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Original article

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

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ABSTRACT

Monitoring of plant species diversity and carbon storage in a dry dipterocarp forest (DDF) on sandstone was carried out in 2010 and 2015 at the Huai Hong Khrai Royal Development Study (HHKRDS) Center, Chiang Mai province. The forest was assessed for species diversity and carbon storage in 2010 using 12 permanent plots, each of size 40 × 40 m^2, and arranged to randomly sample the forest as reported in Part I. 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. Quantitative plant data, plant biomass and carbon amounts derived from the carbon contents in the stem, branch, leaf, and root portions were measured. The DDF was composed of four stands based on the most dominant tree species: Hiang (*Dipterocapus obtusifolius*), Pluang (*D. tuberculatus*), Teng (*Shorea obtusa*) and Rang (*S. siamensis*). It was found that the species richness, family richness, tree density, and species diversity index (SWI) had decreased from 2010 to 2015 with respective values of 60 to 53 species (-7), 31 to 27 families (-4), 3,865 to 2,780 trees ha^{-1} (-1,085), and 3.17 to 3.06 (-0.11), respectively. The death of many individual trees in the forest was the main cause of decreasing species diversity and plant production. However, the FCI increased, and the average amount of plant biomass also increased from 83.74$\pm$12.35 to 90.65$\pm$11.36 Mg ha^{-1} (+6.91). As a result, the average amount of carbon stored in plant biomass from 2010 to 2015 increased from 41.59$\pm$6.26 to 44.79$\pm$5.61 Mg ha^{-1}, being a net increase of 3.20 Mg ha^{-1} (7.7% of the amount in 2010) or only 0.64 Mg ha^{-1} yr^{-1}.

Keywords: carbon storage, dry dipterocarp forest, monitoring, plant species diversity

INTRODUCTION

Little is known about the temporal changes of plant communities in a secondary forest, particularly in dry dipterocarp forest (DDF). The lack of knowledge includes the species composition, richness, diversity, and ecological roles and particularly carbon storage which are all important in forest management. Measuring these ecological parameters over a period will provide information on plant community changes as a monitoring study. DDF usually covers xeric sites in the north, northeast and central of Thailand. Most forest is secondary forest caused by timber harvesting in the past and it has usually been disturbed by forest fires. The soil in this forest varies from very shallow to moderately deep and deep, and is normally unfertile being classified into various soil types from the Order Entisols to Inceptisols and Ultisols (Pamprasit, 1995; Wattanasuksakul, 2012). The growth of tree species in the forest is very slow influenced by the poor soil and also other environmental factors such as the amount of rainfall, topography, altitude, microclimate, fire, and parent rock since the forest covers extensive areas from the apeneplain at about 150 m altitude to slopes and rides of up to 1,300 m (Smithinand *et al*., 1980). Four typical dominant tree species are the xeric dipterocarps: Teng (*Shorea obtusa*), Rang (*S. siamensis*), Hiang (*Dipterocarpus obtusifolius*), and Pluang (*D. tuberculatus*). Parent rocks in DDF 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).

In a forest ecosystem, carbon sequestration by forests through photosynthesis and subsequent storage of carbon as carbohydrate in plant tissues of different portions (stem, branch, leaf, and root) are considered as an important process to reduce carbon dioxide levels in the atmosphere and global warming (Waring and Running, 1998). Some carbon amounts are moved to the forest floor and accumulate in the soil system. The potential carbon storage is usually different among forest types, sub-type communities, and stages of forest succession after human disturbance. The DDF in the study area before the establishment of the HHKRDS Center in 1984 was very poor caused by overharvesting the timber, and the forest is still recovering today. It covers different parent rocks including igneous rock (rhyolite, andesite) and sedimentary rock (sandstone and limestone). Forest protection against tree cutting and fire has been undertaken since 1984.

The objective of this research was to monitor the changes in the plant communities and carbon storage between 2010 and 2015 in the dry dipterocarp forest on sandstone in the Huai Hong Khrai Royal Development Study Center as the basis for forest and watershed management.

