise these observations since data censuses are based on an eight-year period only.

6. MANAGEMENT RECOMMENDATION

6.1 Protection of forest

Continue utilising stand-based mapping of vegetation types monitoring purposes in the management of this conservation area. This management tool may be able to examine spatio-temporal processes of changes in forest quality and conditions.

6.2 Maintenance of PSPs

Permanent plots require ongoing maintenance and when left unattended for long periods of time, they become increasingly difficult to relocate, re-establish, and undertake accurate remeasurements. The maintenance of permanent plots consists of determining the presence of the centre post and tree, including looking out for severe damage to the plots and investigating its cause.

6.3 Establish additional plots

Additional establishment PSPs are required in other parts of the reserve for successional comparison with the existing PSPs that were established in advance-growth forests.

7. SYNTHESIS

Two ecosystems, dryland and wetland, previously disturbed in various regenerative and successional stages, are under continuous monitoring. Over the past 15 years, there has been a noticeable upward trend in forest expansion in dryland areas (30 ha) and swampland (267 ha), accompanied by a significant decline in marshland and shrub cover within dry regions. The forests are in the process of recovering from previous disturbances, a trend evident over the eight-year monitoring period from 2014 to 2023. Positive indicators include overall tree growth, the recruitment of diverse species, and a favourable change in above-ground biomass or carbon. A long-term monitoring program for forest health is crucial to understanding the significant ecosystem services that contribute to ecological balance and human well-being.

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Appendix I Land cover map of Pin Supu Forest Reserve in 2008, 2016, 2020 and 2023.

