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Research paper

Application of Remote Sensing for Estimation of Carbon Storage in a Plantation Forest on Reclaimed Land of Banpu Lignite Mine and Adjacent Natural Forest, Northern Thailand

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Abstract

The carbon storage assessment of a 18-year-old plantation forest (PF) on reclaimed land of Banpu lignite mine, northern Thailand, was compared to nearby natural forest (NF), the dry dipterocarp forest (DDF). Vegetation study was taken using the sampling plot, each of size 40×40 m, and the total number of 12 and 10 plots were used for the PF and the NF, respectively. Data were obtained by measuring stem girths at breast height (1.3 m above ground, gbh) and heights of all trees with height over 1.5 m. The standing biomass and stored carbon amounts were calculated using allometric equations. The relationship between the carbon storage (CS) with actual wavelength associated with the vegetation was taken. LANDSAT-8 OLI images captured in 2015 were used for correlation and the multiple regression analysis for selection of the best equation to estimate the CS. It is found that the total number of 47 species (38 genera, 20 families) and 98 species (85 genera, 45 families) were existed in the PF and the NF, respectively. The CS amounts in plant biomass of the PF and the NF were determined in the following order; 47.80 ± 9.24 Mg ha^{-1} and 64.39 ± 13.7 Mg ha^{-1}. The best-fit model for estimation of the CS in study plots showed the relationship between the ratio vegetation index (RVI) and the normalized difference vegetation index (NDVI); the PF, CS = (3467NDVI) - (743RVI) + 392 with R^2 = 0.96, and the NF, CS = (217RVI) - (542NDVI) - 194 with a coefficient of determination (R^2) of 0.79. The average CS amounts of the NF and the PF by remote sensing assessment were estimated at 63.54 Mg ha^{-1} and 41.60 Mg ha^{-1}, respectively. The CS estimation of the PF was lower than the NF. Improving planting technique is required for forest plantation on the reclaimed mine land to increase plant species diversity, biomass and carbon storages.

Keywords: *Carbon; Dry dipterocarp forest; Plantation forest; Remote sensing; Reclaimed mine land*

1. Introduction

Mining or the extraction of mineral resources in a sustainable framework is a vital for the welfare of human begins. The mining industry has ever been perceived negatively due to its impacts on land, water, and air at local, regional, and global level [1]. The mining industry is Thailand's major primary industry. In the past five years, the mining industry has produced at least 60 billion baht worth of mining resources each year. Also, mining makes Thailand stable raw materials for the industry and country primary infrastructure development. However, the miners must follow academic principles and the laws with environmental protection, and reducing environmental or human community problems. In the processes of mine reclamation and rehabilitation in the mined areas, backfill the pit and mine sump or reclaim the area to the original landforms or decrease the slope area to provide safety and stability or rehabilitate by revegetation are required. The Banpu Public Company Limited had been engaged in lignite mine by open pit mining during 1987 and 2014. In 2004, the mine was closed its operations and the company has reclaimed the dumped area. The original forest in the area was the dry dipterocarp forest covering on xeric sites with poor shallow soil containing fragmented rocks of sandstone. The dominant tree species in the DDF are xeric dipterocarps. The forest is now remained in some parts nearby the mined area. Selective cutting of big trees had been taken by the villagers nearby the forest, and remaining small and intermediate trees. Tree cutting in the forest is now prohibited as it is become the community forest. The villagers can collect the non-wood forest products particularly edible mushrooms. This research used the natural community forest to compare carbon storage in the biomass. Carbon sequestration is the processes that remove carbon from the atmosphere. The carbon sequestration processes in the forest depend on plant growths. The carbon storage in forest ecosystem is important for reducing CO2 in the atmosphere, and reducing global warming [2]; [3]. The carbon storage potentials in the forest vary with forest types subtypes and conditions as poor or good caused by selection tree cutting [4]; [5].

