

**EFFECTS OF ECOSYSTEM RESTORATION ON FOREST
BIODIVERSITY AND CARBON ACCUMULATION**

Compiled by

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Abstract

This study evaluated the long-term effects of forest-ecosystem restoration by the Framework Species Method (FSM) in the upper Mae Sa Valley, northern Thailand on carbon accumulation and biodiversity recovery. The study site was 12-year-old (R12) and 24-year-old (R24) restoration plots, on previously degraded agricultural land within Doi Suthep-Pui National Park, alongside a non-restored control site (CON) and reference upland evergreen forest. Data were collected on tree and soil carbon stocks and bird and mammal communities from May to November 2024.

Tree-carbon accumulation in restored plots followed a recovery trajectory towards reference forest values. R12 and R24 tree carbon stocks reached 48% and 84% of reference forest levels, respectively, and were projected to attain parity within about 34 years. Soil carbon showed more mixed results. While R12 exhibited significant increases in soil organic carbon (SOC) stocks, reaching 86% of reference forest levels, SOC in R24 lagged expectations, likely due to historical land-use legacy. Nevertheless, total carbon stocks, including soil were 154.5 tC/ha in 24-year plots compared to 204 tC/ha in reference forest. These results demonstrate the FSM's efficacy in achieving high carbon-sequestration rates, significantly exceeding those of natural regeneration and plantation systems under similar conditions.

Biodiversity recovery was equally remarkable. Bird surveys identified 140 species across all four habitats, with restored plots approaching the species richness and community composition of reference forests. Twelve species were ubiquitous to all habitats, including frugivorous species like bulbuls and barbets, which likely facilitate seed dispersal and natural forest regeneration. Camera-traps revealed the presence of 18 mammal species across the study area, including the critically endangered Sunda pangolin (*Manis javanica*) in mature forest. Mammal activity in restored plots was over 50% that of reference forest, suggesting steady recovery of trophic interactions and ecological functionality.

Restoration outcomes were facilitated by strategic interventions, including planting high-performing framework species, dense initial stocking (3,100 saplings/ha) and rigorous maintenance during early establishment. These measures catalyzed rapid canopy closure, enhanced seed dispersal and accelerated succession. Furthermore, restoration by the FSM was highly cost effective for carbon sequestration, with costs ranging from \$3.99 to \$10.34 USD/tCO₂, comparable to or lower than national REDD+ implementation estimates.

The study indicates a potential for the FSM to contribute to Payments for Ecosystem Services (PES) schemes. Although significant carbon and biodiversity benefits are achievable, realization of those benefits will require supportive policy mechanisms, including carbon credit markets, low-cost monitoring frameworks, and capacity building for local communities.

EFFECTS OF ECOSYSTEM RESTORATION ON FOREST BIODIVERSITY AND CARBON ACCUMULATION

Project Title:	Effects of ecosystem restoration on forest biodiversity and carbon accumulation
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Prepared by:	Stephen Elliott, Nay Tun Lin, Htet Aung Khant, Phyo Thet Naing & Tun Pyae Shan

Introduction

Forest-ecosystem restoration is defined as: “directing and accelerating ecological succession towards an indigenous reference forest ecosystem of the maximum biomass, structural complexity, biodiversity and ecological functionality that are self-sustainable within climatic and soil limitations” (Elliott et al., 2013). This definition includes the 4 “corner stones” of restoration success. This project addressed two of them. It attempted to determine the long-term effects of applying the framework species method (FSM) to restore evergreen forest to degraded sites in the upper Mae Sa valley on: i) **biomass** (particularly the carbon component of biomass) and ii) **biodiversity**, targeting birds and mammals in particular.

Objectives:

- i) To determine the long-term effects of forest-ecosystem restoration by the FSM on:
 - o carbon accumulation in trees and soils,
 - o bird community composition and species diversity by direct observation and
 - o the species of mammals present, by camera trapping.
- ii) To explore to what extent these attributes might be valued within a “payments for ecological services” (PES) scheme, to provide an incentive for local people support forest ecosystem restoration.

Study Area

The study area was FORRU-CMU’s trial plot system in the upper Mae Sa Valley. The upper Mae Sa Valley lies mostly within Doi Suthep-Pui National Park (DSPNP), in Chiang Mai Province, northern Thailand, with the Hmong hill tribe communities of Ban Mae Sa Mai and Ban Mae Sa Noi (BMS) (combined population of 2,197) situated at 18°52’07.24” N, 98°51’08.47” E, 1,018 m above sea level. The restoration trial plot system is situated at 18°51’46.62” N, 98°50’58.81” E, 1,200–1,325 m above sea level, covering 33 ha of the watershed above the village. The project site was assigned to FORRU-CMU by Doi Suthep-Pui National Authority in 1996 (Figure 1).

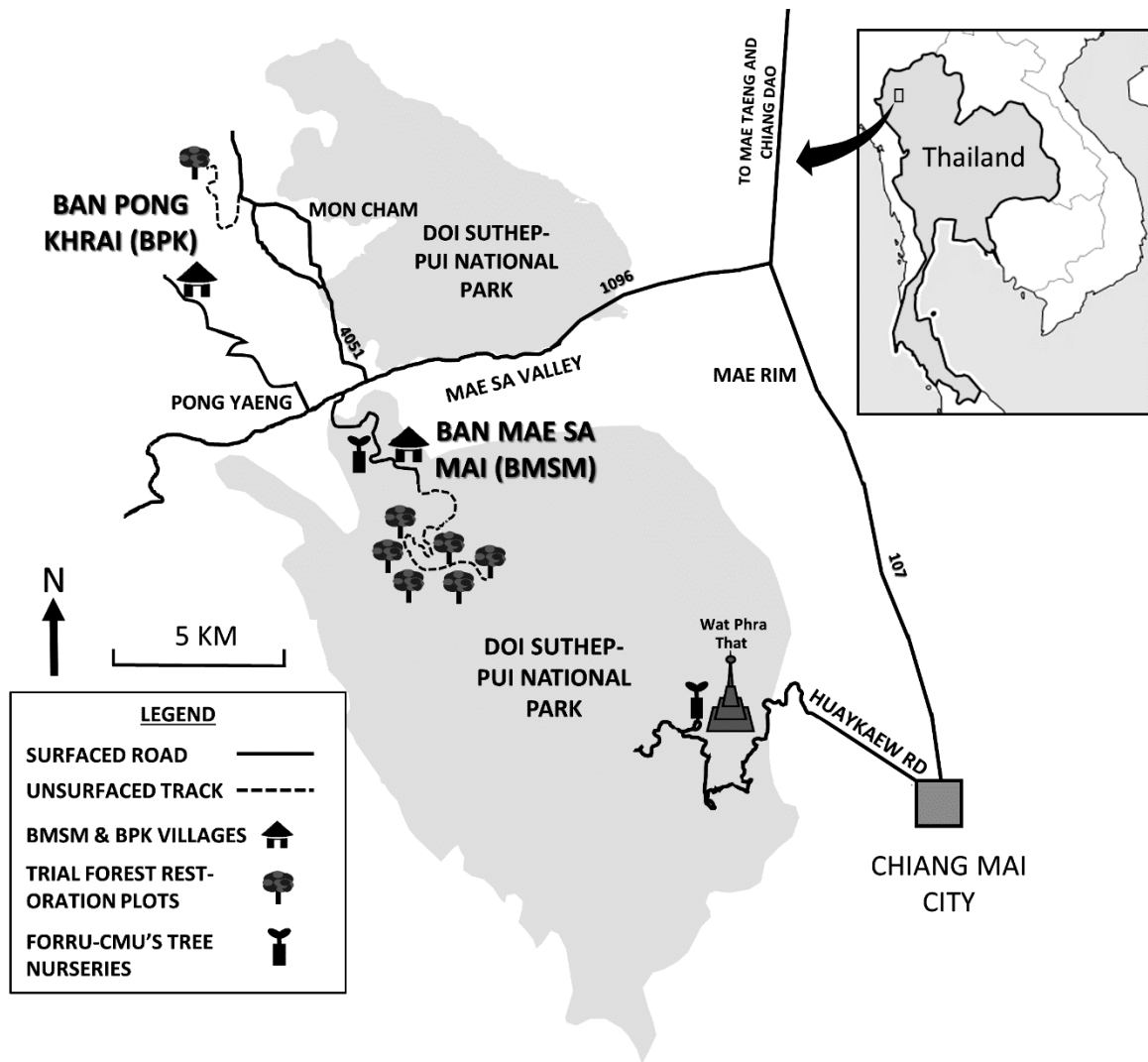


Figure 1 - Location of the study area in relation to Chiang Mai, Doi Suthep-Pui National Park (grey area)

The bed rock is granite. Compared with soil in nearby undisturbed evergreen forest at a similar altitude, soil in the study area before planting was significantly more acidic and contained significantly less organic matter and nitrogen, more sand and less silt and clay ($p < 0.05$), attributable to forest clearance (Table 1).

The area has two main seasons: the wet season (May–October) and the dry season (mean monthly rainfall below 100 mm, November–April). The dry season is subdivided into the cool-dry season (November–January) and the hot-dry season (February–April). Average annual rainfall, recorded at the weather station nearest to the at a similar altitude (Kog-Ma Watershed Research Station), was 1,736 mm (Figure 2). Extreme temperatures range from a minimum of 4.5 °C in December to a maximum of 35.5 °C in March. Fire is a major constraint to forest restoration in this landscape. Villagers use fire to clear land for cultivation and, despite rules to prevent accidents, fires often “escape” and burn out of control over extensive areas.

Table 1. Soil conditions in the restoration site ($n = 16$) and old-growth evergreen forest ($n = 20$) at the same altitude

	Restoration Site		Evergreen Forest		t-test p
	Mean	SD	Mean	SD	
pH	5.438	0.423	6.222	0.545	0.000
Organic Matter (%)	5.351	0.997	7.302	2.480	0.006
Nitrogen (%)	0.257	0.045	0.371	0.121	0.001
Phosphorus (ppm)	27.563	11.399	10.525	5.095	0.000
Potassium (ppm)	274.838	137.637	295.674	72.093	0.562
Moisture at Field Capacity (%)	34.755	2.571	35.345	4.363	0.636
Sand (%)	68.520	6.290	52.130	17.872	0.001
Silt (%)	18.260	3.090	22.040	5.473	0.019
Clay (%)	13.220	3.880	25.830	16.343	0.005
Texture	Sandy Loam		Sandy Loam		na

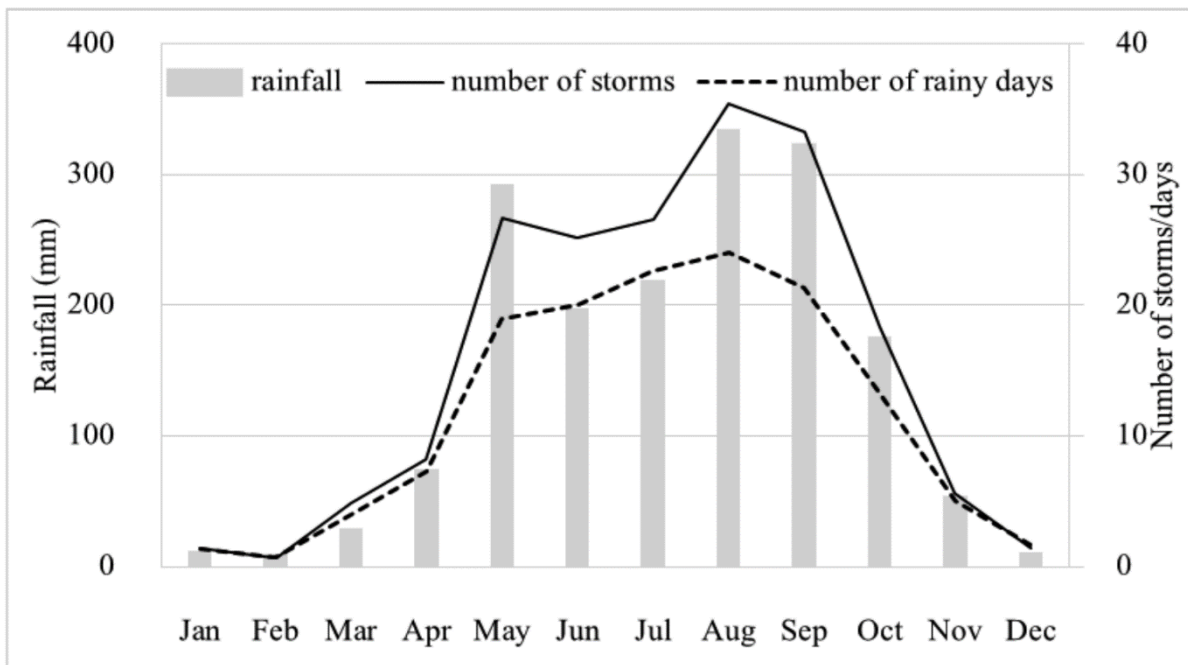


Figure 2 - Mean monthly rainfall data for 1997–2013 (three tipping bucket automatic recording rain gauges at Huai Kog-Ma Watershed Research Station, Chiang Mai Province, 1,400 m a.s.l., 9 km away from the study area.)

Originally, the area had been covered in “Primary, Evergreen, Seasonal Forest” (EGF, *sensu* Maxwell & Elliott (2001) cleared from the 1950’s to the early 80’s, to provide land for the cultivation of cabbages, potatoes, and other cash crops. The condition of the area was stage-3 degradation (*sensu* Elliott et al. (2013), Chapter 3), i.e., regenerants (remnant mature seed trees, live tree stumps capable of coppicing, tree saplings, and tree seedlings, taller than 50 cm.) at densities lower than that needed to initiate canopy closure within 2 years (<3,100/ha), mostly suppressed by dominant weeds, including *Pteridium aquilinum* (L.) Kuhn (Dennstaedtiaceae); *Bidens pilosa* L. var. *minor* (Bl.) Sherf; *Ageratum conyzoides* L.; *Chromolaena odorata* (L.) R.M.King & H.Rob. and *Ageratina adenophora* (Spreng.) R.M.King & H.Rob. (all Compositae); *Commelina diffusa* Burm. F. (Commelinaceae); and grasses, e.g.

Phragmites karka (Retz.) Trin. ex Steud. (Poaceae), *Imperata cylindrica* (L.) Raeusch., and *Thysanolaena latifolia* (Roxb. ex Hornem.) Honda (all Poaceae). A few remnant forest trees, sparsely scattered across the plot system site, provided a potential seed source for natural forest regeneration. The nearest remnant forest, “Pah Dong Saeng”, lies 2–3 km from the plots (disturbed primary EGF, regenerating following opium poppy cultivation during the 1950–60’s in small patches). The villagers regard it as a *de facto* community forest and a sacred area.

Potential dispersers of medium-sized seeds from that forest into the trial plots included birds (particularly bulbuls and barbets) and small mammals (civets, badgers, and small fruit bats). Dispersers of larger seeds (e.g. elephants, rhinos and wild cattle species) had been extirpated from the valley by the 1960’s.

Most of the slopes below the plots were still cultivated for cabbages, when the plot system was initiated. Litchi orchards (*Litchi chinensis* Sonn. (Sapindaceae)) lower down the valley were extensive but are now in decline and being replaced with horticultural crops, using plastic cloches (e.g. salad vegetables, cut flowers, etc.). Villagers have invested heavily in an irrigation system that delivered piped water from the upper watershed to the agricultural field lower down the valley.

Plot system establishment

The trial plot system was established within a 50-ha area, which the villagers had set aside as their contribution towards a national tree-planting project to commemorate the Golden Jubilee of King Bhumibol. Each year plot locations were decided upon during walks around the project area with the villagers and national park officers and by drawing sketch maps. GPS and Google Earth were used later, as those technologies became available.