MATERIALS AND METHODS

Study area

The research area was 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 and 591 m above sea level. The meteorological data between 1985 and 2011 have been recorded using instruments in the Center. The data indicated an average annual rainfall of 1,328.9 mm, average maximum and minimum air temperatures of 32.2°C and 18.9°C, respectively, and average water evaporation of 1,222.6 mm per year. The forest in the Center consists mainly of two deciduous forests dry dipterocarp forest (DDF) and mixed deciduous forest (MDF). The DDF on sandstone is located on dry sites having poor soil in the western area of the Center.

Plant community study

1. Vegetation sampling

Plant community analysis was used for the vegetation study in 2010 and 2015. Twelve permanent sampling plots, each of size 40×40 m^2, were used and arranged randomly throughout the forest. Trees in each plot were numbered sequentially 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.

2. Ecological parameters

The recorded field data were used to calculate ecological parameters of the tree species in 2010 and 2015 consisting of the frequency, density, abundance, importance value index, and Shannon-Wiener Index of species diversity as given by Krebs (1985).

The forest condition index (FCI) in the 12 plots was calculated using an equation given by Seeloy-ounkeaw *et al.* (2014) used for 40×40 m^2 plots. For immature trees, the stem girth class of tree species was divided into 25 cm intervals for stem-gbh up to 100 cm. A 100 cm interval was applied for mature trees with a gbh over 100 cm. This assumed that the greater importance of the mature trees was due to their stem size (which produced merchantable timber harvested under Thailand's now defunct concession system as well as their high ecological influence). A larger number of big trees in the plot resulted in a higher FCI value.

$$FCI = \sum n_1.10^{-4} + n_2.10^{-3} + n_3.10^{-2} + n_4.10^{-1} + 1(n_5) + 2(n_6) + 3(n_7) + \ldots\ldots$$

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
n_7 = number of individuals having GBH 300 to < 400 cm

Plant biomass estimation

The recorded data of stem-gbh and tree height for all tree species in the forest were also used for the calculation of biomass amounts in the stem, branch, leaf, and root using allometric equations developed 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 carbon amounts stored in the plant biomass of all tree species in the forest were determined by multiplying the biomass amounts by the average carbon contents in the plant tissues investigated by Tsutsumi *et al*. (1983). The average carbon contents in the stem, branch, leaf, and root components of 62 tree species in Thailand were reported to be 49.9%, 48.7%, 48.3%, and 48.2%, respectively.

RESULTS AND DISCUSSION

1. Changes in plant species richness and composition, and community structure

1.1 Plant species richness and composition

Table 1 shows the species list of tree species and tree densities, and their differences in the DDF on sandstone between 2010 and 2015. In total, there were 60 species (in 50 genera, 31 families) in 2010 and this decreased to 53 species (in 43 genera, 27 families) in 2015. This indicated that 7 species, 7 genera and 4 families (1,085 trees ha^{-1}) disappeared over that period. The death of many individual tree during this period was mainly due to competition for environmental factors such as space, light, and moisture, nutrient and not from tree cutting and fire as there was effective protection against these anthropogenic activities in the Center's forest.

The decrease in species richness resulted in some change in the species composition. In 2010, seven species *Semecarpus albescens*, *Goniothalamus laoticus*, *Stereospermum neuranthum*, *Casearia gallifera*, *Bridelia retusa*, *Pterospermum semisagittatum*, and *Ulmus lancaifolia,* were represented by only one individual in the 12 plots and these had disappeared by 2015.

Table 1 Species list and densities of plant species in the DDF in 2010 and 2015.

