Measuring forest ecosystem services in Aceh Province for inclusion to local forest resource management plans

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ABSTRACT

The project trained forest managers from Kesatuan Pengelolaan Hutan (KPH) and Social Forestry units in Aceh Province in forest resource data collection and the use of three tools that report important forest ecosystem services. Data were collected in systematic forest plots by local KPH staff and social forestry community members for measuring forest carbon, tree biodiversity and forest ecosystem health. Teams represented nine different forest ecosystems in Aceh Province, Indonesia. Average forest carbon estimates range from a low of 27.14 Mg C ha^{-1} in a coffee agroforestry system to a high of 446.93 Mg C ha^{-1} in a tropical forest area managed under social forestry. Tree biodiversity ranged from a low of one species as expected in a coastal mangrove forest to a high of 35 species in the tropical forest area managed under social forestry. Forest health conditions on average for the nine areas were mostly healthy, with a few noted in fair condition and one considered to be in poor condition. Resources provided at the local level would enable mainstreaming of field data collection for measuring these forest ecosystem services, and continued and expanded training should be considered to meet national demand.

KEYWORDS

Ecosystem services, forest carbon, tree biodiversity, social forestry, sustainable forest management, forest management unit

HIGHLIGHTS

■ Forest ecosystem services can be measured by local forestry staff and communities.

■ Ecosystem services measurement tools enable improved forest management practices.

■ Co-benefit of 18 students trained in ecosystem services tools and data collection.

1. INTRODUCTION

Indonesia has experienced the devolution of forest management through government policy and regulation in the past 20 years. Two mechanisms, in particular, are noteworthy. First, the creation of Forest Management Units (FMU or in Bahasa Indonesia, KPH, *Kesatuan Pengelolaan Hutan*) for watershed-scale sustainable forest management. Second, the promotion of Social Forestry under the Indonesian Ministry of Environment and Forestry (MoEF). KPH units were introduced to enhance state forest management goals and the units act as "intermediaries between local stakeholders and local and national government agencies [sic], which retain responsibilities for forest administration" (Lestari, 2020). According to the MoEF official KPH online database (http://kph.menlhk.go.id/ accessed Dec 1, 2021), there are a total of 688 KPH units in Indonesia, though some of these are planned only and not currently under active management. In addition to KPH local forest management system is a Social Forestry program in Indonesia, which include five different management schemes: village forests (*hutan desa*), community forests (*hutan kemasyarakatan*), community plantation forests (*hutan tanaman rakyat*), forestry partnerships (*kemitraan kehutanan*), and customary forests (*hutan adat*) (MoEF, 2016). According to Rakatama and Pandit (2020), social forestry schemes cover 1.8 million ha of forest land in Indonesia, with plans by the government to increase the area to 12.7 million ha by 2021 (MoEF, 2018).

Along with an emphasis on decentralized forest management, the Indonesian government identified the importance of environmental services in forest ecosystems as early as 2007. Government Regulation No. 6/2007 references the "utilization of environmental services" for KPHL (protection) and KPHP (production) forest units and identifies specifically biodiversity protection and carbon sequestration and storage (Government of Indonesia [GoI], 2007). KPHL and KPHP units are also required to develop 10-year long-term and 1-year short-term forest management plans that include management of environmental services. Social Forestry schemes in Indonesia are also required to develop similar forest management plans. The MoEF Directorate General of Social Forestry (PSKL) regulations give guidelines for preparing village forest management plans (GoI, 2016). Activities specified in the regulations include utilizing Non-Timber Forest Products (NTFPs) such as medicinal plants, the utilization of environmental services through ecotourism activities, and carbon storage and sequestration.

Challenges exist for KPH staff and Social Forestry community members in accurately collecting and reporting information specific to forest ecosystem services such as forest carbon, biodiversity, and the various forest resources that provide provisioning and cultural benefits to local people. Thung (2019) notes that while progress has been made by the Ministry of National Development Planning (BAPPANAS *Badan Perencanaan Pembangunan Nasional*),

the agency responsible for developing KPHs in Indonesia, progress is slow due to several factors, including "lack of technical expertise and experienced staff". Wulandari, Budiono, and Ekayani (2019), in an assessment of the Impacts of the Decentralization Law 23/2014 on implementing community-based forest management in Lampung Province, Indonesia, analyzed qualitative data for several community forests (*hutan kemasyarakatan*) areas in four districts. One of the study's conclusions regarding a decrease in community accountability and participation prior to and after the changes in regulations was an "inadequate number of trained and professional staff". In a literature meta-analysis of social forestry opportunities and challenges in social forestry implementation in Indonesia, Rakatama and Pandit (2020) note several studies that recognize social forestry creates "environmental opportunities and positive impacts on the environment, as well as contribute to sustainable development", "improves community awareness of opportunities to protect forest areas from illegal logging and forest encroachment", help in "educing deforestation, maintaining biodiversity and conservation values, aiding biodiversity conservation and conserving and sustaining forests". They also found, however, that technical assistance provided by the government for managing forests "is limited and insufficient".