In March to April each year, [rapid site assessments](#) were performed, using circular sample sub-plots 5 m in radius, to estimate the density of natural regenerants (remnant mature seed trees, live tree stumps capable of coppicing, tree saplings and tree seedlings, taller than 50 cm). The number of trees to be planted per hectare was calculated as 3,100 minus the estimated density of existing natural regenerants/ha. Plots, ranging in size from 0.48 to 6.4 ha each year, were planted with 20–30 candidate framework tree species in the middle of June (4–6 weeks after the start of the rainy season), once rainfall had become reliable.

Weeds were slashed down to nearly ground level about 6 weeks before planting, followed by a single application of glyphosate about 3 weeks before. Planting stock was saplings 30–50 cm tall, grown from seeds collected locally in EGF. Seedlings were grown in plastic bags (22.8 × 6.35 cm), in a medium of forest soil, peanut husk and coconut husk in the ratio 50:25:25. Most of the trees planted were grown by the villagers in a community tree nursery sponsored by a succession of various donors.

Plots were divided into 40 × 40 m squares, each demarcated with poles and string. The required number of bamboo canes (to mark planting spots), saplings and fertilizer were delivered to each rai a day before planting. Bamboo canes were used to indicate planting spots, averaging 1.8 m between planted trees or away from natural regenerants. Holes were dug, about twice the size of the plastic bags. Saplings were planted into the holes, and soil was added and firmed

down. About 50–100 g of soluble fertilizer (NPK 15:15:15) was added in a ring, about 20–30 cm away from the base of each tree stem, and dead weeds were laid around each tree as mulch. The species planted were varied each year to compare performance among species.

Weeding (by hand) and fertilizer application were repeated three times in both the first and second rainy seasons after planting, to accelerate canopy closure. The villagers implemented a fire-prevention program (see previous report). Monitoring of labelled samples of the planted trees was carried out within 2 weeks of tree planting (to provide baseline data) and was repeated at the end of the first, second, and sometimes third rainy seasons. The root collar diameter of the labelled young saplings was measured by Vernier calipers. As the trees grew larger, tape measures were used to record the girth at breast height (gbh). Tree height was measured by telescopic measuring poles. Such data were used to compare species-specific performance and the effectiveness of various silvicultural treatments in increasing survival and accelerating growth during early plot establishment.

Study Habitats

The project reported here determined to what extent restoration interventions have propelled carbon and wildlife recovery from the starting state (abandoned agricultural land) towards reference forest conditions. Data were collected at 4 sites within the area described above: i) abandoned agricultural land (control – starting conditions) (CON), ii) 12-year old (R12) and iii) 24-year old (R24) restoration plots and iv) in Pah Dong Saeng, which served as the reference forest for this project (REF) (Gann et al., 2019), being the least disturbed forest remnant in the vicinity (Figure 3).

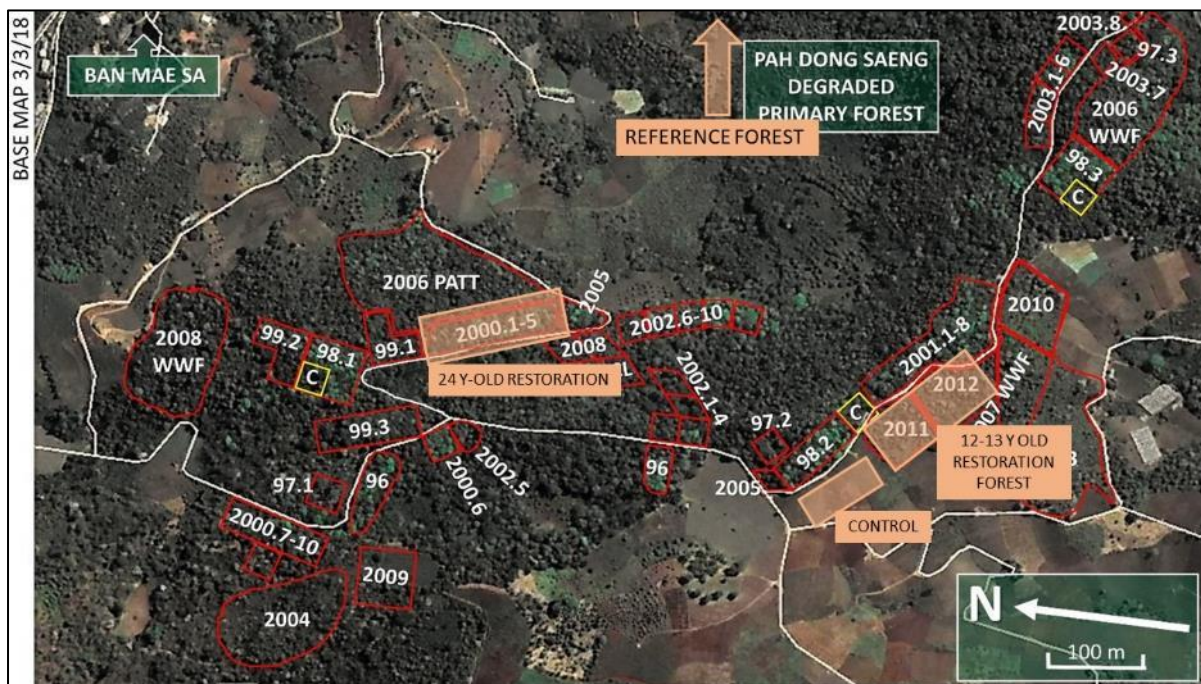


Figure 3 - The framework species demonstration plot system (chrono-sequence) in the Upper Mae Sa Valley. Numbers indicate year of establishment. The location of the study habitats where sample plots were placed for the study reported here are highlighted.

In each of the 4 study habitats, the centre points of 8 circular sample units (SUs) were positioned in an unbiased manner on 1-5/5/24. Plot details were recorded on the appended data sheet 1 and baseline photo monitoring completed (Figure 4). In each circle (5 m in diameter), tree sizes were measured and soil samples collected for carbon analysis. The precise locations of the SUs are shown in Appendix 2.



Figure 4 - Example of baseline photo-monitoring around the 2nd circular sample plot centre in 24-year-old restored forest.

Data collection and analysis

Four sub-projects on i) tree carbon, ii) soil carbon iii) birds and iv) mammals were conducted by four Environmental Science BSc students for their thesis projects. Tun Pyae Shan, from the Czech University of Life Sciences, led on tree-carbon measurements. The other 3 students are studying at CMU: Phyo Thet Naing (soil carbon), Htet Aung Khant (birds) and Nay Tun Lin (mammals). All students submitted project plans on time, which were reviewed by their supervisors and approved. We also coordinated the involvement Tun Pyae Shan via several online meeting with his CZU supervisor (Verner Vladimir).

Trees

Equipment: metal labels (made from drinks cans), permanent marker, metal stylus, wire, nails, tape measures (1.5 m), data sheets, pencils, clip boards, tree height measuring poles and digital clinometer.

A rope 5 m long was used to mark the circumference of the plot, within which all trees, of girth at breast height (GBH) of >5.0 cm, were counted, labelled and identified. Numbered labels were nailed to each tree trunk, so that the upper edge of the label was at exactly 1.3 m above the ground, where GBH was measured (in cm). Galvanized nails 5 cm long, with flat heads were used. On Datasheet 2 appended, the following were recorded: i) the label number, ii) the species name (both local name and scientific name), iii) GBH (using 1.5-m tape), iv) height (by measuring pole or digital clinometer), v) crown length and width.

Carbon in trees was calculated from allometric equations developed for northern Thailand trees by [Pothong et al. \(2022\)](#):

$$AGB = a \times (D^2 \times H \times WD)^b$$

... where **AGB** means above-ground dry biomass (**kg**); **D** = diameter at breast height (**cm**); **H** = tree height (**m**) and **WD** = wood density (**g/cm³**). The parameters “**a**” and “**b**” are constants, derived from Pothong’s field data of felled trees. Recommended values for northern Thailand trees are **0.134** and **0.847** respectively, for trees of D 1 to 20 cm and **0.0673** and **0.976** for trees of D > 20 cm. Wood density was obtained from the data appended (Appendix 4) and from the global wood-density database (<http://db.worldagroforestry.org/wd>)

Root biomass was added, using the mean root/shoot ratio determined by [Cairns et al. \(1997\)](#) for tropical trees—0.24 tons of roots per ton AGB. Pothong reported that average carbon content of the trees in her study was 44.84% of dry biomass. So, the result was multiplied by 0.4484, to convert AGB to above ground carbon (AGC). Values for all trees in each SU (kg/circle) were summed and converted to metric tonnes per ha. Thus, 8 estimates of tree carbon quantity (metric tonnes per ha) were generated for each of the 4 sites. ANOVA and t-tests were used to determine if differences among the 4 sites were significant.

Soil Carbon

Eight soil-sampling points were located in each of the four sites; 1 at each of the 8 poles used to mark the centre of the circular SUs. Samples were collected 1 meter north of each centre pole (to eliminate bias). A split-barrel soil-core sampler (diameter 7.5 cm) was pushed into the soil to a depth of 15 cm and gently withdrawn, keeping the soil column intact, rejecting any cores with thick roots, large stones or with soil missing from parts of the core. Each soil core was divided into three depth layers (sub-cores): 0–5 cm, 5–10 cm, and 10–15 cm. Samples were placed in labeled zip-lock bags, immediately after collection, to prevent water loss. Bags were labelled with SU identification number and date etc. with an indelible marker. Wet and dry soil masses were recorded, and visible stones and roots were removed to maintain sample integrity.

In the lab, each sub-core was placed in a pre-weighed aluminum tray and dried at 105°C for 24 hours in the oven. Before laboratory analysis, the samples were sieved through a 2-mm mesh, to eliminate debris. Dried samples were weighed using an electronic balance. Samples from 2 adjacent SUs were combined for analysis of soil organic matter content (SOM). Thus from each site, 4 samples from each of three depths were sent to the CMU Agriculture Soil Lab for SOM determination, by the Walkley-Black technique, which determine SOM as sample weight loss

when SOM is oxidized using potassium dichromate and sulfuric acid (Bahadori & Tofighi, 2015).

SOM was converted to soil organic carbon (SOC), using the factor of 0.58 (Nelson, et al., 1982). All data were recorded on Data Sheet 3 (see Appendix 3).

To ensure accuracy and reduce potential lab errors, I prepared three standard samples with known carbon percentages (5%, 10%, and 15%). These standards were created by evenly mixing activated charcoal (85% carbon) with sand (0% carbon). I applied a mass-balance equation to calculate the amount of charcoal needed to achieve the desired carbon percentages. The standards were included in the batch of forest soil samples sent to the lab. Deviation of the lab results from the known standard values could thus be used to calculate multipliers to correct the results for lab errors.

Deviation of lab results from the know standard values varied with the amount of carbon in the samples. Therefore, I obtained an equation for calculating the correction factor from empirical curve fitting, using a scatter plot of the difference between the report lab result and the carbon content of the standards vs the reported lab result. A correction factor was then applied to all other data, depending on the reported result.

The critical data thus obtained were: i) total mass (g) of dry soil of each of 8 cores (15 x 7.5 cm) and 24 sub-cores, per site and ii) four determinations of SOM at 3 depths per site from the lab analysis. Carbon in each sub-core (in gm) was determined by multiplying each sub-core dry mass (gm) by the lab-derived per cent carbon content at each respective SU-pair, divided by 100. The carbon mass per sub-core (gm), thus derived, was then divided by the cross-sectional area of the core (44.2 cm²), to calculate a value for SOC in gm/cm² for each sub-core. The result was multiplied by 100,000,000 to get a value “per ha” and divided by 1,000,000 to convert grams to metric tonnes, thus:

$$\text{Soil tC/ha} = \frac{\text{Core dry mass} \times (\% \text{ carbon content}/100) \times 100,000,000}{(3.14159 \times (\text{core radius (cm)})^2) \times 1,000,000}$$

Results for all three sub-cores at each of eight SUs per site /site were summed to derive a value for total carbon per hectare down to 15 cm depth.

Birds

Bird watching was implemented by teams of 12 persons staying overnight in the village 4 times, on May 4-5, July 6-7, September 7-8, November 2-3. Birds were recorded for 3 hours before sunset and for 3 hours after dawn. The bird watchers worked in pairs, with a spotter, relating the birds seen, and a recorder, writing down the information (Figure 5). Therefore, on each trip 12 person-hours observation time was expended at each of the 4 sites or 48 hours in total per site over the four trips.

Bird watchers recorded every bird they could recognize by sight or by sound and the time of the observation.

Bird Survey Record Sheet

File Name: **Restoration Plot 6 years old**

Date: 17.12.05 Weather: sunny, cool Recorder/s: LM, MT, CT
 Block Number: G1 Plot Number: EG-05
 Start time: 7.47am Finish time: 10.30 am

TIME	SPECIES(COMMON NAME)	SONG OR SIGHT	NO. OF INDIVIDUALS	DISTANCE FROM POINT (M)	TREE (SPECIES/ LABEL)	POSITION (CROWN/ TRUNK ETC.)	ACTIVITY (FEEDING, PERCHING, DISPLAYING ETC.)
7.47	Black-crested Bulbul	sight	1	20	Eythrina stricta	crown	feeding and flying
7.52	Bar-winged Flycatcher-shrike	sight	5	30	Ficus altissima	crown	feeding and flying
8.06	Hill Blue Flycatcher	song	1	50	Betula alnoides	tree trunk	flying
8.08	Sooty-headed Bulbul	song	1	25	Gmelina arborea	crown	flying
8.15	Puff-throated Babbler	sight	2	15	Spondias axillaris	tree trunk	flying

Figure 5 - Example bird observations record sheet

For each of the four study habitats, the record sheets were then arranged in order of time and a list was made of the first 10 different bird species observed. Continuing moving down the time record, a second list of 10 different species was compiled. Species already recorded in the first list, were ticked, whilst “new” species were added at the bottom of the 2nd list (Figure 6) This process was repeated until at least ten lists had been compiled. On any one list, each species occurred only once, but a single species could occur on more than one list. The “list” therefore becomes an artificial measure of “observation effort”.

McKinnon Bird Species List - 6 year old Restoration Plot

	List Number										No. of lists on which the species occurs
	1	2	3	4	5	6	7	8	9	10	
1 Black-crested Bulbul	✓			✓	✓	✓		✓	✓		6
2 Bar-winged Flycatcher-shrike	✓	✓						✓			3
3 Hill Blue Flycatcher	✓		✓	✓	✓		✓		✓	✓	7
4 Sooty-headed Bulbul	✓				✓	✓					3
5 Puff-throated Babbler	✓	✓	✓								3
6 White-rumped Shama	✓							✓	✓	✓	4
7 Yellow-browed Warbler	✓			✓		✓	✓	✓			5
8 Golden Spectacled Warbler	✓	✓	✓	✓		✓	✓		✓	✓	8
9 Golden-fronted Leafbird	✓										1
10 Verditer Flycatcher	✓				✓					✓	3
11 Lesser Necklaced Laughing thrush		✓									1
12 Long-tailed Minivet		✓	✓		✓		✓		✓		5
13 Green-billed Malkoha		✓						✓			2
38 Grey-headed Flycatcher							✓			✓	2
39 Scarlet Minivet								✓			1
40 Sulphur-breasted Warbler								✓			1
41 Buff-throated Warbler								✓			1
42 Pin-tailed Pigeon									✓		1
43 Eastern Crowned Warbler									✓		1
44 Brown-breasted Bulbul									✓		1
45 Flavescent Bulbul										✓	1
46 Lanceolated Warbler										✓	1
Number of New Species	10	7	5	5	4	4	3	3	3	2	
Cummulative Species	10	17	22	27	31	35	38	41	44	46	

Figure 6 – Spreadsheet example for compiling successive lists of ten bird species from the observation record time sheets. Note frequency data added to the far-right column and cumulative number of species observed calculated in the bottom row.

