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Original article

Dry Dipterocarp Forest on Sandstone of the Huai Hong Khrai Royal Development Study Center, Chiang Mai Province I. Assessment of Plant Species Diversity and Carbon Storage

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ABSTRACT

Assessment of plant species diversity and carbon storage in a dry dipterocarp forest (DDF) on sandstone located in the Huai Hong Khrai Royal Development Study (HHKRDS) Center, Chiang Mai province, was carried out in 2010. Twelve plots, each of size 40 × 40 m^2, were used for the vegetation study using random sampling over forest having an altitude range between 403 m and 564 m above mean sea level. The plant data were obtained by measuring the stem girth over bark at 1.3 m above ground and the height of all trees taller than 1.5 m. The quantitative characteristics of plants, plant biomass, and carbon amounts derived from the carbon contents in the stem, branch, leaf, and root were measured. The DDF was divided into four stands based on the most dominant tree species: Hiang (*Dipterocapus obtusifolius*), Pluang (*D. tuberculatus*), Rang (*Shorea siamensis*), and Teng (*S. obtusa*), respectively, and most area was covered by the Hiang stand. There were 60 species (50 genera, 31 families) with an average density at 3,865$\pm$1,669 trees ha^{-1} in the four stands. The average amount of plant biomass was calculated to be 83.74$\pm$12.35 Mg ha^{-1}, divided into stem, branch, leaf, and root portions with amounts of 54.45$\pm$8.02 Mg ha^{-1}, 15.71$\pm$2.27 Mg ha^{-1}, 2.08$\pm$0.39 Mg ha^{-1}, and 11.55$\pm$1.85 Mg ha^{-1}, respectively. The carbon amount in biomass was estimated to be 41.59$\pm$6.26 Mg ha^{-1} partitioned into stem, branch, leaf, and root components of 27.16$\pm$4.0 Mg ha^{-1} (65.30%), 7.75$\pm$1.18 Mg ha^{-1} (18.60%), 1.02$\pm$0.20 Mg ha^{-1} (2.50%), and 5.65$\pm$0.97 (13.6%) Mg ha^{-1}, respectively. The Hiang stand had the highest carbon storage. It was considered that this forest still has a low carbon amount stored in plant biomass because it had been a degraded forest before the establishment of the HHKDS Center in 1984.

Keywords: carbon storage, plant diversity, dry dipterocarp forest, plant biomass

INTRODUCTION

It is generally known that dry dipterocarp forest (DDF) covers xeric sites in the northern, northeastern and central regions of Thailand. In the north, the forest can be found on rocky areas (without soil) and various soil types having different parent rocks. The difference in soil types is an important factor in the variation of plant communities in this forest, including the plant species composition, and diversity as well as plant growth and production. Other factors such as the amount of rainfall, topography, altitude, and microclimate also influence the variation, since this forest covers extensive areas from a peneplain at an altitude of about 150 m to slopes and rides of up to 1,300 m (Smithinand *et al*., 1980). Pampasit (1995) found that soils under DDF of four subtype communities in the Doi Inthanon National Park varied from the Order Entisols (very shallow) to Inceptisols (moderately deep) and Ultisols (deep). The DDF dominated by Pluang on the flat area derived from granitic rocks has a deep soil with high clay accumulation in the subsoil of the Order Ultisols (Wattanasuksakul, 2012). The soil on the sloping and ridge sites is usually shallow containing fragmented rocks. The typical dominant tree species in this forest are xeric dipterocarps including Teng, Rang, Hiang, and Pluang. The parent rocks vary from sedimentary rocks (sandstone, limestone) to igneous rocks (granite, andesite). Different parent rocks have influenced the soil physical, chemical, and biological properties (Fisher and Binkley, 2000).

Carbon sequestration by forests through photosynthesis and the accumulation of carbon as carbohydrate in plant tissues of different organs including the stem, branch, leaf, and root are considered as a carbon sink (Landsberg and Gower, 1997; Waring and Running, 1998). A part of this carbon is moved to the forest floor and accumulates in the soil system. The carbon sink in forest ecosystems is an important process for reducing atmospheric carbon dioxide and global warming. However, different forests have different potentials as a carbon sink due to sub-type communities, stages of forest succession caused by human disturbance particularly timber harvesting, and the influences of environmental factors. The DDF in the study area before the establishment of the HHKRDS Center in 1984 was very poor, caused by over harvesting of timber, it is now in the process of recovering. It spreads over different parent rocks, including igneous rock (rhyolite, andesite) and sedimentary rock (sandstone and limestone). Forest protection to prevent tree cutting and forest fires has been undertaken since 1984.

This research aimed to assess the condition of plant species diversity and carbon storage in a dry dipterocarp forest on sandstone at the Huai Hong Khrai Royal Development Study Center, after 26 years of forest protection. The data provide useful information for forest management and further monitoring.

MATERIALS AND METHODS

Study area

The research was conducted in the Huai Hong Khrai Royal Development Study Center, Chiang Mai province, about 27 km to the north of Chiang Mai city. The Center covers an area of about 1,360 ha with an altitude range between 350 m and 591 m above mean sea level (m.s.l.). The meteorological data recorded between 1985 and 2011 using instruments in the Center indicated the average annual rainfall was 1,328.9 mm, the average maximum and minimum air temperatures were 32.2°C and 18.9°C, respectively, and the average water evaporation was 1,222.6 mm per year. The forest in the Center consists mainly of two deciduous forests types-dry dipterocarp forest (DDF) and mixed deciduous forest (MDF). The DDF on sandstone is located in the western part of the Center.