To support overcoming the deficiencies in training and skills required to measure forest ecosystem services and utilize this information in sustainable forest management plans, our team from Michigan State University, Universitas Syiah Kuala and Instiper (*Institut Pertanian STIPER*) developed a training program in three phases for KPH staff and local Social Forestry community members. The training program was implemented in Aceh Province, Indonesia (February to September 2021). This paper presents the results from field data collected in nine forest areas in Aceh. The data were analyzed using three Excel-based forest ecosystem services tools to compute forest carbon, tree biodiversity, forest integrity and health, and forest resources used as cultural and provisioning benefits by local people.

2. METHODOLOGY

2.1. Three Excel-based forest ecosystem services (ES measuring and monitoring tools)

Three Excel-based tools were developed under the USAID LESTARI project (2015–2020) by Michigan State University: a Forest Carbon (FC) tool, a Tree Biodiversity (TB) tool and a Forest Integrity Assessment (FIA+) tool that includes functions for assessing forest resources used for cultural and provisioning benefits by local people. The tools store and manage field-based measurement and observation data. The tools also automatically compute data based on the field data inputs.

2.1.1. FC tool

The FC tool consists of several tabs and includes tabs with user guidance, example data, a user-defined tree species inventory list of local and scientific names, plot data tabs and a synthesis reporting tab. Tree diameter-at-breast-height (dbh; 1.3 m above the ground) measurement data from nested fixed-area plots are input to the tool and are used to compute plot-level biomass carbon using allometric equations specific to the forest type and region (Table 1a). The FC tool includes seven different allometric equations that represent most of the forest types in Aceh Province. Tree height data are computed from three measurements recorded in the field: distance of the observer from the tree, height of the observer's eyes from the ground, and the protractor angle from the clinometer tool as the observer identifies the top of the tree. Tree height and dbh data are used to estimate the biomass volume (m^3) of trees in the plot (Table 1b). The number of trees recorded is used to compute the stem density (number of trees ha^{-1}) of the plot (Table 1c). The tool computes the average tons of carbon per hectare (Mg C ha^{-1}) for all plots where data are collected and estimates the total carbon stock of the forest area (Table 1d). The tool also reports error and confidence accuracies based on the variation of carbon in the plots, the size of the forest

a): allometric equations for estimating tree biomass (kg) in different Aceh forest types for all trees greater than or equal to 5cm dbh			
	Forest ecosystem	**Allometric equation**	**Biomass component**
	Tropical Dipterocarp (primary)[1]	AGB = 0.125*D^2.533	Above-ground live biomass
	Tropical Dipterocarp (secondary)[2]	AGB = -2.75 + 2.591 *lnD	Above-ground live biomass
	Peat Forest (primary)[2]	AGB = 0.0145*D^3 – 0.47*D^2 + 30.64*D – 263.32	Above-ground live biomass
	Peat Forest (secondary)[2]	AGB = 0.153108*D^2.40	Above-ground live biomass
	Mangrove (*Rhriz. apiculata*)[2]	AGB-BGB = 0.75*D^2.23	Above- and below-ground live biomass
	Mangove (*Rhriz. mucronata*)[2]	AGB-BGB = 0.5*D^2.32	Above- and below-ground live biomass
	Pinus[2]	AGB-BGB = 0.103*D^2.459	Above- and below-ground live biomass
Where	D = diameter-at-breast-height, 1.3 m above the ground (cm)		
	AGB = above-ground live biomass (kg)		
	AGB-BGB = above- and below-ground live biomass or total tree (kg)		
Citations	[1] (Manuri et al., 2016)		
	[2] (Krisnawati et al., 2014)		
b): biomass volume (m^3) equations for all trees greater than or equal to 5cm dbh			
	Biomass volume$_{tree}$	$V_{tree} = ((1/4)*((PI*((D/100)^2))*H)*0.6)$	
Where	V_{tree} = biomass volume (m^3)		
	D = diameter-at-breast-height, 1.3 m above the ground (cm)		
	H = Height of tree (m)		
	Biomass volume$_{plot}$	$V_{plot} = \Sigma V_{tree} / P_{ha}$	
Where	V_{plot} = biomass of the plot (m^3 ha^{-1})		
	P_{ha} = Size of the plot in terms of hectares		
c): stem density (number of trees ha^{-1}) for all trees greater than or equal to 5cm dbh			
	Stem density (trees ha^{-1})	$S = \Sigma_{treecount} / P_{ha}$	
Where	Tree count = total number of trees (stems) above 5cm dbh within the plot		
	P_{ha} = Size of the plot in terms of hectares		
d): biomass carbon (tC ha^{-1}) and (tC) for all trees greater than or equal to 5cm dbh			
	Biomass carbon (Mg C)	$C_{tree} = (Biomass_{tree} * CF) / 1000$	
Where	Biomass$_{tree}$ = the tree dry-weight biomass in kg as estimated from an allometric equation (see part a of this table)		
	CF = equals the carbon fraction estimated at 0.50 * Biomass$_{tree}$ (IPCC default value in Penman et al., 2003)		
	Biomass carbon (Mg C ha^{-1})	tCha-1 = $\Sigma C_{tree} / P_{ha}$	
Where	C_{tree} = the carbon (Mg C) value of trees within the plot		
	P_{ha} = Size of the plot in terms of hectares		