The total number of different bird species seen (by making ten lists) can be used as a reliable index of the bird community species richness. The numbers of *new* birds seen on each successive list were counted and a graph was plotted of the *cumulative* number of birds seen vs. no. of lists considered. Next, the no. of lists on which each bird species was counted (species frequency) and added to the far-right column. A graph was plotted of log-frequency along the y axis and no. of lists on which species occur along the x axis (Figure 7). The line of best fit was then extrapolated back to zero. The y intercept provided an estimate of the log no. of species *not seen* during the survey (i.e. those on zero lists). This log value was converted into a number (antilog) and the result added to the cumulative total number of bird species observed, resulting in an estimate of the total species richness of the bird communities in each of the 4 study habitats.

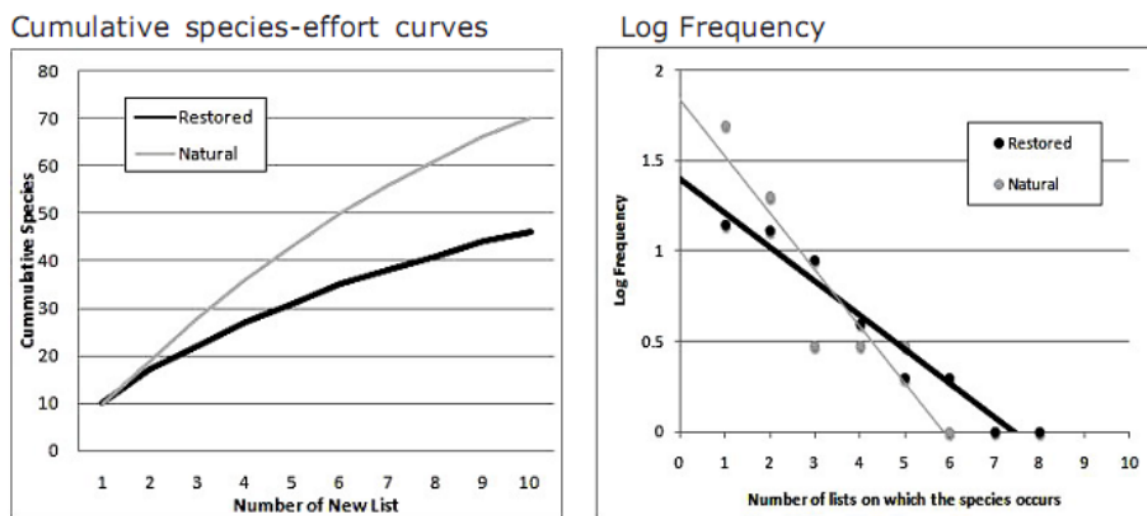


Figure 7 – example graphs of (left) cumulative total bird species observed and (right) an estimate of the number of bird species not observed

Mammals

Cameral traps were installed in each of the 4 study habitats (Figure 8). The cameras are triggered by objects moving in front of the lens. They produce colored photographs in daylight and black and white ones at night. The cameras were attached approximately 40 cm above the ground on tree trunks spaced at least 50 m apart, where animal activity was indicated by tracks and signs etc. Overall, 16 cameras were used, 4 in each habitat. Since the new cameras ordered had not arrived at the start of the project, initially 1 old camera was placed in CON, R12 & R24 on 1/5/24, as a preliminary study. Subsequently 4 cameras were placed simultaneously in each habitat from 9/5/24 to 2/11/24 (totally 712 trap-nights in reference forest and 720 trap-nights in each of the other three sites). The camera positions



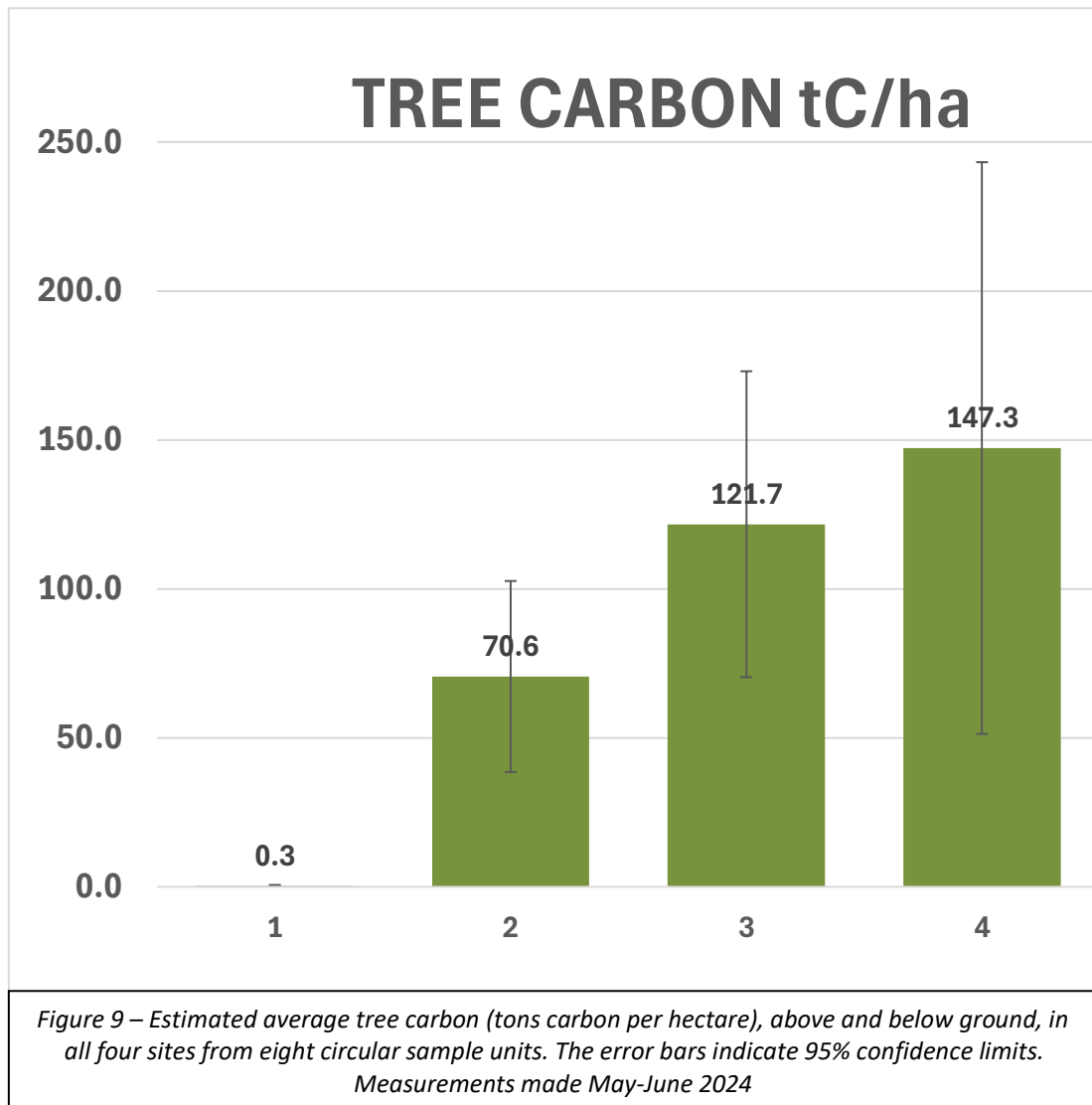
Figure 8 – setting up a camera trap in 24-year-old restored forest May 1st 2024.

in all four habitats were changed every 2 months, to maximize area covered. The memory cards were inspected monthly for records of mammals.

Each time an animal passes in front of a camera trap, it takes up to 3 photos. This counts as 1 animal encounter. When the camera captures multiple animals in 1 photo, multiple encounters are counted. To interpret the results, Frequency of Detection (FD) was calculated using the same formula as in the Relative Abundance Index (RAI) = $(E/TN) * 100$, where E is the number of animal encounters and TN is the total number of trap nights. The relative abundance reveals how common or rare a species is relative to other species in a defined location or community (Kunchorn, 2022). However, the term frequency of detection is used instead of relative abundance in this report.

Results and Discussion

Tree carbon



In 12 years and 24 years, after initiating forest-ecosystem restoration by the FSM, tree-carbon accumulation amounted to 48% and 84% respectively of the reference forest level (Figure 9).

Carbon accumulation followed a logistic curve with the equation:

$$\text{Tree Carbon (tC/ha)} = 142.2 / (1 + \text{EXP}(-0.2 * (\text{Year} - 12.8)))$$

This model predicts a return to reference-forest levels of tree carbon in about 34 years after initiating restoration measures.

Carbon accumulation, recorded during the present study, was lower than that previously reported by Jantawong *et al* (2022) in the same area. They reported an increase of 131 tC/ha (x1.24 to include roots) within the same trial-plot system over 14 years, using a more thorough technique— the partial harvesting method. The equation above predicts around 80 tC/ha carbon accumulation, over the same time frame.

At the nearby restoration-plot system at Mon Cham at similar elevation, tree-carbon accumulation at 10.5-11.5 years, using the FSM, was estimated at 71.7-80.8 tC/ha using the same data-collection methods as for the present study. Again, the present study resulted in lower carbon accumulation, predicted as 52-58 tC/ha for 10-11 years from the above equation.

However, even the lower figures from the current study greatly exceeded the pan-tropical average of 69.2 tC/ha for carbon accumulation over the first 20 years of natural forest succession (Silver *et al.*, 2000). The 20-year estimate, from the current study, is 116 tC/ha. This figure is also much higher than Jha *et al.*'s (2020) estimate of an average gain in tree carbon of 83 tC/ha (x1.24 to include roots) over the first 20 years of natural regeneration in Khao Yai National Park, Central Thailand (with similar climatic conditions as the present study), derived from remote-sensing data. In contrast, in teak plantations in western Thailand, average tree-carbon accumulation over the first 17 years amounted to just 20 tC/ha (x1.24 to include roots) (Chayaporn, 2021) (compared with a predicted estimate of 100 tC/ha @17 years from the current study).

There are three main reasons why the FSM results in much higher carbon accumulation rates than natural forest regeneration or plantations under similar conditions:

- i. the method deliberately selects tree species with highest survival and growth rates from among those representative of the reference forest ecosystem i.e. those species with highest productivity;
- ii. the method raises the initial stocking density to a high level (3,100/ha or 1.8 m spacing) by complementing natural regenerants with planted trees and
- iii. intense maintenance (weeding and fertilizer application 3 times/y), applied over the first two years after tree planting, allows the highly productive species selected to attain their full potential.

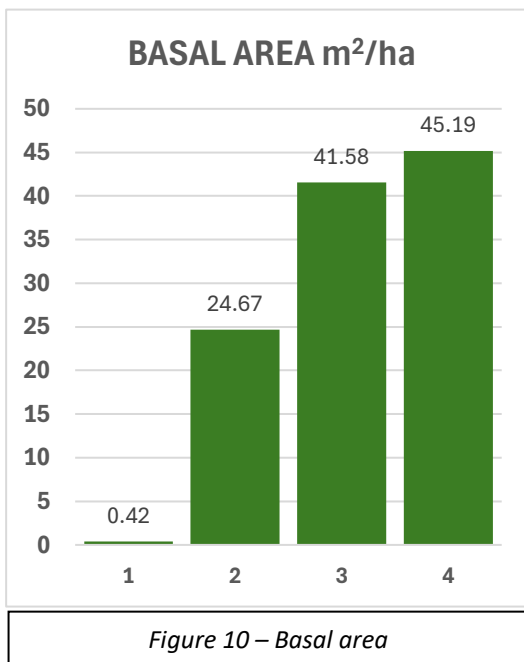
The equation above is specific for the early establishment phase of forest restoration (first 24 years), during which annual carbon increment increases almost exponentially—a pattern also reported by Jha *et al.* (2000) for young forest. Obviously, this will not continue indefinitely. The

data exhibit decelerating growth, averaging 5.9 tC/ha/y over the first 12 years, 4.3 over the second 12 years and 2.1 beyond 24 years; hence our use of a logistic model to make interim estimates of carbon accumulation.

This pattern of growth is expected since, as trees age, carbon respired by non-photosynthetic, structural, tree organs increases disproportionately more than that fixed by photosynthesis (West, 2020). Silver et al. (2000) reported that carbon accumulation rates, in recovering tropical secondary forests, decrease after 50–60 years and Chayaporn et al. (2021) also presented a logistic growth model for teak trees in Thailand, which trends towards an asymptote at 80–90 years. Clearly, additional data on the carbon balance in the later stages of logistic growth are needed, to compare carbon revenue, with other land uses over longer time spans.

Tree Community and Diversity

A total of 362 trees were recorded representing 102 species over all 32 circles.



Stocking density in R12 & R24 (stems per hectare) was 67 and 63% of reference forest levels respectively. From an initial high planting density of 3,100/ha, stocking density had declined to an estimated 1,607 and 1,512 trees/ha (DBH>5 cm), after 12 and 24 years respectively, probably due to competition and self-thinning. However, when tree size was taken into account i.e. basal area (ground occupied by tree trunks (m²/ha)), it was clear that the BA of the restoration plots approached that of the reference forest, shortly after 24 years. The R12 and R24 values were 56 and 92% of the reference forest value respectively. Typical BA values for tropical forests range from 20 to 40 m²/ha, so the values recorded in our study are considered high.

Table 2. Indices of diversity based on tree species recorded in 8 circular sample plots of 5 m radius at each habitat.

Index	CON	R12	R24	REF
No. species	1.00	50.00	41.00	56.00
N1	1.00	40.89	26.57	40.82
N2	1.00	33.89	14.11	31.45
E5	0.00	0.82	0.51	0.76

N1 and N2 are standard indices of biodiversity, which combine numbers of species (species richness) with their relative abundances. They are derived from the Shannon-Wiener index (H')

and Simpson's index (D), respectively, and are sometimes called "Hill numbers" or "effective numbers of species." $N1$ gives equal weighting to all species, whereas $N2$ weights abundant species more highly and gives less weight to rare species compared to $N1$. $N2$ is always lower than $N1$. $E5$ is an index of evenness (the distribution of individuals among species). An $E5$ of one indicates that all species are represented by the same number of individuals, whereas lower values indicate increasing dominance of a small number of species alongside many rare ones (Ludwig and Reynolds, 1988).

Species richness ($N0$) approached that of reference forest (Table 2). It is interesting to note that, of the 41 species found in the 8 SUs in R24, only 15 (37%) were planted. The rest must have established naturally from seeds dispersed into the plot by wind (five wind-dispersed species: *Albizia chinensis*, *A. odoratissima*, *Kydia calycina*, *Markhamia stipulata* and *Wendlandia paniculata*) or by birds and mammals. This validates the proposition that planting framework tree species catalyses biodiversity recovery. The full species lists for each site are presented in the Appendix 1 (Table A1.1). Both $N1$ and $N2$ values in R12 exceeded those of reference forest, indicating rapid recovery of tree species richness and high evenness. In contrast, in R24, both diversity and evenness indices were lower than those of the reference forest. This was because fewer species were recorded in the SUs and the high prevalence of one of the planted tree species, *Choerospondias axillaris*. A single very common species reduces both calculated evenness and diversity indices.

