A segregated assessment of total carbon stocks by the mode of origin and ecological functions of forests: implication on restoration potential

P.R. NEUPANE[a,b], A. GAULI[a,b], T. MARASENI[c], D. KÜBLER[a], P. MUNDHENK[a], M.V. DANG[d] and M. KÖHL[a]

[a]*Institute for World Forestry, University of Hamburg, Germany*
[b]*Friends of Nature, Nepal*
[c]*Institute for Agriculture and the Environment, University of Southern Queensland, Australia*
[d]*Thai Nguyen University, Thai Nguyen, Vietnam*

Email: prem.raj.neupane@uni-hamburg.de, archana.gauli@uni-hamburg.de, tek.maraseni@usq.edu.au, daniel.kuebler@uni-hamburg.de, philip.mundhenk@uni-hamburg.de, minhdv@tnu.edu.vn, michael.koehl@uni-hamburg.de

SUMMARY

In depth understanding of variation of biomass and carbon pools in different forest ecosystems is crucial for monitoring, reporting and verification of forest carbon stocks in the context of forest landscape restoration (FLR). The study compares carbon stocks from five carbon pools by the mode of origin (natural vs planted forests) and ecological functions (Special use, Protection and Production forests) of the forests. An intensive forest carbon inventory was conducted in six communes of Dinh Hoa district, Vietnam. Soil organic carbon (SOC) was found to be the largest carbon pool. Mean SOC densities were not significantly different between natural forests and planted forests, but were significantly different among different forest types classified based on ecological functions. When considering the total of all carbon pools, mean carbon densities were neither significantly different between natural and planted forests, nor among Special use, Protection and Production forests. Our study provides evidence that different FLR interventions may provide equivalent potentials for increasing forest carbon stocks. We link FLR with the United Nations Framework Convention on Climate Change (UNFCCC) initiative Reducing Emissions from Deforestation and Forest Degradation in developing countries (REDD+) to highlight synergies between processes of regaining ecological functionality, enhancement of human well-being across deforested or degraded forest landscapes, and contribution to the enhancement of forest carbon stocks.

Keywords: carbon density, ecological function, forest landscape restoration, mode of origin, soil organic carbon

Evaluation séparée des stocks totaux de carbone en utilisant les fonctions écologiques et originaires des forêts: implications sur le potentiel de restauration

P.R. NEUPANE, A. GAULI, T. MARASENI, D. KÜBLER, P. MUNDHENK, M.V. DANG et M. KÖHL

Une compréhension en profondeur de la variation de la biomasse et des bains de carbone dans différents écosystèmes forestiers est cruciale pour gérer, rapporter et vérifier les stocks de carbone forestier dans le contexte de la restauration du paysage forestier (FLR). L'étude compare les stocks de carbone dans cinq bains de carbone dans le mode des fonctions d'origine (forêts naturelles plutôt que de plantation) et écologiques (forêts de production, protégées et à utilisation spéciale) des forêts. Un inventaire de carbone forestier intensif a été conduit dans six communes du district Dinh Hoa au Vietnam. La teneur du sol en carbone organique (SOC) s'est trouvée être le bain de carbone le plus important. Les densités moyennes de SOC ne variaient guère entre les forêts naturelles et celles de plantation, mais étaient largement différentes entre divers types de forêts classifiés en se basant sur leurs fonctions écologiques. Quand le total de tous les bains de carbone était considéré, les densités moyennes de carbone variaient peu entre les forêts naturelles et celles de plantation, pas plus qu'entre celles à utilisation spéciale, protégées et les forêts de production. Notre étude offre des preuves que différentes interventions FLR pourraient fournir des potentiels équivalents à même de faire croître les stocks de carbone forestier. Nous établissons de liens entre la FLR et l'initiative du Cadre de la Convention sur le changement climatique des Nations-Unies (UNFCCC), la Réduction des émissions résultant de la déforestation et de la dégradation forestière (REDD+) pour souligner les synergies entre les processus de recouvrer une fonctionnalité écologique, d'améliorer le bien-être humain dans les paysages forestiers dégradés ou déboisés, et de contribuer à un remplissage des stocks de carbone forestier.

Una evaluación segregada de las reservas totales de carbono según la modalidad de su origen y las funciones ecológicas de los bosques: implicaciones en el potencial de restauración

P.R. NEUPANE, A. GAULI, T. MARASENI, D. KÜBLER, P. MUNDHENK, M.V. DANG y M. KÖHL

El conocimiento en profundidad de la variación de los reservorios de biomasa y de carbono en los diferentes ecosistemas forestales es crucial para el monitoreo, la presentación de informes y la verificación de las reservas forestales de carbono en el contexto de la restauración del paisaje forestal (RPF). El estudio compara las reservas de carbono de cinco reservorios de carbono en función de la modalidad de su origen (bosques naturales vs bosques plantados) y de las funciones ecológicas de los bosques (uso especial, bosques de protección y de producción). Se realizó un inventario intensivo del carbono forestal en seis comunas del distrito de Dinh Hoa (Vietnam). Se encontró que el carbono orgánico del suelo (COS) constituye el mayor reservorio de carbono. Las densidades promedio del COS no fueron significativamente diferentes entre los bosques naturales y los plantados, pero fueron significativamente diferentes entre los diferentes tipos de bosques clasificados en función de sus funciones ecológicas. Cuando se evaluó el total de todas las reservas de carbono, las densidades medias de carbono no fueron significativamente diferentes entre los bosques naturales y plantados, ni entre los bosques de uso especial, protección o producción. El estudio proporciona pruebas de que las diferentes intervenciones de RPF pueden proporcionar potenciales equivalentes para aumentar las reservas de carbono forestal. El artículo vincula la RPF con la iniciativa de Reducción de las Emisiones de la Deforestación y la Degradación de Bosques (REDD+) de la Convención Marco de las Naciones Unidas sobre el Cambio Climático (CMNUCC), para resaltar las sinergias entre los procesos de recuperación de la funcionalidad ecológica, la mejora del bienestar humano en paisajes forestales deforestados o degradados, y la contribución a la mejora de las reservas de carbono forestal.

INTRODUCTION

Between 1990 and 2015, global forest area has reduced from 4,128 million ha to 3,999 million ha (FAO 2015). Although the annual rate of deforestation has been slowed down in recent years—from 0.18% in the 1990s to 0.08% in the period 2010–2015—still every year some 12 million ha forests are degraded while 7.6 million ha of forests are deforested to other land uses (FAO 2015, FAO and Global Mechanism of the UNCCD 2015). While boreal forests area is relatively stable, most of the deforestation and forest degradation are still occurring in tropical forests (FAO 2016). Since the 1992 Rio Summit, about 250 million ha of tropical forests have been cleared and converted, mostly for agriculture (ISU 2015).

Tropical forests make multiple contributions to the welfare of people across the tropics, throughout concerned nations and people all over the world (Myers 1992). The services include storage of a quarter of a trillion tons of carbon, reduction of carbon dioxide (CO_2) concentrations in the atmosphere through bio-sequestration, regulation of local, regional and global water and climate services, maintenance of a rich array of flora and fauna, soil formation and protection, and regulation of sediment outflows (ISU 2015).

Forest covers only 30.6% of the total world's land area (FAO 2015), but it stores 45% of terrestrial carbon and shares more than 39% of all carbon stored in soils (Bonan 2008, Eliasch 2008). Despite high deforestation and forest degradation rates, tropical forests have the highest carbon densities in the world, and store over 470 GtC (Goodman and Herold 2014). Therefore, tropical deforestation is considered to remain a major driver of global warming, emitting 0.8–0.9 GtC per year. This is equal to 8% of the total global carbon emissions. Less widely recognized is the fact that tropical forest degradation accounts for a further 0.6–1.5 GtC per year, equating to a range of 6–14% of all anthropogenic carbon releases (ISU 2015). On the other side of the tropical forest carbon ledger, tropical forests serve a vital role as a natural buffer to climate change by capturing 2.2–2.7 GtC per year (Goodman and Herold 2014).

Realizing these facts, global community is strongly motivated to forestlands and degraded landscapes restoration and embrace ambitious restoration targets of: (1) >150 million ha of degraded land by 2020 (the Bonn Challenge), (2) >15% of degraded ecosystems by 2020 (Aichi Target 15 of the Convention on Biological Diversity), and (3) 350 million ha of degraded land by 2030 (New York Declaration on Forests) (United Nations 2014, FAO and Global Mechanism of the UNCCD 2015). The global forest landscape restoration movement is gaining momentum (Chazdon *et al.* 2017) and the ambitious restoration targets, mentioned above, send a credible signal to policy-makers and investors for their credible actions related to forest landscape restoration (FLR) activities. However, one of the key challenges of meeting these targets is securing adequate and predictable financial resources. For example, US$ 360 billion and US$ 830 billion is required to achieve the targets of Bonn Challenge and the New York Declaration on Forests, respectively (FAO and Global Mechanism of the UNCCD 2015). Although the business case for FLR is very promising — offering substantial internal rates of return 7% to 79% (TEEB 2009) — convincing donors, financing companies and private sectors is still a huge challenge, mainly because of the issue of insecure business environment, poor governance and tenure rights in the tropical countries (Global Witness 2009, Cadman and Maraseni 2013, FAO and Global Mechanism of the UNCCD 2015, Cadman *et al.* 2016, Cadman *et al.* 2017).

One of the globally agreed financing vehicles for FLR for developing countries is Reducing Emissions from Deforestation and Forest Degradation in developing countries (REDD+) which provides a financial incentive for reducing emissions from deforestation and forest degradation, including conservation of forest carbon stocks, sustainable management of forests and enhancement of forest carbon stocks (REDD+) (Maraseni *et al.* 2014, Sanz and Penman 2016). REDD+ has enormous potential to slow down the deforestation and forest degradation rates, store huge amount of carbon in soil and biomass and secure several other co-benefits (FAO 2016). There are several studies about the potential contributions of forestry to climate change mitigation (see Houghton 2013, Grace *et al.* 2014, Smith *et al.* 2014). Houghton (2013) estimated emissions from avoiding deforestation (0.81 GtC) and forest degradation (1.47 GtC) and safeguarding current sequestration (1.17 GtC) produces a combined climate change mitigation potential of 3.45 GtC per year by tropical forests. Similarly, Grace *et al*. (2014) suggested at 3.86 GtC of combined potential and Smith *et al*. (2014) suggested a combined emissions reductions potential of 0.2 to 13.8 Gt CO_2e per year, by 2030, at carbon prices up to US$100/t CO_2e and to reductions of 0.01 to 1.45 Gt CO_2e per year at prices below US$20/t CO_2e (Smith *et al*. 2014). This underscores forests have potential to be managed to reduce atmospheric concentration of CO_2 and thus mitigate climate change (Neupane 2015).

Vietnam is one of the most committed tropical countries in increasing forest cover. Over the past 25 years (1990–2015), about 129 million ha of forests was lost globally but during the same period, the forest area in Vietnam increased by about 5 million ha (FAO 2015, Pistorius *et al.* 2016). The Five Million Hectares Reforestation Program (5MHRP), formulated under Decision 661/1998/QD-TTg, aimed at gaining five million hectare forest cover through restoration of degraded forest/bare land and afforestation. The program is mostly a continuation of its predecessor (Program 327). The program is incorporated into forest land allocation program (FLA), the contemporary policy of which is Decision No. 178/2001/QD-TTg (Webb 2008). FLA policy is implemented to increase the nation's forest cover by creating incentives for local people to sustainably manage forests and invest in plantations (Phuc *et al.* 2013). The FLA together with the implementation of the 5MHRP is believed to be a main driver of the rapid expansion of forest plantations in Vietnam (ibid.). Nghi and Xuan Phuc (2015) suggested that forest land allocation has positive impacts on local livelihoods, contributes to improved household income and increase forest cover through plantation expansion. As a result of its strong forest-centric land use policy and stable business environment, Vietnam is one of the most favourable REDD+ countries for donors and investors (Forest Trends 2015). It is the second highest recipient in the Asia Pacific region, to receive commitments of 88 million US$ (Forest Trends 2015).