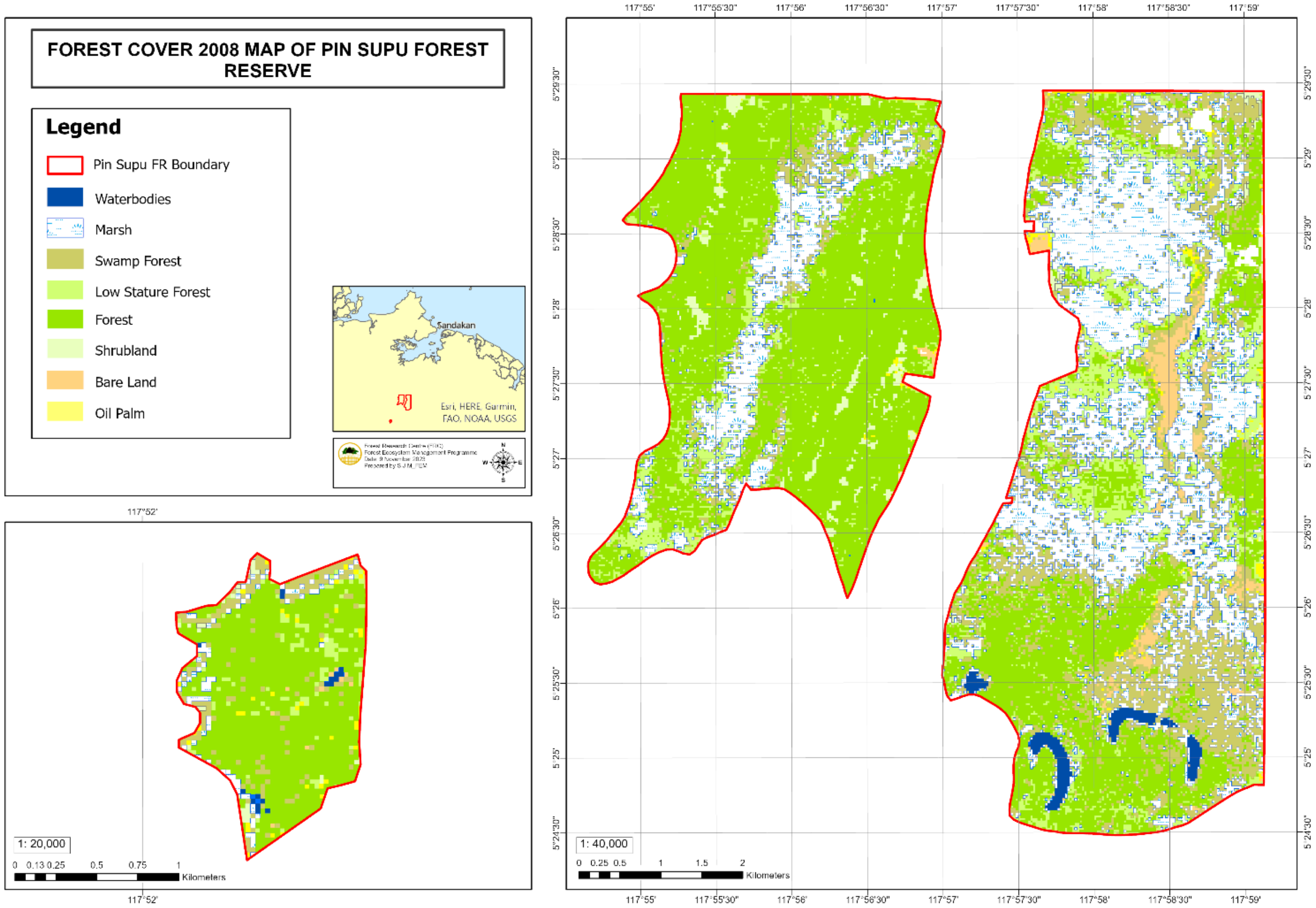

Figure 3. Land cover map of Pin Supu Forest Reserve in 2008.