Family	Scientific name	Appearance	
		2010	2015
1. Anacardiaceae	1. *Buchanania lanzan* Spreng.	√	√
	2. *Gluta usitata* (Wall.) Ding Hou	√	√
	3. *Semecarpus albescens* Kurz	√	-
2. Annonaceae	4. *Goniothalamus laoticus* (Finet & Gagnep.) Bân	√	-
3. Apocynaceae	5. *Amphineurion marginatum* (Roxb.) D.J. Middleton	√	√
4. Bignoniaceae	6. *Dolichandrone serrulata* (Wall. ex DC.) Seem.	√	√
	7. *Stereospermum neuranthum* Kurz	√	-
5. Burseraceae	8. *Canarium subulatum* Guillaumin	√	√
6. Chrysobalanaceae	9. *Parinari anamensis* Hance	√	√
7. Clusiaceae	10. *Garcinia cowa* Roxb. ex Choisy	√	√
8. Combretaceae	11. *Terminalia chebula* Retz. var. *chebula*	√	√
	12. *Terminalia mucronata* Craib & Hutch.	√	√
9. Compositae	13. *Vernonia volkameriifolia* Wall ex DC.	√	√
10. Dilleniaceae	14. *Dillenia obovata* (Blume) Hoogland	√	√
11. Dipterocarpaceae	15. *Dipterocarpus obtusifolius* Teijsm. ex Miq.	√	√
	16. *Dipterocarpus tuberculatus* Roxb.	√	√
	17. *Shorea obtusa* Wall. ex Blume	√	√
	18. *Shorea siamensis* Miq.	√	√
12. Ebenaceae	19. *Diospyros ehretioides* Wall. ex G. Don	√	√
13. Ericaceae	20. *Craibiodendron stellatum* (Pierre) W.W.Sm.	√	√
14. Fabaceae	21. *Albizia odoratissima* (L.f.) Benth.	√	√
	22. *Cassia fistula* L.	√	√
	23. *Dalbergia assamica* Benth	√	√
	24. *Dalbergia oliveri* Gamble ex Prain	√	√
	25. *Dalbergia ovata* Graham ex Benth.	√	√
	26. *Dallbergia velutina* Benth.	√	√
	27. *Millettia extensa* (Benth.) Baker	√	√
	28. *Pterocarpus macrocarpus* Kurz	√	√
	29. *Spatholobus parviflorus* (Roxb. ex DC.) Kuntze	√	√
15. Fagaceae	30. *Quercus brandisiana* Kurz	√	√
	31. *Quercus kerrii* Craib	√	√
16. Hypericaceae	32. *Cratoxylum formosum* (Jacq.) Benn. & Hook.f. ex Dyer	√	√
17. Irvingiaceae	33. *Irvingia malayana* Oliv. ex A.W. Benn.	√	√
18. Lamiaceae	34. *Tectona grandis* L.f.	√	√
	35. *Vitex peduncularis* Wall. ex Schauer	√	√
	36. *Vitex pinnata* L.	√	√
19. Melastomataceae	37. *Memecylon scutellatum* (Lour.) Hook. & Arn.	√	√
20. Moraceae	38. *Ficus* sp.	√	√
21. Myrtaceae	39. *Syzygium albiflorum* (Duthie ex Kurz) Bahadur & R.C. Gaur	√	√
	40. *Syzygium cumini* (L.) Skeels		
	41. *Tristaniopsis burmanica* (Griff.) Peter G. Wailson	√	√
	& J.T. Waterh.	√	√
22. Malvaceae	42. *Pterospermum semisagittatum* Buch.-Ham.ex Roxb.	√	-
23. Ochnaceae	43. *Ochna integerrima* (Lour.) Merr.	√	√
24. Pentaphylacaceae	44. *Anneslea fragrans* Wall.	√	√
25. Phyllanthaceae	45. *Aporosa villosa* (Wall. ex Lindl.) Baill.	√	√
	46. *Bridelia retusa* (L.) A. Juss.	√	-
	47. *Phyllanthus emblica* L.	√	√
26. Rubiaceae	48. *Catunaregam spathulifolia* Tirveng	√	√
	49. *Gardenia obtusifolia* Roxb. ex Hook.f.	√	√
	50. *Gardenia sootepensis* Hutch.	√	√
	51. *Haldina cordifolia* (Roxb.) Ridsdale	√	√
	52. *Ixora cibdela* Craib	√	√
	53. *Morinda coreia* Buch.-Ham	√	√
	54. *Pavetta indica* L.var. *indica*	√	√
	55. *Wendlandia tinctoria* (Roxb.) DC.	√	√
27. Salicaceae	56. *Casearia gallifera* Tathana	√	-
28. Sapotaceae	57. *Madhuca esculenta* H.R. Fletcher	√	√
29. Simaroubaceae	58. *Eurycoma longifolia* Jack	√	√
30. Symplocaceae	59. *Symplocos racemosa* Roxb.	√	√
31. Ulmaceae	60. *Ulmus lanceifolia* Roxb. ex Wall.	√	-

1.2 Plant community structure

Table 2 shows the changes in the quantitative characteristics of plant species in the DDF on sandstone between 2010 and 2015 for frequency, density, stem basal area, relative frequency, relative density, relative dominance, and relative IVI.