Remote sensing data and analysis techniques are now providing detailed information for detecting and monitoring changes in land cover and land use [6]. Key benefits of remote sensing in mine monitoring can be enabling a regular visit to the area under study by programming the satellites and serving a large archive of historical data with continuous data acquisition [1]. The vegetation and physical indices with satellite imageries were integrated for carbon storage estimation in forest plantation, including Eucalyptus, Para rubber and teak [7]. Carbon storage in these plantations was identified at 25.9 Mg ha^{-1}, 135.03 Mg ha^{-1} and 38.50 Mg ha^{-1}, respectively. Carbon storages stored on reclaimed land increased the plantation age, and increased rapidly at the age of 5 to 6 years after planting which is the indicator of the recovery of land carbon stocks disturbed land due to coal mining [8]. The NDVI value and soil index can use for monitor the growth of vegetation in mine reclamation area [9]. The best-fit model was used for estimation of the above-ground carbon sequestration of dry evergreen forest, hill evergreen forest, mixed deciduous forest and dry dipterocarp forest using remote sensing techniques [10].

This research aims to assess the carbon storage in standing plant biomass of a 18-year-old plantation forest on the reclaimed dumpsite area of Ban Pu lignite mine compared to nearby natural forest, northern Thailand by an application of remote sensing compared to the field study. The data are basic information as guidelines for monitoring the carbon storages in the plantation forests and improving techniques of forest plantation on the reclaimed mine land.

2. Materials and Methods

This research was conducted at the Ban Pu lignite mine, Li district, Lamphun province, northern Thailand. It is about 150 km to the south of Chiang Mai city. The mine project covers an area of about 184 ha with an altitude range of 436 m to 507 m above mean sea level. The original forest in this area is mainly the dry dipterocarp forest (the DDF) covering on sloping areas with poor forest condition because it is close to the Ban Hong village, and selection cutting of big and intermediate-sized trees had been taken since long time ago. It is now become the community forest of the village, and tree cutting is prohibited. The forest along the streams and flat area is the mixed deciduous forest with dominated teak, however, most areas are changed to be paddy fields since the soil is fertile and has the high moistures during rainy season. The DDF has a poor shallow soil containing many gravels and fragmented rocks of sandstone. At the end of the mining project, the land must be restored by forest plantation to be the forest according to the law since it is situated in the national reserved forest, and two deep ponds were remained in the area.

2.1 Vegetation Sampling and Estimation of Biomass-Carbon Amounts

A method of plant community analysis was used for vegetation study in the PF and the NF. A total of 22 sampling plots (12 plots in the PF and 10 plots in the NF), each of size 40 x 40 m, were used for plant census. They were arranged randomly in these forests. Plant data were obtained by measuring stem girths at breast height (gbh, 1.3 m above ground) and tree heights of all tree species with height over 1.5 m. All plots were located using the GPS. The data were calculated for above-ground standing plant biomass in each plot using allometric equations (D2H = m3) [11], and root biomass (D2H = cm2.m) [12]: WS (stem) = 189 (D2H)0.902 (kg/tree), WB (branch) = 0.125 WS1.204 (kg/tree), WL (leaf) = 1/(11.4/WS0.90 + 0.172) (kg/tree), and WR (root) = 0.026 (D2H) 0.775. (W = biomass of stem, branch, leaf or root, D = diameter, cm or m, and H = tree height, m). The carbon amounts in biomass of stem, branch, leaf and root components were calculated by multiplying biomass amount with the carbon content according to average values [13]. The average carbon contents in stem, branch, leaf and root are 49.90%, 48.70%, 48.30% and 48.12%, respectively.

2.2 Estimation of Carbon Storage Using Remote Sensing Techniques

The carbon storages in plant biomass in the PF and the NF were estimated using the LANDSAT-8 OLI image captured in November 2015; Band 2 (Blue: B), Band 3 (Green: G), Band 4 (Red: R) and Band 5 (Near Infrared: NIR). The relationship was taken between the carbon storage (variable independent) with the energy reflected from the Earth's surface, the actual wavelength associated with vegetation, including vegetation index; ratio vegetation index (RVI: NIR/R), normalized difference vegetation index (NDVI: (NIR-R)/(NIR+R)), transformed vegetation index (TVI: ((NIR-R)/(NIR+R)+0.5)0.5) and green vegetation index (GVI: -0229G-056R+0.6IR+0.49IR). The correlation analysis was used to explore the relationship between independent variables and the dependent variables for the decision making to choose the independent variables in the equation. The stepwise multiple regression analysis was then applied as the following equation: Y = a + b1X1 + b2X2 + b3X3 + b4X4 + … + bnXn (Y = carbon storage obtained from the field data, X1, X2, X3,…,Xn = Satellite image data (Vegetation index), a = Y – Intercept, and b1, b2, b3, b4, bn = coefficient of regression. The best equation for estimation of the carbon storage was then obtained, and used for calculating carbon amounts in plant biomass of the PF and the NF.