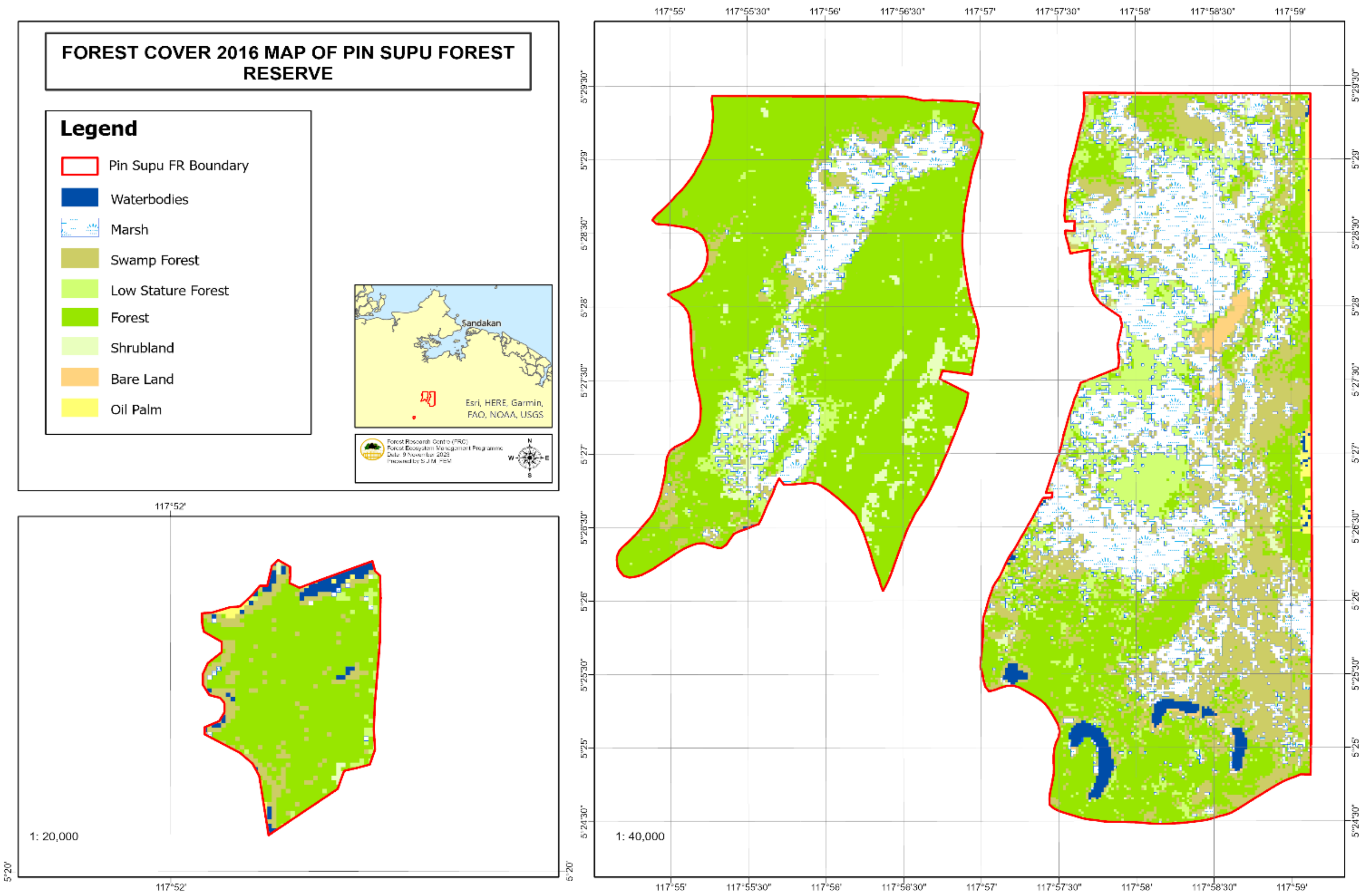

Figure 4. Land cover map of Pin Supu Forest Reserve in 2016.