TABLE 1. FC Tool computation equations.

area, and the sample size.

2.1.2. TB tool

The TB tool has a similar set of tabs as the FC tool. Plot inventory data are recorded for the number of each tree species greater than 5 cm dbh present in the largest of the nested fixed-area plots and seedlings species (less than 5 cm dbh) in the 2 x 2m subplots. Biodiversity indices are then computed that include species richness, Shannon index of species diversity, Simpson index of diversity, evenness, and abundance (Table 2). The same plot area used for the carbon tool data collection is also used for the biodiversity tool.

2.1.3. FIA+ tool

The FIA+ tool is a modified and adapted version of The Forest Integrity Assessment Tool (FIAT) developed by the High Conservation Value Resource Network (HCVRN). FIAT is a checklist and scoring tool used for assessing and monitoring biodiversity conditions in forests and forest remnants (Lindhe & Drakenberg, 2019). The modified encoded FIA+ data sheets in Excel include automatic computations and reporting. This tool is an essential complement to the TB tool, which tends toward a more scientific assessment. The FIA+ tool includes four sections for data observations: (1) forest structure and composition, (2) impacts and threats to the forest, (3)

Indices	Equation
Species richness	S = total number of species observed
Menhinick's Richness Index	D = S/(SQRT N)
Margalef's Richness Index	(S-1)/ln(N)
Shannon Index of Species Diversity	H' = $\sum$[(pi) * log(pi)]
Simpson Index of Diversity	1 - D
Evenness Index	E = H'/lnS
Where	
S = total number of species observed	
N = the total number of individual organisms in the sample	
pi = Proportion of individuals of i-th species in a whole community	

TABLE 2. TB Tool Computation Equations.

the forest's focal habitats, and (4) the forest's focal species. We also include data collection tabs in the tool to document the forest resources used by local communities and households that are provisioning cultural services.

The FIA+ tool scores the presence or absence of 20 forest structure characteristics and evidence or absence of 20 observed impacts or threats to the forest ecosystem. The observations are recorded in each of the same plots where data are collected for the FC and TB tools. An average score is computed from the multiple plot FIA+ scores. Scores between 0–10 indicate the forest ecosystem is in poor condition; between 11–20, it is in fair health; between 21–30, it is mostly healthy; and between 31–40, it is very healthy. Focal habitats and species are also identified when present in a plot. Also noted is the presence of any forest resource species (flora or fauna) identified by local people as being utilized for provisioning or cultural needs.

2.2. Phased training program for KPH staff and Social Forestry community members

A three-phase training program was implemented to build the capacity of KPH staff and Social Forestry community members. Phase 1 training focused on: introducing participants to the fundamental concepts of ecosystems and ecosystem services, review of several scientific phenomena (carbon cycle, greenhouse effect, climate change), explanation of the five pools of measurable forest carbon, the use of allometric equations for measuring biomass, field measurements and sample plot

designs for forest inventory, and a preview of the three ES tools.

Phase 2 was a field-based practicum where participants were given hands-on training in demarking fixed-area nested plots and collecting plot-level data for use in the three tools. Data collected included: tree dbh, measurements to compute tree height (distance from tree, angle of clinometer, height above ground to observer's eye level), tree species counts, seedling counts in 2x2 m plots, and FIA+ checklist observations.

After participant teams collected field inventory data, a Phase 3 training was convened and focused on understanding the results of the Tool analyses and how best to use each of the ES Tool's information for developing improved forest management plans.

2.3. Field data collection protocol

KPH and Social Forestry community teams collected field data for use in each of the three ES tools using a systematic protocol for plot sample locations, plot design and data collection procedures. Data collection teams ranged from 3 to 10 members.

Field plot locations were established on a regular grid pattern. Each plot was located at a minimum distance of 100 m from any forest edge and 50 m from rivers or streams. The plots were located at a minimum distance of 50m from each other. No plots were located in non-tree areas.