3. Results

3.1 Species Composition and Richness in Forest Communities

Plant species sampled within 12 plots in the 18-year-old PF were identified to a total of 47 species in 38 genera and 20 families. These included 9 big trees, 11 medium-sized trees, 19 small trees, 2 shrubs and 6 climbers. The species richness varied among the plots, 5 to 15 species. In the NF, the number of plant species within 10 plots were higher than the PF (98 species in 85 genera, 45 families). These included 20 big trees, 28 medium-sized trees, 37 small trees, 5 shrubs and 8 climbers. The tree species in the PF included planted species and successional species. About ten species of native and exotic species were planted. The most abundant species was teak (Tectona grandis), followed by Lagerstroemia tomentosa, Azadirachta indica, Syzygium cumini and Afzelia xylocarpa. In the NF, the most abundant species was Shorea obtusa, followed by Shorea siamensis, Dipterocarpus obtusifolius, Canarium subulatum, Gluta usitata, Lannea coromandelica, Aporosa villosa, Dalbergia oliveri, Pterocarpus macrocarpus, etc.

All tree species had the great variations of stem gbh and height growths. Teak had the highest gbh among the species, 45.77 cm on average. The other species had the values in a range of 40.53 to 43.43 cm, except for Senna siamea which had the lower value, 28.71 cm. Their percentages coefficient of variance (C.V.) fluctuated between 53.77 and 88.65. Tree heights of most species were nearly the same, about 11 to 12 m, except for Senna siamea (8.57 m). The C.V values varied in a range of 41.46% to 64.64%. However, all species had almost the same crown widths, 5.5 to 5.9 m, with the lower C.V. percentages of 20.18% to 36.97%. The tree densities in the PF varied among plots, 394 to 1,244 trees ha-1, 661±231 trees ha-1 on average. Teak had the highest density, 314 trees ha-1 or 47.50% of the total, followed by Lagerstroemia tomentosa, Azadirachta indica, Acacia mangium, Acacia auriculiformis, Senna siamea, Syzygium cumini and Afzelia xylocarpa. These 8 species accounted for 87.29% of the total individuals. The remained 39 species had the lower density, below 10 trees ha-1. The average density in the NF was higher than the PF, 2775±583 tree ha-1. Among 98 species, Shorea obtusa had the highest density, 688 trees ha-1 or 24.79% of the total density, followed by Shorea siamensis, Dipterocarpus obtusifoliua, Gluta usitata, Canarium subulatum, Aporosa villosa, Lannea coromandelica and Dalbergia oliverli. These 8 species accounted for 72.10% of the total.

3.2 Estimation of Biomass and Stored Carbon by Field Investigation

The amounts of plant biomass within 12 plots of the PF varied from 58.36 to 122.01 Mg ha-1, 96.72±18.70 Mg ha-1 on average (Table 1). The biomass in stem, branch, leaf and root were estimated at 63.15 Mg ha-1 (65.29%), 20.71 Mg ha-1 (21.41%), 4.20 Mg ha-1 (4.34%) and 8.66 Mg ha-1 (8.96%), respectively. Among 47 species, Teak had the highest biomass, 59.06 Mg ha-1 or 61.32% of the total, followed by Acacia mangium, Lagerstroemia tomentosa, Azadirachta indica, Acacia auriculiformia, Afzelia xylocarpa, Senna siamea and Syzygium cumini. These 8 species accounted for 97.25% of the total biomass.