International climate negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) conceive a nationwide approach to performance evaluation and national-level carbon accounting for REDD+. In line with this approach, Vietnam is developing a national REDD+ strategy, building measurement, reporting and verification (MRV) capacity, establishing forest reference levels, and piloting benefit-distribution systems. Among many scientific challenges, quantifying nations' carbon emissions from deforestation and forest degradation is the major one. Setting aside all other issues, this study aims to estimate the forest carbon stock in all five carbon pools: (1) biomass of the living tree, (2) understory vegetation biomass, (3) litter biomass, (4) root biomass, and (5) soil organic matter in six communes of Dinh Hoa district of Vietnam. The intention here is to compare carbon stocks by mode of origin/regeneration (planted vs natural) and forest use (management) types (Special use, Protection and Production forests), and to provide the estimates/ information to guide a system of measurement, monitoring, reporting and verification of biomass/carbon stocks in the context of forest landscape restoration.

Vietnam has over one million hectares of heavily degraded natural production forests, and has handed over such degraded forests to local households and individuals. The study area reflects the similar situation. Therefore, the outcomes of this study provide guidance on forest landscape restoration initiatives to the other areas of similar nature in the country.

METHODOLOGY

Study area

The study was conducted in Dinh Hoa district, Vietnam. The district is composed of 23 communes and one town. Six communes were selected (Fig. 1) for the study in such a way that each of the communes shares a common (forest) land tenure system. Other sub-ordinate selection criteria include, (1) communes consisting of forest types, according to designated ecological function (Special use forest, Protection forest and Production forest), (2) communes consisting of forest types, according to method of regeneration (natural forest and planted forest), and (3) communes representing districts' geographical and altitudinal variation. Special use forests are protected areas used for nature conservation, protection of historical and cultural relics, and tourism and environmental protection. Protection forests are used mainly for protection of water sources and watersheds, prevention of soil erosion and desertification, and natural disaster mitigation. Production forests are mainly designated for production of timber and non-timber forest products in combination with environmental protection.

In the district, the process of forest land allocation (FLA) to households was started in 1992 to achieve the twin objectives of forest protection/forest land restoration and poverty reduction. Between 1993 and 2010, forest area in the district has increased from 15,555 ha to 30,991 ha (Neupane 2015). Until 2010, nearly half of the total forest area of the district was occupied by forest plantations and most of the plantations were established in the forest lands allocated to individual households (ibid.).

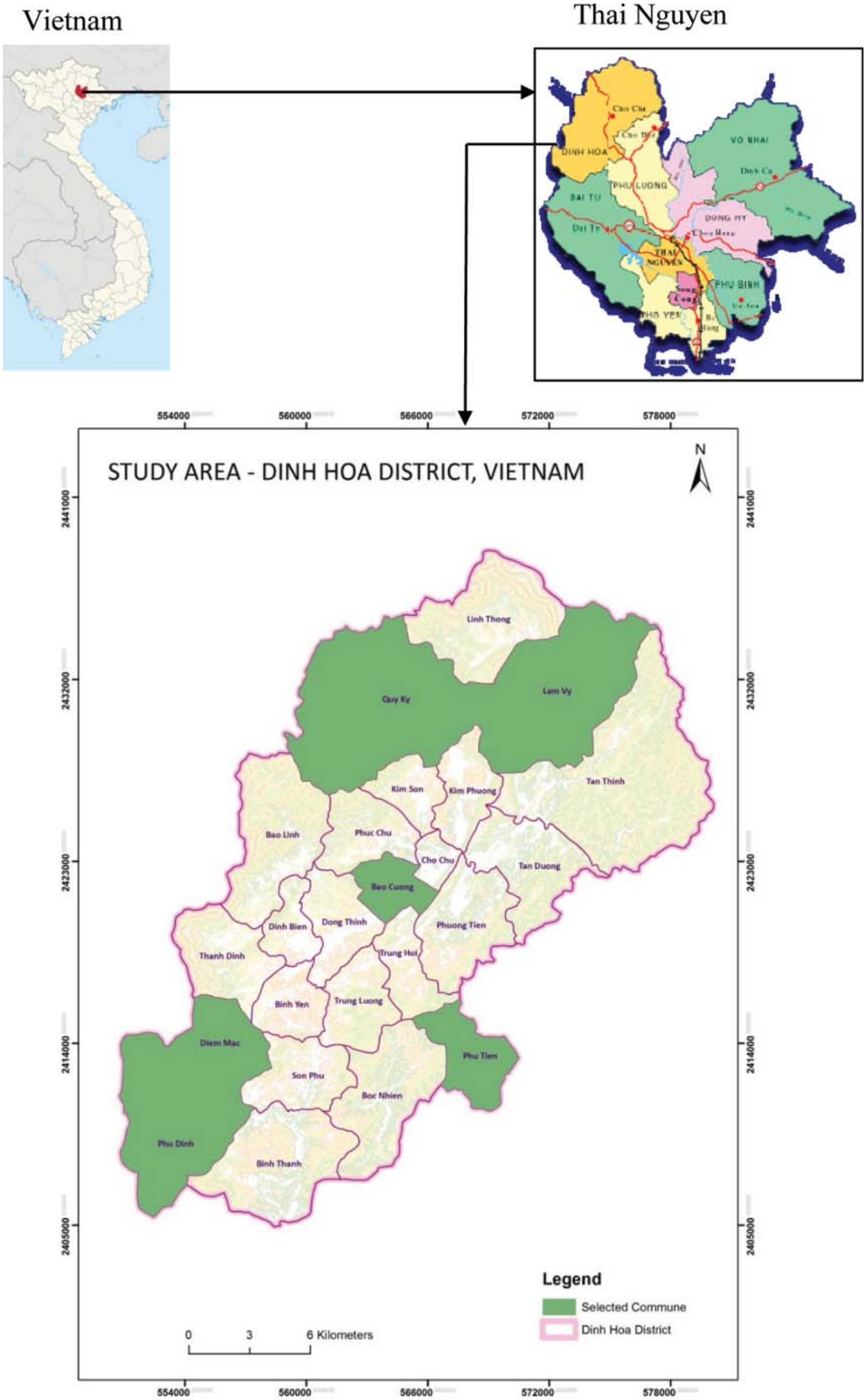
Agriculture and forestry are major land uses of the study area. Due to past agricultural practice (such as slash-and-burn) and over-exploitation of the forests, remaining natural forests in the district are severely degraded. Planted forests mostly consist of introduced tropical fast growing species such as acacia (e.g., *Acacia auriculiformis, Acacia mangium,* and hybrid of *A. auriculiformis* and *A. mangium*) and eucalypts (e.g., *Eucalyptus exserta*).

Forest inventory and data collection

Sampling intensity, sample plot lay-out and plot measurements

A pilot survey which included 68 randomly selected plots was conducted to estimate the plot level variance of basal area, which served as a guiding variable for estimating the required number of sample plots for forest inventory. Following the pilot study, forest inventory was performed using 200 sample plots altogether. The number of allocated sample plots to

FIGURE 1 *Map showing the study area. The study area consists of six communes as shown in forest green colour*



each of the six communes was proportional to the forest area each commune contains. Forest area of each commune was obtained from the Department of Agriculture and Rural Development, Thai Nguyen. Concentric circular sample plots (CCSPs), each consisting of four circular nested sub-plots with different radii (Fig. 2a) were used. The sample plots were systematically distributed by allocating the centers of the CCSP at the intersection of grid coordinates (Fig. 2b). The minimum tree size tallied got progressively larger with increase in the plot radius as seen in Figure 2. Tree species were recorded for seedlings/wildings (diameter <1 cm, height ≤1.3 m), saplings (1 cm ≤ dbh<5 cm), trees of dbh 5 cm ≤ dbh <25 cm (small trees), and trees of dbh ≥25 cm (big trees). All living standing trees within sub-plot 3 and sub-plot 4 were tallied. Seedlings/wildings were counted in sub-plot 1 at the distance of r_5 (5.64 m) and saplings were recorded in sub-plot 2. Samples of understory woody and herbaceous plants were taken from sub-plot 1 at the distance of r_5. Litter samples and soil samples were taken from sub-plot 1 at the plot center. In order to describe general and geographic situation of each sample plot, altitude, plot (center) coordinates, slope, aspects, micro relief, soil types and forest types were collected. The study used a measurement protocol following Köhl *et al.* (2008) for defining and specifying tree and stand attributes.

Quadratic mean diameter

Using quadratic mean ($\bar{d}_q$), average tree diameter was estimated. The study followed Curtis and Marshall (2000) to estimate the quadratic mean. Use of quadratic mean diameter (QMD) is a very old and standard practice in forestry which goes back to 19th century in Germany and the USA. Curtis and Marshal (2000) describes several mensurational advantages of the QMD.

The study used following equation, suggested by Curtis and Marshall (2000), to estimate the quadratic mean:

$$\bar{d}_q = \sqrt{\frac{\sum d_{1.3i}^2}{n}} \qquad \text{Equation 1}$$

where,
$d_{1.3i}$ is the diameter at breast height (over bark) of the individual tree, and
n is the total number of tallied trees in a sample plot.

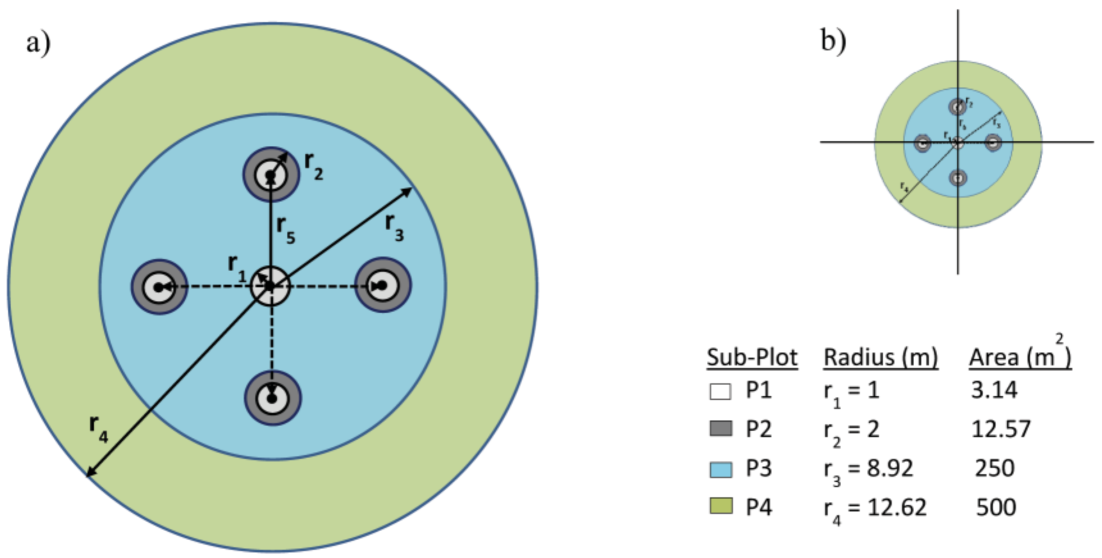
Above ground tree biomass

Due to a large number of tree species in humid and tropical forests, enormous efforts are needed to develop species-specific biomass equations. Relatively few species-specific equations have been developed for tropical tree species (Ketterings *et al.* 2001). Hence, mixed species tree biomass regression models are preferred and mostly used (Chave *et al.* 2005). The study used a mixed-species regression model (Equation 2), suggested by Chave *et al.* (2005), to estimate above ground tree biomass (AGTB) of individual trees. The biomass predictive model has already included the correction factor (Chave *et al.* 2005).

$$\begin{aligned} AGTB_{est} &= \exp(-2.977 + \ln(\rho d_{1.3}{}^2 h)) \\ &\equiv 0.0509 + \rho d_{1.3}{}^2 h \end{aligned} \qquad \text{Equation 2}$$

where,
$AGTB_{est}$ = estimated AGTB (Kg) for individual tree in a sample plot,
ρ = wood specific density (g/cm^3),
$d_{1.3}$ = diameter at 1.3 m height (cm), and
h = total tree height (m).