Field plots for the FC tool were three square nested plots in which specific diameter class trees were measured: 20 x 20 m plot for trees greater than

20 cm dbh, 10 x 10 m plot for trees less than 20cm and greater than or equal to 10 cm dbh, and 5 x 5 m plot for trees less than 10cm and greater than or equal to 5cm dbh. Seedling counts by species were recorded from two 2 x 2m plots located outside the 20 x 20 m plot. Within the three nested plots, tree species, dbh, and data for calculating tree height were recorded for all trees ≥ 5 cm dbh.

The same plot was used to also record data for use in the TB and FIA+ tools. Total tree species counts for all trees ≥ 5 cm dbh within the 20 x 20 m plot were recorded for the TB tool. Observations of forest structure, impacts, focal habitats, focal species as well as forest resources noted as used by local people for provisioning and cultural uses were recorded while standing inside the 20 x 20 m plot. All noted observances of these indicators and species within the plot or seen outside the plot while observing from inside the plot were noted.

Field data were recorded on paper field sheets and then input to the appropriate ES tool following data collection.

3. RESULTS AND DISCUSSION

KPH staff and Social Forestry community members collected data in nine forest areas in Aceh Province. The locations and extents of the nine forest areas are specific forest areas each training group manages as part of a KPH or social forest area. Table 3 is a summary table of the nine forest areas and Figure 1 shows their location with a centre point pin. The teams established a total of 83 field plots. The number of plots ranged from four in one of the mangrove areas to twelve in each of the two urban forest areas. The sampling area percent ranged from 0.10% in the largest forest area, Desa Agusen LPHD Gembuluh berkah, to 20.17% in the smallest forest area, Mangrove Telaga Tujuh.

3.1. Forest carbon and tree biodiversity in nine forest areas in Aceh Province

We summarize the forest carbon average (Mg C ha^{-1}) and total carbon stock (Mg C) listing the allometric equation used and the tree biodiversity species richness, evenness and dominant species

for the nine forest areas in Table 4. The results from the FC and TB tools are what we would expect. Higher average carbon per hectare values in the tropical evergreen and mangrove forest types than in the coffee agroforestry or pine forest types. The range is from a high of 446.93 Mg C ha^{-1} in the tropical evergreen social forestry of HKm Rumah Rungkoh to a low of only 27.14 Mg C ha^{-1} in the young coffee agroforestry area. Also, low biodiversity in the mangrove and pine forests than what is measured in the tropical evergreen forests. HKm Rumah Rungkoh and the two urban forest areas, Kota Langsa and Kota Nagan Raya, are considered secondary tropical evergreen forest (35, 33 and 33 species richness, respectively, with evenness values close to 1: 0.86, 0.79 and 0.84). The evenness values close to 1 indicate that the forest is not dominated by just one or two species. The two mangrove areas and the pine forest area have very low species richness values, 1, 2 and 3 species only, and their evenness values are closer to zero, with the pine forest evenness the lowest at 0.06.

The overall forest carbon stock and tree diversity are important in general for a forest area, but perhaps equally important is the spatial variation of the forest carbon and tree diversity which is information that can be useful for forest resource management activities. Understanding the variation of carbon and tree biodiversity across the plots can assist in developing management plans and actions not just in general for the forest area as a whole but to specific areas within the forest itself.

Table 5 shows the range of carbon and species diversity for the nine forest areas. Again, as expected, the mangrove forest areas and also the pine forest areas have low species richness values and, therefore, the maximum–minimum range between plots is small (mangrove 1–3 species and pine 1 species). Noteworthy from these plot level species richness data in comparison to species richness of the forest areas as a whole are the tropical evergreen forests. While HKm Rumah Rungkoh and the two urban forests have species richness values greater than 30, none of the plots in

No	KPH / Social Forest / National Park	Forest Type	Area (ha)	Plots	Sample area %
1	HKm. Rumah Rungkoh	Primary tropical	105	10	0.38%
2	Desa Agusen LPHD Gembuluh berkah	Coffee agroforestry	382	10	0.10%
3	Hutan Kota Langsa	Trop. evergreen (Urban)	2.38	12	20.17%
4	Mangrove Telaga Tujuh	Mangrove	40	10	1.00%
5	Swamp Group	Swamp	1	5	20.00%
6	Pinus Group Reje Pudung/Terangun Gayo Lues	Pine	10	10	4.00%
7	Mangrove Group	Mangrove	72	4	0.22%
8	Coffee group KPH II	Coffee agroforestry	10	10	4.00%
9	Hutan Kota Nagan Raya	Secondary Trop. (Urban)	5	12	9.60%