A small change in the frequency of tree species was observed. The five common species-Hiang, *G usitata*, Teng, Pluang and Rang retained their 100% frequency, while *A. villosa* decreased to 92%. The frequency values of many species decreased such as *T burmanica*, *Anneslea fragrans*, *C. stellatum*, *P. macrocarpus*, *O. intergerrima*, *S. cumini*, *P. indica*, and *Q. kerrii*. This indicated a decrease in their spatial distribution. However, only two species *D. assamica* and *P. emblica* showed small increases in frequency.

The death of many individuals of most tree species resulted in large changes in tree densities and the population structure in the forest. The most dominant tree in the forest, Hiang, had the highest number of deaths (275 trees ha^{-1}), followed by Teng (132), *M. scutellatum* (108), *D. oliverli* (78), *T. burmanica* (63), Pluang and Rang (both 59), *G. usitata* (58), *A. villosa* and *C. subulatum* (29), *A. fragrans* (27), *W. tinctoria* (23), *B. lanzan* (21), *C. stellatum* (17), and *G. cowa* (16). Deaths for other species were less than 10 trees ha^{-1}. Most dead individuals were small trees having a gbh below 25 cm, and the number of deaths was less for the bigger individuals. The population structure of the plant community in the DDF changed from 2010 to 2015 as shown in Figure 1. From Table 3, the average tree density in the Hiang stand changed from 4,763 trees ha^{-1} in 2010 to 3,405 trees ha^{-1} in 2015, with a net decrease of 1,359 trees ha^{-1}. The net decrease in tree density for the Rang, Pluang, and Teng stands was 403 trees ha^{-1}, 288 trees ha^{-1}, and 1,063 trees ha^{-1}, respectively.

Although many individual trees died between 2010 and 2015, the stem basal area and dominance of the most dominant species slightly increased, except for Pluang, where there was slow growth on the remaining trees. Hiang had the highest net increase in basal area (8.0 m^2 ha^{-1}), followed by *G usitata* (2.13), Rang (1.06), and Teng (0.06), whereas Pluang had a net decrease (1.5). The remaining species maintained almost the same values of basal area, and some species had either a small decrease or increase. The net differences in the basal area in the Hiang, Rang, Pluang, and Teng stands during this period were +0.15, +0.10, 0, and +0.16 m^2 ha^{-1} (Table 3).

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 net increase of the IVI was highest for *G. usitata* (0.67% of the total value), followed by Hiang (0.48%), Rang (0.38%), *A. villosa* (0.11%), and *M. scutellatum* (0.06). A net decrease was found for Teng (0.06) and Pluang (0.17). Small changes in IVI values were observed for the remaining species. Among the four stands, the net differences in the relative IVI of the most dominant tree species in the Teng, Hiang, Rang, and Pluang stands between 2010 and 2015 were +5.3%, +0.87%, +0.31%, and -0.42%, respectively (Table 3).

Table 2 Changes in quantitative characteristics of tree species in the DDF between 2010 and 2015.