FIGURE 2 *Layout of an inventory plot showing: a) design of forest inventory plot, b) plot centre coinciding with intersection of grid coordinates. r represents radii of nested sub-plots. P1, P2, P3 and P4 are sub-plot 1, sub-plot 2, sub-plot 3 and sub-plot 4 respectively. If P1 and P2, at a distance of r_5 (5.64 m) at cardinal point N, are not accessible, then the plots are established towards E, or S, or W, as shown by dotted lines*



Sub-Plot	Radius (m)	Area (m^2)
P1	r_1 = 1	3.14
P2	r_2 = 2	12.57
P3	r_3 = 8.92	250
P4	r_4 = 12.62	500

Summation of AGTB of all the tallied trees in a plot gives total AGTB of the plot. The plot estimate was expanded to AGTB per hectare (ha) using plot expansion factors.

Wood specific density

Wood specific density values were collected from different sources of literature and databases (Wood density database of World Agroforestry Centre (http://db.worldagroforestry.org/wd); Jackson 1994, FIPI 1996, Brown 1997, Ketterings *et al.* 2001, MARD 2002, IPCC 2006, WWF and GIZ 2011, the plant list of the Royal Botanic Gardens, Kew and Missouri Botanical Garden (http://www.theplantlist.org/), and Vietnam Plant Data Center (http://www.botanyvn.com/default.asp?lg=en)). For those species for which species level wood specific densities were available in literatures and publicly available wood density databases, we used densities as provided in the sources. For species with unknown species level wood specific density value, we used the value of nearest sub-species/varieties, species average, genus level, plot-weighted average and site average.

Litter and understorey green biomass

Litter is the uppermost layer of organic matter on forest floor and consists of plant debris such as leaves, needles, twigs, bark, seeds/nuts, or fruits (Hairiah *et al.* 2001). In this study, non-living biomass of non-woody and woody components with <5 cm in diameter were collected.

All vegetation <5 cm diameter at breast height including perennial plants, shrubs, herbs and grasses (inside the sub-plot 1 at the distance of r_5) were destructively harvested at level to the ground as a understorey green biomass.

Fresh weight of the collected litter and understorey biomass samples was recorded and samples then oven dried at 65°C to 75°C until the weight of the samples was constant. Dry weight of each sample was determined and wet-to-dry weight ratio was calculated. The amount of biomass per sample plot area is then given by:

$$B_{sample.plot} = W_{forest.sample.plot} \times \frac{W_{dried.subsample}}{W_{wet.subsample}}$$

Equation 3 (Pearson *et al.* 2013)

where,
$B_{sample.plot}$ = litter biomass of sample plot (Kg),
$W_{forest.sample.plot}$ = weight of sampled biomass in sample plot (Kg),
$W_{dried.subsample}$ = weight of oven-dried subsample (kg), and
$W_{wet.subsample}$ = weight of fresh subsample (Kg).

Per hectare biomass estimate was calculated using plot expansion factors.

Below-ground biomass

Several authors have provided root to shoot ratios as default values (Cairns *et al.* 1997, MacDicken 1997, Li *et al.* 2003, Mokany *et al.* 2006). The study used root to shoot ratio of 0.205 as suggested by Mokany *et al*. (2006).

Estimation of forest carbon stock

The main carbon pool in the forest ecosystems are the biomass of the living tree, understory vegetation biomass, woody debris and litter biomass, root biomass and soil organic matter. The five pools were grouped into two broader categories: above ground carbon (comprised of the former three pools) and below ground carbon (included carbon in root biomass and soil organic carbon) pools. All five carbon pools were assessed. The amount of dead wood was negligible and therefore excluded from analysis. Bamboos and palms were not included while conducting forest inventory. Biomass estimates (t ha^{-1}) were converted to carbon content (tC ha^{-1}) multiplying by 0.5, the default carbon fraction. Total forest carbon stocks were estimated as the sum of above and below ground carbon (IPCC 2003).

Estimation of soil bulk density

Soil samples were collected from sub-plot 1 (Fig. 2) located at sample plot center. A total of 600 soil sub-samples (soil cores) were collected from 200 soil pits, three from each pit. The sub-samples were taken at 0–10, 10–20 and 20–30 cm depth. Wet-weight of the individual soil sub-samples were recorded in gram to one decimal place. From each soil sub-sample, approximately 100 g of soils (replicate) were taken out for soil bulk density measurement. Oven dried weight of the soil replicates were taken after oven drying samples at 105° C for 24 hours. Bulk density (*BD, g/m*^{3}) for each replicate was calculated as the ratio of weight of dry soil in the replicate to volume of soil in a sampling tube (or soil core or plastic tube). Average soil bulk density for the 30 cm soil profiles was determined as an average of the bulk densities of the three replicates.

Estimation of soil carbon density

To estimate organic carbon in mineral soils, calculation of soil organic carbon (SOC) density (tC/ha) was required. The SOC density estimation involves soil bulk density (*BD*) (g/cm^3) at a specified depth and determination of SOC concentration (%). The SOC concentration was then converted to tonnes per hectare using the *BD*, soil depth (i.e. 30 cm) and area (1 ha) as following (Ravindranath and Ostwald, 2008):

$$SOC\left(tC/ha\right) = \left[soil\,mass\,in\;0-30\;cm\;\;layer \;*SOC\,concentration\left(\%\right)\right]/100$$

Equation 4

where,

$$Soil\;mass\;(t/ha) = [area\;(10000\;m^2/ha) \;*depth\;(0.3\;m)*BD\;(t/m^3)]$$

Equation 5

Estimation of soil organic carbon

For the estimation of the SOC, composite soil samples were air-dried. Soil lumps were then crushed, and gravels, roots and large organic residues were removed. Remaining soil was sieved through a two mm sieve and grinded in a mortar. Determination of SOC (%) was performed using the CHN analyzer following the procedures suggested by Ravindranath and Ostwald (2008).

TABLE 1 *Mean tree (dbh ≥5 cm) density (N/ha) and its descriptive statistics. Sample size, mean tree density and confidence interval (CI) are given for different tree forms and forest types, classified based on mode of forest origin and designated ecological function*

Forest type	Tree (dbh)	Sample size (n)	Mean (N/ha)	CI (95%)
Natural	Trees (5 cm ≤ dbh <25 cm)	150	375	62
	Trees (dbh ≥25 cm)	150	10	3
Planted	Trees (5 cm ≤ dbh <25 cm)	50	741	153
	Trees (dbh ≥25 cm)	50	5	5
Production	Trees (5 cm ≤ dbh <25 cm)	81	431	84
	Trees (dbh ≥25 cm)	81	5	3
Protection	Trees (5 cm ≤ dbh <25 cm)	59	588	159
	Trees (dbh ≥25 cm)	59	9	5
Special use	Trees (5 cm ≤ dbh <25 cm)	60	394	84
	Trees (dbh ≥25 cm)	60	14	7

Data analysis

Analysis of the data was carried out using Microsoft Excel and R version 3.1.1 (R Core, Team 2010). Statistical estimators such as sample mean, median, variance, standard deviation, standard errors, and confidence intervals of measured and predicted tree and soil attributes were estimated. Relationships between biomass and carbon stocks were analyzed using linear regressions and the effect of forest types on biomass and carbon stocks were tested using Kruskal-Wallis chi square test.

RESULTS

Tree species

More than 430 tree species were found in the 200 sample plots. There were 257 tree species with dbh ≥5 cm belonging to 62 families. Planted forests comprised of 72 species of 30 families.

Quadratic mean diameter (dbh), stem density, and mean height

Quadratic mean diameter

The quadratic mean diameter (QMD) of Production, Protection and Special use forests were 10.32 cm (n = 81, SD = 6.61 cm), 12.29 cm (n = 59, SD = 5.16 cm) and 12.90 cm (n = 60, SD = 9.98 cm) respectively. Similarly, the QMD of natural and planted forest were 12.17 cm (n = 150, SD = 8.07 cm) and 11.10 cm (n = 50, SD = 5.19 cm) respectively.

Tree (dbh ≥5 cm) density

Planted forests had higher tree density of 746 trees per ha than that of natural forests, i.e. 385 trees per ha. Among the Protection, Production and Special use forests, Protection forests had the highest tree density. The proportion of trees of dbh ≥25 cm was very low compared with the tree of dbh between > 5 cm and <25 cm (Table 1).

Mean height

Tree height ranged from 3 m to 30 m with mean height ranged from 8.6 m (naturally originated Special use forest) to 11.7 m (planted protection forest) (Table 2).

Above ground biomass

Average AGTB (dbh ≥5 cm) for entire forest area was 19.34 t/ha (n = 200, SD = 22.42, CI = ±3.12). Biomass in litter averaged 2.80±0.26 t/ha (n = 200, SD = 1.9). Average understorey biomass density was 3.17±0.54 t/ha (n = 200, SD = 3.86) (Table 3). Means and medians of the AGTB, litter biomass and understorey biomass of different forest types are shown in Figure 3, 4 and 5, respectively.

AGTB density (t/ha) was higher in planted forests than in natural forests. Protection forests had the highest AGTB density among the forest types, classified based on designated

TABLE 2 *Mean tree height and its descriptive statistics. Minimum (Min.), Maximum (Max.) and Standard deviation (std.) are given for different forest types, classified based on mode of forest origin and designated ecological function*

Forest function	Forest origin	Height [m]			
		Min.	Max.	Mean	Std.
Production	Natural	3.1	28.85	9.3	3.8
Production	Planted	3.0	21.60	9.3	3.4
Protection	Natural	4.3	29.80	11.2	4.1
Protection	Planted	4.2	27.60	11.7	3.6
Special use	Natural	3.0	28.10	9.0	4.0
Special use	Planted	3.1	25.80	8.6	4.8

TABLE 3 *Distribution of above ground biomass (t/ha) in different biomass pools corresponding to different forest types in Dinh Hoa. Above ground tree biomass, understorey biomass and biomass in litter are presented. Mean biomass density (t/ha) and its descriptive statistics: sample size, standard deviation (SD), standard error (SE) and confidence interval (CI) are given for different forest types*

Criteria	Forest types	Sample size	Mean	SD	SE	CI (95%)
Above Ground Tree (dbh ≥5 cm) Biomass (AGTB)						
Entire forest	**Entire forest**	200	19.34	22.42	1.58	±3.12
Mode of origin	Natural forest	150	16.97	20.27	1.66	±3.27
	Planted forest	50	26.45	26.89	3.8	±7.64
Forest functions	Special use forest	60	17.83	24.79	3.2	±6.40
	Protection forest	59	26.12	23.43	3.05	±6.10
	Production forest	81	15.52	18.67	2.07	±4.12
Understorey biomass (oven dry biomass in shrub/herb/grass)						
Entire forest	**Entire forest**	200	3.17	3.86	0.27	±0.54
Mode of origin	Natural forest	150	3.25	4.07	0.33	±0.66
	Planted forest	50	2.93	3.21	0.45	±0.91
Forest functions	Special use forest	60	2.92	3.46	0.45	±0.89
	Protection forest	59	3.25	4.36	0.57	±1.14
	Production forest	81	3.28	3.80	0.42	±0.84
Biomass in litter (oven dry biomass in litter)						
Entire forest	**Entire forest**	200	2.80	1.9	0.13	±0.26
Mode of origin	Natural forest	150	2.92	1.98	0.16	±0.32
	Planted forest	50	2.44	1.60	0.23	±0.45
Forest functions	Special use forest	60	2.48	1.50	0.19	±0.39
	Protection forest	59	3.74	2.44	0.32	±0.63
	Production forest	81	2.36	1.44	1.60	±0.32

FIGURE 3 *Mean and median of above ground tree biomass density (t/ha) of different forest types. Medians are shown by horizontal bars inside box plots. Means and medians are given according to forest types, classified based on a) designated ecological function, and b) mode of forest origin*