Soil Carbon

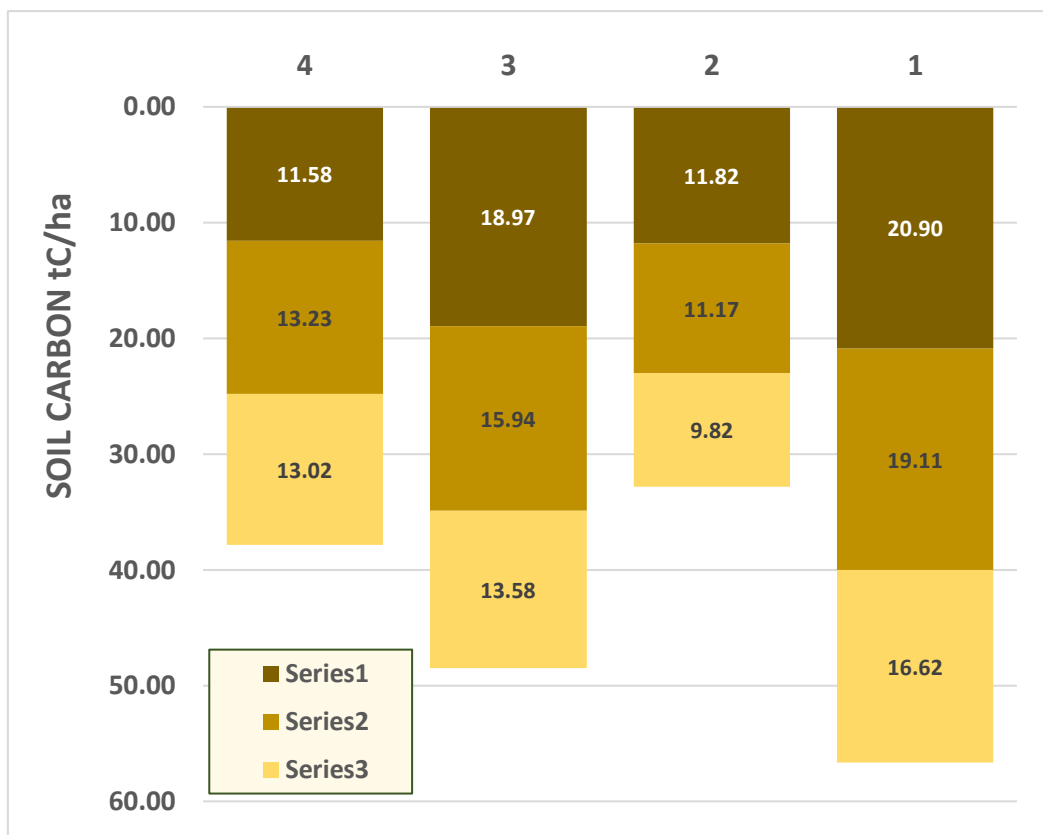


Figure 11 - Estimated SOM stock (tC/ha) at three depths across four site

During restoration as trees grow, depositing leaf litter and woody debris onto the soil surface, SOC is expected to increase. This is because the litter deposition rate usually slightly exceeds the decomposition rate. Furthermore, some of the carbon in the soil comes from the agents of decomposition (soil microbes and fauna) and some from recalcitrant organic compounds that resist further decomposition. These comprise humus, a stable form of SOM. Thus, carbon is expected to accumulate in the soil, as restoration proceeds. Whilst this appeared to be true for R12, SOC levels in R24 were well below expectations.

SOC stock in R12 exceeded that of the control habitat at all depths (Figure 11). Total R12 SOC stock (0-15 cm) was 10.66 tC/ha (or 28.2%) higher than that of the control habitat. These two habitats were adjacent to each other and both were on land with similar aspect and slopes. The starting conditions of R12 were very similar to the present-day conditions of the control habitat—previously cleared and cultivated for many years, dominated by herbaceous weeds with very few scattered trees. Therefore, the substantially higher SOC observed in R12 (compared with CON) probably represents a sharp increase since tree planting, attributable to large carbon inputs from the restored forest trees, which now cover the site. Furthermore, within 12 years, R12 SOC stock had recovered to about 86% of the REF value. It is striking to note how close the in R12 %SOC values are to those of the reference forest at all three depths (Table 3).

Table 3. Per cent SOC and total SOC recorded at four habitats and three soil depths

	Mean %SOC (corrected)	SD %SOC	Mean SOC stock 0-15 cm (tC/ha)	SD total SOC
CON			37.82	9.17
0-5 cm	3.43	0.96		
5-10 cm	3.45	1.01		
10-15 cm	3.01	0.91		
R12			48.48	5.75
0-5 cm	6.99	0.86		
5-10 cm	5.67	0.85		
10-15 cm	4.36	0.67		
R24			32.81	5.75
0-5 cm	4.25	0.58		
5-10 cm	3.90	0.56		
10-15 cm	3.23	0.95		
REF			56.64	15.74
0-5 cm	6.91	1.87		
5-10 cm	5.76	1.90		
10-15 cm	4.58	1.99		

The lower levels of SOC in the R24 habitat (Figure 11) are more difficult to explain. Although SOC stock in the uppermost layer matched that of the control habitat, it was substantially lower in the 5-10 and 10-15 cm layers. This resulted in SOC R24 being 5 tC/ha (13.2%) lower than that of the control habitat. Mean %SOC in the upper most layer of R24 was higher than that of the control, but in the lower two depths, it was very similar to the agricultural soil of the control. This hints at over cultivation and soil degradation (perhaps a land slide) in the distant past. Such a land-use legacy may not yet have been counteracted by inputs of carbon from the trees above.

Not surprisingly SOC was highest in the reference forest where human disturbance was least intense. The site did not have a history of logging or regeneration following clearance. Therefore, its relatively high SOC could be attributed to continuous input of organic matter from litterfall at a higher rate than decomposition. Furthermore, the dense root systems of the trees help to minimize soil erosion and promote the retention of organic matter.

Working in adjacent (but different) plots to those used in the present study, aged 2, 7 and 11 years since implementing restoration and measuring SOC stocks in soil pits dug down to 2 m depth, Kavinchan *et al.* (2015) reported that the FSM greatly increased SOC stocks compared with pre-restoration data, predicting a return to reference forest levels in less than 21.5 years after commencing restoration interventions. Similarly to the present study, they also reported that SOC did not increase in sequence with forest age. Reported mean values (0-2 m) were 205.8 tC/ha in their control habitat, 254.4 in R2, 251.1 in R7, 161.8 in R11 and 244.9 in the reference forest. They also attributed the incongruously low SOC value, observed in their R11 plot, to “persistent, overriding, effects of land-use history, reducing SOC in the lower soil layers”. They reported that %SOC declined with soil depth, following reliable power functions.

At Mon Cham (MC), a study using the same sampling techniques, also found that SOC did not correlate well with restoration progression. In that study SOC was estimated over an interval of 14 months in a control plot (CON), restoration plots aged 6 month-1.5 Y (MC22) and 10.5-11.5 Y (MC12) and the nearby reference forest (REF) (disturbed primary forest). The results were: CON=23.43-17.86 (tC/ha); MC22=26.61-26.00; MC12=22.22-19.29 & REF=25.63-27.50—roughly half the carbon observed in the study reported here. This may reflect greater and more recent and widespread disturbance at the Mon Cham sites compared with the BMS sites.

Total Carbon – costs and benefits

Table 4 shows total combined tree and soil carbon, compared with the Mon Cham study. The BMS sites stored more carbon overall than the previously studied Mon Cham sites. Although tree carbon at the MC sites was higher than at BMS, this was counteracted by considerably low lower soil carbon at MC, attributable to more intense and a longer history of disturbance at MC since it lies outside of the protection of Doi Suthep-Pui National Park. However it is interesting to note that the overall difference in total carbon between the two study areas was fairly consistent at 18-20 tC/ha.

Table 4 – Total soil and tree carbon storage (excluding ground vegetation) at all four habitats (tC/ha). The Mon Cham figures are included for comparison.
*11½ years after restoration commenced

	BMS			Mon Cham		
	SOIL	TREES	TOTAL	SOIL	TREES	MON CHAM
CON	37.82	0.30	38.12	17.86	0.00	17.86
R12	48.48	70.60	119.08	19.29	80.83	*100.12
R24	32.81	121.70	154.51	-	-	-
REF	56.64	147.30	203.94	27.5	157.99	185.49

Costs of carbon sequestration by the FSM range from 3.99 to 10.34 USD/tCO₂ (134-347 THB/tCO₂ (Jantawong *et al.*, 2022)). This figure compares well with Deesai’s (2011) estimated total cost of 9.87 USD/tCO₂ (adjusted for cumulative inflation at 17%, since 2011) for REDD+ implementation in Thailand (based solely on forest protection).

Since we were unable to prove that forest restoration increases soil carbon substantially in this study, we should can calculate value carbon gains for the trees only. Accumulation of 122 tC/ha tree carbon over 24 years (Figure 9, Table 4) is equivalent to 447 tCO₂/ha. If this could be traded on global carbon markets, it would yield (at the [current price of @72 €/tCO₂](#)) 32,184€ = 1.12 million THB/ha or 47,000 THB/y. Subtracting establishment costs of 16,348-42,334 THB (122 x (134-347 THB)) leaves around **1.10-1.07 million THB/ha profit over 24 years**.

Jantawong *et al.*, (2020) showed that converting maize fields to forest, using the FSM, would yield around 16 times more income than continuing with maize cultivation—maize being the main driver of deforestation in northern Thailand.

However, there is no cap-and-trade system for offsetting industrial carbon emissions in Thailand. Companies are not compelled by law to compete for carbon credits in an open market, which would drive prices up to global levels. Furthermore, there is no open carbon-credit market in Thailand, whereby the balance between supply and demand determine would price. Only low-priced “voluntary” carbon credits are purchased occasionally by a very small number of companies. Therefore, if farmers are to benefit from converting their fields to forests for carbon trading, the following conditions will be required:

- i) a cap-and-trade system to compel carbon-emitting industries to offset their emissions by purchasing compliance carbon credits;
- ii) a market for trading compliance credits (not voluntary credits);
- iii) low-interest startup loans, to cover initial tree planting costs;
- iv) low-cost monitoring and evaluation;
- v) capacity building and
- vi) simplification of carbon credit rules and regulations.

Birds

Over all habitats and observation periods, a total of 140 bird species (not including unidentified species) were observed. This markedly exceeded the 88 bird species, reported by Toktang (2007), working in the same plot system with bi-monthly observations from June 2002 to July 2003.

The McKinnon's list allows prediction of total species present from the slope of species accumulation curves, using successive lists of ten consecutive different bird species seen for each list, as the unit of observation effort. However, the predictive power of the equations for not seen species was variable with $R^2 = 0.20 - 0.71$. The observed and predicted number of species for each of the 4 habitats are listed in Table 1. The data support the proposition that hypothesis that forest-structure diversification, as restoration proceeds, increases diversity of habitats, which are then occupied by a greater diversity of bird species. The data show that both restoration habitats are far along a trajectory towards the bird species richness of the reference forest.

Table 5 – Numbers of bird species seen and predicted at each of the four habitats over four observation periods, totally 48h observation per habitat

Habitats	Observed	Predicted not observed	Total
CON	45	20	65
R12	70	9	79
R24	72	10	82
REF	83	17	100

For comparison, at MC the predicted total numbers of bird species were 89 for the control, 70 for 10–11-year-old restoration and 73 for the reference forest.

Table 6 lists 12 species which were recorded at all four habitats. Since such species are likely to fly from forest areas into deforested sites, the frugivores among them are the species most likely to have been responsible for depositing the seeds which catalyzed tree-species gain in restoration plots. The list clearly shows that Barbets and Bulbuls are the most likely habitat generalists to perform such a vital ecological role, initiating natural forest regeneration on open sites and increasing tree species richness at restoration plots.

Table 6 – Ubiquitous bird species recorded in all four habitats. Those listed as frugivores are most likely to catalyze forest regeneration and enhance restoration, through natural seed dispersal from forest to open sites.

Common Name	Scientific Name	Family	Habitat	Diet
Black-crested Bulbul	<i>Rubigula flaviventris</i>	Pycnonotidae	Forest edges, secondary growth, gardens	Frugivore
Blue-throated Barbet	<i>Psilopogon asiaticus</i>	Megalaimidae	Forests, woodlands, gardens	Frugivore
Common Tailorbird	<i>Orthotomus sutorius</i>	Cisticolidae	Shrublands, gardens, forests	Insectivore
Gray-eyed Bulbul	<i>Iole propinqua</i>	Pycnonotidae	Forests, secondary growth	Frugivore
Gray-headed Canary-flycatcher	<i>Culicicapa ceylonensis</i>	Stenostiridae	Forests, woodlands	Insectivore
Little Spiderhunter	<i>Arachnothera longirostra</i>	Nectariniidae	Forests, plantations, gardens	Nectarivore
Oriental White-eye	<i>Zosterops palpebrosus</i>	Zosteropidae	Forests, gardens, shrublands	Insectivore
Puff-throated Bulbul	<i>Alophoixus pallidus</i>	Pycnonotidae	Forests, bamboo thickets	Frugivore
Rufescent Prinia	<i>Prinia rufescens</i>	Cisticolidae	Grasslands, scrub, open forests	Insectivore
Sooty-headed Bulbul	<i>Pycnonotus aurigaster</i>	Pycnonotidae	Open woodlands, gardens, agricultural areas	Frugivore
White-rumped Shama	<i>Copsychus malabaricus</i>	Muscicapidae	Forests, bamboo groves, gardens	Insectivore
Yellow-browed Warbler	<i>Phylloscopus inornatus</i>	Phylloscopidae	Forests, woodlands, shrublands	Insectivore

Table 7 lists the species unique to each habitat, likely to be habitat specialists. The numbers of such species were 14, 18, 17 & 29 in CON, R12, R24 and REF respectively, suggesting that the number of specialists increases as restoration proceeds. Table 8 shows that as restoration advances, bird communities become less similar to the control habitat and more similar to the reference forest. This supports the hypothesis that as restoration progresses, more bird species recognize the developing forest as suitable habitat, with similar provision of food, nesting sites and other essential resources. Birds' eyes are more critical than human eyes for recognizing if restoration is achieving its ultimate goal of recreating the ecological functionality of the original forest.

It is interesting to note that the frequency of bird observations was fairly similar for all habitats: ranging from 6.5 for REF to 8.0 for R24 (Appendix 1, Table A1.2). This indicates that the overall bird population and activity is similar across all habitats. The main difference is that there are far more rare species in the forested habitats than in the control. The rate of observations in REF can be explained by difficulty of observation in dense forest.

Table 7 - Species unique to each habitat.

CON	R12	R24	Reference Forest
Black-necked Tailorbird	Arctic Warbler	Ashy Minivet	Amur Paradise Flycatcher
Bright-headed Cisticola	Asian Barred Owlet	Collared Owlet	Ashy Bulbul
Dusky Warbler	Asian Stubtail	Crested Serpent-Eagle	Ashy Drongo
Eastern Stonechat	Black-naped Oriole	Eurasian Tree Sparrow	Asian Fairy Bluebird
Eurasian Hoopoe	Blue-throated Bulbul	Flavescent Bulbul	Banded Kingfisher
Eurasian Skylark	Blyth's leaf Warbler	Gray pecked Woodpecker	Black shaded Bulbul
Gray breasted Prinia	Booted Eagle	Lesser Racked-tailed Drongo	Blue-and-white Flycatcher
Gray Bushchat	Brown Flycatcher	Lesser Yellownape	Brown-cheeked Fulvetta
Long-tailed Shrike	Greater Racket-tailed Drongo	Orange-bellied Leafbird	Common Green-Magpie
Oriental Honey-buzzard	Large-billed Crow	Red-billed Blue-Magpie	Gray Wagtail
Rufous-corgeated Flycatcher	Olive-backed Pipit	Rocket-tailed Treepie	Gray-throated Babbler
Scaly-headed Munia	Pale-legged Leaf Warbler	Silver Pheasant	Great spotted Woodpecker
Wood Sandpiper	Plain Prinia	Small Minivet	Indian Paradise-Flycatcher
Zitting Cisticola	Pygmy Wren Babbler *	Speckled Piculet	Little Pied Flycatcher
	Red Crossbill	Stripe-throated Bulbul	Orange-headed Thrush
	Scaly-breasted Munia	White-crested Laughing Thrush	Oriental dollarbird
	Scarlet backed Flowerpecker	White-throated Fantail	Rufous-throated Fulvetta *
	Swinhoe's White-eye		Rufous Treepie
			Shikra
			Slaty-backed Forktail
			Spotted Owlet
			Straited Bulbul
			Tickell's Blue Flycatcher
			Verditer Flycatcher
			Violet Cuckoo
			White Rumped Munia
			White-bellied Erpornis
			White-browed Piculet
			Yellow-bellied Warbler
14	18	17	29

Table 8 – Similarity of bird species composition among habitats. Yellow: no. spp. shared between two habitats; Red – total species observed (no. spp. unique to each habitat); blue – Sorensen's index of similarity (0 indicates totally different to 1= identical).