Plant community study

1. Vegetation sampling

A method of plant community analysis was used for the vegetation study. Twelve permanent sampling plots, each of size 40 × 40 m^2, were used, and arranged randomly over the forest over an altitude range of 403-564 m m.s.l. Trees in each plot were sequentially numbered on the stem. The stem girth over bark at breast height (gbh, 1.3 m above ground) and the tree height of all tree species taller than 1.5 m were measured. All plots were located using a GPS. The growth forms of these plant species were determined according to their nature and the field observation experience of the researchers as big tree, medium-sized tree, small tree, and shrub, with maximum heights of approximately >25 m, 20–25 m, 5–20 m, and <5m, respectively.

2. Ecological parameters

The recorded field data of the tree species were used to calculate ecological parameters-plant frequency, abundance, density, dominance, importance value index, and Shannon-Wiener Index (SWI) of species diversity using equations given by Krebs (1985). The forest condition index (FCI) was based on an equation of Seeloy-ounkeaw *et al.* (2014) used for the plot of 40 × 40 m^2 size. For immature trees, the stem girth classes of tree species were divided into 25 cm intervals for the gbh up to 100 cm, and a 100 cm interval was applied for mature trees having a gbh over 100 cm. This equation assumed a greater importance for the mature trees due to the stem size (which provided merchantable timber as part of a past Thai timber concession as well as their high ecological influence). Thus, an increasing number of big trees in the plot will result in a higher FCI value.

$$FCI = \sum n_1.10^{-4} + n_2.10^{-3} + n_3.10^{-2} + n_4.10^{-1} + 1(n_5) + 2(n_6) + \ldots$$

where
n_1 = number of tree individuals having GBH<25 cm
n_2 = number of individuals having GBH 25 to <50 cm
n_3 = number of individuals having GBH 50 to <75 cm
n_4 = number of individuals having GBH 75 to <100 cm
n_5 = number of individuals having GBH 100 to < 200 cm
n_6 = number of individuals having GBH 200 to < 300 cm

Plant biomass estimation

The data of stem gbh and tree height of all tree species were also used for calculation of the biomass amounts in the stem, branch, leaf, and root using allometric equations for deciduous forests in Thailand by Ogino *et al.* (1967).

$$W_S = 189 (D^2H)^{0.902}$$
$$W_B = 0.125Ws^{1.204}$$
$$1/W_L = (11.4/Ws^{0.90}) + 0.172$$

where

W_S = stem biomass in kilograms
W_B = branch biomass in kilograms
W_L = leaf biomass in kilograms

The stem diameter (D) and tree height (H) are measured in meters. The root biomass was calculated using an equation of Ogawa *et al.* (1965)

$$W_R = 0.026 (D^2H)^{0.775}$$

where the root biomass (W_R) is measured in kilograms, stem diameter (D) in centimeters and tree height (H) in meters.

Carbon storages in plant biomass

The amounts of carbon stored in the plant biomass of all tree species in the forest were calculated by multiplying biomass amounts by the average carbon contents in plant tissues as reported by Tsutsumi *et al*. (1983). The average carbon contents in the stem, branch, leaf, and root organs of the 62 tree species in Thailand were reported to be 49.9%, 48.7%, 48.3% and 48.2%, respectively.

RESULTS AND DISCUSSION

Plant species composition and richness

Within the 12 plots each of 0.16 ha, 60 plant species in 50 genera and 31 families were identified from the samples (Table 1). These included 13 big trees, 19 medium-sized trees, 19 small trees, 5 shrubs, and 4 climbers. Table 2 shows the quantitative characteristics of all species in the forest. The DDF was divided into four stands according to the most dominant species. Most area in the forest was dominated by the Hiang stand, whereas the stands of Rang, Pluang and Teng covered only some sites.

The average density of all species taller than 1.5 m was 3,865±1,669 trees ha^{-1}. The species with the highest density was Hiang with 24.80% of the total density (959 trees ha^{-1}), followed by Teng (447), *G. usitata* (357), *M. scutellatum* (352) Rang (267), *T. burmanica* (226), Pluang (221), *D. oliverli* (166), *A. fragrans* (146), *A. villosa* (125), *W. tinctoria* (83), and *C. subulatum* (70). These 12 species accounted for 88.40% of the total individuals. The remaining 48 species had a lower density of less than 60 trees ha^{-1}.

The 12 abundant species had a frequency above 75%. Six species Hiang, *G. usitata*, Teng, Pluang, Rang, and *A. villosa* had 100% frequency, followed by *C. subulatum*, *W. tinctoria*, *M. scutellatum*, *T. burmanicum*, *D. oliverli*, and *A. fragrans*, with 75-92% frequency.

Species that colonize with high abundance in restricted areas were identified by calculating the abundance of each species as the total number of individuals divided by the number of plots with its presence. A relatively high abundance was observed for *M. scutellatum*, *T. burmanicum*, *D. oliverli*, *A. fragrans*, *G. cowa*, *M. extensa*, *Q. brandisiana*, and *S. albiflorum*.

The dominance was calculated on the basis of the stem basal area; the total basal area was 37.36 m^2 ha^{-1}. Hiang had the highest dominance (42.66% of all species), followed by *G. usitata* (15.14), Pluang (10.54), Teng (9.45), and Rang (8.16); these five species accounted for 85.95% of the total dominance.