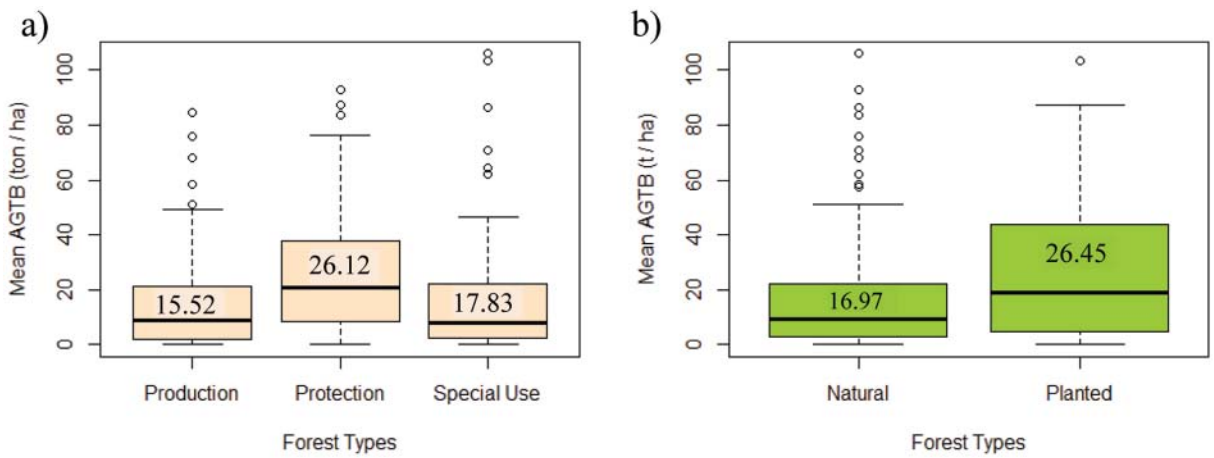


FIGURE 4 *Mean and median of litter biomass density (t/ha) of different forest types. Medians are shown by horizontal bars inside box plots. Litter biomass means and medians are given according to forest types, classified based on a) designated ecological function, and b) mode of forest origin*

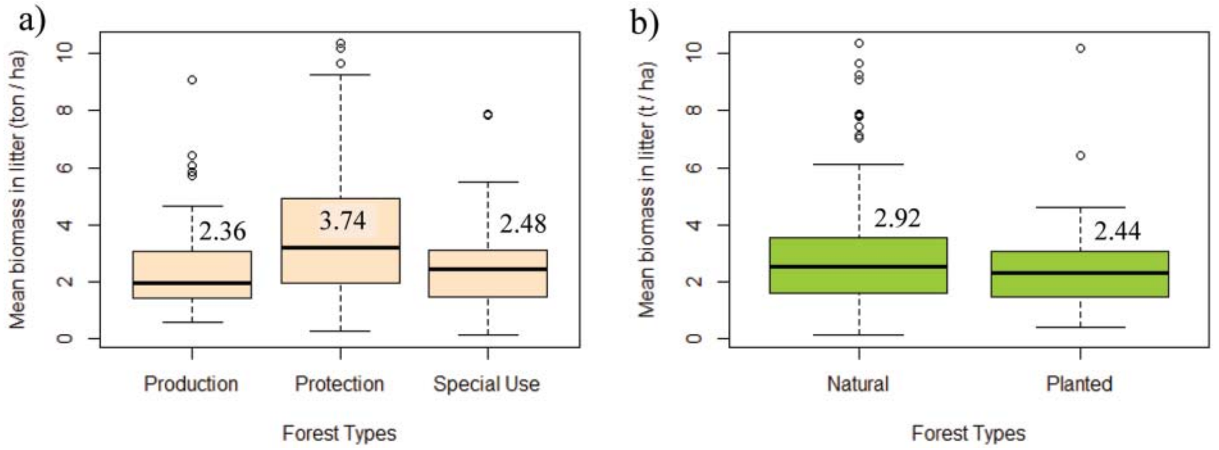
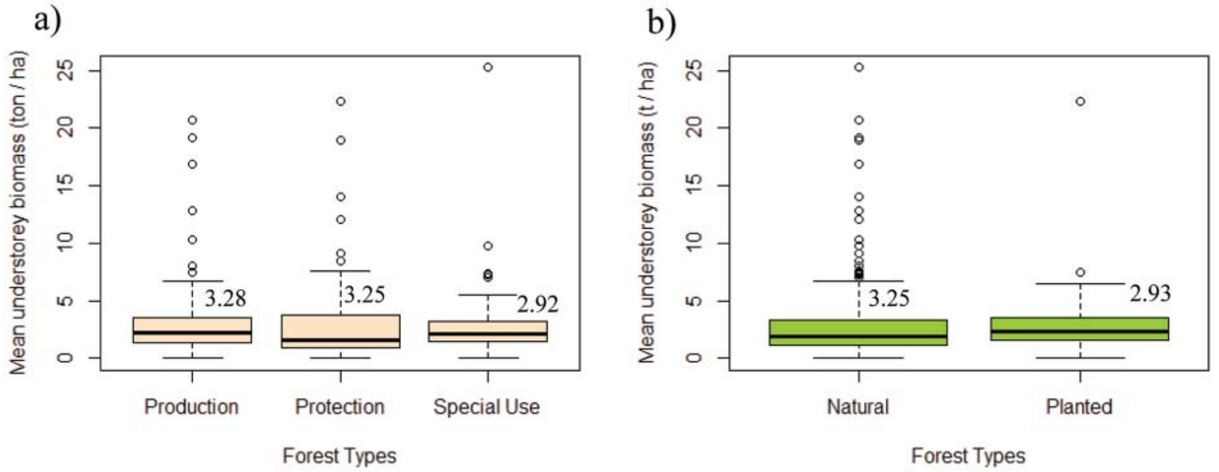


FIGURE 5 *Mean and median of understorey biomass density (t/ha) of different forest types. Medians are shown by horizontal bars inside box plots. Understorey biomass means and medians are given according to forest types, classified based on designated ecological function (a), and mode of forest origin (b)*



ecological functions. The Kruskal Wallis test revealed statistically non-significant effects of mode of forest origin on the AGTB ($\chi^2 = 3.76$, $P = 0.052$). In contrast, designated ecological functions have imposed significant effects on the AGTB ($\chi^2 = 12.25$, $P = 0.002$).

Neither the designated ecological functions ($\chi^2 = 0.98$, $P = 0.32$) nor the mode of forest origin ($\chi^2 = 1.84$, $P = 0.39$) affected understorey biomass density. However, litter biomass was significantly affected by designated forest functions ($\chi^2 = 15.84$, $P = 0.0003$). Protection forests had the highest litter biomass density. Forest origin did not exert significant influence on litter biomass density ($\chi^2 = 2.12$, $P = 0.14$).

Below ground root biomass

The mean root biomass was estimated to be 3.96±0.64 t/ha (n = 200, SD = 4.59). Kruskal Wallis test revealed similar result as that of AGTB with forest functions having statistically significant effect ($\chi^2 = 12.26$, $P = 0.002$) on root biomass while forest origin have no significant effects ($\chi^2 = 3.77$, $P = 0.052$).

Soil organic carbon

Soil organic carbon was by far the largest carbon pool containing 73% of the total carbon stock in Dinh Hoa forests. The SOC pool contributed 75% to the total carbon storage of natural forests and 67% of planted forests. The mean SOC densities of natural forests (39.94±2.98 t/ha) and of planted forests (37.69±2.61) are presented in Table 4. The effect of mode of forest origin was statistically non-significant ($\chi^2 = 0.2934$, $P = 0.59$) on the SOC stocks.

The designated ecological functions showed highly significant impact ($\chi^2 = 22.95$, $P < 0.001$) on the SOC density.

TABLE 4 *Distribution of carbon stock (t/ha) in different forest carbon pools in natural forests and planted forests. Mean carbon density (t/ha) and its descriptive statistics: sample size, standard deviation (SD), standard error (SE) and confidence interval (CI) are given for different forest carbon pools of natural forests and planted forests*

Forest types	Description of variable	Sample size (N)	Mean	SD	SE	CI (95%)
Natural	**Carbon density (t/ha)**	**150**	**53.24**	**21.04**	**1.72**	**3.37**
	Above ground carbon density (t/ha)	*150*	*11.57*	*10.82*	*0.88*	*1.73*
	Above ground tree carbon (t/ha)	150	8.48	10.14	0.83	1.62
	Carbon in understorey biomass (t/ha)	150	1.62	2.03	0.17	0.33
	Carbon in litter biomass (t/ha)	150	1.46	0.99	0.08	0.16
	Below ground carbon density (t/ha)	*150*	*41.67*	*18.48*	*1.51*	*2.96*
	Carbon in (tree) root biomass (t/ha)	150	1.74	2.08	0.17	0.33
	Soil organic carbon (t/ha)	150	39.94	18.63	1.52	2.98
Planted	**Carbon density (t/ha)**	**50**	**56.31**	**18.04**	**2.55**	**5.00**
	Above ground carbon density (t/ha)	*50*	*15.91*	*14.26*	*2.02*	*3.95*
	Above ground tree carbon (t/ha)	50	13.22	13.45	1.90	3.73
	Carbon in understorey biomass (t/ha)	50	1.46	1.61	0.23	0.45
	Carbon in litter biomass (t/ha)	50	1.22	0.80	0.11	0.22
	Below ground carbon density (t/ha)	*50*	*40.40*	*9.35*	*1.32*	*2.59*
	Carbon in (tree) root biomass (t/ha)	50	2.71	2.76	0.39	0.76
	Soil organic carbon (t/ha)	50	37.69	9.40	1.33	2.61

Special use forest contained the highest mean SOC density among the three forest types (Table 5). Mean SOC densities of Special use, Production and Protection forests were 45.36± 5.88 t/ha, 39.38±2.50 t/ha and 33.28±3.27 t/ha respectively.

Distribution of forest carbon stocks among carbon pools

Forest carbon density averaged 54.01±2.82 t/ha (n = 200, SD = 20.33). Average above ground carbon density was 12.65±1.65 t/ha (n = 200, SD = 11.88). Below ground carbon density averaged 41.36±2.31 t/ha (n = 200, SD = 16.66) (Table 6).

Contribution of the carbon pools to total forest carbon stocks varied. Major share to the total carbon stock was contributed by below ground carbon. The SOC pool contributed about 73% to the total forest carbon stock with a mean carbon density of 39.37±2.33 t/ha. Above ground tree carbon (AGTC) was the second largest contributor to the total carbon stock. AGTC shared 18% of the total carbon stock with a mean carbon density of 9.67±1.55 t/ha. Compared with AGTC and SOC, remaining three carbon pools contributed considerably less amount, each pool contributing with less than 4% (Table 6).

Distribution of carbon stocks among carbon pools in natural and planted forests

Average carbon density of planted forests (56.31±5 t/ha), was slightly higher than that of natural forests (53.24±3.37 t/ha) (Table 4). Mode of forest origin did not show statistically significant effect (χ^2 = 3.746, P = 0.052) on the carbon storage between planted forests and natural forests. Total carbon storage in above- and below ground portions of natural and planted forests varied (Table 4). Below ground carbon comprised 78% and 72% of the total carbon stocks of natural forests and planted forests respectively.

Among the five carbon pools, SOC pool contributed 75% of the total carbon of natural forests and 67% of planted forests with mean carbon densities of 39.94±2.98 t/ha and 37.69±2.61 t/ha respectively (Table 4). The AGTC shared 16% of the total carbon of natural forest with a mean of 11.57±1.73 t/ha. The AGTC was slightly higher in planted forests than that of natural forests. The pool shared 23.5% of the total stock of planted forest with a mean of 15.91±3.95 t/ha.

Distribution of carbon stocks among carbon pools in Production, Protection, and Special use forests

Mean carbon densities of Production, Protection and Special use forests were 51.55±3.70 t/ha, 52.52±4.36 t/ha and 58.80± 6.61 t/ha respectively (Table 5). At the time of assessment, Special use forest had the highest carbon density among the three forest types. However, designated ecological functions did not affect the carbon density significantly (χ^2 = 1.99, P = 0.369).