The biomass in the NF in 10 plots were varied, 130.36 Mg ha-1 on average (Table 2). The amounts in stem, branch, leaf and root were calculated in the following order: 84.40 Mg ha-1 (64.74%), 26.24 Mg ha-1 (20.13%), 2.83 Mg ha-1 (2.17%) and 16.89 Mg ha-1 (12.96%), respectively. Among 98 species, Shorea obtusa had the highest biomass, 26.09 Mg ha-1 (20.01% of the total), followed by Shorea siamensis, Dipterocarpus obtusifolius, Canarium subulatum, Gluta usitata, Lannea coromandelica, Dipterocarpus tuberculatus, Dalbergia oliverli, Pterocarpus macrocarpus and Morinda coreia. These 10 species accounted for 76.63% of the total. The carbon stored in biomass in the PF varied among 12 plots, 47.80±9.24 Mg ha-1 on average. The carbon in stem, branch, leaf and root were estimated at 31.51 Mg ha-1, 10.09 Mg ha-1, 2.03 Mg ha-1 and 4.17 Mg ha-1, respectively. Among 47 species, teak had also the highest amount, 29.19 Mg ha-1 (61.32% of the total), followed by Acacia mangium, Lagerstroemia tomentosa, Azadirachta indica, Acacia auriculiformia, Afzelia xylocarpa, Senna siamea and Syzygium cumini. These 8 species accounted for 97.25% of the total. In the NF as well, average carbon amount was 64.39 Mg ha-1. The amounts in stem, branch, leaf and root were calculated in the following order: 42.12 Mg ha-1, 12.78 Mg ha-1, 1.37 Mg ha-1 and 8.13 Mg ha-1, respectively. Among 98 species, Shorea obtusa had the highest carbon amount, 12.89 Mg ha-1 or 20.01% of the total.

3.3 Estimation of Carbon Storage by Remote Sensing

The LANDSAT image was interpreted as vegetation index (Table 3 and Table 4). The NDVI range of the PF (0.260-0.334) was lower than the NF (0.298-0.382). The RVI range of the PF (1.704-2.004) was lower than the NF (1.850-2.235). The TVI range of the PF (0.380-0.417) was lower than the NF (0.399-0.441), and the GVI range of the PF (0.149-0.183) was lower than the NF (0.155-0.210). The carbon storage amounts within 12 plots of the PF and 10 plots of the NF were correlated to the vegetation index, and then the formula for determining CS by using the remote sensing technique was obtained. The best-fit model was taken for estimation of the carbon amounts the PF and the NF of study plots between the ratio vegetation index (RVI) and the normalized difference vegetation index (NDVI), the PF was CS = (3467NDVI)-(743RVI)+ 392 with R2 = 0.96, the NF was CS = (217RVI)-(542NDVI) -194 with a coefficient of determination (R2) of 0.79. The two best equations were used for the assessment of carbon storage. Their values varied among sampling plots for both the PF and the NF caused by variation of plant communities obtained from the filed investigation. Figure 1 shows the aerial photo of two areas and represents the estimation of the CS map; the CS values in the NF area higher than the PF area. The CS average value of the NF area and the PF area were 63.54 and 41.60 Mg ha-1, respectively. In comparison to the field study, their values were 56.26 Mg ha-1 and 43.63 Mg ha-1, respectively. The total CS amount stored in 39.75 ha of the PF was estimated at 1,654 Mg which was lower than the same area of the NF (2,526 Mg).

4. Discussion

The field investigation of carbon storages in the PF compared to the NF had time consume and high cost. It provided the details of plant species composition, richness, diversity and quantitative features of plant species within adequate number of sampling plots. The biomass amounts in the PF and the NF could be estimated using allometric equations of deciduous forest in Thailand [11], [12] and the carbon amounts stored plant biomass were then calculated. The carbon amount in the 18-year-old PF was compared to the NF. The contribution of each tree species to the carbon storages in the PF and the NF was determined. In the PF, variation of plant communities in dumped area was observed since the seedlings of about ten native and exotic species were planted irregularly. As seedlings grew up to be the trees during 18 years after planting, plant community had developed. Within 12 plots, seven plots or plant communities were dominated by teak, and the remains were Azadiracta indica, Lagerstroemia tomentosa and Acacia auriculiformis. The species composition, richness and Forest condition index (FCI) were different among the plots. These variations implied to different plant communities. Different tree species are thought to have different Albedo (% light reflectance) [14], since they usually have different compensation point (CP), the light intensity which CO2 uptake is equal to CO2 release in respiration. The high light intensity is required for light demanding tree species, and lower for shade tolerant species. The light reflection from forest canopy may be different among different plots. In the NF, variable plant communities was also caused by dominant species, specie composition, tree densities and forest conditions. Within 10 plots, seven plots were dominated by Shorea obtusa, and the remains were Shorea siamensis and Dipterocarpus obtusifolius. The species richness, tree densities, FCI varied in the following order: 29 to 50 species, 271 to 608 trees ha-1, and 0.50 to 6.68.