All censuses				
	CONTROL	R12	R24	REF FOREST
CONTROL	45 (14)	21	16	13
R12	0.42	70 (18)	36	28
R24	0.32	0.55	72 (17)	32
REF FOREST	0.23	0.42	0.50	83 (29)



Figure 12 – Example of bird species observed: (a) Black-crested Bulbul abundant in all forested sites and seen occasionally in the control plot; (b) Speckled Piculet –seen only once in R24; (c) Rufescent Prinia – common in CON and rare in the forested plots; (d) Hill Blue Flycatcher – found only in the forested plots; (e) White-rumped Shama common in advanced restoration and (f) Blue throated barbet – excellent seed disperser in restored plots where it thrives.

Mammals

A total of at least 18 small and medium sized mammal species were recorded in the camera-trap survey (Table 9), including 1 critically endangered species: the Sunda Pangolin (*Manis javanica*), and 1 vulnerable species: Hog Badger (*Arctonyx collaris*), according to the IUCN Red List. All others were considered of least concern, in terms of their conservation status.

The pangolin (Figure 13) is a highly valuable species, much prized for Chinese medicine, and consequently it is intensely hunted. Its presence in the study area may indicate that hunting may be in decline there. When camera traps were first set up in Pah Dong Saeng 10 years ago, they often detected men carrying guns, whereas in the present survey, no hunters were photographed.



Figure 13 – the Sunda Pangolin in the reference forest. Its presence suggests that hunting may not be as frequent as it was in the past.

The most important detected mammal species for forest restoration was the common palm civet (Figure 14). It is highly frugivorous and ranges widely across both forested and open habitats. It was also the most frequently detected mammal species over the entire study (Table 10). Therefore, it is likely to be the most prolific seed-dispersing mammal species in the area, catalyzing natural forest regeneration on open sites and adding to tree-species richness in restoration plots.

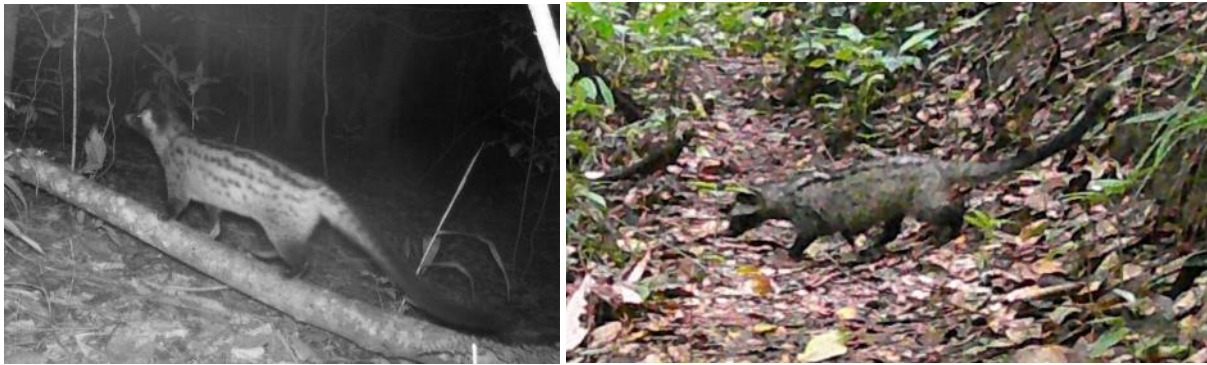


Figure 14 – Common Palm Civet using a log to move easily through R24 (above left), defaecating in the same plot (left) and crossing a trackway in reference forest in daylight (above right), showing that the species is not exclusively nocturnal. This species is a prolific disperser of seeds from forest into restoration plots. Previous observations showed that it dispersed coffee beans over many kilometers into restoration plots

A close relative of the Common Palm Civet, the Large Indian Civet (Figure 15) was the second most frequently detected mammal species (Table 10). Although fruits are occasionally part of its diet, the species is considered to be mostly carnivorous. Therefore, it is less likely to play a major role in seed dispersal than its smaller relative. The crab-eating mongoose (Figure 15) is likewise opportunistically and only occasionally frugivorous (particularly in forest habitats) and is unlikely to be a prolific seed disperser.



Figure 15 – In R12, a Large Indian Civet (left) and Crab-eating Mongoose preying on a snake.

The abundance of Leopard Cats (Figure 16) in all three forested habitats is also good for restoration. Although they are not seed-dispersers, the cats prey on rodents, which are mainly seed predators. By helping to control the populations of such seed predators, the cats increase the chances that incoming seeds will germinate. The camera traps also captured evidence that the Large Indian Civet may play a similar ecological role (Figure 16).



Figure 16 – The top predators of the mammal communities were the Leopard Cat (left), photographed in the day time in R12, and the Large Indian Civet, photographed at night carrying a large rodent, also in R12.

Both R12 and R24 supported more than double the number of mammal species recorded in the control habitat and more than half of the number of mammal species recorded in the reference forest. This strongly suggests that forest restoration by the framework species method promotes recovery of small and medium sized mammal communities and that such communities in the R12 and R24 sites are well along a trajectory towards attaining a high species richness similar to that of the reference forest.

This conclusion was further supported by the mammal activity data (frequency of detection, (Table 10). Highest mammal activity was recorded in reference forest (FD = 42.69) and the lowest in control habitat (FD = 1.94). FD values in R12 and R24 were 43% and 55.3% of the reference forest value, indicating steady increase in mammal activity as restoration progresses.

The results of the present study were very similar to those of a previous study (Feb-Dec 2021) (Kunchorn, 2022), which compared mammal communities in 7-year-old restoration at Mon Long (R7) and 9-year-old restoration at Mon Cham (R9) with reference evergreen forest and a control site; totally 1,026 camera-trap nights per habitat. Twelve species were recorded in natural forest. The Large Indian Civet (*Viverra zibetha*) had the highest FD value of 4.09. R7 supported 7 recorded species, with the Northern Treeshrew (*Tupaia belangeri*) having the highest FD (0.39). Six species were recorded in R9 with the Leopard Cat (*Prionailurus bengalensis*) having the highest frequency (FD 0.88). The similarity of mammal species between R9 and REF was 67%, between R7 and REF 32% and between R7 and R9, 46%. That study also confirmed that restoration provides habitats for local mammals, and attracts seed dispersers which can contribute towards natural regeneration via seed dispersal.



Figure 17 – Top: Hog Badger in reference forest (left) and R12 (right). Red Muntjac (middle left) and Eurasian Wild Pig (middle right) in reference forest. Red-Cheeked Squirrel in reference forest (left) and Large-toothed Ferret-Badger in R24.

Table 9 and Figure 17 –Mammal species recorded in all four habitats. Green cells = species detected in only 1 habitat (specialists); Orange cells = species detected in all habitats

ENGLISH NAME	SCIENTIFIC NAME	FAMILY	CONSERVATION STATUS*	DIET	PREFERRED HABITAT	RECORDED IN ...			
						CON	R12	R24	NF
Common palm civet	<i>Paradoxurus hermaphroditus</i>	Viverridae	LC	Omnivorous (fruits, small animals)	Forests, plantations, urban areas	✓	✓	✓	✓
Large Indian civet	<i>Viverra zibetha</i>	Viverridae	LC	Carnivorous (small mammals, insects)	Forests, grasslands, agricultural areas	✓	✓	✓	✓
Crab-eating mongoose	<i>Herpestes urva</i>	Herpestidae	LC	Carnivorous (crabs, amphibians, insects)	Riversides, forests, wetlands	✓	✓	✓	✓
Burmese hare	<i>Lepus peguensis</i>	Leporidae	LC	Herbivorous (grasses, leaves)	Grasslands, open forests	✓			
Hog badger	<i>Arctonyx collaris</i>	Mustelidae	V	Omnivorous (roots, invertebrates, small animals)	Forests, grasslands		✓	✓	✓
Leopard cat	<i>Prionailurus bengalensis</i>	Felidae	LC	Carnivorous (small mammals, birds)	Forests, grasslands, agricultural areas		✓	✓	✓
Large-toothed ferret-badger	<i>Melogale personata</i>	Mustelidae	LC	Omnivorous (insects, fruits, small vertebrates)	Forests, grasslands			✓	✓
Sunda pangolin	<i>Manis javanica</i>	Manidae	CE	Insectivorous (ants, termites)	Forests, grasslands		✓		✓
Eurasian wild pig	<i>Sus scrofa</i>	Suidae	LC	Omnivorous (roots, fruits, small animals)	Forests, grasslands, agricultural areas		✓		✓
Western striped squirrel	<i>Tamiops mccllellandii</i>	Sciuridae	LC	Herbivorous (seeds, fruits)	Forests			✓	
Red muntjac	<i>Muntiacus muntjak</i>	Cervidae	LC	Herbivorous (leaves, fruits, grass)	Forests, grasslands				✓
Red-cheeked squirrel	<i>Dremomys rufigenis</i>	Sciuridae	LC	Herbivorous (seeds, fruits)	Forests				✓
Variable squirrel	<i>Callosciurus finlaysonii</i>	Sciuridae	LC	Herbivorous (seeds, fruits, leaves)	Forests, gardens				✓
Nothern treeshrew	<i>Tupaia belangeri</i>	Tupaiaidae	LC	Omnivorous (insects, fruits)	Forests, plantations				✓
Unidentified bat									✓
Unidentified squirrel							✓	✓	✓
Unidentified rat							✓	✓	✓
Unidentified species							✓	✓	✓

*LC= least concern; V=vulnerable;CE=critically endangered

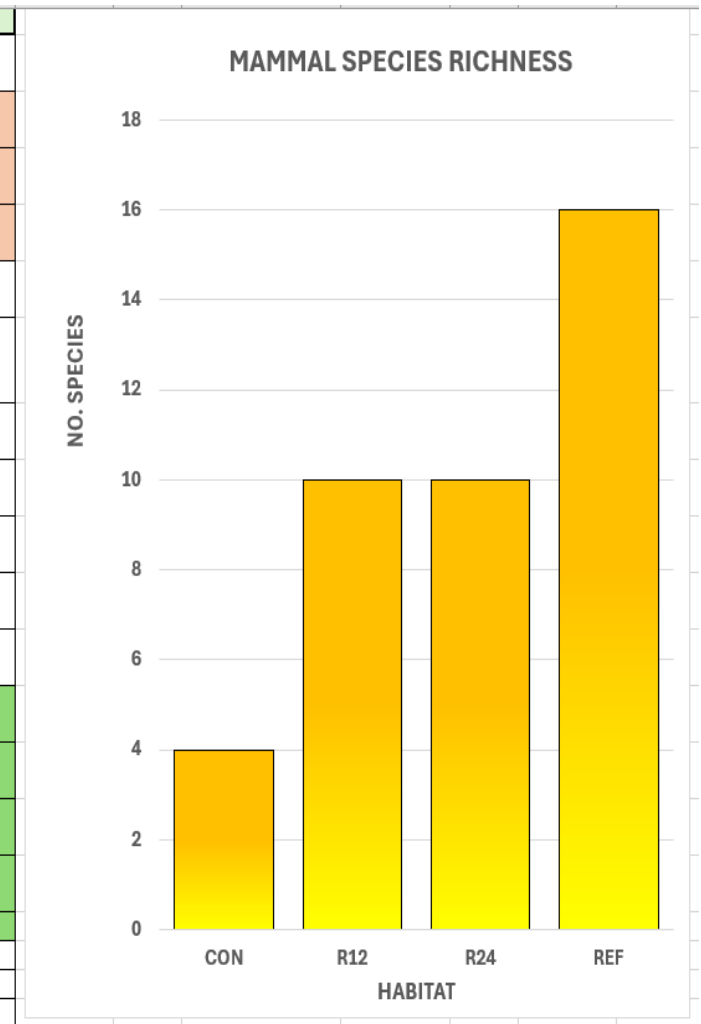
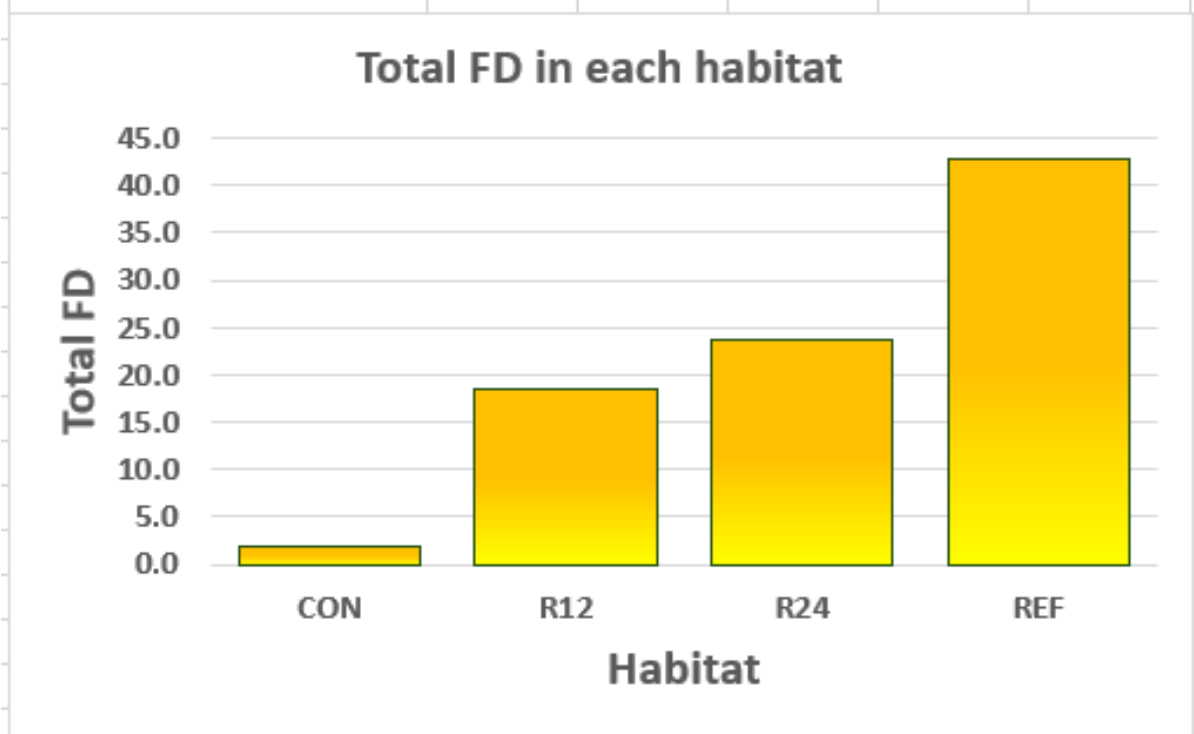


Table 10 and Figure 18 –Mammal species frequency of detection (FD) in all four habitats.