Above ground carbon densities of Production, Protection, and Special use forests were 10.58±2.22 t/ha, 16.56±3.25 t/ha, and 11.62±3.13 t/ha, which represent 21%, 32% and 20% of

TABLE 5 *Distribution of carbon stock (t/ha) in different forest carbon pools in Production, Protection, and Special use forests. Mean carbon density (t/ha) and its descriptive statistics: sample size, standard deviation (SD), standard error (SE) and confidence interval (CI) are given for different forest carbon pools of the forests*

Forest types	Description of variable	Sample size (n)	Mean	SD	SE	CI (95%)
Production	**Carbon density (t/ha)**	**81**	**51.55**	**16.99**	**1.89**	**3.70**
	Above ground carbon density (t/ha)	*81*	*10.58*	*10.19*	*1.13*	*2.22*
	Above ground tree carbon (t/ha)	81	7.76	9.33	1.04	2.03
	Carbon in understorey biomass (t/ha)	81	1.64	1.90	0.21	0.41
	Carbon in litter biomass (t/ha)	81	1.18	0.72	0.08	0.16
	Below ground carbon density (t/ha)	*81*	*40.97*	*11.78*	*1.31*	*2.57*
	Carbon in (tree) root biomass (t/ha)	81	1.59	1.91	0.21	0.42
	Soil organic carbon (t/ha)	81	39.38	11.47	1.27	2.50
Protection	**Carbon density (t/ha)**	**59**	**52.52**	**17.10**	**2.23**	**4.36**
	Above ground carbon density (t/ha)	*59*	*16.56*	*12.75*	*1.66*	*3.25*
	Above ground tree carbon (t/ha)	59	13.06	11.71	1.53	2.99
	Carbon in understorey biomass (t/ha)	59	1.63	2.18	0.28	0.56
	Carbon in litter biomass (t/ha)	59	1.87	1.22	0.16	0.31
	Below ground carbon density (t/ha)	*59*	*35.96*	*12.43*	*1.62*	*3.17*
	Carbon in (tree) root biomass (t/ha)	59	2.68	2.40	0.31	0.61
	Soil organic carbon (t/ha)	59	33.28	12.82	1.67	3.27
Special use	**Carbon density (t/ha)**	**60**	**58.80**	**26.11**	**3.37**	**6.61**
	Above ground carbon density (t/ha)	*60*	*11.62*	*12.38*	*1.60*	*3.13*
	Above ground tree carbon (t/ha)	60	8.92	12.40	1.60	3.14
	Carbon in understorey biomass (t/ha)	60	1.46	1.73	0.22	0.44
	Carbon in litter biomass (t/ha)	60	1.24	0.75	0.10	0.19
	Below ground carbon density (t/ha)	*60*	*47.19*	*23.06*	*2.98*	*5.84*
	Carbon in (tree) root biomass (t/ha)	60	1.83	2.54	0.33	0.64
	Soil organic carbon (t/ha)	60	45.36	23.24	3.00	5.88

TABLE 6 *Distribution of carbon stock (t/ha) in different forest carbon pools. Mean carbon density (t/ha) and its descriptive statistics: sample size, standard deviation (SD), standard error (SE) and confidence interval (CI) are given for different forest carbon pools*

Description of carbon pool	Sample size (n)	Mean	SD	SE	CI (95%)
Carbon density (t/ha)	**200**	**54.01**	**20.33**	**1.44**	**2.82**
Above ground carbon density (t/ha)	*200*	*12.65*	*11.88*	*0.84*	*1.65*
Above ground tree carbon (t/ha)	200	9.67	11.21	0.79	1.55
Carbon in understorey biomass (t/ha)	200	1.58	1.93	0.14	0.27
Carbon in litter biomass (t/ha)	200	1.40	0.95	0.07	0.13
Below ground carbon density (t/ha)	*200*	*41.36*	*16.66*	*1.18*	*2.31*
Carbon in (tree) root biomass (t/ha)	200	1.98	2.30	0.16	0.32
Soil organic carbon (t/ha)	200	39.37	16.81	1.19	2.33

the total carbon density of each forest type respectively. This implies carbon stocks in the forests were dominated by below ground carbon. Among the forests, Protection forest had the highest above-ground carbon density which was contributed by the highest amount of AGTC.

Among the five carbon pools, SOC was the largest carbon pool for all types of forests and far-seconded by AGTC pool. SOC pool contributed 77%, 63%, and 76% to the total carbon stocks of Special use, Protection, and Production forests respectively. AGTC shared 15% of the total carbon stock of Special use forest and Production forest, and 25% of the total carbon of Protection forest. Mean AGTC densities of Production, Protection, and Special use forests were 7.76±2.03 t/ha, 13.06±2.99 t/ha, and 8.92±3.14 t/ha respectively. Carbon in understorey biomass ranged from 2.5% to 3.2%, and carbon in litter biomass ranges from 2.1% to 3.6% of the total carbon stocks of the forests.

DISCUSSION

Implications of high tree species diversity for forest landscape restoration

The forests of Dinh Hoa contain a high diversity of native and indigenous trees. Moreover, occurrence of a larger number of native and indigenous tree species in Acacia dominated planted forests indicated a thriving of natural regeneration of the native trees in the plantations. The use of native and indigenous tree species to restore degraded forest lands has been increasingly recognized as an effective means of restoring ecosystem functions and biodiversity of degraded areas across the world (Lu *et al.* 2017). The mixtures of the diverse native and indigenous species can restore ecosystem functions, conserve biological diversity, and diversify forest products in such degraded landscapes (Erskine *et al.* 2006, McNamara *et al.* 2006, Lu *et al.* 2017). High tree species diversity offers the potential for selecting species that provide multiple benefits and best fulfil local needs (Song *et al.* 2017). However, the necessary ecological information to select the species for forest landscape restoration is inadequate in developing countries (Lu *et al.* 2017). Presence or absence of particular species in the given restored area hence will provide the necessary information to understand species adaptation and guide future forest landscape restoration in the similar ecological regions. The forests, at the time of survey, were characterized by lower carbon stocks (see Table 4 and Table 5) and were managed by highly forest-dependent and low-income households. Therefore, in addition to the carbon, special focus on the co-benefits such as biodiversity should be given to make use of the promising potential of forests to be fully included in the REDD+ mechanism.

Effectiveness of forest landscape restoration

The average tree diameter (dbh) of less than 12 cm indicated that most of the natural forests in the district were regrowth natural forests, and the planted forests were dominated by short-rotation plantations. The forests were regenerating either following heavy exploitation of timber or in abandoned agricultural land or unused land, i.e. natural forest expansion and/or forest land restoration. Neupane (2015) assessed 1993–2010 land use/forest cover change of the district indicated that district forest area increased at a rate of 5.5% per year between 1993 and 2010. Planted forests contributed a significant share of the forest area increase. Planted forest area was increased from 531 ha in 1993 to 14,473 ha in 2010, while, the area of non-forest land decreased by 900 ha annually for the same period. Comparing our results with Neupane (2015), make it evident that the natural forest expansion after protection of severely degraded forest patches and barren forest, and afforestation and reforestation (A/R) activities in barren lands contributed significantly to the forest landscape restoration along with the forest land allocation in the district. Moreover, the results indicated that enhancement of forest carbon stocks through conversion of barren and unused land to forest land, i.e. active forest landscape restoration is practically achievable in Vietnam.

Low above ground biomass due to restoration of degraded forests, and short-rotation plantations

Observed above ground biomass density for the Dinh Hoa forests was substantially lower than the country average (i.e. ~ 123 t/ha), (FAO 2010). The natural forest expansion and the FLR, as discussed in previous section, may have contributed to lower average growing stock (and eventually to low above ground biomass and carbon stocks), and small stand diameter (12.17 cm) in natural forests (section 'Quadratic mean diameter'). The small stand diameter indicates early development stage and low timber harvesting potential of the forests. Furthermore, trees with dbh ≥25 cm were sparsely distributed (0.7% to 3.4% of the total tree (dbh ≥5 cm) density. Observed low mean diameter and low tree density with higher diameter might have contributed to such a low above ground tree biomass estimate.

Several other factors might have been contributed to the low above ground biomass estimates, and consequently low forest carbon stocks. For instance, the study used a conservative approach of biomass estimation. Wood specific gravity values for many tree species were available in a range of minimum to maximum values. Wherever the values were given in a range, the study used the lowermost value for biomass estimation, and hence might have resulted in low (conservative) biomass estimation. The AGTB calculation included only living standing trees. Importantly, the AGTB estimate excluded bamboo and palm. Substantially low shares of understorey and litter biomass also contributed to the low above ground biomass. Despite the observed low AGTB, it should be viewed very positively that forests currently under household management have commenced in and rehabilitated from a severely degraded condition.

Low carbon density

Average carbon density of Dinh Hoa forests (54 t/ha) was found nearly half of the country average (i.e. 124 t/ha) for

2010 (FAO 2010, FAO 2010). FAO estimates of the country carbon stock were solely based on conversion factors and IPCC default values. FAO (2010) estimated country average of carbon in above ground biomass to be 61.6 t/ha which includes carbon in litter (5.2 t/ha). Similarly, the country average reported for above ground carbon density (FAO 2010, FAO 2010) was very high as compared to Dinh Hoa average of 12.65 t/ha. One of the plausible reasons for such discrepancy might be the exclusion of carbon in bamboo (forest) and palm from the calculation in our study. Several studies suggested that bamboo forests have a high carbon sequestration and high carbon storage potentials (Nath *et al*. 2015, Isagi 1994, Singh and Singh, 1999). The biomass storage and high carbon stock potential of the woody bamboo is comparable to the woody biomass of tree species (Indo-Asian News Service 2013) and the fast growing tree species from tropical and subtropical regions (INBAR 2010).

Furthermore, the expansion of the natural forests containing low growing-stock in general, and short-rotation plantations might have contributed in the observed low forest carbon densities in the district. As discussed earlier (section 'Effectiveness of forest landscape restoration'), the forest are regenerating, and thus, the carbon storage potential is often difficult to assess completely. This calls for more research to be conducted to identify whether carbon storage potential is high enough to attract carbon funds or not.

Soil organic carbon was the largest carbon pool

Soil organic carbon pool was the largest carbon pool for all of the forest types found in the district. Despite the substantial difference in carbon in above ground biomass between country average and the study area average, soil organic carbon density of the study area (39.37 t/ha) was close to the country average of 47.2 t/ha.

There are several studies on the impact of land use change on soil carbon. In general, the conversion of forest to agriculture results in the loss of about 20–50% soil carbon (Lal 2005), and the conversion of native scrubland to cultivation lost about 60% of soil carbon (Maraseni 2007, Maraseni *et al.* 2008). Dang (2007) found that soil organic carbon stocks in forest (16.3 mg g^{-1}) and 10-year old tea plantation (13.2 mg g^{-1}) were significantly different in the northern mountainous zone of Vietnam. Brown and Lugo (1990) conducted a study collecting soil samples from mature and secondary forests and agricultural sites to determine the effects of forest conversion to agriculture on SOC and nitrogen contents. Carbon contents of the agricultural sites were 44% and 31% lower as a percent of corresponding mature forests in wet and moist conditions respectively. Likewise, Phien and Siem (1998) found 3.01% organic matter in natural forest, 2.64% in tea cultivation, 1.88% in maize cultivation and 1.75% in cassava cultivation in ferralic acrisols of Vietnam (cited in The Dang and Klinnert 2001). In general, in annual cropping systems, especially in cash crop and vegetable farming, carbon stocks in Vietnamese soils are slowly decreasing (Ha 2010). However, these trends are reversed during forest succession or fallow when the organic matter and nutrient content generally increase (Brown and Lugo 1990). This implies that afforestation and reforestation in abandoned agricultural land, degraded and barren forest lands, and non-productive and unused lands could be an active vehicle for forest landscape restoration to reverse the loss of soil organic carbon. However, by doing afforestation on highly clapped agricultural land, soil carbon would never return to its original condition (Maraseni 2007, Maraseni *et al.* 2008). Therefore, we should never undermine the role of natural forest expansion in ecological restoration of and provision of diverse forest products including non-wood forest products from the restored forest landscape.

Impact of forest management regimes on biomass/carbon pools

The above ground tree biomass densities were neither significantly different between natural forests and planted forests, nor among the Special use, Protection and Production forests. The study has shown that the ecological functions designated to the Special use, Protection and Production forests imposed significant effects on the SOC.

Special use forest constituted the largest stock of the SOC. Special use forests are used mainly for conservation of nature, specimens of the national forest ecosystems and forest biological genetic resource, for scientific research, protection of historical and cultural relics as well as landscapes, in service of recreation and tourism in combination with protection, contributing to environmental protection (GSRV 2004). This implies that most of the Special use forests are natural forests, however, forest plantation is also considered as one of the means to restore forest ecosystem. For ecological restoration zones, the special use forest management boards shall assign Special use forests to local households and individuals (GSRV 2004), and the contracts are made on a long-term basis (usually 50 years) with households in ecological restoration areas for afforestation and protection (Phuong 2000). Decision No. 186/2006/QD-TTg stipulates that it is allowed to plant or regenerate forests and carry out bio-forestrial methods in order to raise the quality of forests in service-administrative zones of the Special use forests (GSRV 2006). In such areas, where it is necessary to plant forests, priority shall be given to the planting of indigenous plants of such forests (GSRV 2006).