Field study is important for the first assessment of the PF and the NF, however, monitoring by remote sensing can save the time consume and reducing cost of operation [9]. The application of remote sensing technology to monitor the reclaimed reforestation area is the better choice. However, the use of remote sensing technology has some limitations of selecting the satellite images. Field data collection should be taken at the same time as satellite imagery data. In fact, the forests reflect the solar radiation energy in different waves range [15]. The moisture or drought at any time affects the recording of satellite data [10]. In this study, the PF and NF were deciduous forests, and application of remote sensing could be not taken in rainy reason (May to September) by the cloud effect, and in the dry season (February to April) by the effect of leaf fall (or no leaves on the trees). The suitable time of investigation and use of satellite images for this study was November to January.

5. Conclusion

The satellite imagery can be used to determine the vegetation index and constructing the model for estimate carbon storage in spatial data. The RVI and NDVI were the most correlates with vegetation in study areas. The results can be used as a guideline for applying remote sensing technology to monitor and evaluate the reclamation progressions of all mines in Thailand. However, any agency of the Thai Government that their works related to mine rehabilitation monitoring should verify the effectiveness of these processes by applying them to many case studies from a variety of mines. In this study, the CS estimation of the PF was lower than the NF. Therefore, improvement of planting technique is required for forest plantation on the reclaimed mine land to increase plant species diversity, biomass and carbon storage.

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Table 1: Carbon amounts stored in plant biomass within 12 plots of the 18-year-old PF

Plot	Most dominant	Standing plant biomass (Mg ha^{-1})					Carbon (Mg ha^{-1})				
No.	**tree species**	**Stem**	**Branch**	**Leaf**	**Root**	**Total**	**Stem**	**Branch**	**Leaf**	**Root**	**Total**
PF01	*Azadirachta indica*	65.17	21.43	3.45	10.28	100.32	32.52	10.43	1.67	4.94	49.57
PF02	*Tectona grandis*	80.30	24.83	7.42	9.45	122.01	40.07	12.09	3.58	4.55	60.30
PF03	*Lagerstroemia* sp.	66.39	23.94	2.67	10.46	103.46	33.13	11.66	1.29	5.04	51.11
PF04	*Tectona grandis*	76.65	26.04	5.00	10.27	117.97	38.25	12.68	2.41	4.94	58.29
PF05	*Tectona grandis*	62.58	20.17	3.95	8.90	95.61	31.23	9.82	1.91	4.28	47.24
PF06	*Lagerstroemia* sp.	70.00	24.22	3.20	10.64	108.05	34.93	11.79	1.54	5.12	53.39
PF07	*Tectona grandis*	65.76	21.18	4.80	8.64	100.38	32.82	10.32	2.32	4.16	49.61
PF08	*Tectona grandis*	58.71	19.15	5.42	8.22	91.50	29.30	9.33	2.62	3.96	45.20
PF09	*Tectona grandis*	51.76	15.82	4.22	6.08	77.88	25.83	7.70	2.04	2.93	38.50
PF10	*Tectona grandis*	74.11	23.06	5.66	8.00	110.83	36.98	11.23	2.74	3.85	54.80
PF11	*Acacia* sp.	38.29	12.06	2.18	5.83	58.36	19.11	5.87	1.05	2.80	28.84
PF12	*Tectona grandis*	48.10	16.68	2.38	7.18	74.33	24.00	8.12	1.15	3.45	36.73
	Mean	63.15	20.71	4.20	8.66	96.72	31.51	10.09	2.03	4.17	47.80
	S.D.	12.28	4.18	1.55	1.67	18.70	6.13	2.04	0.75	0.80	9.24