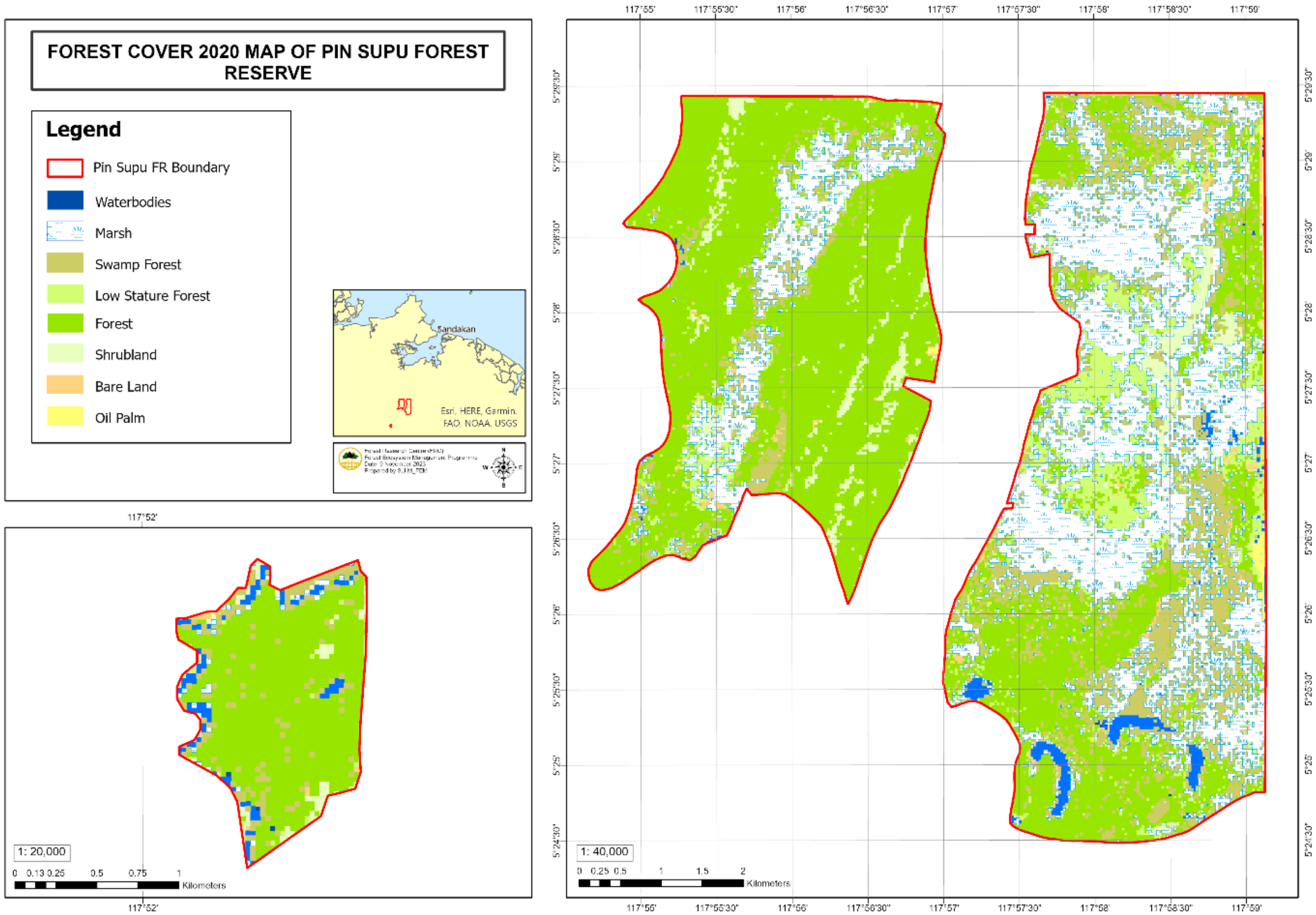

Figure 5. Land cover map of Pin Supu Forest Reserve in 2020.