Households are entitled to collect dead or felled trees, non-timber forest plants for their own use (Phuong 2000, GSRV 2004). Eco-environmental tourism activities is allowed in the service-administrative zones of Special use forests (GSRV 2004). Furthermore, special use forest management boards may provide contract jobs of forest protection, breeding and plantation, tending and enrichment to local households, individuals, village communities or people's armed force units for forest protection and development (GSRV 2006).

The results resonate with the findings from different other studies suggesting land use and management affects the SOC stock (see, Glaser *et al.* 2000 (Kyrgyzia), Shrestha *et al.* 2004, Sitaula *et al.* 2004 (Nepal), Brown and Lugo 1990 (Puerto Rico and US Virgin islands), The Dang and Klinnert 2001

(Vietnam)). On the contrary, origin of the forest has no statistically significant impact on the SOC. The finding resonates with Li *et al*. (2005), who found no significant difference in total SOC between a pine plantation and secondary forests.

Our study suggests forest management regimes/objectives are the major determinants of the AGTB and SOC pools of the forests. The strong association of the carbon stocks with the forests under the different management regimes and with particular carbon pool provides valuable information for policy makers to make informed choice of forest management regime, forest types and carbon pools for the forest landscape restoration.

CONCLUSION

Based on the data from intensive forest inventories carried out in six communes of Dinh Hoa district, Vietnam, soil and biomass carbon pools in different types of forest stands were studied to quantify their contributions to the total forest carbon stocks. The forest stands were classified according to the mode of origin (natural forests and planted forests), and assigned ecological functions (Special use, Protection and Production forests). Soil organic carbon and the above ground tree carbon are the largest and second largest forest carbon pools, respectively, for all of the forest types in the district. The study observed no significant difference in soil organic carbon stocks between natural forests and planted forests. In contrast, the ecological functions of forests had significant impact on the mean soil organic carbon with Special use forest having the highest carbon content. Mean carbon densities of the total of all carbon pools were neither significantly different between natural and planted forests, nor among the Special use, Protection and Production forests. The study provides evidence that restoration interventions focused on planting trees or protection of degraded natural forests may provide equivalent potentials for increasing forest carbon stocks.

Since the soil organic carbon and the above ground tree carbon contribute the significant shares to the total forest carbon stocks in the study area, afforestation and reforestation activities in barren forest lands and un-used lands as a means of active forest landscape restoration provide ample opportunity to reverse, restore and enhance the forest carbon stocks in the area. However, forest landscape restoration strategies should not be applied solely to increase carbon sinks.

The case study presents an example of a good practice of restoring degraded forests and forest lands from the bottom up approach. This demonstrates an effective approach to multi-stakeholder engagement of individual households, local governments and local leaders, and commune and district level forestry practitioners/authorities in restoration planning and implementation at a comparable scale tailored to national forest landscape restoration targets. Moreover, the results indicated enhancement of forest carbon stocks through conversion of barren and unused lands to forest land, i.e. active forest landscape restoration is practically attainable in Vietnam. Therefore, forest landscape restoration through afforestation and reforestation activities in millions of ha of barren forest lands and non-productive lands should be integral components of the intended nationally determined contributions. The bottom-up approach of the forest landscape restoration seems pragmatic and politically feasible, however, policy-makers interested in rapid and robust progress toward forest landscape restoration should focus on developing realistic forest landscape restoration targets.

The study provides in-depth understanding of distribution of carbon content in five different carbon pools in different forest ecosystems, which are currently scarce in Vietnam. This is crucial for carbon accounting, carbon budgeting and designing appropriate carbon sequestration strategies. Moreover, the estimates/information are valuable to develop a robust and transparent system of measurement, monitoring, reporting and verification of carbon stocks, and accurate assessments of outcomes in the context of forest landscape restoration and REDD+.

An adequate and predictable financial resource is one of the key challenges for the forest landscape restoration at a large scale. REDD+ is seen as a financial vehicle for forest landscape restoration interventions. Nevertheless, to make use of the promising potential of forests managed by highly forest-dependent households to be fully included in the REDD+ mechanism, special focus on the co-benefits, e.g., biodiversity and livelihoods enhancement should be ascertained. Another constraint to REDD+ participation is the naturally low carbon storage potential in severely degraded forests, which is being handed over to the local households. The inclusive and comprehensive forest landscape restoration interventions, which integrate with REDD+ and payment for ecosystem services, could be more pragmatic for securing finance and multiple ecosystem services.

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SUPPLEMENTARY MATERIALS

TABLE 1 *Wood specific density used for the study. Where wood density was provided in a range, the lowermost value was used for the study*

SN	Scientific name	Local/VN name	Family	WD (Kg/m³)
1	*Acacia auriculiformis* A. Cunn. ex Benth.	Keo lá tràm	*Mimosaceae*	560
2	*Acacia auriculiformis* x *mangium*	Keo lai	*Mimosaceae*	538
3	*Acacia mangium* Willd.	Keo tai tượng	*Mimosaceae*	586
4	*Acer fabri* Hance (*Acer tonkinense* Lecomte)	Thích bắc bộ	*Aceraceae*	750-790
5	*Acer oblongum* Wall. ex DC.	Thích lá thuôn	*Aceraceae*	720
6	*Acronychia pedunculata* Roxb. (L.) Miq.	Bưởi bung	*Rutaceae*	490-650-830
7	*Actephila excelsa* Muell-Arg.	Chè rừng	*Euphorbiaceae*	
8	*Actinodaphne pilosa* (Lour.) Merr.	Kháo lông	*Lauraceae*	430-815
9	*Actinodaphne sesquipedalis* Hook.	Bộp lá to, Roa	*Lauraceae*	430-815
10	*Adenanthera microsperma* Teijm et Binn.	Muồng ràng ràng, Ràng cam thảo, Lim váng	*Leguminosae*	600-800-1050
11	*Aesculus chinensis* Bunge	Kẹn	*Hippocastanaceae*	750
12	*Aglaia gigantea* (Pierre) Pellegrin	Gội nếp (Gội tía)	*Meliaceae*	600-790
13	*Aglaia spectabilis* (Miq.) Jain & Bennet.	Gội, Gội nep, Gội nui	*Meliaceae*	600-790
14	*Aidia pycnantha* (Drake) Tirveng.	Mãi táp	*Rubiaceae*	910
15	*Ailanthus altissima* (Mill) Swinggle	Thanh thất núi cao, Chạ hương	*Simaroubaceae*	330-435
16	*Ailanthus malabarica* DC.	Thanh thất, Chàng hơ thơm (5), Bút (5)	*Simaroubaceae*	435
17	*Alangium chinense* (Lour.) Harms	Thôi ba (Tu va)	*Alangiaceae*	540
18	*Alangium kurzii* Craib.	Thôi ba lông (Thôi chanh, Lăng quăng)	*Alangiaceae*	440-520-560
19	*Albizia procera* (Willd) Benth.	Muồng xanh	*Leguminosae*	590
20	*Alchornea rugosa* (Lour.) Muell.-Arg.	Đom đóm	*Euphorbiaceae*	
21	*Aleurites montana* (Lour.) Wils.	Trẩu	*Euphorbiaceae*	420
22	*Alphonsea monogyna* Merr. et Chun.	Thau lĩnh	*Annonaceae*	610-975
23	*Alphonsea tonkinensis* DC.	Thau lĩnh lá nhỏ	*Annonaceae*	610-975
24	*Alstonia scholaris* (L.) R.Br.	Sữa	*Apocynaceae*	490
25	*Amesiodendron chinense* (Merr.) Hu	Trường sâng (Trường ngấn)	*Sapindaceae*	1010
26	*Antidesma bunius* (L.) Spreng	Chòi mòi đất	*Euphorbiaceae*	580-640-690
27	*Antidesma montanum* Blume	Chòi mòi	*Euphorbiaceae*	730
28	*Aphanamixis grandifolia* Blume	Gội trắng (Gội, Gội gác, Gội nước)	*Melliaceae*	580
29	*Aporosa dioica* (Roxb.) Muell.-Arg.	Thẩu tấu (Thẩu tấu gốc khác)	*Euphorbiaceae*	700
30	*Archidendron balansae* (Oliv.) I. Nielsen	Phân mã (Cứt ngựa)	*Leguminosae*	350-860
31	*Archidendron clypearia* (Jack) I. Nielsen	Mán đỉa thường	*Leguminosae*	350-460-600
32	*Artocapus heterophyllus* Lamk	Mít, Mít mật (Chay Cúc Phương)	*Moraceae*	630
33	*Artocarpus masticatus* Gagnep.	Vỏ đỏ	*Moraceae*	560-670-800
34	*Artocarpus styracifolius* Pierre	Chay rừng, Vỏ khoai (Chay lá bồ đề)	*Moraceae*	580
35	*Artocarpus tonkinensis* A. Chev. Ex Gagnep.	Chay bắc bộ, Vỏ đỏ	*Moraceae*	580
36	*Averrhoa carrambola* L.	Khế	*Oxalidaceae*	710
37	*Baccaurea ramiflora* Lour.	Dâu da đất	*Euphorbiaceae*	630-950
38	*Barringtonia acutangula* (L.) Gaertn.	Lộc vừng (Lộc mưng, Chiếc)	*Lecythidaceae*	570-590-610

SN	Scientific name	Local/VN name	Family	WD (Kg/m³)
39	*Beilschmiedia laevis* Allen	Kháo nhẵn	*Lauraceae*	610
40	*Betula alnoides* Buch.-Ham.	Cáng lò	*Betulaceae*	650
41	*Bischofia javanica* Blume	Nhội	*Euphorbiaceae*	620
42	*Blastus cochinchinensis* Lour.	Mua đất	*Melastomataceae*	
43	*Bombax ceiba* L.	Gạo	*Bombacaceae*	330
44	*Bridelia balansae* Tutcher	Đỏm gai, Cứt dúi, Thẩu mật)	*Euphorbiaceae*	450-880
45	*Bridelia monoica* (Lour.) Merr.	Đỏm lông	*Euphorbiaceae*	760-770-820
46	*Bridelia penangiana* Hook. f.	Đỏm	*Euphorbiaceae*	550
47	*Broussonetia pappyrifera* (L.) L. Her. ex Vent.	Dướng (Mề đay)	*Moraceae*	380
48	*Brownlowia tabularis* Pierre	Lò bo	*Tilliaceae*	465-640
49	*Caesalpinia pulcherrima* (L.) Sw.	Kim phượng	*Caesalpiniaceae*	1050
50	*Callicarpa arborea* Roxb	Tu hú	*Verbenaceae*	455-510
51	*Callicarpa rubella* Lindl.	Cơm riệu	*Verbenaceae*	455-510
52	*Canarium album* (Lour.) Raeusch.	Trám (Trám trắng)	*Burseraceae*	568
53	*Canarium bengalensis* Guill	Trám ba cạnh	*Burseraceae*	547
54	*Canarium tonkinense* Engl.	Trám chim (Sấn chim)	*Burseraceae*	440
55	*Canarium tramdenum* Dai et Jakovl	Trám đen	*Burseraceae*	735
56	*Canthium dicoccum* (Gaertn.) Merr.	Xương cá	*Rubiaceae*	750-810
57	*Canthium horridum* Blume	Găng	*Rubiaceae*	560-1060
58	*Canthium umbellatum* Wight	Xương gà, Cà phê rừng	*Rubiaceae*	750-810
59	*Carallia diplopetala* Hand.-Mazz.	Răng cá, Da cá, Chả Bứa	*Rhizophoraceae*	640-1050
60	*Cassia javanica* L. *(Zenia insignis* Chun)	Muồng hoa đào	*Leguminosae* (*Caesalpiniaceae*)	690
61	*Cassia siamea* Lamarck	Muồng đen	*Leguminosae*	810
62	*Cassia* sp.	Muồng	*Caesalpiniaceae*	810
63	*Castanopsis echinocarpa* A. DC.	Dẻ gai nhim (Giẻ mỡ gà), Ca oi la nho (5)	*Fagaceae*	710
64	*Castanopsis indica* (Roxb.) A. DC.	Dẻ gai, Giẻ gai, Giẻ gai Ấn Độ	*Fagaceae*	720
65	*Castanopsis* sp.	Giẻ, Dẻ	*Fagaceae*	720
66	*Castanopsis tonkinensis* Seemen ex Engl.	Cà gai bắc bộ, Giẻ gai thô, Dẻ gai ấn độ	*Fagaceae*	680
67	*Chisocheton paniculatus* (Roxb.) Hiern.	Quyếch, Quyếch tía, Gội nước	*Meliaceae*	425-790-1000
68	*Choerospondias axillaris* (Roxb.) B. L. Burtt. & Hill	Xoan nhừ, Lát xoan, Đội bầu	*Anacardiaceae*	400
69	*Chukrasia tabularis* A. Juss.	Lát hoa	*Meliaceae*	680
70	*Cinnadenia paniculata* (Hook. f.) Kosterm.	Kháo xanh	*Lauraceae*	
71	*Cinnamomum iners* Reinw.	Quế lợn	*Lauraceae*	380-570-630
72	*Cinnamomum* sp.	Re	*Lauraceae*	430
73	*Cinnamomuum bejolghota* (Buch.-Ham. ex Nees) Sweet	Re bầu, Re trắng, Re lá tù, Quế lợn	*Lauraceae*	500
74	*Cipadessa cinerescens* (Pellegr.) H.M.	Cà muối	*Meliaceae*	720-839
75	*Citrus grandis* (L.) Osbeck	Bưởi	*Rutaceae*	590
76	*Claoxylon polot* (burm) Merr.	Lộc mại	*Euphorbiaceae*	440-450-470
77	*Clausena anisata (Willd.) Hook. f. ex Benth.*	Hồng bì rừng	*Rutaceae*	
78	*Clausena excavata* Burm. f.	Hồng bì, Mắc mật	*Rutaceae*	