	HABITATS				Total
	CON	R12	R24	REF	
Common palm civet	0.1389	3.7500	8.6111	16.5730	29.0730
Large Indian civet	0.9722	6.8056	8.6111	0.7022	17.0911
Unidentified rat	0.0000	2.6389	3.7500	3.7921	10.1810
Unidentified squirrel	0.0000	0.5556	0.4167	6.7416	7.7138
Red-cheeked squirrel	0.0000	0.0000	0.0000	5.6180	5.6180
Leopard cat	0.0000	1.6667	0.9722	1.9663	4.6052
Unidentified species	0.0000	0.6944	0.1389	1.8258	2.6592
Hog badger	0.0000	1.3889	0.2778	0.7022	2.3689
Crab-eating mongoose	0.6944	0.6944	0.5556	0.2809	2.2253
Eurasian wild pig	0.0000	0.1389	0.0000	1.4045	1.5434
Variable squirrel	0.0000	0.0000	0.0000	1.2640	1.2640
Nothern treeshrew	0.0000	0.0000	0.0000	0.9831	0.9831
Large-toothed ferret-badger	0.0000	0.0000	0.1389	0.4213	0.5602
Sunda pangolin	0.0000	0.1389	0.0000	0.1404	0.2793
Red muntjac	0.0000	0.0000	0.0000	0.1404	0.1404
Unidentified bat	0.0000	0.0000	0.0000	0.1404	0.1404
Burmese hare	0.1389	0.0000	0.0000	0.0000	0.1389
Western striped squirrel	0.0000	0.0000	0.1389	0.0000	0.1389
Total	1.9444	18.4722	23.6111	42.6966	86.7244



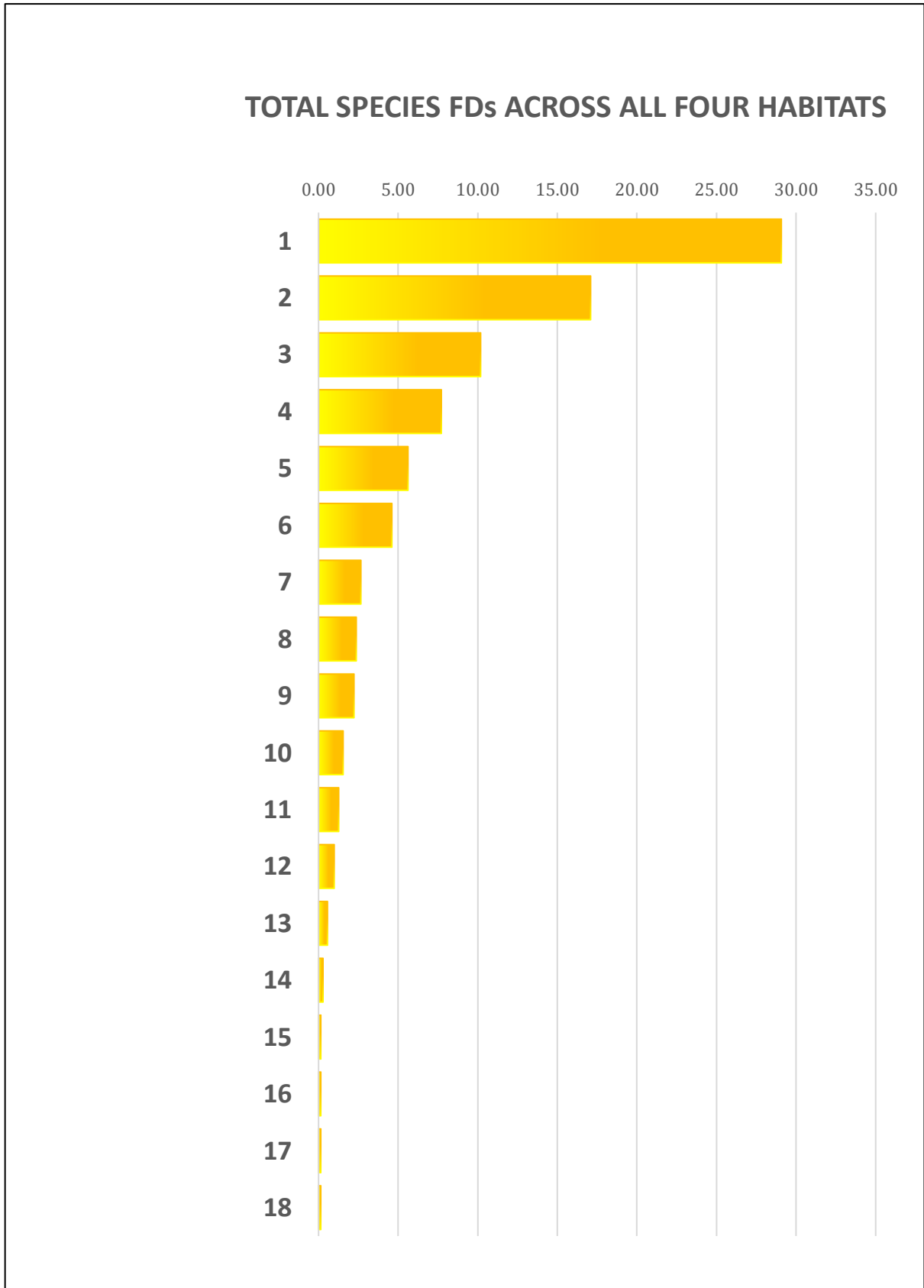


Figure 19 – Total frequency of detection for each species across all four habitats

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APPENDIX 1 - DATA

Tabel A1.1 – Tree species and no. individuals recorded in 8 circular sample units of 5 m radius

SPECIES	CONTROL	12-Y-OLD RESTN	24-Y-OLD RESTN	REFERENCE FOREST	TOTAL
<i>Actinodaphne henryi</i>				3	3
<i>Alangium kurzii</i>		1		1	2
<i>Albizia chinensis</i>			1		1
<i>Albizia odoratissima</i>		2	3	1	6
<i>Antidesma bunius</i>				4	4
<i>Antidesma ghaesembilla</i>		1			1
<i>Aporosa villosa</i>		1		9	10
<i>Artocarpus lanceolata</i>		4	1		5
<i>Artocarpus lacucha</i>				3	3
<i>Artocarpus lakoocha</i>		3	1	1	5
<i>Artocarpus rigidus</i>		1			1
<i>Baccaurea ramiflora</i>			1		1
<i>Balakata baccata</i>			3		3
<i>Berrya mollis</i>		1			1
<i>Bischofia javanica</i>		2			2
<i>Bridelia glauca</i>				2	2
<i>Castanopsis acuminatissima</i>		1	1	4	6
<i>Castanopsis calathiformis</i>		3			3
<i>Castanopsis diversifolia</i>		1		3	4
<i>Castanopsis tribuloides</i>			2		2
<i>Choerospondias axillaris</i>		6	20		26
<i>Cinnamomum inners</i>		1			1
<i>Cinnamomum longipetiolatum</i>				1	1
<i>Colona floribunda</i>				1	1
<i>Croton roxburghii</i>				6	6
<i>Cryptocarya amygdalina</i>				5	5
<i>Dalbergia cultrata</i>				2	2
<i>Dalbergia ovata</i>		6	1	6	13
<i>Dalbergia spinosa</i>				6	6
<i>Dillenia parvifolia</i>			2		2
<i>Elaeocarpus glandiflorus</i>		1			1
<i>Elaeocarpus lanceifolius</i>		2			2
<i>Engelhardia spicata</i>		1			1
<i>Engelhardtia spicata</i>		1		1	2
<i>Erythrina stricta</i>		2			2
<i>Eugenia albiflora</i>				4	4

SPECIES	CONTROL	12-Y-OLD RESTN	24-Y-OLD RESTN	REFERENCE FOREST	TOTAL
<i>Eugenia claviflora</i>		2	2		4
<i>Eurya acuminata</i>		4		1	5
<i>Fernandoa adenophylla</i>		2		2	4
<i>Ficus benjamina</i>			2		2
<i>Ficus fistulosa</i>		1	1	1	3
<i>Ficus glaberrima</i>			5		5
<i>Ficus hispida</i>		2			2
<i>Ficus subulata</i>				1	1
<i>Ficus superba</i>			2		2
<i>Garcinia merguensis</i>				1	1
<i>Garuga pinnata</i>			1		1
<i>Gluta usitata</i>				1	1
<i>Gmelina arborea</i>			1	1	2
<i>Grewia eriocarpa</i>				1	1
<i>Helicia nilagirica</i>			1		1
<i>Heliciopsis terminalis</i>				1	1
<i>Heynea trijuga</i>			1		1
<i>Horsfieldia amygdalina</i>		2		1	3
<i>Hovenia dulcis</i>		1	1		2
<i>Ilex umbelulata</i>		2			2
<i>Kydia calycina</i>			1		1
<i>Lannea coromandelica</i>			1		1
<i>Lithocarpus elegans</i>			1	6	7
<i>Lithocarpus garrttianus</i>		4	1		5
<i>Litsea glutinosa</i>		1	1		2
<i>Litsea salicifolia</i>		2	2	12	16
<i>Macaranga denticulata</i>				1	1
<i>Machilus bombycina</i>		1	3	4	8
<i>Magnolia champaca</i>		1			1
<i>Magnolia liliifera</i>			2		2
<i>Markhamia stipulata</i>		4	2	1	7
<i>Matadina trichotoma</i>				1	1
<i>Measa ramenta</i>		1	1		2
<i>Meliosma simplicifolia</i>				1	1
<i>Michelia baillonii</i>		2		1	3
<i>Micromelum minutum</i>				1	1
<i>Miliusa velutina</i>			1		1
<i>Morus macroura</i>				1	1
<i>Nothaphoebe umbelliflora</i>		4		5	9
<i>Nyssa javanica</i>			1		1

SPECIES	CONTROL	12-Y-OLD RESTN	24-Y-OLD RESTN	REFERENCE FOREST	TOTAL
<i>Ostodes paniculata</i>				3	3
<i>Persea americana</i>	15				15
<i>Phoebe cathia</i>				1	1
<i>Phoebe lanceolata</i>		1	5	7	13
<i>Prunus arborea</i>			1		1
<i>Prunus cerasoides</i>		5	9		14
<i>Pterocarpus ovata</i>		1			1
<i>Quercus semiserrata</i>				2	2
<i>Reevesia pubescens</i>				3	3
<i>Sapindus rarak</i>			1	2	3
<i>Sarcosperma arboreum</i>		1	1	2	4
<i>Schima wallichii</i>		1		3	4
<i>Semecarpus cochinchinensis</i>		2			2
<i>Sterculia villosa</i>		1		1	2
<i>Stereospermum colais</i>				1	1
<i>Styrax benzoides</i>		1			1
<i>Styrax benzoin</i>				2	2
<i>Symplocos racemosa</i>		1		4	5
<i>Tarenna hoensis</i>				1	1
<i>Toona ciliata</i>		1			1
<i>Trevesia palmata</i>			1		1
<i>Turpinia pomifera</i>		2	3	8	13
<i>Vernonia volkameriifolia</i>		2			2
<i>Vitex quinata</i>				1	1
<i>Wendlandia paniculata</i>			4	2	6
<i>Wendlandia tinctoria</i>		5			5
No. of trees	15	101	95	151	362
No. of tree species	1	50	41	56	102

Tabel A1.2– Bird species - number of records and records per observation person-hour in all four habitats (totally 48 h person-hours observation effort per site)

Bird Species	CON		R12		R24		REF	
	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h
Amur Paradise Flycatcher		0.00		0.00		0.00	1	0.02
Arctic Warbler		0.00	1	0.02		0.00		0.00
Ashy Bulbul		0.00		0.00		0.00	1	0.02
Ashy Drongo		0.00	4	0.08	4	0.08	4	0.08
Ashy Minivet		0.00		0.00	1	0.02		0.00
Asian Barred Owlet		0.00	1	0.02		0.00		0.00
Asian Brown Flycatcher	10	0.21	5	0.10		0.00		0.00
Asian Fairy Bluebird		0.00		0.00		0.00	2	0.04
Asian Green Bee-eater		0.00	4	0.08	1	0.02		0.00
Asian Palm Swift	36	0.75		0.00		0.00	1	0.02
Asian Paradise Flycatcher		0.00	1	0.02	3	0.06		0.00
Asian Stubtail		0.00	1	0.02		0.00		0.00
Banded Kingfisher		0.00		0.00		0.00	1	0.02
Bar-winged Flycatcher-shrike	1	0.02	1	0.02	1	0.02		0.00
Barn Swallow	1	0.02	1	0.02		0.00		0.00
Black naped Monarch		0.00		0.00	4	0.08		0.00
Black naped Oriole		0.00	1	0.02		0.00		0.00
Black shaded Bulbul		0.00		0.00		0.00	1	0.02
Black throated Sunbird		0.00		0.00	7	0.15	3	0.06
Black-crested Bulbul	4	0.08	32	0.67	47	0.98	10	0.21
Black-headed Bulbul		0.00		0.00	1	0.02	5	0.10
Black-naped Monarch		0.00		0.00		0.00	5	0.10
Black-necked Tailorbird	16	0.33		0.00		0.00		0.00
Black-throated Sunbird		0.00	4	0.08		0.00	1	0.02
Blue and white Flycatcher		0.00		0.00		0.00	1	0.02
Blue Bee eater	1	0.02		0.00	2	0.04		0.00
Blue-throated Barbet	4	0.08	32	0.67	34	0.71	24	0.50
Blue-throated blue Flycatcher		0.00		0.00		0.00	3	0.06
Blue-throated Bulbul		0.00	3	0.06		0.00		0.00
Blue-throated Flycatcher		0.00		0.00	2	0.04		0.00
Blue-winged Leafbird		0.00	1	0.02	1	0.02	1	0.02
Blyth's leaf Warbler		0.00	1	0.02		0.00		0.00
Blyth's shrike-Babbler		0.00		0.00	2	0.04	2	0.04
Booted Eagle		0.00	1	0.02		0.00		0.00
Bright-headed Cisticola	1	0.02		0.00		0.00		0.00
Bronzed Drongo		0.00		0.00	2	0.04	7	0.15

Bird Species	CON		R12		R24		REF	
	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h
Brown Flycatcher		0.00	1	0.02		0.00		0.00
Brown-cheeked Fulvetta		0.00		0.00		0.00	2	0.04
Buff-breasted Babbler		0.00	3	0.06	3	0.06	4	0.08
Claudia's Leaf Warbler		0.00		0.00		0.00	2	0.04
Collared Owlet		0.00		0.00	1	0.02		0.00
Common Dove		0.00		0.00	1	0.02		0.00
Common Green-Magpie		0.00		0.00		0.00	1	0.02
Common Iora		0.00	2	0.04		0.00	1	0.02
Common tailorbird	51	1.06	16	0.33	18	0.38	16	0.33
Crested Serpent Eagle		0.00		0.00	2	0.04		0.00
Dark-necked Tailorbird		0.00	1	0.02	5	0.10	4	0.08
Dark-sided Flycatcher		0.00	1	0.02	3	0.06		0.00
Davison's Leaf Warbler		0.00		0.00	1	0.02	1	0.02
Dusky Warbler	9	0.19		0.00		0.00	1	0.02
Eastern Stonechat	5	0.10		0.00		0.00		0.00
Eurasian Hoopoe	4	0.08		0.00		0.00		0.00
Eurasian Skylark	1	0.02		0.00		0.00		0.00
Eurasian Tree Sparrow		0.00		0.00	1	0.02		0.00
Ferruginous Flycatcher		0.00	1	0.02		0.00	3	0.06
Fire-breasted Flowerpecker		0.00	4	0.08	1	0.02		0.00
Flavescent Bulbul		0.00		0.00	1	0.02		0.00
Gray Bushchat	8	0.17		0.00		0.00		0.00
Gray pecked Woodpecker		0.00		0.00	1	0.02		0.00
Gray throated Babbler		0.00		0.00		0.00	4	0.08
Gray Treepie		0.00	3	0.06	1	0.02		0.00
Gray-eyed Bulbul	1	0.02	24	0.50	27	0.56	17	0.35
Great Barbet		0.00	13	0.27	5	0.10	10	0.21
Great spotted Woodpecker		0.00		0.00		0.00	1	0.02
Greater Coucal	2	0.04	5	0.10	3	0.06		0.00
Greater Racket-tailed Drongo		0.00	1	0.02		0.00		0.00
Green-billed Malkoha		0.00		0.00	2	0.04	1	0.02
Greenish Warbler		0.00	9	0.19	3	0.06	2	0.04
Grey breasted Prinia	7	0.15		0.00		0.00		0.00
Grey Wagtail		0.00		0.00		0.00	1	0.02
Grey-headed Canary-flycatcher	1	0.02	25	0.52	22	0.46	16	0.33
Grey-throated Babbler		0.00		0.00		0.00		0.00
Hainan blue Flycatcher		0.00	2	0.04	2	0.04	3	0.06
Hair Crested Drongo		0.00	4	0.08	4	0.08	1	0.02
Hill Blue Flycatcher		0.00	1	0.02	8	0.17	4	0.08