Plant name	Frequency (%)			Density (trees ha^{-1})			Basal area (m^2/plot)			R. Frequency (%)			R. Density (%)			R. Dominance (%)			R. IVI (%)		
	2010	2,015	Net	2,010	2,015	Net	2010	2015	Net	2010	2015	Net	2010	2015	Net	2010	2015	Net	2010	2015	Net
1. *D. obtusifolius*	100	100	0	954.7	680.2	-274.5	15.94	17.22	1.28	3.81	4.35	0.54	24.67	24.47	-0.20	42.66	43.76	1.10	23.71	24.19	0.48
2. *G. usitata*	100	100	0	356.8	298.4	-58.4	5.65	5.99	0.34	3.81	4.35	0.54	9.37	10.74	1.37	15.14	15.24	0.10	9.44	10.11	0.67
3. *S. obtusa*	100	100	0	447	315	-132	3.53	3.54	0.01	3.81	4.35	0.54	11.57	11.32	-0.25	9.45	9.00	-0.45	8.28	8.22	-0.06
4. *D. tuberculatus*	100	100	0	221.4	162	-59.4	3.94	3.70	-0.24	3.81	4.35	0.54	5.76	5.83	0.07	10.54	9.41	-1.13	6.7	6.53	-0.17
5. *S. siamensis*	100	100	0	266.7	207.3	-59.4	3.05	3.22	0.17	3.81	4.35	0.54	6.87	7.46	0.59	8.16	8.18	0.02	6.28	6.66	0.38
6. *M. scutellatum*	75	75	0	351.6	243.2	-108.4	0.46	0.51	0.05	2.86	3.26	0.40	9.05	8.75	-0.30	1.23	1.31	0.08	4.38	4.44	0.06
7. *T. burmanica*	75	58	-17	225.5	163	-62.5	0.40	0.39	-0.01	2.86	2.54	-0.32	5.84	5.86	0.02	1.06	0.99	-0.07	3.25	3.13	-0.12
8. *D. oliverli*	75	75	0	165.6	87.5	-78.1	0.78	0.90	0.11	2.86	3.26	0.40	4.19	3.15	-1.04	2.1	2.28	0.18	3.05	2.90	-0.15
9. *A. villosa*	100	92	-8	125	96.4	-28.6	0.71	0.73	0.02	3.81	3.99	0.18	3.25	3.47	0.22	1.89	1.85	-0.04	2.99	3.10	0.11
10. *A. fragrans*	75	50	-25	145.3	118.8	-26.5	0.26	0.29	0.03	2.86	2.17	-0.69	3.79	4.27	0.48	0.69	0.73	0.04	2.45	2.39	-0.06
11. *C. subulatum*	92	92	0	69.8	40.6	-29.2	0.35	0.37	0.02	3.49	3.99	0.50	1.79	1.46	-0.33	0.94	0.95	0.01	2.07	2.13	0.06
12. *W. tinctoria*	83	75	-8	83.3	60.4	-22.9	0.13	0.16	0.03	3.17	3.26	0.09	2.16	2.17	0.01	0.35	0.41	0.06	1.89	1.95	0.06
13. *C. stellatum*	75	58	-17	55.7	38.5	-17,2	0.18	0.17	-0.01	2.86	2.54	-0.32	1.45	1.39	-0.06	0.48	0.44	-0.04	1.59	1.45	-0.14
14. *B. lanzan*	83	75	-8	39.1	18.2	-20.8	0.10	0.08	-0.02	3.17	3.26	0.09	0.79	0.66	-0.13	0.28	0.21	-0.07	1.42	1.38	-0.04
15. *P. macrocarpus*	75	67	-8	22.9	13.5	-9.4	0.29	0.30	0.01	2.86	2.90	0.04	0.59	0.49	-0.10	0.78	0.77	-0.01	1.41	1.39	-0.02
16-60 Other																					
Total	2,625	2,300	-315	3,865	2,780	-1,085	37.36	39.34	1.98	100	100		100	100		100	100		100	100	

Table 3 Changes of ecological parameters and values for dominant species in 12 plots of 4 stands in the DDF between 2010 and 2015.