The importance value index (IVI) combines the relative frequency, relative density, and relative dominance into a measure that can be used to indicate the ecological influence of each species in the forest. The species with the highest IVI was Hiang (23.71% of all species), followed by *G. usitata* (9.44), Teng (8.28), Pluang (6.70), Rang (6.28), *M. scutellatum* (4.38), *T. burmanicum* (3.25), *D. oliverli* (3.05), *A. villosa* (2.99), *A. fragrans* (2.45), *C. subulatum* (2.07), and *W. tinctoria* (1.89). These 12 species accounted for 75% of the total IVI value.

Figure 1 shows the population distribution according to different stem-gbh classes in the four stands of the DDF. The total number of trees in the Hiang stand (4,763 trees ha^{-1}) having gbh classes of <25 cm, 26–50 cm, 51–75 cm, 76–100 cm, and 101–200 cm were: 3,689, 812, 218, 41, and 3 trees ha^{-1}, respectively. Similarly for the Rang stand (1,763 trees ha^{-1}) the numbers were: 1,028, 491, 175, 59, and 9 trees ha^{-1}; for the Pluang stand (1,525 trees ha^{-1}) the numbers were: 644, 594, 238, 44, and 6 trees ha^{-1}, respectively, and for the Teng stand (3,225 trees ha^{-1}) were 2,063, 888, 256, 13, and 6 trees ha^{-1}, respectively. The total numbers for all stands (3,865 trees ha^{-1}) by the same gbh classes were 2,856, 746, 216, 42, and 5 trees ha^{-1}, respectively. This indicated that the Hiang stand had better regeneration than the others because of the higher population of saplings (<25 cm gbh) and young trees (26–50 cm) than the others.

Quantitative characteristics of tree species

It was found that the species composition, species richness, density, species diversity index, and forest condition were different among the four stands (Table 3).

1. Hiang stand

Eight plots were used for vegetation sampling in the Hiang stand which contained 59 species. The tree density varied between 1,638 and 5,925 trees ha^{-1}, with 4,763 trees ha^{-1} on average, and the average stem basal area was 20.88 m^2 ha^{-1} (17.0 to 23.75 m^2 ha^{-1}). The species with the greatest dominance (Hiang) had relative density, relative dominance, and IVI values of 26.66%, 50.72%, and 38.69%, respectively.

2. Rang stand

The two plots of the Rang stand had different ecological parameters for species richness (19 species), density (1,763 trees ha^{-1}) and basal area (16.0 m^2 ha^{-1}). Rang had relative density, relative dominance, and IVI values of 30.93%, 34.40%, and 32.67%, respectively.

3. Pluang stand

One plot was classified as a Pluang stand with the ecological parameters being species richness (20 species), density (1,525 trees ha^{-1}), and basal area (17.25 m^2 ha^{-1}). Pluang had relative density, relative dominance, and IVI values of 37.30%, 35.81%, and 36.55%, respectively.

4. Teng stand

One plot was classified as a Teng stand, and its ecological parameters were species richness (28 species) density (3,225 trees ha^{-1}) and basal area (19.81 m^2 ha^{-1}). The relative density, relative dominance, and IVI values of Teng were 27.91%, 37.93%, and 32.92%, respectively.

The number of species per plot (species richness) in the Hiang stand varied between 17 and 37 species, with 29 species on average. The species richness in the Rang, Pluang, and Teng stands was 16, 20, and 28 species, respectively. The highest density was observed in the Hiang stand (4,763 trees ha^{-1}), followed by the stands of Teng (3,225), Rang (1,763), and Pluang (1,525), whereas the stem basal areas of these stands were 20.88 m^2 ha^{-1}, 19.81 m^2 ha^{-1}, 16.0 m^2 ha^{-1} , and 17.25 m^2 ha^{-1}, respectively.

The relative density, relative dominance, and relative IVI of the most dominant species were considered for each stand. The average relative density in the four stands was 26.75±7.58%, and some differences were found among the stands. The average dominance and relative IVI in these stands was 43.02±14.23% and 34.84±9.52%, respectively. The ecological roles of the most dominant species in these stands had small differences.