TABLE 3. Nine forest areas in Aceh Province for Initial ES Assessment.
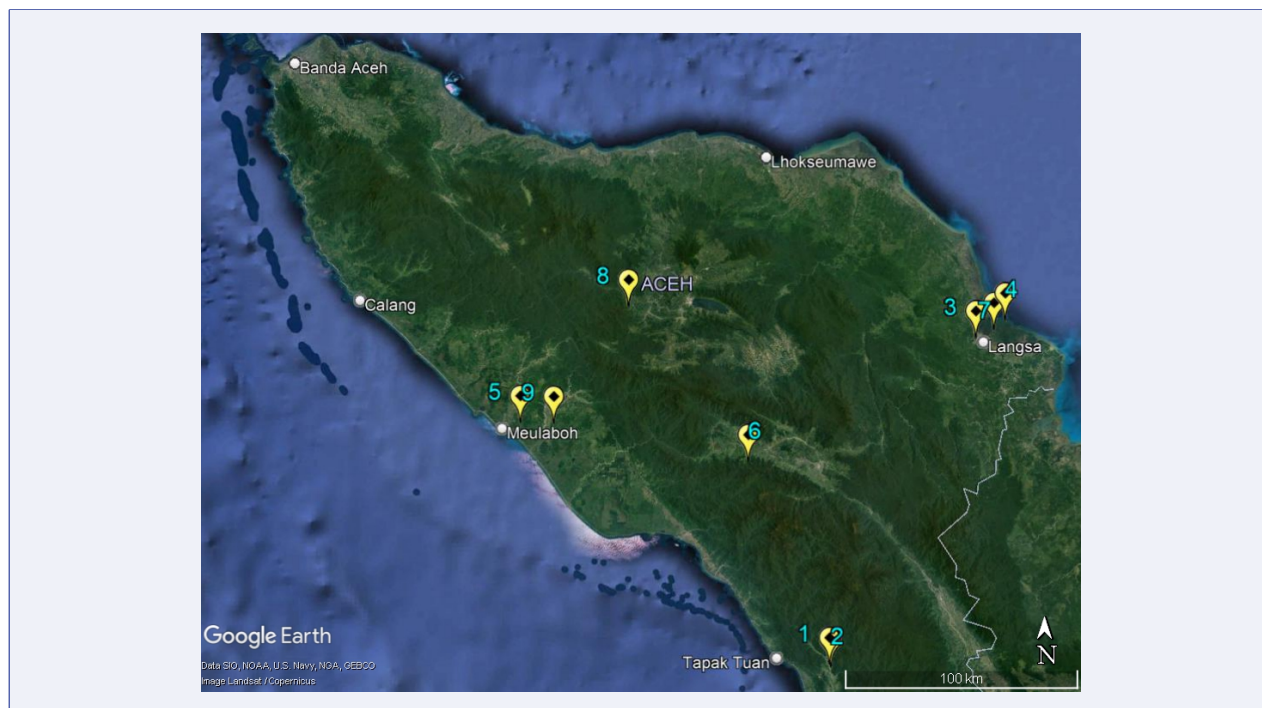
FIGURE 1. Location of Project Forest Areas. 1 = HKm. Rumah Rungkoh – Tropical Evergreen; 2 = Desa Agusen LPHD Gembuluh Berkah - Coffee Agroforestry; 3 = Hutan Kota Langsa – Secondary Tropical Evergreen Urban Forest; 4 = Telaga Tujuh KPH III – Mangrove; 5 = KPH IV – Swamp Forest; 6 = KPH V and PSDKU Gayo Lues – Pine; 7 = KPH III – Mangrove; 8 = KPH II – Coffee Agroforestry; 9 = Hutan Kota Nagan Raya – Secondary Tropical Evergreen Urban Forest.

any of these forest areas include 20 or more species. Some of the tree species, therefore, are present only in some of the plots. Furthermore, in the two urban forest areas, there is at least one plot in each forest area with only three species present and in HKm Rumah Rungkoh, only eleven species present. These forest areas, while overall having a high evenness value, are not uniform in their diversity across the landscape. This is true also for forest carbon. The range in plot-level carbon is greatest in one of the mangrove forest areas with a maximum-minimum value of 667.00 Mg C ha^{-1}. The forest area with the smallest range is the coffee agroforestry area, with

a maximum-minimum range of only 36.78 Mg C ha^{-1} between plots.