Plot No.	Dominant species	Frequency (%)			Density (trees ha^{-1})			Basal area (m^2 ha^{-1})			Values for dominant species: Relative density (%)			Relative dominance (%)			Relative IVI (%)			SWI		
		2010	2015	net	2010	2015	net	2010	2015	net	2010	2015	net	2010	2015	net	2010	2015	net	2010	2015	net
1	Hiang	30	30	0	5,925	5,056	-869	3.43	3.59	0.16	28.38	28.92	0.54	52.89	53.98	1.09	40.63	41.45	0.82	3.13	3.17	0.04
2	Hiang	17	16	-1	1,638	1,419	-219	2.72	2.70	-0.02	24.43	25.11	0.68	22.24	24.44	2.2	23.33	24.78	1.45	2.83	2.73	-0.10
3	Hiang	26	26	0	5,588	4,988	-600	3.27	3.47	0.2	23.83	22.39	-1.44	53.45	52.86	-0.59	38.64	37.62	-1.02	3.58	3.56	-0.03
4	Hiang	28	24	-4	4,388	2,769	-1,619	3.21	3.38	0.17	33.62	35.21	1.59	62.29	64.18	1.89	47.96	49.7	1.74	3.32	3.08	-0.24
5	Hiang	31	26	-5	4,925	2,881	-2,044	3.66	3.77	0.11	26.78	27.77	0.99	54.39	55.28	0.89	40.59	41.52	0.93	3.34	3.26	-0.08
6	Hiang	31	26	-5	4,694	3,438	-1,256	3.5	3.65	0.15	23.83	24.00	0.17	54.62	58.17	3.55	39.23	41.09	1.86	3.46	3.29	-0.17
7	Hiang	37	23	-14	5,581	2,063	-3,519	3.14	3.23	0.09	25.42	24.55	-0.87	52.93	55.21	2.28	39.17	39.88	0.71	3.21	2.8	-0.41
8	Hiang	34	32	-3	5,369	4,625	-744	3.8	4.14	0.34	27.01	26.70	-0.31	52.96	54.13	1.17	39.99	40.42	0.43	3.41	3.41	-0.05
	Mean	29	25	-4	4,763	3,405	-1,359	3.34	3.49	0.15	26.66	26.83	0.17	50.72	52.28	1.56	38.69	39.56	0.87	3.29	3.16	-0.13
	SD	6	5	5	1,363	1,370	7	0.34	0.42	0.08	3.25	3.99	0.74	11.93	11.81	-0.12	6.88	6.92	0.04	0.23	0.29	0.14
9	Rang	18	16	-2	1,456	1,181	-275	2.55	2.78	0.23	28.33	31.22	2.89	38.71	39.03	0.32	33.52	35.12	1.60	2.81	2.72	-0.09
10	Rang	15	15	0	2,069	1,538	-531	2.56	2.54	-0.02	33.53	31.71	-1.82	30.09	29.97	-0.12	31.81	30.84	-0.97	2.58	2.62	0.04
	Mean	16.5	15.5	-1	1,763	1,359	-403	2.56	2.66	0.1	30.93	31.46	0.53	34.40	34.50	0.10	32.67	32.98	0.31	2.7	2.67	-0.03
11	Pluang	20	16	-4	1,525	1,238	- 288	2.76	2.76	0	37.3	36.36	-0.54	35.81	35.91	0.10	36.55	36.13	-0.42	2.88	3	0.12
12	Teng	28	24	-4	3,225	2,163	-1,063	3.17	3.33	0.16	27.91	37.28	9.37	37.93	39.16	1.23	32.92	38.22	5.30	3.46	3.07	-0.39
Mean		**26**	**23**	**-4**	**3,865**	**2,780**	**-1,085**	**2.93**	**3.28**	**0.35**	**26.75**	**29.27**	**2.52**	**43.02**	**46.86**	**3.84**	**34.84**	**38.06**	**3.22**	**3.17**	**3.06**	**-0.11**
S.D.		7	6	4	1,669	1,443	-226	0.83	0.49	-0.34	7.58	5.07	-2.51	14.23	12.56	-1.67	9.52	6.17	-3.35	0.32	0.30	0.16

2. Changes in plant species diversity and forest condition

2.1 Plant species diversity

Species diversity was not only considered using species richness, but also by the relative abundance of all species. The Shannon-Wiener Index (SWI) was used to determine the species diversity according to the combined concept of species richness and heterogeneity (Krebs, 1985) as shown in Table 3. The mean values of the SWI in 2010 and 2015 were 3.17±0.32 and 3.06±0.30, respectively, with a net change of -0.11. This implied there was only a small decrease in plant species diversity in the DDF during this period.

Some differences were observed among the four stands. The SWI in the eight plots of the Hiang stand varied between 2.83 and 3.58 (3.29±0.23 on average) in 2010, and the values varied between 2.73 and 3.56 (3.16±0.29 on average) in 2015, with a net decrease of 0.13. The average value in the Rang stand was 2.70 in 2010 and 2.67 in 2015, representing a net decrease of 0.03, whereas the value in the Pluang stand was 2.88 in 2010 and 3.0 in 2015, indicating a net increase of 0.12. In the Teng stand, there was a net decrease of 0.39 from 3.46 in 2010 to 3.07 in 2015.

2.2 Forest condition:

Table 4 shows the number of individual trees with different stem-girth classes used for the calculation of FCI values in the 12 plots of four stands in the DDF. The mean values of the FCI in 2010 and 2015 were 1.94±1.98 and 2.27±1.36, respectively, with a positive net change of 0.33. Therefore, the DDF on sandstone showed little increase in forest condition from 2010 to 2015.