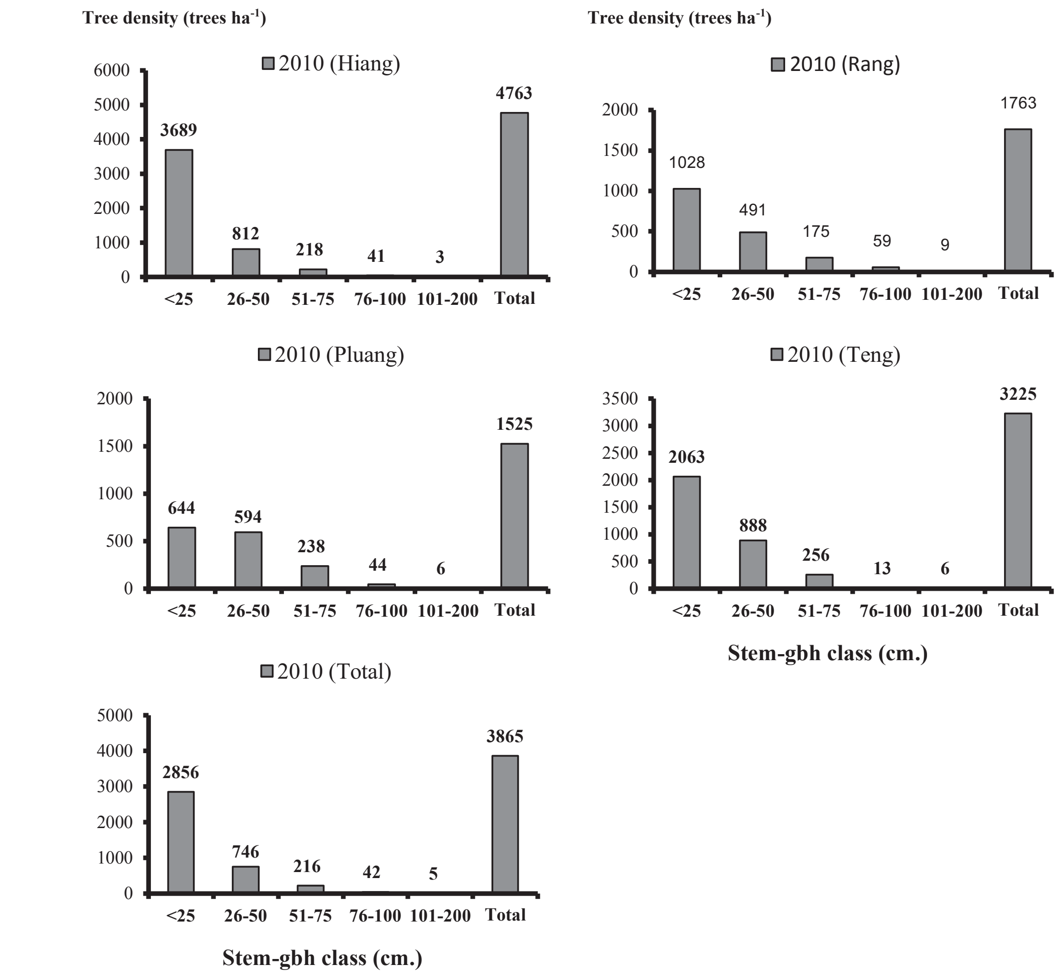

Figure 1 Population distribution of plant species based on stem-gbh classes in four stands of DDF

Table 1 Species list and growth forms of plant species in DDF on sandstone.

Family	Scientific name	Growth form
1. Anacardiaceae	1. *Buchanania lanzan* Spreng.	Big tree
	2. *Gluta usitata* (Wall.) Ding Hou	Big tree
	3. *Semecarpus albescens* Kurz	Medium-sized tree
2. Annonaceae	4. *Goniothalamus laoticus* (Finet & Gagnep.) Bân	Medium-sized tree
3. Apocynaceae	5. *Amphineurion marginatum* (Roxb.) D.J. Middleton	Climber
4. Bignoniaceae	6. *Dolichandrone serrulata* (Wall. ex DC.) Seem.	Small tree
	7. *Stereospermum neuranthum* Kurz	Big tree
5. Burseraceae	8. *Canarium subulatum* Guillaumin	Big tree
6. Chrysobalanaceae	9. *Parinari anamensis* Hance	Medium-sized tree
7. Clusiaceae	10. *Garcinia cowa* Roxb. ex Choisy	Small tree
8. Combretaceae	11. *Terminalia chebula* Retz. var. *chebula*	Medium-sized tree
	12. *Terminalia mucronata* Craib & Hutch.	Big tree
9. Compositae	13. *Vernonia volkameriifolia* Wall ex DC.	Shrub
10. Dilleniaceae	14. *Dillenia obovata* (Blume) Hoogland	Small tree
11. Dipterocarpaceae	15. *Dipterocarpus obtusifolius* Teijsm. ex Miq.	Big tree
	16. *Dipterocarpus tuberculatus* Roxb.	Big tree
	17. *Shorea obtusa* Wall. ex Blume	Big tree
12. Ebenaceae	18. *Shorea siamensis* Miq.	Big tree
	19. *Diospyros ehretioides* Wall. ex G. Don	Small tree
	19. *Diospyros ehretioides* Wall. ex G. Don	Small tree
13. Ericaceae	20. *Craibiodendron stellatum* (Pierre) W.W.Sm.	Small tree
14. Fabaceae	21. *Albizia odoratissima* (L.f.) Benth.	Medium-sized tree
	22. *Cassia fistula* L.	Medium-sized tree
	23. *Dalbergia assamica* Benth	Big tree
	24. *Dalbergia oliveri* Gamble ex Prain	Medium-sized tree
	25. *Dalbergia ovata* Graham ex Benth.	Medium-sized tree
	26. *Dallbergia velutina* Benth.	Climber
	27. *Millettia extensa* (Benth.) Baker	Climber
	28. *Pterocarpus macrocarpus* Kurz	Big tree
	29. *Spatholobus parviflorus* (Roxb. ex DC.) Kuntze	Climber
15. Fagaceae	30. *Quercus brandisiana* Kurz	Medium-sized tree
	31. *Quercus kerrii* Craib	Medium-sized tree
16. Hypericaceae	32. *Cratoxylum formosum* (Jacq.) Benn. & Hook.f. ex Dyer	Small tree
17. Irvingiaceae	33. *Irvingia malayana* Oliv. ex A.W. Benn.	Big tree
18. Lamiaceae	34. *Tectona grandis* L.f.	Big tree
	35. *Vitex peduncularis* Wall. ex Schauer	Medium-sized tree
	36. *Vitex pinnata* L.	Medium-sized tree
19. Melastomataceae	37. *Memecylon scutellatum* (Lour.) Hook. & Arn.	Small tree
20. Moraceae	38. *Ficus* sp.	Medium-sized tree
21. Myrtaceae	39. *Syzygium albiflorum* (Duthie ex Kurz) Bahadur & R.C. Gaur	Medium-sized tree
	40. *Syzygium cumini* (L.) Skeels	Medium-sized tree
	41. *Tristaniopsis burmanica* (Griff.) Peter G. Wailson & J.T. Waterh.	Small tree
22. Malvaceae	42. *Pterospermum semisagittatum* Buch.-Ham.ex Roxb.	Medium-sized tree
23. Ochnaceae	43. *Ochna integerrima* (Lour.) Merr.	Small tree
24. Pentaphylacaceae	44. *Anneslea fragrans* Wall.	Medium-sized tree
25. Phyllanthaceae	45. *Aporosa villosa* (Wall. ex Lindl.) Baill.	Small tree
	46. *Bridelia retusa* (L.) A. Juss.	Small tree
	47. *Phyllanthus emblica* L.	Small tree
26. Rubiaceae	48. *Catunaregam spathulifolia* Tirveng	Small tree
	49. *Gardenia obtusifolia* Roxb. ex Hook.f.	Shrub
	50. *Gardenia sootepensis* Hutch.	Small tree
	51. *Haldina cordifolia* (Roxb.) Ridsdale	Medium-sized tree
	52. *Ixora cibdela* Craib	Shrub
	53. *Morinda coreia* Buch.-Ham	Medium-sized tree
	54. *Pavetta indica* L.var. *indica*	Shrub
	55. *Wendlandia tinctoria* (Roxb.) DC.	Small tree
27. Salicaceae	56. *Casearia gallifera* Tathana	Small tree
28. Sapotaceae	57. *Madhuca esculenta* H.R. Fletcher	Small tree
29. Simaroubaceae	58. *Eurycoma longifolia* Jack	Shrub
30. Symplocaceae	59. *Symplocos racemosa* Roxb.	Small tree
31. Ulmaceae	60. *Ulmus lanceifolia* Roxb. ex Wall.	Small tree