3.2. Forest integrity and health in nine forest areas in Aceh Province

The FIA+ tool provides a more qualitative assessment of the health and integrity of the forest ecosystem scoring a forest by the presence or absence of specific attributes. These include attributes such as the presence of large trees or the absence of stumps which indicate impacts from logging. Teams from seven of the nine forest areas were able to collect field data for the FIA+ tool. The presence or absence of focal species in the forest

Forest Area & Allometric Equation Used	Mg C ha^{-1}	Total Carbon (Mg C)	Species Richness	Evenness	Dominant Species
HKm. Rumah Rungkoh / Tropical Dipterocarp (primary)	446.93	46,928	35	0.86	Sangkotan (*Buchanania auriculata*)
Desa Agusen LPHD Gembuluh berkah / Tropical Dipterocarp (secondary)	99.52	38,095	10	0.63	Kopi (*Coffee arabica*)
Hutan Kota Langsa / Tropical Dipterocarp (secondary)	119.07	238.39	33	0.79	Meranti seraya (*Shorea platyclados*)
Mangrove Telaga Tujuh / Mangrove (*Rhriz. apiculata*)	269.86	10,794	2	0.14	Bangka minyak (*Rhizophora apiculata*)
Swamp Group / Peat Forest (secondary)	121.53	121	10	0.59	Simpur (*Dillenia spp*)
Pinus Group Reje Pudung/Terangun Gayo Lues / Pinus	76.65	767	1	0.06	Pine (*Pinus merkusil*)
Mangrove Group / Mangrove (*Rhriz. apiculata*)[1]	240.91	17,345	3	0.43	Lindur (*Bruguiera gymnorrhiza*)
Coffee group KPH II / Tropical Dipterocarp (secondary)	27.14	271	12	0.78	Gamal (*Gliricidia sepium*)
Hutan Kota Nagan Raya / Tropical Dipterocarp (secondary)	70.74	353	33	0.84	Mane (*Vitex pubescens*)

[1]*Bruguiera gymnorrhiza* and *Rhriz. apiculate* are of the same botanical order and family.

TABLE 4. Forest carbon and tree biodiversity in nine forest areas, Aceh Province.

Forest Area	Forest Carbon (Mg C ha^{-1})		Tree Diversity (species richness)	
	Min	Max	Min	Max
HKm. Rumah Rungkoh	275.11	702.86	11	19
Desa Agusen LPHD Gembuluh berkah	45.66	82.44	2	7
Hutan Kota Langsa	28.69	340.37	3	9
Mangrove Telaga Tujuh	156.20	418.60	1	1
Swamp Group	81.59	188.41	3	4
Pinus Group Reje Pudung/Terangun Gayo Lues	22.22	210.27	1	1
Mangrove Group	15.94	682.94	1	3
Coffee group KPH II	5.00	93.02	1	4
Hutan Kota Nagan Raya	18.59	120.85	3	11

TABLE 5. Range of carbon and species richness in forest area plots.

area is also an indicator of a forest ecosystem's health. It is presumed that in highly degraded, poor forest ecosystems, there are few focal species. Since many faunae focal species can be difficult to observe directly, data collectors record the presence of a focal species through other means as well, such as a species nest, their call or song in the case of a bird, their marks as in the case of a sun bear, or their faeces. Table 6 includes the average, minimum and maximum FIA+scores at the plot level, the number of focal species observed and the number of observations for the focal species list.

The mangrove forest in Telaga Tujah has the highest average FIA+ score, followed closely by HKm Rumah Rungkoh, 32.7 and 30.8, respectively,

out of a total of 40 points possible. Desa Agusen LPHD Gembuluh Berkah, a coffee agroforestry area, had the lowest score of 8.2, indicating a highly degraded forest, which is supported by the low number of focal species and observations of focal species, four and nine, respectively. HKm Rumah Rungkoh has 11 focal species present with 42 observations and the mangrove forest in Telaga Tujah has seven species with 62 observations. Hutan Kota Langsa also has 11 focal species present with 27 observations; however, this urban forest is also a zoo. Table 7 lists the focal species observed for each forest area.

Forest Area	FIA+ Score	Min	Max	Focal Species	Total Observances
HKm. Rumah Rungkoh	30.8	28	33	11	42
Desa Agusen LPHD Gembuluh berkah	8.2	5	10	4	9
Hutan Kota Langsa	25.5	20	32	11	27
Mangrove Telaga Tujuh	32.7	31	35	7	62
Mangrove Group	20.25	19	22	6	24
Coffee group KPH II	18.5	13	25	4	16
Hutan Kota Nagan Raya	24.92	18	29	4	10

TABLE 6. FIA+ data for seven forest areas in Aceh Province.