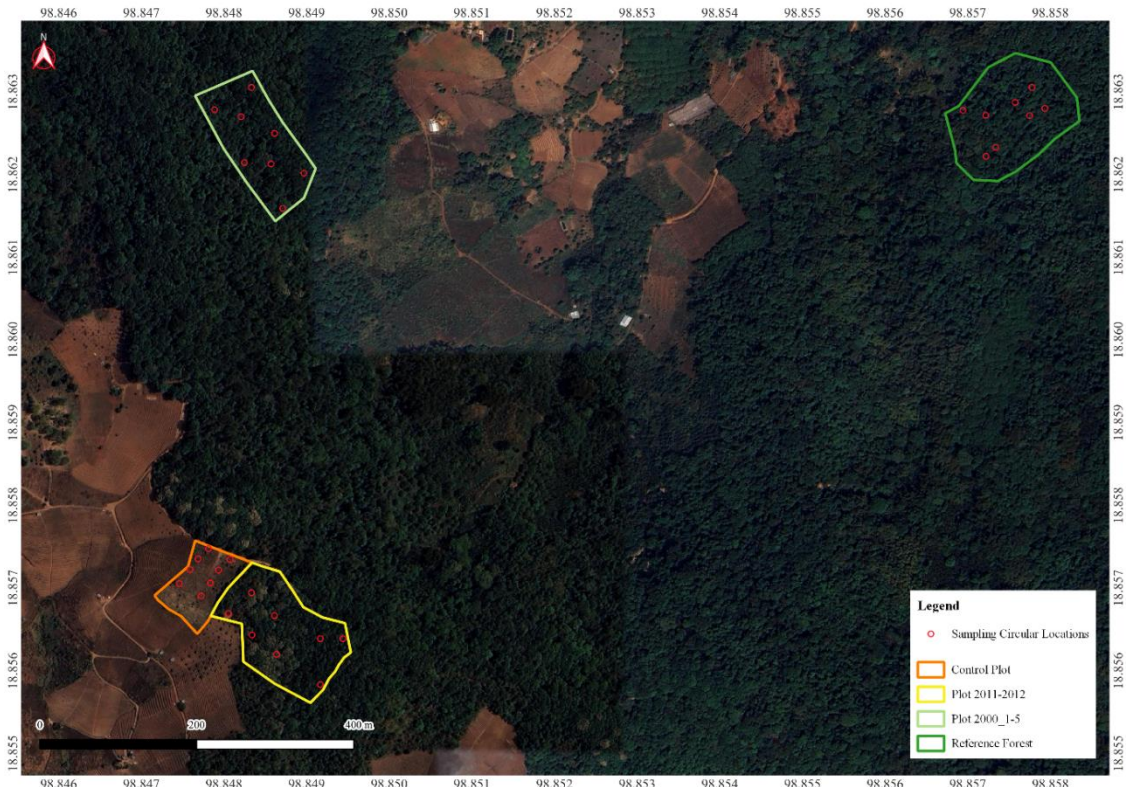
Bird Species	CON		R12		R24		REF	
	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h
House Swift	17	0.35	3	0.06	3	0.06		0.00
Indian Paradise-Flycatcher		0.00		0.00		0.00	1	0.02
Indian White-eye		0.00	6	0.13	1	0.02	2	0.04
Indo Blue Flycatcher		0.00		0.00		0.00	1	0.02
Large-billed Crown		0.00	1	0.02		0.00		0.00
Lesser Racket-tailed Drongo		0.00		0.00	1	0.02		0.00
Lesser Yellownappe		0.00		0.00	1	0.02		0.00
Little Pied Flycatcher		0.00		0.00		0.00	2	0.04
Little Spiderhunter	14	0.29	2	0.04	14	0.29	16	0.33
Long-tailed Shrike	1	0.02		0.00		0.00		0.00
Mountain Bulbul		0.00	4	0.08	7	0.15	5	0.10
Olive-backed Pipit		0.00	2	0.04	1	0.02		0.00
Olive-backed Sunbird		0.00	2	0.04		0.00	1	0.02
Orange-bellied Leafbird		0.00		0.00	1	0.02		0.00
Orange-headed Thrush		0.00		0.00		0.00	3	0.06
Oriental dollarbird		0.00		0.00		0.00	1	0.02
Oriental Honey-buzzard	6	0.13		0.00		0.00		0.00
Oriental Magpie Robin	5	0.10	3	0.06		0.00		0.00
Oriental White eye	4	0.08	1	0.02	6	0.13	1	0.02
Pale-legged Leaf Warbler		0.00	1	0.02		0.00	1	0.02
Pied Bushchat	21	0.44	2	0.04		0.00		0.00
Pin-striped Tit-Babbler		0.00	3	0.06	6	0.13	7	0.15
Plain Prinia		0.00	1	0.02		0.00		0.00
Plaintive Cuckoo		0.00	1	0.02	1	0.02		0.00
Puff-throated Babbler		0.00	13	0.27	4	0.08	3	0.06
Puff-throated Bulbul	2	0.04	4	0.08	6	0.13	10	0.21
Pygmy Wren Babbler		0.00	1	0.02		0.00		0.00
Red crossbill		0.00	1	0.02		0.00		0.00
Red whiskered Bulbul	4	0.08	6	0.13	2	0.04	1	0.02
Red-billed Blue-Magpie		0.00		0.00	1	0.02		0.00
Rocket-tailed Treepie		0.00		0.00	1	0.02		0.00
Rufescent Prinia	14	0.29	2	0.04	3	0.06	1	0.02
Rufous -throated Fulvetta		0.00		0.00		0.00	1	0.02
Rufous Buzzard		0.00		0.00	1	0.02		0.00
Rufous Treepie		0.00		0.00		0.00	1	0.02
Rufous-corgeated Flycatcher	1	0.02		0.00		0.00		0.00
Scaly-breasted Munia		0.00	1	0.02		0.00		0.00
Scaly-headed Munia	2	0.04		0.00		0.00		0.00
Scarlet backed Flowerpecker		0.00	3	0.06		0.00	1	0.02

Bird Species	CON		R12		R24		REF	
	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h
Scarlet Minivet		0.00		0.00	3	0.06	7	0.15
Silver Pheasant		0.00		0.00	1	0.02		0.00
Silver-breasted Broadbill		0.00		0.00	2	0.04	5	0.10
Slaty-backed Flycatcher		0.00		0.00		0.00	1	0.02
Slaty-backed Forktail		0.00		0.00		0.00	1	0.02
Small Minivet		0.00		0.00	1	0.02		0.00
Sooty headed Bulbul	66	1.38	10	0.21	1	0.02	2	0.04
Speckled Piculet		0.00		0.00	1	0.02		0.00
Spotted Dove	15	0.31	3	0.06		0.00		0.00
Spotted Owlet		0.00		0.00		0.00	1	0.02
Straited Bulbul		0.00		0.00		0.00	1	0.02
Streaked Spiderhunter		0.00	9	0.19	13	0.27	4	0.08
Stripe-throated Bulbul		0.00		0.00	3	0.06		0.00
Swinhoe's White-eye		0.00	1	0.02		0.00		0.00
Taiga Flycatcher		0.00	2	0.04	3	0.06	1	0.02
Tickell's Blue Flycatcher		0.00		0.00		0.00	2	0.04
Unidentified Bulbul	1	0.02	1	0.02		0.00		0.00
Unidentified Bushchat	1	0.02		0.00		0.00		0.00
Unidentified Flycatcher		0.00	1	0.02		0.00		0.00
Unidentified Minivet	1	0.02	1	0.02		0.00	1	0.02
Unidentified Munia	2	0.04		0.00		0.00		0.00
Unidentified Warbler	1	0.02	2	0.04	1	0.02		0.00
Unidentified Woodpecker		0.00		0.00		0.00		0.00
Unidentified Oriole		0.00		0.00		0.00		0.00
Unidentified Sunbird	2	0.04		0.00		0.00	1	0.02
Unidentified Swift	2	0.04		0.00		0.00		0.00
Velvet-fronted Nuthatch		0.00		0.00	1	0.02	2	0.04
Verditer Flycatcher		0.00		0.00		0.00	1	0.02
Violet Cuckoo		0.00		0.00		0.00	1	0.02
White Rumped Munia		0.00		0.00		0.00	1	0.02
White Rumped Shama	1	0.02	11	0.23	39	0.81	24	0.50
White-bellied Erpornis		0.00		0.00		0.00	1	0.02
White-browed Scimitar-Babbler		0.00	2	0.04		0.00	2	0.04
White-browed shrike Babbler		0.00		0.00	2	0.04	1	0.02
White-browed Piculet		0.00		0.00		0.00	1	0.02
White-crested Laughing Thrush		0.00		0.00	2	0.04		0.00
White-rumped Shama	1	0.02	7	0.15	15	0.31	13	0.27
White-throated Fantail		0.00		0.00	3	0.06		0.00
Wood Sandpiper	1	0.02		0.00		0.00		0.00

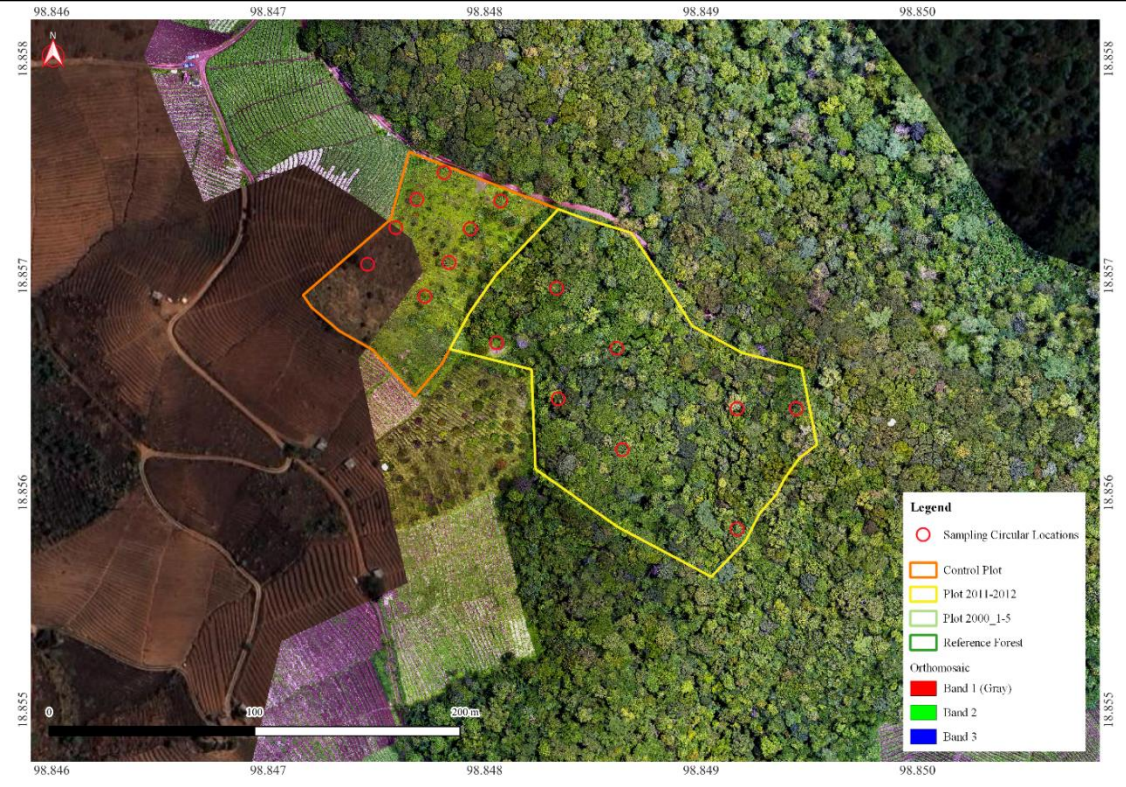
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Bird Species	CON		R12		R24		REF	
	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h	No. Obs	Obs/h
Yellow browed Warbler	4	0.08	12	0.25	6	0.13	6	0.13
Yellow-bellied Warbler		0.00		0.00		0.00	2	0.04
Yellow-streaked Warbler		0.00		0.00		0.00	1	0.02
Zitting Cisticola	8	0.17		0.00		0.00		0.00
TOTAL OBSERVATIONS	360	7.5	335	7.0	384	8.0	310	6.5
TOTAL OBSERVED SPECIES	45		70		72		83	