Table 2 Quantitative characteristics of tree species in DDF.

Name	Frequency (%)	Abundance	Density	Basal area	Relative values (%)			IVI	
		Trees ha^{-1}		m^2 ha^{-1}	Frequency	Density	Dominance	300	%
1. *D. obtusifolius*	100	959	959	15.94	3.81	24.67	42.66	71.14	23.71
2. *G. usitata*	100	357	357	5.65	3.81	9.37	15.14	28.32	9.44
3. *S. obtusa*	100	447	447	3.53	3.81	11.57	9.45	24.83	8.28
4. *D. tuberculatus*	100	221	221	3.94	3.81	5.76	10.54	20.11	6.70
5. *S. siamensis*	100	267	267	3.05	3.81	6.87	8.16	18.84	6.28
6. *M. esculenta*	75	469	352	0.46	2.86	9.05	1.23	13.14	4.38
7. *T. burmanicum*	75	301	226	0.40	2.86	5.84	1.06	9.76	3.25
8. *D. oliverli*	75	221	166	0.78	2.86	4.19	2.10	9.15	3.05
9. *A. villosa*	100	125	125	0.71	3.81	3.25	1.89	8.96	2.99
10. *A. fragrans*	75	194	146	0.26	2.86	3.79	0.69	7.34	2.45
11. *C. subulatum*	92	76	70	0.35	3.49	1.79	0.94	6.22	2.07
12. *W. tinctoria*	83	100	83	0.13	3.17	2.16	0.35	5.68	1.89
13. *C. stellatum*	75	74	56	0.18	2.86	1.45	0.48	4.78	1.59
14. *B. lanzan*	83	47	39	0.11	3.17	0.79	0.28	4.25	1.42
15. *P. macrocarpus*	75	31	23	0.29	2.86	0.59	0.78	4.23	1.41
16. *M. esculata*	83	22	18	0.19	3.17	0.47	0.50	4.14	1.38
17. *G. obtusifolius*	75	38	28	0.07	2.86	0.74	0.19	3.79	1.26
18. *O. intergerrima*	83	17	14	0.05	3.17	0.36	0.14	3.68	1.23
19. *G. cowa*	58	73	43	0.05	2.22	1.19	0.12	3.54	1.18
20. *S. cumini*	58	41	18	0.16	2.22	0.46	0.42	3.10	1.03
21. *I. malayana*	50	33	16	0.24	1.90	0.47	0.64	3.02	1.01
22. *C. spathulifolia*	58	22	13	0.03	2.22	0.33	0.08	2.63	0.88
23. *P. anamensis*	50	18	9	0.15	1.90	0.23	0.40	2.53	0.84
24. *G. sootepensis*	50	34	18	0.05	1.90	0.46	0.14	2.50	0.83
25. *S. recemosa*	58	11	6	0.03	2.22	0.17	0.08	2.48	0.83
26. *P. indica*	58	13	8	0.01	2.22	0.20	0.02	2.44	0.81
27. *Q. kerrii*	50	21	11	0.06	1.90	0.27	0.17	2.34	0.78
28. *D. obovata*	50	18	9	0.07	1.90	0.24	0.19	2.33	0.78
29. *M. extensa*	33	64	21	0.04	1.27	0.56	0.11	1.94	0.65
30. *V.peduncularis*	33	33	11	0.01	1.27	0.28	0.03	1.58	0.53
31. *S .paviflorus*	33	20	7	0.02	1.27	0.17	0.04	1.49	0.50
32. *H. cordiforia*	33	17	6	0.01	1.27	0.15	0.02	1.44	0.48
33. *Q. brandisiana*	8	47	24	0.18	0.32	0.63	0.49	1.43	0.48
34. *S. albiflorum*	17	100	17	0.07	0.63	0.60	0.18	1.42	0.47
35. *C. formosum*	33	11	4	<0.01	1.27	0.09	0.00	1.36	0.45
36. *A. marginatum*	33	8	3	<0.01	1.27	0.07	0.01	1.34	0.45
37. *D. ehretioides*	25	4	1	0.03	0.95	0.04	0.09	1.08	0.36
38. *A. odoratissima*	25	8	2	0.01	0.95	0.05	0.02	1.03	0.34
39. *U. lanceifolia*	25	10	3	<0.01	0.95	0.07	0.00	1.02	0.34
40. *M. coreia*	17	9	2	0.02	0.63	0.04	0.05	0.73	0.24
41. *T. chebula*	17	3	1	<0.01	0.63	0.03	0.00	0.66	0.22
42. *V. pinnata*	17	6	1	<0.01	0.63	0.03	0.00	0.66	0.22
43. *P. emblica*	8	38	3	<0.01	0.32	0.08	0.01	0.41	0.14
44. *D. assamica*	8	13	1	0.01	0.32	0.03	0.02	0.37	0.12
45. *I. cibdela*	8	19	2	<0.01	0.32	0.04	0.00	0.36	0.12
46. *S. albescens*	8	6	1	0.01	0.32	0.01	0.02	0.35	0.12
47. *D. serrulata*	8	6	1	0.01	0.32	0.01	0.02	0.35	0.12
48. *T. mucronata*	8	13	1	<0.01	0.32	0.03	0.00	0.35	0.12
49.*V.volkameriifolia*	8	13	1	<0.01	0.32	0.03	0.00	0.35	0.12
50.*C. fistula*	8	6	1	<0.01	0.32	0.01	0.01	0.34	0.11
51.*T. grandis*	8	6	1	<0.01	0.32	0.01	0.01	0.34	0.11
52. *Ficus sp.*	8	6	1	<0.01	0.32	0.01	0.00	0.33	0.11
53. *D. ovata*	8	6	1	<0.01	0.32	0.01	0.00	0.33	0.11
54. *S. neuranthum*	8	6	1	<0.01	0.32	0.01	0.00	0.33	0.11
55. *G. laoticus*	8	6	1	<0.01	0.32	0.01	0.00	0.33	0.11
56. *C. gallifera*	8	6	1	<0.01	0.32	0.01	0.00	0.33	0.11
57. *E. longifolia*	8	6	1	<0.01	0.32	0.01	0.00	0.33	0.11
58. *B. retusa*	8	6	1	<0.01	0.32	0.01	0.00	0.33	0.11
59. *D. velutina*	8	6	1	<0.01	0.32	0.01	0.00	0.33	0.11
60. *P. semisagittatum*	8	6	1	<0.01	0.32	0.01	0.00	0.33	0.11
Total	2,625		3,865	37.36	100	100	100	300	100