3.3. Carbon stock estimate accuracy and error

The limited number of plots in some of the forest areas and the wide variation in carbon values among these plots do impact the statistical accuracy for reporting carbon stock in the full forest area. The FC tool includes several metrics to understand the accuracy of the forest carbon stock estimates. Both the standard error and sample error are reported in the FC tool for the field plot inventory data. The FC tool also reports the lower and upper bound average Mg C ha^{-1} at the 95% confidence interval. These values are used to compute a lower and upper total carbon (Mg C) stock value along with the estimate computed from the average Mg C ha^{-1} for all plots. The tool also reports, based on the plot data input (given the standard and sampling errors, the mean, and standard deviation of the plot carbon (Mg C ha^{-1})), an estimated total number of plots to meet an accuracy of 95% confidence interval (CI) at 10%, 15%, and 20% error. Table 8 shows the two error values, mean plot carbon, upper and lower bound plot carbon, and the number of field plots together with the estimated number needed to meet an accuracy of 95% CI at 10%, 15% and 20% error for each of the nine forest areas.

The range of carbon values at the plot level is an obviously important factor. For any set of plots where the standard deviation is close to the mean carbon value, this, too, is an important factor. Only two forest area carbon estimates have a sufficient number of plots with low enough sampling and standard errors for accuracy at 95% CI and better than 15% error. These are Desa Agusen LPHD Gembuluh berkah and Pinus Group Reje Pudung/Teran-

gun Gayo Lues. Two areas have an accuracy right at 95% CI and 20% error: HKm. Rumah Rungkoh and Mangrove Telaga Tujuh. The rest of the forest areas estimate carbon stock values with an accuracy of greater than 20% error at 95% CI. In the case of the mangrove forest with only four plots, there is such high variation in the plot carbon values that another 144 plots would be needed for an accuracy at 20% error, 95% CI (assuming no change to the mean carbon and standard deviation with the inclusion of the additional plots).

In the forest areas with fewer plots than required for significant accuracy, the lower bound estimate of carbon stock should be reported. It may also be prudent to stratify the forest area to help lower the variation of carbon at the plot level when estimating the forest carbon.

4. CONCLUSION

The results of data collection by KPH staff and Social Forestry community members and their training on the use of the three ecosystem services tools is a proof of concept that several aspects of locally managed forest ecosystems can be measured. Forest carbon, tree biodiversity, forest integrity and health can develop forest management plans and actions that sustain and protect these services. Repeat measurements every two to five years can be used to monitor the effectiveness of forest resource management activities and provide necessary data for updating management plans and actions. This utilization of forest ecosystem services information is beneficial to forest managers responsible for balancing resource preservation, ecosystem health and resource use and in developing management

Forest Area	Local Name	English Name	Scientific Name
HKm. Rumah Rungkoh	Cuca hijau	Bornean leaf bird	*Chloropsis kinabaluensis*
	Serindit	Blue crowned hanging parrot	*Loriculus galgulus*
	Dolar Bet	White chested babbler	*Trichastoma rostratum*
	Takur tohtor	Red crowned barbet	*Psilopogon rafflesii*
	Merbah Cerucuk	Yellow vented bulbul	*Pynonotus goiavier*
	Orangutan	Orang utan	*Pongo abelli*
	Kambing hutan	Wild goat	*Capra aegagrus hircus*
	Siamang	Sumatra lar Gibbon	*Hylobates lar vestitus*
	Cinenen	Ashy tailorbird	*Orthotomus ruficeps*
	Julang Emas	Wrinkled Hornbill	*Aceros corrugatus*
	Olva Sumatera	Sumatra lar Gibbon type 2	*Hylobates lar vestitus*
Desa Agusen LPHD Gembuluh Berkah	Elang	Eagle	*Haliastur indus*
	Burung kedi	Great knot bird	*Calidris tenuirostris*
	Monyet ekor panjang	Crab eating macaque	*Macaca fascicularis*
	Burung Elang	Eagle type 2	*Haliastur indus*
Hutan Kota Langsa (Includes a zoo)	Damar	Resin tree	*Agathis borneensis Warb*
	Burung bujuk/jalak	Starling	*Sturnus contra*
	Burung raja udang	Alcedo meninting	*Blue eared kingfisher*
	Burung perkutut	Western Spotted dove	*Spilopelia suratensis*
	Meranti Merah	Red meranti	*Shorea leprosula*
	Beringin	Fig tree	*Ficus benyamina*
	Biawak	Monitor lizard, Goanna	*Varanus salvator*
	Rusa	Deer	*Cervus unicolor*
	Kuda	Horse	*Equus ferus caballus*
	Kura-Kura	Freshwater tortoises / terrapins	*Batagur baska*
	Buaya	Saltwater Crocodile	*Crocodylus porosus*
Mangrove Telaga Tujuh	Monyet ekor panjang	Crab eating macaque	*Macaca fascicularis*
	Kelelawar	Bat	*Craseonycteris thonglonglay*
	Kepiting	Crab	*Ocypode quadrata*
	Kerang	Shellfish	*Anadara granosa*
	Siput	Snail	*Cornu aspersum*
	Cicak terbang	Flying lizards, flying dragons or gliding lizards	*Draco volans*
	Bangka minyak	Mangrove tree A	*Rhizopora apiculata*
	Bangka kurap	Mangrove tree B	*Rhizopora mucronata*
Mangrove Group	Monyet ekor panjang	Crab eating macaque	*Macaca fascicularis*
	Elang	Eagle	*Haliastur indus*
	Burung raja udang	Alcedo meninting	*Blue eared kingfisher*
	Kepiting	Crab	*Ocypode quadrata*
	Kerang	Shellfish	*Anadara granosa*
	Siput	Snail	*Cornu aspersum*
	Belangkas	Horseshoe Crab	*Carcinuscorpius rotundicauda*
Coffee group KPH II	Burung kuning	Hairy backed bulbul	*Tricholestes criniger*
	Tupai	Squirrel/treeshrew	*Tupaia glis*
	Burung ekor putih/kutilang	Sooty headed bulbul	*Pycnonotus aurigaster*
	Luwak	Mongoose/Asian palm civet	*Paradoxurus hermaphroditus*
Hutan Kota Nagan Raya	Burung prenjak	Bar winged prinia	*Prinia familiaris*
	Burung duit	White chested babbler	*Trichastoma rostratum*
	Burung tekukur	Spotted dove	*Spilopelia chinensis*
	Burung gereja	Sparrow	*Passer montanus*