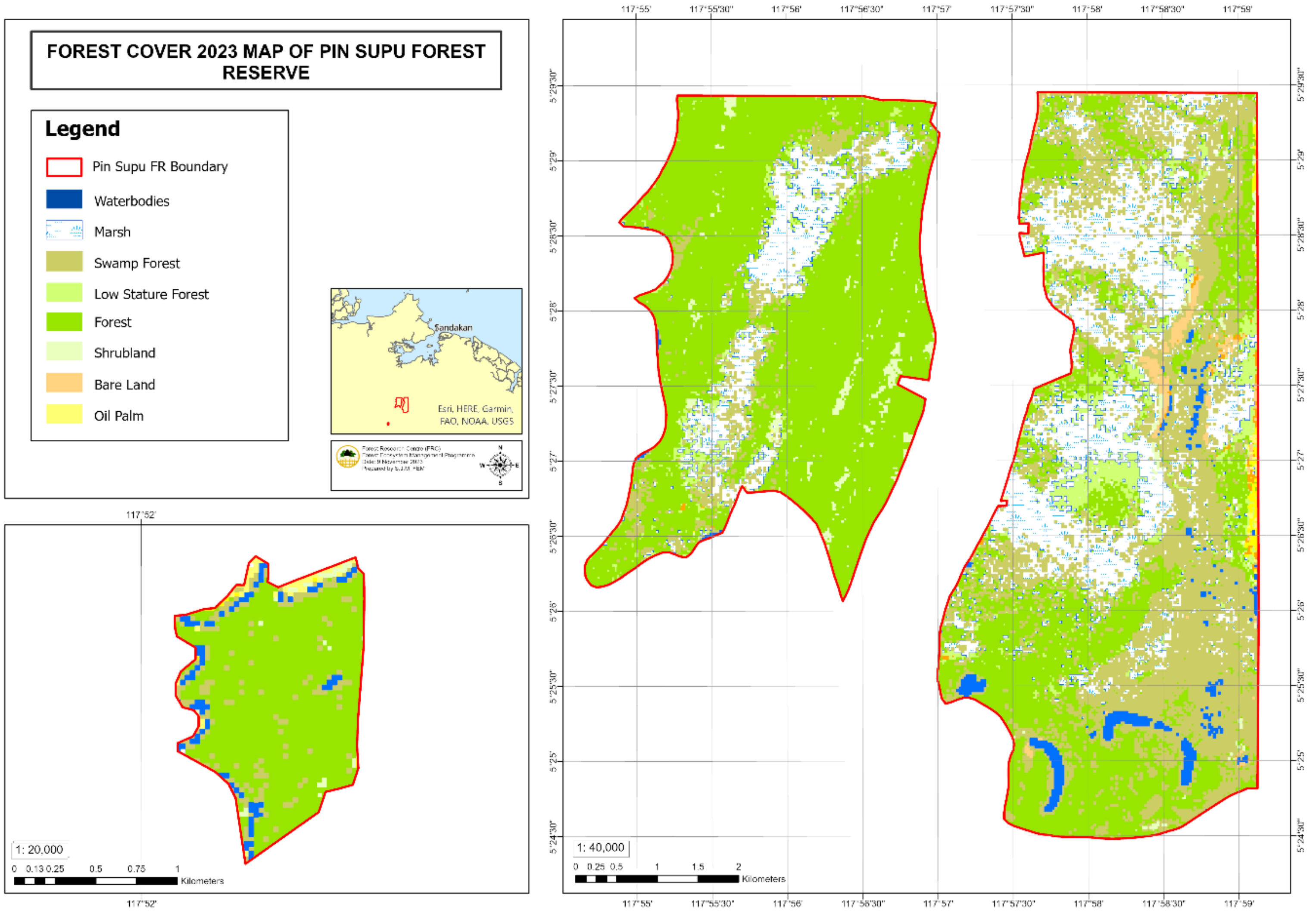

Figure 6. Land cover map of Pin Supu Forest Reserve in 2023.

APPENDIX II List of species recorded in various forest ecosystems

Forest	Species	Recorded in 2018	Recorded in 2023
Mixed Dipterocarp Forest (MDF)	*Alangium sp.*		✓
	Anisoptera grossivenia	✓	✓
	Annonaceae 1	✓	✓
	Annonaceae 2	✓	✓
	Annonaceae 3	✓	✓
	Annonaceae 4	✓	✓
	Ardisia	✓	✓
	Artocarpus anisophyllus	✓	✓
	Artocarpus nitidus	✓	✓
	Atuna	✓	✓
	Barringtonia lanceolata	✓	✓
	Barringtonia macrophylla	✓	
	Canarium	✓	✓
	Canarium denticulatum	✓	✓
	Canthium	✓	✓
	Chisocheton	✓	✓
	Cleistanthus	✓	✓
	Crypteronia griffithii	✓	✓
	Ctenolophon parvifolius	✓	
	Cyathocalyx	✓	✓
	Cynometra	✓	✓
	Diospyros	✓	✓
	Diospyros diepenhorstii	✓	✓
	Diospyros sungkang	✓	✓
	Dipterocarpus acutangulus	✓	✓
	Dipterocarpus confertus	✓	✓
	Dipterocarpus kerrii	✓	✓
	Dipterocarpus khortalsii	✓	✓
	Drypetes	✓	✓
	Durio	✓	✓
	Dyera costulata	✓	✓
	Dyzoxylum	✓	✓
	Eusideroxylon zwageri	✓	✓
	Fordia splendidissima	✓	✓
	Garcinia	✓	✓
	Gardenia sp.		✓
	Gironniera nervosa	✓	✓
	Gironniera subaequalis	✓	✓
	Glochidion rubrum	✓	
	Gluta		✓
	Gluta wallichii	✓	✓
	Gonystylus sp.	✓	✓
	Guioa		
	Heritiera elata	✓	✓
	Heritiera sumatrana	✓	✓
	Hopea	✓	✓
	Hydnocarpus	✓	✓
	Hydnocarpus sumatrana	✓	✓

Knema latericia	✓	✓
Knema latifolia	✓	✓
Knema sp.		✓
Lithocarpus	✓	
Lithocarpus sp.	✓	✓
Litsea lucida	✓	
Lophopetalum	✓	✓
Macaranga	✓	✓
Macaranga 22	✓	
Macaranga conifera	✓	✓
Macaranga gigantea		
Macaranga hypoleuca	✓	
Maclurodendron	✓	✓
Madhuca	✓	✓
Magnolia	✓	✓
Mallotus	✓	✓
Melanochyla	✓	✓
Melicope cf confusa	✓	✓
Melicope confusa		
Mesua	✓	✓
Microcos	✓	✓
Nauclea subdita	✓	✓
Neonauclea artocarpoides	✓	✓
Nephelium	✓	✓
Olacaceae	✓	✓
Paranephelium xestophyllum	✓	✓
Parashorea malaanonan	✓	✓
Pentace borneensis	✓	✓
Pentace laxiflora		
Phoebe	✓	✓
Planchonia valida	✓	✓
Pleiocarpidia paniculata	✓	✓
Pleiocarpidia sandakanica	✓	✓
Porterandia chanii	✓	✓
Pternandra coerulescens	✓	✓
Reinwardtiodendron humile	✓	✓
Saraca declinata	✓	✓
Scaphium longipetiolatum	✓	✓
Shorea acuminatissima	✓	✓
Shorea argentifolia	✓	
Shorea cf domatosia	✓	✓
Shorea domatosia	✓	✓
Shorea laevis	✓	✓
Shorea macroptera	✓	✓
Shorea multiflora	✓	✓
Shorea pauciflora	✓	✓
Shorea scrobiculata	✓	✓
Spathiostemon	✓	✓
Spathiostemon javensis	✓	✓
Streblus	✓	✓
Sumbaviopsis albicans	✓	✓
Syzygium	✓	✓