Table 3 Quantitative characteristics of plants in 12 plots of four stands in DDF.

Plot no.	Dominant species	Species richnesss	Frequen-cydensity trees ha^{-1}	Basal area m^2 ha^{-1}	Values for the most dominant species (%)			SWI
					R. density	R. domnance	IVI	
1	*D. obtusifolius*	30	5,925	21.44	28.38	52.89	40.63	3.13
2	*D. obtusifolius*	17	1,638	17.00	24.43	22.24	23.33	2.83
3	*D. obtusifolius*	26	5,588	20.44	23.83	53.45	38.64	3.58
4	*D. obtusifolius*	28	4,388	20.06	33.62	62.29	47.96	3.32
5	*D. obtusifolius*	31	4,925	22.88	26.78	54.39	40.59	3.34
6	*D. obtusifolius*	31	4,694	21.88	23.83	54.62	39.23	3.46
7	*D. obtusifolius*	37	5,581	19.63	25.42	52.93	39.17	3.21
8	*D. obtusifolius*	34	5,369	23.75	27.01	52.96	39.99	3.41
	Mean	29	4,763	20.88	26.66	50.72	38.69	3.29
	S.D.	6	1.363	2.13	3.25	11.93	6.88	0.23
9	*S. siamensis*	18	1,456	15.94	28.33	38.71	33.52	2.81
10	*S. siamensis*	15	2,069	16.00	33.53	30.09	31.81	2.58
	Mean	16.5	1,763	16.00	30.93	34.40	32.67	2.7
11	*D. tuberculata*	20	1,525	17.25	37.30	35.81	36.55	2.88
12	*S. obtusa*	28	3,225	19.81	27.91	37.93	32.92	3.46
Mean		26	3,865	18.31	26.75	43.02	34.84	3.17
S.D.		7	1,669	5.19	7.58	14.23	9.52	0.32

Species diversity and forest condition

Species diversity in the 12 plots of the four stands in the DDF was determined using the Shannon-Wiener function (SWI) as shown in Table 3. The SWI values in the eight plots of the Hiang stand varied between 2.83 and 3.58, with 3.29 on average. The values in the Rang, Pluang, and Teng stands were 2.70, 2.88, and 3.46, respectively. Therefore, the Teng stand had the highest species diversity.

The forest condition indices based on an equation of Seeloy-ounkeaw (2014) are shown in Table 4. The FCI in the eight plots of the Hiang stand varied in the range 0.84–3.15, with 1.70 on average. Those values for the Rang, Pluang, and Teng stands were 2.83, 2.19, and 1.79, respectively. The Rang stand had the best forest condition, because it was composed of a higher density of immature trees (50–100 cm gbh) and mature trees (>100 cm) compared to the others.