Some differences in FCI values among the four stands were observed. In the Hiang stand, the FCI in the eight plots varied between 0.84 and 3.15 (1.70±0.75 on average) in 2010, and the values varied between 1.17 and 3.90 (2.13±0.96 on average) in 2015, with a net increase of 0.43. In the Rang stand, the average FCI was 2.83 in 2010 and 3.48 in 2015, indicating a net increase of 0.65, while the value in the Pluang stand was 2.19 in 2010 and 2.46 in 2015, with a net increase of 0.27. In the Teng stand, the FCI value was 1.79 in 2010 and 0.82 in 2015, with a net decrease of 0.97.

Table 4 Changes of tree individuals with different stem gbh class and FCI in 4 stands in the DDF between 2010 and 2015.

No. of plots	Dominant tree	Number of tree individuals (with different gbh-classes in cm) (trees ha^{-1}) <25 cm			26-50 cm			51-75 cm			76-100 cm			101-200 cm			Total			FCI		
		2011	2015	Net	2010	2015	Net	2011	2015	Net	2010	2015	Net	2010	2015	Net	2010	2015	Net	2010	2015	Net
8	Hiang	3,689	2,341	-1,348	812	770	-41	218	237	19	41	52	11	3	5	2	4,763	3,405	-1,359	1.7	2.13	0.43
2	Rang	1,028	581	-447	491	516	25	175	181	6	59	69	9	9	13	3	1,763	1,359	-403	2.83	3.48	0.65
1	Pluang	644	369	-275	594	575	-19	238	225	-13	44	63	19	6	6	0	1,525	1,238	-288	2.19	2.46	0.27
1	Teng	2,063	1,025	-1,038	888	825	-63	256	294	38	13	13	0	6	0	-6	3,225	2,163	-1,063	1.79	0.82	-0.97
Mean		2,856	1,773	-1,083	746	716	-30	216	231	16	42	53	10	5	6	1	3,865	2,780	-1,085	1.94	2.27	0.33
S.D.		1,674	1,366	933	185	169	42	53	54	17	21	22	14	6	8	4	1,768	1,450	949	1.98	1.36	0.38

3. Changes of plant biomass in the DDF

The plant biomass in the DDF on sandstone could be separated into stem, branch, leaf, and root components (Table 5). The mean amount of plant biomass increased from 83.74±12.35 Mg ha^{-1} in 2010 to 90.65±11.36 Mg ha^{-1} in 2015, with a net increase of 6.91 Mg ha^{-1}. The annual increment was 1.38 Mg ha^{-1}, which was only 1.5% higher than the plant biomass in 2010.

Some variations among the four stands occurred. In the Hiang stand, the biomass amounts in the eight plots in 2010 varied between 75.71 Mg ha^{-1} and 98.35 Mg ha^{-1}, (90.18 Mg ha^{-1} on average). In 2015, the amounts varied between 75.06 Mg ha^{-1} and 104.69 Mg ha^{-1}, (95.25 Mg ha^{-1} on average). The net increase was 5.07 Mg ha^{-1} (1.02 Mg ha^{-1} yr^{-1}). The Rang stand had an average biomass of 64.50 Mg ha^{-1} in 2010, which had increased to 80.33 Mg ha^{-1} in 2015, resulting in a net increase of 15.83 Mg ha^{-1} (3.16 Mg ha^{-1} yr^{-1}). The Pluang stand had a biomass of 72.19 Mg ha^{-1} in 2010, which had increased to 77.22 Mg ha^{-1} in 2015, with a net increase of 5.03 Mg ha^{-1} (1.01 Mg ha^{-1} yr^{-1}). The Teng stand had biomass of 82.23 Mg ha^{-1} in 2010, and this had increased to 87.86 Mg ha^{-1} in 2015, representing a net gain of 5.63 Mg ha^{-1} (1.12 Mg ha^{-1} yr^{-1}).

Table 5 Amounts of plant biomass in 4 stands in the DDF between 2010 and 2015.