	Syzygium caudatilimbum	✓	✓
	Tabernaemontana macrocarpa	✓	✓
	Teijsmanniodendron simplicifolium	✓	✓
	Terminalia	✓	✓
	Vatica chartacea	✓	✓
	Vatica oblongifolia	✓	✓
	Vernonia arborea		
	Xanthophyllum	✓	✓
	Xanthophyllum sp.		✓
Riparian (previously on mixed dipterocarp forest)	*Alangium javanicum*	✓	✓
	Alseodaphne	✓	✓
	Chionanthus	✓	✓
	Colona serrata		
	Dillenia excelsa		
	Dracontomelon dao	✓	✓
	Ficus nota	✓	✓
	Garcinia parvifolia	✓	✓
	Kleinhovia hospita	✓	✓
	Knema laurina	✓	✓
	Microcos crassifolia	✓	✓
	Palaquium	✓	✓
	Planchonia valida		✓
	Polyalthia obliqua	✓	✓
	Pterospermum	✓	
	Pterospermum elongatum	✓	✓
	Rauvolfia sumatrana	✓	✓
	Semecarpus	✓	✓
Talisai Paya swamp (previously seasonal freshwater swamp forest)	*Alstonia cf spatulata*	✓	✓
	Cananga odorata	✓	✓
	Crateva	✓	✓
	Dillenia excelsa	✓	
	Diospyros	✓	✓
	Nauclea subdita	✓	✓
	Terminalia copelandii	✓	✓
	Vitex elata	✓	
Seasonal Freshwater Swamp Forest (SFWSF)	*Antidesma thwaitesianum*	✓	✓
	Baccaurea	✓	✓
	Baccaurea tetrandra	✓	✓
	Beilschmiedia	✓	✓
	Canarium denticulatum	✓	✓
	Chionanthus		✓
	Cratoxylum cochinchinense	✓	✓
	Dehaasia	✓	✓
	Dillenia excelsa	✓	✓
	Dimocarpus longan	✓	✓
	Diospyros	✓	✓
	Diospyros 5	✓	✓
	Diospyros elliptifolia	✓	✓
	Diospyros sungkang	✓	✓
	Diospyros wallichii		✓
	Dipterocarpus validus	✓	✓

	Drypetes	✓	✓
	Erythroxylum	✓	✓
	Ficus strangling fig	✓	✓
	Garcinia sp 1	✓	✓
	Garcinia sp 2	✓	✓
	Garcinia sp.		✓
	Hydnocarpus	✓	✓
	Lagerstroemia speciosa	✓	✓
	Leea indica	✓	✓
	Litsea/Beilschmiedia	✓	✓
	Ludekia borneensis	✓	✓
	Memecylon	✓	✓
	Mezzetia/Polyalthia	✓	✓
	Mishocarpus	✓	✓
	Palaquium	✓	✓
	Pterospermum	✓	✓
	Sindora	✓	✓
	Syzygium	✓	✓
	Teijsmanniodendron	✓	✓
	Vitex	✓	✓
	Vitex pinnata	✓	✓
	Xanthophyllum flavescens	✓	✓
Freshwater swamp forest (FWSF)	*Antidesma thwaitesianum*	✓	✓
	Dillenia excelsa	✓	✓
	Homalium	✓	✓
	Lagerstroemia		
	Mallotus muticus	✓	✓
	Nauclea orientalis	✓	✓
	Vitex pinnata	✓	✓