Amounts of plant biomass

Table 5 shows the amounts of plant biomass and its allocation to different organs of the plant species in the four stands of the DDF. It was found that the average biomass amount in the 12 plots was 83.74±12.35 Mg ha^{-1}. The biomass allocation in the stem, branch, leaf, and root portions was 54.45 Mg ha^{-1}, 15.71 Mg ha^{-1}, 2.08 Mg ha^{-1}, and 11.55 Mg ha^{-1}, respectively. In the Hiang stand, the biomass amounts in the eight plots varied between 75.71 Mg ha^{-1} and 98.35 Mg ha^{-1}, with 90.18 Mg ha^{-1}on average. The amounts in the Rang, Pluang, and Teng stands were in the following order: 64.50 Mg ha^{-1}, 72.19 Mg ha^{-1} and 82.23 Mg ha^{-1}. Therefore, the Hiang stand had the highest biomass.

Amounts of carbon stored in plant biomass

As shown in Table 6, the average carbon amount stored in the plant biomass in the 12 plots was 41.59±6.26 Mg ha^{-1}. The carbon allocation in the different plant components showed the same patterns as for the biomass, and those amounts in stem, branch, leaf, and root portions were estimated at 27.16, 7.75, 1.02, and 5.65 Mg ha^{-1}, respectively. The Hiang stand had the highest potential for biomass carbon storage (44.83 Mg ha^{-1}), followed by the Teng (41.04 Mg ha^{-1}), Pluang (35.67 Mg ha^{-1}), and Rang (31.87 Mg ha^{-1}) stands.

Based on the 12 sample plots located randomly in the DDF on sandstone, four stand types were classified; however, most of the area was covered by the Hiang stand, while the Teng, Pluang, and Rang stands were found on some sites. In total, 60 species (in 50 genera and 31 families) were identified with an average density of 3,865±1,699 trees ha^{-1}. The mean values of species richness within the sample plots, species diversity index (SWI), and forest condition index (FCI) of these stands were 26±7, 3.17±0.32, and 1.94±0.98, respectively. DDF is usually identified as a species-poor ecosystem compared to other forests. However, it is difficult to compare the species richness among numerous studies because of differences in plot size and the number of plots used for the investigation. Pampasit (1995) investigated four stands of DDF on metamorphic rock and igneous rock (granite) in the Doi Inthanon National Park using 12 plots for each stand. He found that the species richness (40×40 m^2 plot size) in the Teng, Rang, Hiang, and Plung stands was 30, 31, 28, and 27 species, respectively, whereas the SWI values were 2.94, 3.15, 3.37, and 3.67, respectively. Phoncharoen (2009) studied the forest community at Ban Sai Thong, Lamphun province, using 10 plots of size 40×40 m^2 in the poor and intermediate sites. The species richness and SWI of the two sites were reported to be 60 and 71 species, respectively, and 3.80 and 3.33, respectively. These two studies did not determine the FCI using the present equation. Phongkhamphanh (2015) reported that the DDF on granitic rock within 15 plots of size 40×40 m^2 in Mae Tha community forest, Lamphun province, had higher species richness with 83 species (71 genera, 38 families), whereas the SWI and FCI were 3.35 and 4.53, respectively. Though the species richness in the DDF was different among the various locations, the SWI had the same range variation. The forest condition of the DDF in this study was poorer than in the Mae Tha community forest.

The amounts of plant biomass and stored carbon in the DDF on sandstone were estimated to be 83.74±12.35 Mg ha^{-1} and 41.59±6.26 Mg ha^{-1}, respectively. Compared to other locations, Phoncharoen (2009) found that the amounts were different for poor and intermediate sites, with biomass amounts of 47.65 Mg $ha^{-1}$and 119.83 Mg ha^{-1}, respectively, containing carbon amounts of 23.50 Mg ha^{-1} and 59.16 Mg ha^{-1}, respectively. Wattanasuksakul *et al*. (2012) estimated the biomass and carbon of DDF using two 1 ha plots in Mae Tang district, Chiang Mai province to be 106.63 and 52.63 Mg ha^{-1}, respectively. The Mae Tha community forest studied by Phongkhamphanh (2015) had higher amounts of biomass and carbon (125.5 Mg $ha^{-1}$and 62.0 Mg ha^{-1}, respectively) compared to the present study. The severe disturbance of the DDF on sandstone in the HHKRDS Center resulting from timber harvesting before 1984 was the main cause of the smaller amount of carbon storage in plant biomass compared to the other locations. In comparison, Seeloy-ounkeaw (2014) in lower montane forest used 50 plots of size 40×40 m^2 in the conservation community forest at Nong Tao village, and identified 244 species (166 genera, 71 families). The SWI and FCI values were higher than in DDF (4.49 and 15.97, respectively). The amounts of biomass (252.36 Mg ha^{-1}) and stored carbon (126.88 Mg ha^{-1}) were about three times higher than those in the DDF on sandstone.

Table 4 Number of trees with different stem-gbh classes used for calculation of FCI values in 12 plots of four stands in DDF.