SN	Scientific name	Local/VN name	Family	WD (Kg/m³)
79	*Clausena sp.*	Nhậm rừng	*Rutaceae*	
80	*Cleistanthus tonkinensis* Jabl.	Cọc rào	*Euphorbiaceae*	550-820
81	*Crataeva religiosa* Forst.	Bún, Ràng ràng xanh	*Capparidaceae (Fabaceae)*	530
82	*Cratoxylum cochinchinense* (Lour.) Blume	Lành ngạh nam bộ, Thành ngạnh nam	*Hypericaceae*	780
83	*Cratoxylum pruniflorum* Kurz	Đỏ ngọn, Thành ngạnh dẹp	*Hypericaceae*	820-950-1060
84	*Croton sp.*	Bã đậu lá nhỏ	*Euphorbiaceae*	630-700
85	*Croton tiglium* L.	Bã đậu, Bã đậu lá tròn	*Euphorbiaceae*	630-700
86	*Cryptocarya lenticellata* Lecomte	Nanh chuột, Mò lá nhỏ	*Lauraceae*	350-(440-830)-870
87	*Cryptocarya impressa* Miq.	Mò quả xanh	*Lauraceae*	560-610-670
88	*Cryptocarya infectoria* (Blume) Miq.	Mò gỗ	*Lauraceae*	700-770-800
89	*Daphniphyllum marchandii aff.* (H. Lev.) Croizat et Metc.	Giao phương	*Daphniphyllaceae*	490
90	*Dendrocnide urentissima* (Gagnep.) Chew	Han (Mán voi; Han voi; Lá han)	*Ulmaceae*	380
91	*Deutzianthus tonkinensis* Gagnep.	Mọ	*Euphorbiaceae*	
92	*Dillenia heterosepala* Fin. & Gagnep.	Lọng bàng	*Dilleniaceae*	590
93	*Dimocarpus longan* Lour.	Nhãn	*Sapindaceae*	820-870-920
94	*Diospyros apiculata* Hiern.	Hồng, Thị rừng	*Ebenaceae*	700
95	*Diospyros eriantha* Champ. ex Benth.	Nhọ nồi, Thị lông vàng, Chín tầng, Nặng đẳm	*Ebenaceae*	780
96	*Dipterocarpus retusus* Blume (D. *tonkinensis* A. Chev.)	Chò nâu	*Dipterocarpaceae*	820
97	*Dracontomelon mangiferum* Bl. (*Dracontomelon duperreanum* Pierre)	Sấu	*Anacardiaceae*	520
98	*Duabanga grandiflora* (Roxb. ex DC.) Walp.	Phay sừng, Bẵng làng, Bẵng sư, Mía tương	*Sonneratiaceae*	450
99	*Eberhardtia aurata* H. Lec. (*Eberhardtia tonkinensis* Lecomte)	Cồng sữa (Mắc niễng)	*Sapotaceae*	
100	*Elaeocarpus griffithii* (Wight) A. Gray	Côm, Côm tầng, Bàng giành	*Elaeocarpaceae*	650
101	*Elaeocarpus stipularis Blume (Elaeocarpus thorelli* Pierre)	Côm lá kèm	*Elaeocarpaceae*	650
102	*Endospermum sinensis* Benth.	Vạng trứng (Vạng)	*Euphorbiaceae*	476
103	*Engelhardtia chrysolepis* Hance (Syn: *Engelhardtia roxburghiana* Wall.)	Chẹo, Chẹo tía	*Juglandaceae*	330-660
104	*Erythrophloeum fordii* Oliver	Lim, Lim xanh	*Caesalpiniaceae*	930
105	*Eucalyptus exserta* F. Muell.	Bạch đàn xoắn	*Myrtaceae*	950-1010
106	*Euodia bodinieri* Dode	Chua chanh (Thôi chanh trắng)	*Rutaceae*	334
107	*Euodia meliaefolia* (Hance) Benth.	Ba chạc lá xoan, Thôi chanh, Thôi chanh tía, Ba chạc	*Rutaceae*	334
108	*Eurya nitida* Korth.	Súm lá trơn	*Theaceae*	700
109	*Evodia lepta* (Spreng.) Merr. (Syn: *Euodia lepta* (Spreng) Merr.)	Ba gạc	*Rutaceae*	334
110	*Ficus cunia* Buch.-Ham.	Cọ nọt	*Moraceae*	390
111	*Ficus fistulosa* Reinw. ex Blume	Sung rừng lá to, Sung rừng lá lớn, Sung rừng lá dài, Sung rừng cuống dài, Sung rừng cao	*Moraceae*	430-470-530

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112	*Ficus fulva* Reinw.	Mán, Ngõa khỉ	*Moraceae*	550
113	*Ficus fulva* Reinw. ex Blume	Vú bò lông, Ngõa lông	*Moraceae*	550
114	*Ficus gibbosa* Bl. (Syn: *Ficus semicordata* Buch.-Ham. ex Smith)	Đa lá lệch	*Moraceae*	390
115	*Ficus glandulifera* (Miq.) Wall. ex King	Vỏ mản	*Moraceae*	390
116	*Ficus harlandii* Benth	Sung rừng	*Moraceae*	430-470-530
117	*Ficus hispida* L. f.	Ngái	*Moraceae*	440
118	*Ficus lacor* Buch.-Ham.	Sung rừng quả nhỏ	*Moraceae*	460
119	*Ficus macrophylla* Desf	Đa lông vàng	*Moraceae*	390
120	*Ficus racemosa* L.	Sung, Cọ đưa, Sung đỏ	*Moraceae*	480
121	*Ficus heterophylla* L. f. (*Ficus simplicissima Lour.)*	Vú bò	*Moraceae*	390
122	*Ficus vasculosa* Wall. ex Miq.	Mít rừng	*Moraceae*	260-380-460
123	*Flacourtia indica* (Burm. f.) Merr.	Bồ quân	*Flacourtiaceae*	850-860-880
124	*Garcinia mulltiflora* Champ.	Dọc	*Clusiaceae (Guttiferae)*	750
125	*Garcinia oblongifolia* Champ. ex Benth.	Bứa	*Clusiaceae*	750
126	*Garuga pinnata* Roxb.	Trám mao	*Burseraceae*	640
127	*Gironniera subaequalis* Planch.	Ngát, Tăng mô	*Ulmaceae*	540
128	*Gleditsia fera* (Lour.) Merr.	Bồ kết rừng	*Caesalpiniaceae*	580
129	*Glochidion* sp.	Vỏ rộp, Bọt ếch, Sóc	*Euphorbiaceae*	440-890
130	*Gmelina arborea* Roxb.	Lõi thọ	*Verbenaceae*	420-640
131	*Gymnocladus angustifolius* (Gagnep.) J. E. Vidal	Muồng ràng ràng quả to, Muồng Sp (Lôi khoai), Ràng ràng quả to	*Caesalpiniaceae*	
132	*Helicia robusta* (Roxb.) Blume	Mạ sưa lá xẻ	*Proteaceae*	505-790
133	*Heliciopsis lobata* (Merr.) Sleum.	Đung, Mạ sưa phan thuy	*Proteaceae*	520-550
134	*Heteropanax fragrans* (Roxb.) Seem.	Đại khải, Tung trang	*Araliaceae*	
135	*Homalium ceylanicum* (Gardn.) Benth.	Bông trắng, Chà ran xây lan	*Flacourtiaceae*	800-840
136	*Hopea chinensis* (Merr.) Hand.-Mazz.	Sao hòn gai, Táu, Mạy chi	*Dipterocarpaceae*	649
137	*Horsfieldia amygdalina* (Wall.) Warb.	Sang máu, Máu chó; Máu chó lá to	*Myristicaceae*	523
138	*Hydnocarpus anthelminthica* Pierre ex Gagnep.	Đại phong tử, Chùm bao	*Flacourtiaceae*	690-950
139	*Hydnocarpus kurzii* (King) Warb.	Nang trứng	*Flacourtiaceae*	690-950
140	*Ilex rotunda* Thunb.	Nhựa (Nhựa ruồi)	*Aquifoliaceae*	490-680
141	*Ilex* sp.	Chè đắng	*Aquifoliaceae*	490-680
142	*Itoa orientalis* Hemsl.	Cườm đỏ	*Flacourtiaceae*	
143	*Kibatalia macrophylla* (Pierre in Planch. ex Hua) Woodson	Thừng mực trâu, Thừng mực lá to	*Apocynaceae*	385-610
144	*Knema conferta* (King) Warb. *(Knema corticosa* Lour.)	Máu chó lá nhỏ	*Myristicaceae*	530
145	*Knema pierrei* Warb.	Máu chó, Máu chó lá lớn, Máu chó lá to	*Myristicaceae*	530
146	*Lindera balansae* H. Lec.	Lòng trứng	*Lauraceae*	400-480
147	*Lithocarpus balansae* (Drake) A. Camus	Sồi (Sồi lá mác)	*Fagaceae*	840
148	*Lithocarpus cyrtocarpus* (Drake) A. Camus	Sồi bàn	*Fagaceae*	840
149	*Lithocarpus mairei* (Schottky) Rchd.	Sồi hồng	*Fagaceae*	840