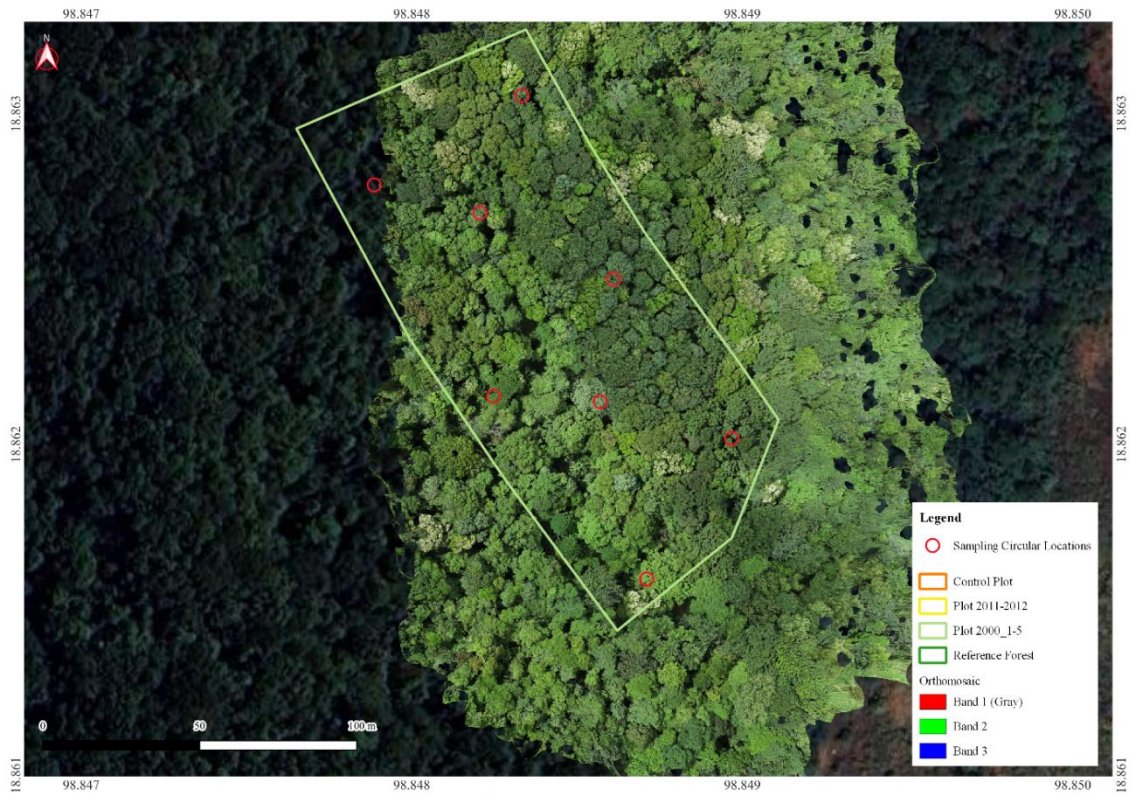
APPENDIX 2 – MAPS



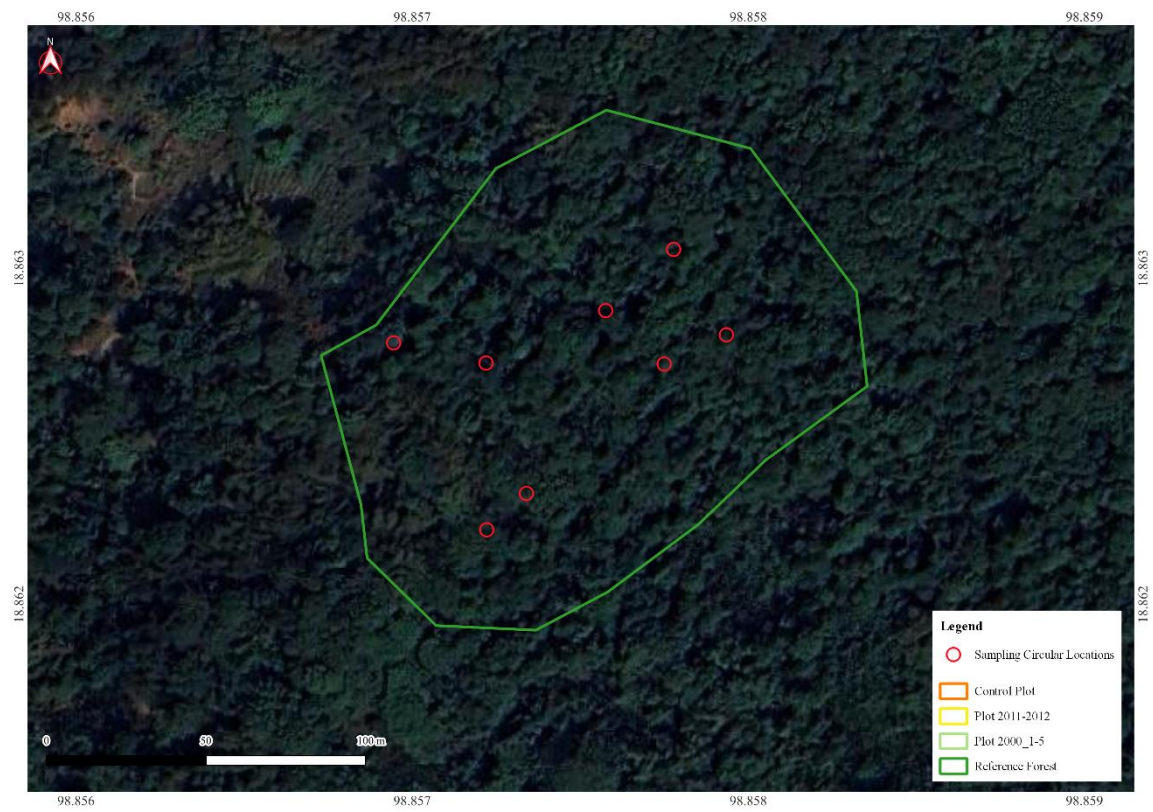
Overview – all habitats. Orange – CON, Yellow R12, Light Green R24, Dark Green REF. Red circles mark the position of the circular sample units 10 m in diameter



Control (orange boundary) and R12 sites (yellow boundary). Red circular sample units 10 m in diameter.



R2 site with eight circular sample units (red) 10 m in diameter



Reference evergreen forest with eight circular sample units shown in red 10 m diameter.

APPENDIX 3– DATA FORMATS

Data Sheet 1 - Sample Unit (SU) Details

SAMPLE UNIT DETAILS		
		Sample Unit I.D. #:
Diameter (m):		CONT / RESTN / REF FOR
Slope:	Aspect:	Elevation:
GPS:	N	E
Signs of Fire:		
Signs of livestock impact:		
Signs of erosion:		
Distinguishing features:		
Photos	Compass direction (degrees)	Photo File I.D. #
N		
E		
S		
W		

Data Sheet 2 – Tree Size

LOCATION						DATE:
SAMPLE UNIT ID #:		RECORDER:		CONT / RESTN / REF FOR		
Within 5-m radius circle - count tree of GBH >5 cm only						
Label	Tree Species	GBH (cm)	Height (m)	Crown Length (m)	Crown Width (m)	Notes
	Local					
	Sci.					
	Local					
	Sci.					
	Local					
	Sci.					
	Local					
	Sci.					
	Local					
	Sci.					
	Local					
	Sci.					
	Local					
	Sci.					
	Local					
	Sci.					
	Local					
	Sci.					

APPENDIX 4- SPECIES-SPECIFIC WOOD DENSITY DATA FOR NORTHERN THAILAND TREES

Supplementary data from Pothong et al. (2021) <https://www.forru.org/library/0000230>

Supplementary table S5

Average wood density (WD) of tree species in Pothong et al. (2021) study and the Global Wood Density Database (GWD). Genus from Zanne et al. (2009).

Species name	WD (g cm ⁻³) (This study)			GWD (g cm ⁻³)			Genus (g cm ⁻³)		
	$\bar{x}\pm SD$	n	min-max	$\bar{x}\pm SD$	n	min-max	$\bar{x}\pm SD$	n	min-max
<i>Actinodaphne henryi</i>							0.51±0.09	8	0.4-0.65
<i>Adenanthera microsperma</i>				0.64	1				
<i>Albizia chinensis</i>	0.4±0.07	9	0.26-0.49	0.30	1				
<i>Albizia lebbeck</i>				0.6±0.12	6	0.45-0.8			
<i>Albizia odoratissima</i>	0.63	1		0.64±0.06	6	0.57-0.71			
<i>Alstonia rostrata</i>	0.37±0	2	0.36-0.37						
<i>Anneslea fragrans</i>	0.58±0.07	2	0.53-0.63	0.68±0.05	3	0.63-0.72			
<i>Anogeissus acuminata</i>				0.88	1				
<i>Antidesma acidum</i>							0.65±0.08	13	0.51-0.8
<i>Antidesma sootepensis</i>	0.53±0.07	4	0.47-0.62						
<i>Aporosa octandra</i>	0.58±0.01	2	0.57-0.58						
<i>Aporosa villosa</i>	0.51±0.08	70	0.46-0.54						
<i>Archidendron clypearia</i>	0.41±0.04	8	0.34-0.47	0.32±0.06	3	0.26-0.37			
<i>Artocarpus lacucha</i>							0.48±0.1	63	0.27-0.73
<i>Berrya mollis</i>	0.44±0.03	4	0.39-0.46						
<i>Bombax anceps</i>	0.19±0.01	2	0.19-0.2	0.41	1				
<i>Buchanania lanzan</i>	0.47±0.07	3	0.42-0.56	0.39±0.09	2	0.33-0.45			
<i>Callicarpa arborea</i>	0.44	1							
<i>Calophyllum inophyllum</i>	0.34	1		0.58±0.04	5	0.53-0.64			
<i>Canarium subulatum</i>	0.41±0.08	38	0.2-0.52						
<i>Canthium glabrum</i>	0.54±0.05	11	0.47-0.63	0.41	1				
<i>Castanopsis acuminatissima</i>	0.59±0.11	26	0.42-0.76	0.58±0.01	2	0.58-0.59			
<i>Castanopsis calathiformis</i>	0.67±0.03	2	0.65-0.69						
<i>Castanopsis diversifolia</i>	0.57±0.09	35	0.35-0.78						
<i>Castanopsis lucida</i>	0.51±0.03	6	0.46-0.54	0.53	1				
<i>Castanopsis tribuloides</i>	0.6±0.07	30	0.48-0.77	0.59±0.12	2	0.51-0.68			

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Species name	WD (g cm-3) (This study)			GWD (g cm-3)			Genus (g cm-3)		
	$\bar{x}\pm SD$	n	min-max	$\bar{x}\pm SD$	n	min-max	$\bar{x}\pm SD$	n	min-max
<i>Celtis tetrandra</i>	0.58±0.05	2	0.55-0.62	0.52	1				
<i>Cinnamomum camphora</i>				0.49±0.08	5	0.42-0.62			
<i>Cinnamomum verum</i>				0.50	1				
<i>Colona winitii</i>	0.44	1							
<i>Craibiodendron stellatum</i>	0.62±0.05	3	0.56-0.67						
<i>Cratoxylum cochinchinense</i>				0.67±0.1	2	0.6-0.74			
<i>Cratoxylum formosum</i>	0.62±0.02	3	0.6-0.64	0.72±0.06	4	0.64-0.76			
<i>Dalbergia cana</i>	0.62±0.08	2	0.57-0.68						
<i>Dalbergia cultrata</i>	0.53±0.05	32	0.43-0.67	0.77	1				
<i>Dalbergia oliveri</i>	0.46±0.03	2	0.44-0.48	0.88±0.04	2	0.85-0.91			
<i>Dalbergia ovata*</i>				0.68	1				
<i>Dillenia parviflora</i>	0.6±0.06	5	0.53-0.68	0.56	1				
<i>Dimocarpus longan</i>				0.70	1				
<i>Diospyros glandulosa</i>	0.51±0.06	2	0.47-0.55						
<i>Dodonaea viscosa</i>				0.95±0.15	2	0.84-1.05			
<i>Elaeocarpus stipularis</i>	0.64	1		0.45±0.02	2	0.43-0.46			
<i>Engelhardtia serrata</i>				0.37	1				
<i>Engelhardtia spicata</i>				0.44±0.06	3	0.37-0.49			
<i>Eriolaena candollei</i>				0.70	1				
<i>Erythrina subumbrans</i>	0.32	1		0.23	1				
<i>Eugenia albiflora</i>							0.73±0.12	95	0.49-1.3
<i>Eugenia cumini</i>	0.57±0.05	3	0.52-0.61	0.56	1				
<i>Eugenia fruticosa</i>	0.49±0.09	31	0.34-0.71						
<i>Eurya acuminata</i>	0.56±0.06	6	0.47-0.62	0.50	1				
<i>Fernandoa adenophylla</i>	0.63±0.04	2	0.61-0.66	0.49	1				
<i>Ficus fistulosa</i>	0.24±0.05	9	0.14-0.31	0.38	1				
<i>Ficus hirta</i>							0.41±0.09	153	0.14-0.68
<i>Ficus hispida</i>				0.38±0.04	2	0.35-0.41			
<i>Ficus semicordata</i>	0.36±0.08	8	0.25-0.5						
<i>Flacourtia indica</i>	0.67±0.03	4	0.65-0.71	0.74±0.07	2	0.69-0.78			
<i>Garcinia cowa</i>				0.55	1				
<i>Garcinia xanthochymus</i>				0.79	1				
<i>Gardenia sootepensis</i>							0.67±0.07	14	0.56-0.77

Final Report to The Next Forest

Species name	WD (g cm-3) (This study)			GWD (g cm-3)			Genus (g cm-3)		
	$\bar{x}\pm SD$	n	min-max	$\bar{x}\pm SD$	n	min-max	$\bar{x}\pm SD$	n	min-max
Glochidion rubrum				0.64	1				
Glochidion sphaerogynum	0.46	1							
Gluta usitata	0.64	1		0.74	1				
Grewia eriocarpa	0.47±0.01	2	0.46-0.49	0.67	1				
Helicia nilagirica	0.53±0.07	36	0.42-0.76	0.64±0.02	3	0.62-0.66			
Heynea trijuga	0.53±0.07	2	0.48-0.57	0.45	2	0.45-0.55			
Ilex umbellulata	0.44±0.06	24	0.28-0.54						
Ixora cibdela							0.79±0.1	7	0.69-0.96
Knema cinerea							0.53±0.05	19	0.44-0.63
Lagerstroemia tomentosa				0.54	1				
Lepisanthes tetraphylla*				0.81±0.21	2	0.66-0.96			
Lindera meisneri							0.52±0.1	8	0.36-0.64
Lithocarpus garrettianus							0.67±0.12	65	0.44-0.88
Lithocarpus polystachyus	0.65±0.11	119	0.41-1.03						
Litsea glutinosa	0.29	1		0.5±0.08	2	0.44-0.56			
Litsea lancifolia	0.43	1							
Litsea monopetala	0.44	1		0.42±0.03	6	0.38-0.45			
Macaranga denticulata				0.43±0.07	4	0.33-0.49			
Macaranga kurzii							0.38±0.12	57	0.23-0.7
Magnolia baillonii	0.42±0.04	2	0.39-0.45						
Magnolia hodgsonii	0.51±0.15	3	0.41-0.69	0.62	1				
Mallotus philippensis							0.5±0.12	29	0.32-0.7
Mangifera indica				0.55±0.07	6	0.48-0.68			
Markhamia stipulata	0.44±0.06	2	0.4-0.48	0.68±0.18	2	0.55-0.8			
Meliosma simplicifolia				0.45	1				
Memecylon scutellatum	0.41	1							
Muntingia calabura				0.30	1				
Olea rosea Craib	0.59±0.11	4	0.45-0.68						
Oroxylum indicum	0.32	1		0.41±0.07	3	0.34-0.48			
Phoebe lanceolata	0.52±0.09	24	0.4-0.78	0.69	1				
Phyllanthus emblica	0.5±0.07	72	0.35-0.72	0.64±0.06	3	0.57-0.68			
Polyalthia cerasoides	0.56±0.09	4	0.43-0.63	0.76±0.11	2	0.68-0.83			
Polyalthia viridis	0.49±0.03	3	0.45-0.52						

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Species name	WD (g cm-3) (This study)			GWD (g cm-3)			Genus (g cm-3)		
	$\bar{x}\pm SD$	n	min-max	$\bar{x}\pm SD$	n	min-max	$\bar{x}\pm SD$	n	min-max
Protium serratum	0.43	1							
Pterocarpus macrocarpus				0.70	1				
Quercus kerrii	0.68	1							
Quercus kingiana	0.58±0.09	50	0.29-0.78						
Quercus semiserrata	0.63±0.05	9	0.55-0.73	0.71±0.05	3	0.66-0.76			
Rapanea yunnanensis	0.59±0.05	3	0.53-0.63						
Rhus chinensis							0.59±0.21	14	0.37-1.01
Sapindus rarak	0.48±0.04	8	0.43-0.55	0.51	1				
Sarcosperma arboreum	0.54±0.02	2	0.53-0.56	0.46	1				
Schima wallichii	0.53±0.06	47	0.39-0.72	0.56±0.04	8	0.5-0.62			
Schoepfia fragrans	0.57	1							
Semecarpus albescens	0.54±0.03	4	0.5-0.58	0.26	1				
Shorea roxburghii	0.64±0.05	3	0.61-0.71	0.70	1				
Spondias lakonensis	0.29	1							
Spondias pinnata	0.34	1		0.29±0.06	5	0.22-0.36			
Sterculia balanghas							0.43±0.13	79	0.2-0.7
Stereospermum colais	0.45±0.05	3	0.4-0.49						
Stereospermum neuranthum	0.61±0.06	3	0.54-0.66						
Styrax benzoides	0.58±0.07	33	0.35-0.8	0.00	1				
Symplocos macrophylla	0.53	1							
Toona ciliata	0.49	1		0.38±0.04	6	0.33-0.43			
Turpinia pomifera	0.49±0.04	5	0.45-0.56						
Vitex limonifolia							0.55±0.12	41	0.4-0.9
Wendlandia tinctoria	0.55±0.09	27	0.37-0.73						
Xanthophyllum virens	0.54	1							
Average	0.51±0.11	883	0.14-1.03	0.56±0.15	142	0.22-0.88			

*Trees of these species died before sample collection