Plot no.	Dominant tree	Number of trees (per plot) based on different stem gbh-classes in cm						FCI
		<25	26-50	51-75	76-100	101-200	Total	
1	*D. obtusifolius*	780	133	28	6	1	948	2.09
2	*D. obtusifolius*	105	126	21	8	2	262	3.15
3	*D. obtusifolius*	749	106	30	9	0	894	1.38
4	*D. obtusifolius*	517	148	34	3	0	702	0.84
5	*D. obtusifolius*	597	137	51	3	0	788	1.01
6	*D. obtusifolius*	572	128	46	4	1	751	2.05
7	*D. obtusifolius*	752	92	36	13	0	893	1.83
8	*D. obtusifolius*	650	169	33	7	0	859	1.26
	Mean	590	130	35	7	1	762	1.70
	S.D.	218	24	10	3	1	218	0.75
9	*S. siamensis*	129	65	26	10	3	233	4.34
10	*S. siamensis*	200	92	30	9	0	331	1.31
	Mean	165	78.5	28	9.5	3	282	2.83
11	*D. tuberculatas*	103	95	38	7	1	244	2.19
12	*S. obtusa*	330	142	41	2	1	516	1.79
Mean		457	119	35	7	1	618	1.94
S.D.		268	30	9	3	1	283	1.98

Table 5 Amounts of plant biomass in 12 plots of four stands in DDF.

Plot No.	Dominant tree	Plant biomass (Mg ha^{-1})				
		Stem	**Branch**	**Leaf**	**Root**	**Total**
1	*D. obtusifolius*	58.53	16.43	2.39	12.81	90.16
2	*D. obtusifolius*	49.08	14.98	1.70	9.95	75.71
3	*D. obtusifolius*	57.62	16.55	2.23	12.35	88.75
4	*D. obtusifolius*	53.98	14.57	2.29	11.88	82.72
5	*D. obtusifolius*	64.05	18.18	2.49	13.62	98.35
6	*D. obtusifolius*	63.21	18.44	2.35	13.23	97.23
7	*D. obtusifolius*	59.51	18.38	1.98	12.05	91.93
8	*D. obtusifolius*	62.88	17.30	2.62	13.77	96.57
	Mean	58.61	16.85	2.26	12.46	90.18
	S.D.	5.11	1.50	0.29	1.23	7.81
9	*S. siamensis*	44.80	13.94	1.45	8.90	69.09
10	*S. siamensis*	39.07	10.87	1.57	8.39	59.91
	Mean	41.93	12.41	1.51	8.65	64.50
11	*D. tuberculatas*	47.03	13.79	1.70	9.67	72.19
12	*S. obtusa*	53.60	15.07	2.13	11.43	82.23
Mean		54.45	15.71	2.08	11.55	83.74
S.D.		8.02	2.27	0.39	1.85	12.35

Table 6 Amounts of carbon stored in plant biomass in 12 plots of four stands in DDF.

Plot no.	Dominant tree	Carbon amount (Mg ha^{-1})				
		Stem	**Branch**	**Leaf**	**Root**	**Total**
1	*D. obtusifolius*	29.14	7.99	1.15	6.16	44.44
2	*D. obtusifolius*	24.49	7.30	0.82	4.80	37.41
3	*D. obtusifolius*	28.75	8.06	1.08	5.95	43.84
4	*D. obtusifolius*	26.93	7.27	1.14	5.93	41.28
5	*D. obtusifolius*	31.96	9.07	1.24	6.80	49.08
6	*D. obtusifolius*	31.54	9.20	1.17	6.60	48.52
7	*D. obtusifolius*	29.69	9.17	0.99	6.02	45.87
8	*D. obtusifolius*	31.38	8.63	1.31	6.87	48.19
	Mean	29.24	8.34	1.11	6.14	44.83
	SD	2.55	0.80	0.15	0.66	4.02
9	*S. siamensis*	22.35	6.79	0.70	4.29	34.14
10	*S. siamensis*	19.50	5.30	0.76	4.04	29.60
	Mean	20.93	6.04	0.73	4.17	31.87
11	*D. tuberculatas*	23.47	6.72	0.82	4.66	35.67
12	*S. obtusa*	26.75	7.52	1.06	5.71	41.04
Mean		27.16	7.75	1.02	5.65	41.59
S.D.		4.00	1.18	0.20	0.97	6.26
	%	65.30	18.60	2.50	13.60	100

CONCLUSION

The results of the assessment of plant species diversity and carbon storage in the DDF on sandstone at the Huai Hong Khrai Royal Development Study Center, Chiang Mai province can be summarized as follows:

1. The study area consisted of secondary forest composed of four stands/sub-type plant communities based on the most dominant dipterocarp tree species: Teng (*S. obtusa*), Rang (*S. siamensis*), Hiang (*D. obtusifolius*), and Pluang (*D. tuberculatus*). However, most forest area was covered by the Hiang stand.

2. In total, 60 species (50 genera and 31 families) were identified in the forest. Hiang had the highest density, dominance, and ecological importance in the forest, followed by *G. usitata*, Teng, Pluang, and Rang, respectively. The species diversity index using SWI was 3.17 and the forest was still in poor condition.

3. The amounts of plant biomass in the Hiang, Rang, Pluang, and Teng stands were estimated at 90.18 Mg ha^{-1}, 64.50 Mg ha^{-1}, 72.19 Mg ha^{-1} and 82.23 Mg ha^{-1}, respectively (83.74$\pm$12.35 Mg ha^{-1} on average). These biomass amounts contained carbon amounts of 44.83 Mg ha^{-1}, 31.87 Mg ha^{-1}, 35.67 Mg ha^{-1}, and 41.04 Mg ha^{-1}, respectively (41.59$\pm$6.26 Mg ha^{-1} on average).

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