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150	*Lithocarpus pseudosundaicus* (Hickel & A. Camus) A. Camus	Sồi xanh	*Fagaceae*	510-(600-1000)-1105
151	*Lithocarpus* sp.	Sồi giẻ	*Fagaceae*	510-(600-1000)-1105
152	*Lithocarpus truncatus* (King) Rehd. et Wils.	Sồi quả vát	*Fagaceae*	840
153	*Litsea sebifera* Pers. (Syn: *Litsea glutinosa* (Lour.) C.B. Robins))	Bời lời nhớt	*Lauraceae*	600-839
154	*Litsea balansae* Lecomte	Mò roi	*Lauraceae*	400
155	*Litsea baviensis* Lecomte (Syn: *Litsea lancilimba*)	Bời lời	*Lauraceae*	540-570
156	*Litsea cubeba* (Lour.) Pers.	Màng tang (Mần tang)	*Lauraceae*	580
157	*Litsea garretii* Pers. *(Litsea baviensis* Lecomte)	Bời lời xanh	*Lauraceae*	400
158	*Litsea monopetala* (Roxb.) Pers.	Mò, Mò giấy, Mò lá tròn	*Lauraceae*	620
159	*Litsea monopetala* (Roxb.) Pers.	Bời lời lá tròn (Bời lời giấy)	*Lauraceae*	620
160	*Litsea oblongata* Hook. f.	Bời lời lông	*Lauraceae*	400
161	*Litsea rotundifolia* (Wall. ex Nees) Hemsl. var. *oblongifolia* (Nees) Allen	Kháo sp	*Lauraceae*	400
162	*Litsea verticillata* Hance	Kháo vòng, Bời lời vỏng	*Lauraceae*	400
163	*Macaranga denticulata* (Blume) Muell.-Arg.	Lá nến	*Euphorbiaceae*	580
164	*Macaranga denticulata* Muell-Arg.	Ba soi (Hu ba soi)	*Euphorbiaceae*	580
165	*Machilus leptophylla* Hand.-Mazz.	Rè nhớt	*Lauraceae*	655
166	*Machilus odoratissima* Nees	Kháo thơm, Kháo nhậm; Khao tía, Kháo, Kháo đỏ, Kháo khỉnh, Kháo lá nhỏ, Kháo thối	*Lauraceae*	709
167	*Machilus booni Lecomte* Benth.	Kháo hoa vàng, Rè bon, Nhựa	*Lauraceae*	630
168	*Madhuca pasquieri* H.Lec.	Sến, Sến mật	*Sapotaceae*	1060
169	*Mallotus apelta* (Lour.) Muell.-Arg.	Ba bét trắng, Ba bét	*Euphorbiaceae*	370-830
170	*Mallotus barbatus* (Wall.) Muell.-Arg.	Bùm bụp (Bùng bục)	*Euphorbiaceae*	370-830
171	*Mallotus cochinchinensis* Lour	Ba bét nam bộ	*Euphorbiaceae*	390-420-490
172	*Mallotus paniculatus* (Lamk.) Muell.-Arg.	Ba Soi	*Euphorbiaceae*	390-420-490
173	*Mallotus philippinensis* (Lamk.) Muell.- Arg.	Cánh kiến	*Euphorbiaceae*	640
174	*Mallotus yunnanensis* Pax & Hoffm.	Ba bét Vân Nam	*Euphorbiaceae*	370-830
175	*Manglietia coniera* Dandy	Mỡ	*Magnoliaceae*	480
176	*Markhamia stipulata* (Wall.) Seem. ex Schum. var. *kerrii* Sprague	Kè đuôi giông	*Bignoniaceae*	990
177	*Markhamia stipulata* Seem (M.indica (Lour) Phamh.))	Đinh, Đinh khét, Kè đuôi giông	*Bignoniaceae*	990
178	*Melia azedarach* L.	Xoan, Xoan ta	*Meliaceae*	540
179	*Melochia umbellata* (Wight) Stapf	Trứng cua rừng	*Sterculiaceae*	320-400-430
180	*Michelia balansae* (A.DC.) Dandy	Giổi (Giổi lông, Giổi bà)	*Myristicaceae*	580
181	*Microcos paniculata* L.	Mánh, Cò ke	*Tiliaceae*	740-800-840
182	*Microdesmis caseariaefolia* Planch. ex Hook.	Chẩn (Sắng rừng, Chanh ốc)	*Euphorbiaceae*	
183	*Micromelum falcatum* Tanaka	Hồng bì rừng lá lớn	*Rutaceae*	
184	*Miliusa balansae* Fin. et Gagnep.	Màu cau, Na hồng	*Annonaceae*	630-890
185	*Miliusa* sp.	Họ na	*Annonaceae*	630-890

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186	*Millettia pulchra* (Colebr. ex Benth.) Kurz	Bạch chỉ nan	*Fabaceae*	720
187	*Morus alba* L.	Dâu	*Moraceae*	600-900
188	*Mussaenda dehiscens* Craib	Bướm cây	*Rubiaceae*	
189	*Neonauclea purpurea* (Roxb.) Merr.	Vàng kiêng (Gáo đỏ)	*Rubiaceae*	550
190	*Nephelium chryseum* Bl.	Vải guốc (Trường chua)	*Sapindaceae*	800-910-1010
191	*Ormosia pinnata* (Lour.) Merr.	Ràng ràng xanh	*Leguminosae*	700-730
192	*Ormosia* sp.	Thàn mát quả dày	*Leguminosae*	590
193	*Ormosia* sp.	Ràng ràng	*Leguminosae*	590
194	*Oroxylum indicum* (L.) Vent	Núc nác	*Bignoniaceae*	320
195	*Osmanthus matsumuranus* Hayata	Vỏ sạn, Vỏ sạn lá tròn	*Oleaceae*	
196	*Pavieasia annamensis* Pierre	Trường mật (Mắc kẹn)	*Sapindaceae*	
197	*Peltophorum dasyrrhachis* (Miq.) Kurz var. *tonkinense* (Pierre) K. & S. Larsen	Lim vàng, Hoàng linh, Hoàng linh nam	*Caesalpiniaceae*	615
198	*Peltophorum tonkinensis* A. Chev.	Lim xẹt	*Caesalpiniaceae*	750
199	*Phoebe cuneata* (Blume) Blume	Kháo lá to, Kháo, Su lá to	*Lauraceae*	540-630-750
200	*Phoebe pallida* (Nees) Nees	Kháo nước, Kháo	*Lauraceae*	480-750
201	*Phoebe* sp.	Kháo Sp	*Lauraceae*	480-750
202	*Pithecellobium clypearia* Benth. Var. *acuminatum* Gagnep.	Mán đỉa	*Mimosaceae*	350-460-600
203	*Polyalthia nemoralis* A.DC.	Nhọc lá nhỏ, Nhọc đen, Nhọc rừng, Ran rừng, Lèo heo	*Annonaceae*	555-645-900
204	*Polyalthia* sp.	Nhọc lá nhị, Ran, Chạ chuối, Nhọc lá nhỏ	*Annonaceae*	555-645-900
205	*Polyalthia* sp.	Vàng mương, Nóc, Quần dầu	*Annonaceae*	555-645-900
206	*Prunus arborea* (Blume) Kalkm.	Xoan đào, Mạy thông, Dô Ca	*Rosaceae*	620
207	*Pterospermum heterophyllum* Hance	Lòng mang	*Sterculaceae*	300-780
208	*Pterospermum truncatolobatum* Gagnep.	Lòng mang thường, Măng cụt	*Sterculiaceae*	300-780
209	*Quercus platycalyx* Hickel & A. Camus	Dẻ cau, Giẻ cau	*Fagaceae*	700
210	*Randia acuminatissima* Merr.	Mãi táp lông	*Rubiaceae*	910
211	*Randia spinosa* (Thunb.) Poir.	Găng	*Rubiaceae*	910
212	*Rhamnoneuron balansae* (Drake) Gilg in Engl. & Prantl	Dó (Gió)	*Thymelaeaceae*	
213	*Rhus chinensis* Mill.	Muối	*Anacardiaceae*	480-599
214	*Sambucus javanica* Reinw. ex Blume	Cơm cháy	*Caprifoliaceae*	
215	*Sapium discolor* (Champ. ex Benth.) Muell.-Arg.	Sòi tía	*Euphorbiaceae*	350-400-490
216	*Saraca dives* Pierre	Vàng anh (Cọ mạ)	*Leguminosae*	470-600-730
217	*Saurauia tristyla* DC.	Nóng lá lớn, Nóng sổ	*Actinidiaceae*	
219	*Schefflera heptaphylla* (L.) Harms. (*Vitex parviflora* Juss)	Chân chim, Ngũ gia bì	*Araliaceae*	420
220	*Sterculia coccinea* Roxb.	Trôm đỏ	*Sterculiaceae*	550
221	*Sterculia hymenocalyx* K. Schum.	Dùi trống	*Sterculiaceae*	550
222	*Sterculia lanceolata* Cavan	Trôm mề gà, Sảng nhung, Sảng	*Sterculiaceae*	600
224	*Sterculia tonkinensis* A.DC.	Thang, Sảng hoa thưa, Trôm bắc bộ	*Sterculiaceae*	550
225	*Streblus macrophyllus* Bl.	Nhò vàng	*Moraceae*	

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226	*Styrax tonkinensis* (Pierre) Craib ex Hartwiss	Bồ đề, Cánh kiêna trắng	*Styracaceae*	470-540-630
227	*Styrax tonkinensis* (Pierre) Craib ex Hartwiss	Bồ đề trắng	*Styracaceae*	470-540-630
228	*Symplocos cochinchinensis* (Lour.) S. Moore	Dung nam, Dung sạn, Dung nam bộ, Dung bốp	*Symplocaceae*	520
229	*Symplocos laurina* (Retz) Wall. var. *acuminata* (Miq.) Brand.	Dung giấy, Dung lá trá	*Symplocaceae*	560
230	*Symplocos lucida* (Thunb.) Sieb. & Zucc.	Dung mỡ	*Symplocaceae*	580
231	*Syzygium brachyata* Roxb	Trâm muỗi	*Myrtaceae*	690
232	*Syzygium cinereum* Wall.	Soi chạ, Trâm tía	*Myrtaceae*	690
233	*Syzygium malayanum* (Gagnep.) Merr. & Perry	Roi rừng	*Myrtaceae*	690
234	*Syzygium wightianum* Wall.	Trâm, Trâm trắng	*Myrtaceae*	690
235	*Tapiscia sinensis* Oliv.	Trương hôi	*Staphyleaceae*	
236	*Toona sinensis* (Adr. Juss.) M. J. Roemer	Tông dù, Xuấn sủ, Xuấn	*Meliaceae*	550-610
237	*Toona sureni* (Blume) Merr.	Lát khét, Tông van, Xuong moc, Ma nham	*Meliaceae*	690
238	*Toxicodendron succedanea* (L.) Mold.	Sơn ta, Sơn	*Anacardiaceae*	790
239	*Trema angustifolia* (Planch.) Blume	Hu đay lá hẹp, Kháo mít	*Ulmaceae*	400
240	*Trema orientalis* (L.) Blume	Hu đay, Hu lá nhỏ	*Ulmaceae*	310
241	*Trevesia palmate* (Roxb.ex Lindl.)	Đu đủ rừng	*Araliaceae*	
242	*Triumfetta pseudocana* Sprague & Craib	Gai đầu lông, Tiêng	*Tiliaceae*	
243	*Vernicia montana* Lour.	Trẩu, Trẩu nhăn, Trẩu nhẵn, Trẩu ta	*Euphorbiaceae*	420
244	*Vernonia arborea* Buch.-Ham. ex D. Don	Bông bạc	*Asteraceae*	400-500
245	*Vitex piereana* P.Dop	Đẻn gai, Đẹn đài lông mịn	*Verbenaceae*	650
246	*Vitex trifoliata* L.f. (*Vitex tripinnata* (Lour.) Merr.)	Đẻn ba lá, Quan âm, Mạn kính	*Verbenaceae*	650
247	*Wendlandia glabrata* DC.	Hoắc quang tía	*Rubiaceae*	740-790-820
248	*Wendlandia paniculata* (Roxb.) DC.	Hoắc quang	*Rubiaceae*	740-790-820
249	*Wendlandia* sp.	Cà phê	*Rubiaceae*	740-790-820
250	*Wrightia annamensis*	Thừng mực	*Apocynaceae*	470-490
251	*Wrightia arborea*	Lòng mức	*Apocynaceae*	620
252	*Wrightia laevis* Hook. f.	Thừng mực mỡ, Thừng mực lá nhỏ	*Apocynaceae*	410-480
253	*Xerospermum noronhianum* (Blume) Blume	Trường (Trường quách)	*Sapindaceae*	815
254	*Zanthoxylum avicennae* (Lamk.) DC.	Xẻn gai (Truống lá nhỏ, Sẻn, Hoàng mộc)	*Rutaceae*	330
255	*Zanthoxylum rhetsa* (Roxb.) DC.	Trám Sp., Hoàng mộc nhiều gai	*Rutaceae*	330
256		Chả sắn		
257		Lồng đèn	*Anonaceae*	

Some photographs of Dinh Hoa forests

Land clearance for Acacia plantation in Bao Cuong Commune, Dinh Hoa

Natural forests over the Limestone Mountains, Dinh Hoa

Acacia plantation in Lam Vi Commune, Dinh Hoa

Bamboo Forests in Quy Ky Commune, Dinh Hoa

Regrowth (restored) forest in Quy Ky Commune, Dinh Hoa

Degraded forest landscape in Diem Mac Commune, Dinh Hoa

Restoring forest landscape in Lam Vi Commune, Dinh Hoa