TABLE 7. FIA+ focal species observed in the forest areas.

Forest Area	Standard Error	Sampling Error	Mg C ha^{-1}		
			Mean	95% CI Lower Bound	95% CI Upper Bound
HKm. Rumah Rungkoh	43.88	3.35	446.93	431.95	461.92
Desa Agusen LPHD Gembuluh berkah	5.51	5.34	99.52	94.21	104.83
Hutan Kota Langsa	16.86	7.59	119.07	110.03	128.11
Mangrove Telaga Tujuh	26.54	4.32	269.86	258.2	281.51
Swamp Group	16.56	9.3	121.53	110.23	132.83
Pinus Group Reje Pudung/Terangun Gayo Lues	3.52	5.54	76.65	72.41	80.89
Mangrove Group	153.1	16.35	240.91	201.53	280.29
Coffee group KPH II	8.75	24.65	27.14	20.45	33.84
Hutan Kota Nagan Raya	8.38	9.01	70.74	64.37	77.12

Forest Area	No. of Plots	Plots for 95% CI at #% Error		
		10%	15%	20%
HKm. Rumah Rungkoh	10	38	17	10
Desa Agusen LPHD Gembuluh berkah	10	12	5	3
Hutan Kota Langsa	12	40	28	20
Mangrove Telaga Tujuh	10	38	17	10
Swamp Group	5	16	11	7
Pinus Group Reje Pudung/Terangun Gayo Lues	10	8	3	2
Mangrove Group	4	476	248	148
Coffee group KPH II	10	158	108	75
Hutan Kota Nagan Raya	12	46	26	16

TABLE 8. Confidence and error of carbon estimates.

plans that consider explicitly ecosystem services.

Two key factors impact the utility of measuring forest ecosystem services at the local level by KPH staff and Social Forestry community members. The first factor is allocating resources required to support field data collection. Data collection in forest ecosystems does not require expensive equipment, but it does take time and requires some specialized skilled labour for laying out nested plots, collecting tree biometric data, knowledge of local tree species and expert forest resource observation abilities. Teams of trained data collectors in certain forest conditions may only be able to complete data collection for one or two plots in a single day. Data allocation within large forest tracts may also require teams to hike several kilometres in adverse conditions (thick vegetation, heat, rain, steep topography, etc.). Funding data collection is a necessity to ensure enough plots are established to compute ecosystem services with some level of accuracy.

The second factor important for measuring forest ecosystem services is continued and expanded training for KPH staff and local people. This APN project was able to train 40 individuals from several KPH units and Social Forestry areas in Aceh Province. However, the need for these skills is national in Indonesia, with more than 600 KPH units planned and a goal of 12.7 million ha of lands under Social Forestry permits. Skills exist at several universities in Indonesia and through collaboration with non-national researchers and scientists outside of Indonesia that is sufficient to develop and implement a national training program for local forest managers at the KPH and community level. A training program scaled to the national level, however, will also require resources.

One final note of the value for this APN project beyond the forest ecosystem services results detailed in this technical report is one important and unexpected co-benefit. The implementation of the project through project collaborators at Universitas Syiah Kuala (USK) meant the opportunity also to

train students at the undergraduate and graduate levels. Eighteen students from USK participated in data collection and training to use the tools and have included this in their academic education and research.

5. ACKNOWLEDGEMENT

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