Table 2: Carbon amounts stored in plant biomass within 10 plots in the NF

Plot	Most dominant	Standing plant biomass (Mg ha^{-1})					Carbon (Mg ha^{-1})				
no.	**tree species**	**Stem**	**Branch**	**Leaf**	**Root**	**Total**	**Stem**	**Branch**	**Leaf**	**Root**	**Total**
NF01	*Shorea siamensis*	88.23	28.65	2.82	17.32	137.01	44.02	13.95	1.36	8.33	67.67
NF02	*Shorea obtusa*	92.83	28.92	3.02	18.41	143.18	46.32	14.08	1.46	8.86	70.72
NF03	*Dipterocarpus obtusifolius*	75.53	24.42	2.25	14.57	116.78	37.69	11.89	1.09	7.01	57.68
NF04	*Dipterocarpus obtusifolius*	53.49	14.82	2.17	11.51	81.99	26.69	7.22	1.05	5.54	40.49
NF05	*Shorea obtusa*	85.83	24.29	3.38	18.22	131.72	42.83	11.83	1.63	8.77	65.06
NF06	*Shorea obtusa*	83.61	24.69	3.04	17.21	128.56	41.72	12.03	1.47	8.28	63.50
NF07	*Shorea obtusa*	89.07	26.34	3.21	18.32	136.94	44.45	12.83	1.55	8.82	67.64
NF08	*Shorea obtusa*	72.65	22.96	2.33	14.36	112.29	36.25	11.18	1.13	6.91	55.47
NF09	*Shorea obtusa*	81.82	24.60	2.85	16.63	125.90	40.83	11.98	1.38	8.00	62.19
NF10	*Shorea obtusa*	120.97	42.68	3.19	22.37	189.22	60.36	20.79	1.54	10.76	93.46
	Mean	84.40	26.24	2.83	16.89	130.36	42.12	12.78	1.37	8.13	64.39
	S.D.	17.08	6.97	0.43	2.93	27.06	8.52	3.39	0.21	1.41	13.37

Table 3: Vegetation index of plantation forest using LANDSAT-8 OLI image in 2015

Plot (PF)	01	02	03	04	05	06	07	08	09	10	11	12	Mean	S.D.
NDVI	0.288	0.334	0.300	0.322	0.291	0.305	0.299	0.291	0.279	0.306	0.260	0.279	0.296	0.021
RVI	1.807	2.004	1.856	1.952	1.821	1.877	1.852	1.819	1.772	1.881	1.704	1.774	1.843	0.084

TVI	0.394	0.417	0.400	0.411	0.395	0.402	0.399	0.395	0.389	0.403	0.380	0.390	0.398	0.010
GVI	0.154	0.183	0.162	0.182	0.157	0.161	0.157	0.153	0.167	0.166	0.149	0.164	0.163	0.011

Table 4: Vegetation index of natural forest using LANDSAT-8 OLI image in 2015

Plot (NF)	01	02	03	04	05	06	07	08	09	10	Mean	S.D.
NDVI	0.334	0.374	0.312	0.298	0.350	0.339	0.359	0.333	0.340	0.382	0.342	0.026
RVI	2.005	2.197	1.908	1.850	2.076	2.026	2.120	1.999	2.032	2.235	2.045	0.119
TVI	0.417	0.437	0.406	0.399	0.425	0.420	0.429	0.417	0.420	0.441	0.421	0.013
GVI	0.180	0.210	0.173	0.155	0.191	0.192	0.195	0.188	0.181	0.210	0.188	0.017

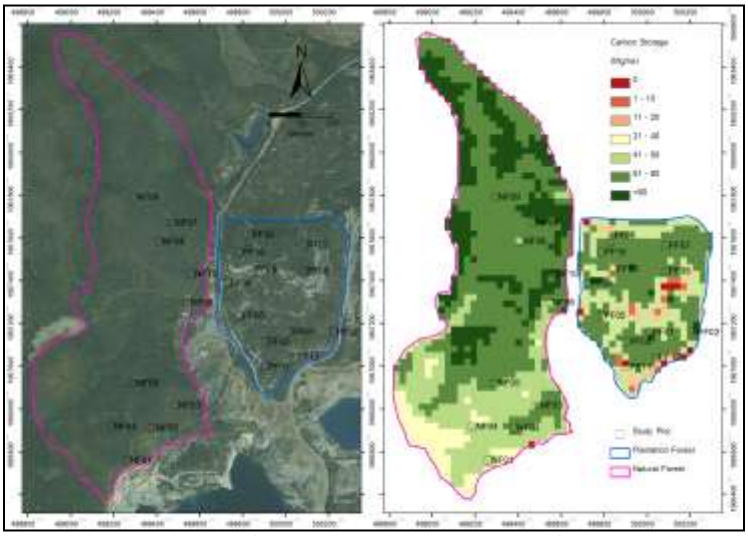

Figure 1: Aerial photo (left) and carbon storage map (right) of the PF and the NF