No. of plots	Dominant tree	Plant biomass (Mg ha^{-1})														
		Stem			Branch			Leaf			Root			Total		
		2010	2015	Net	2010	2015	Net	2010	2015	Net	2010	2015	Net	2010	2015	Net
8	Hiang	58.61	62.78	4.17	16.85	18.63	1.78	2.26	2.28	0.02	12.46	13.03	0.57	90.18	95.25	5.07
2	Rang	41.93	52.81	10.88	12.41	16.98	4.57	1.51	1.61	0.1	8.65	10.29	1.64	64.5	80.33	15.83
1	Pluang	47.03	51.13	4.1	13.79	15.66	1.87	1.7	1.7	0	9.67	10.2	0.53	72.19	77.22	5.03
1	Teng	53.6	58.36	4.75	15.07	16.82	1.75	2.13	0.73	-1.4	11.43	12.17	0.74	82.23	87.86	5.63
Mean		54.45	59.78	5.33	15.71	17.96	2.25	2.08	1.99	-0.09	11.55	12.26	0.71	83.74	90.65	6.91
S.D.		8.02	7.42	-0.6	2.27	2.23	-0.04	0.39	0.56	0.17	1.85	1.74	-0.11	12.35	11.36	-0.99
%		65.02	64.98	-0.04	18.76	19.52	0.76	2.48	2.17	-0.31	13.74	13.33	-0.41	100	100	

Table 6 Carbon amounts stored in plant biomass in 4 stands in the DDF between 2010 and 2015.

No. of plots	Dominant tree species	Carbon in plant biomass (Mg ha^{-1})														
		Stem			Branch			Leaf			Root			Total		
		2010	2015	Net	2010	2015	Net	2010	2015	Net	2010	2015	Net	2010	2015	Net
8	Hiang	29.24	31.33	2.09	8.34	9.07	0.73	1.11	1.1	-0.01	6.14	6.27	0.13	44.83	47.06	2.23
2	Rang	20.93	26.35	5.43	6.04	8.27	2.22	0.73	0.78	0.05	4.17	4.95	0.78	31.87	39.69	7.82
1	Pluang	23.47	25.51	2.04	6.72	7.63	0.91	0.82	0.82	0	4.66	4.91	0.25	35.67	38.16	2.49
1	Teng	26.75	29.12	2.37	7.52	8.19	0.67	1.06	0.35	-0.71	5.71	5.86	0.15	41.04	43.41	2.37
Mean		27.16	29.83	2.67	7.75	8.75	0.99	1.02	0.96	-0.06	5.65	5.9	0.25	41.59	44.79	3.2
S.D.		4	3.7	-0.03	1.18	1.09	-0.08	0.2	0.27	0.07	0.97	0.84	-0.13	6.26	5.61	-0.65
%		65.32	66.6	1.28	18.64	19.53	0.89	2.46	2.12	-0.34	12.62	13.18	0.56	100	100	

4. Changes of carbon amount stored in plant biomass

The amounts of carbon stored in plant biomass (stem, branch, leaf, and root) in the DDF on sandstone are given in Table 6. The average carbon amount in the forest increased from 41.59±6.26 Mg ha^{-1} in 2010 to 44.79±5.61 Mg ha^{-1} in 2015, with a net increase of 3.20 Mg ha^{-1}. The annual increment of carbon storage was only 0.64 Mg ha^{-1} yr^{-1}, 1.5% higher than the amount in 2010. The carbon amounts stored in the eight plots of the Hiang stand in 2010 varied between 37.41 Mg ha^{-1} and 49.08 Mg ha^{-1} (44.83 Mg ha^{-1} on average). In 2015, the amounts varied between 37.09 Mg ha^{-1} and 51.73 Mg ha^{-1}, (47.06 Mg ha^{-1} on average). The net increase was 2.23 Mg ha^{-1} (0.45 Mg ha^{-1} yr^{-1}). In the Rang stand, the average carbon amount in 2010 was 31.87 Mg ha^{-1} and increased to 39.69 Mg ha^{-1} in 2015, representing a net increase of 7.82 Mg ha^{-1} (1.56 Mg ha^{-1} yr^{-1}). The Pluang stand had stored carbon in 2010 amounting to 35.67 Mg ha^{-1} and this increased to 38.16 Mg ha^{-1} in 2015, showing a net increase of 2.49 Mg ha^{-1} (0.50 Mg ha^{-1} yr^{-1}), whereas the amount of carbon stored in the Teng stand was 41.04 Mg ha^{-1} in 2010 and increased to 43.41 Mg ha^{-1} in 2015, with a net increase of 2.37 Mg ha^{-1} (0.47 Mg ha^{-1} yr^{-1}).

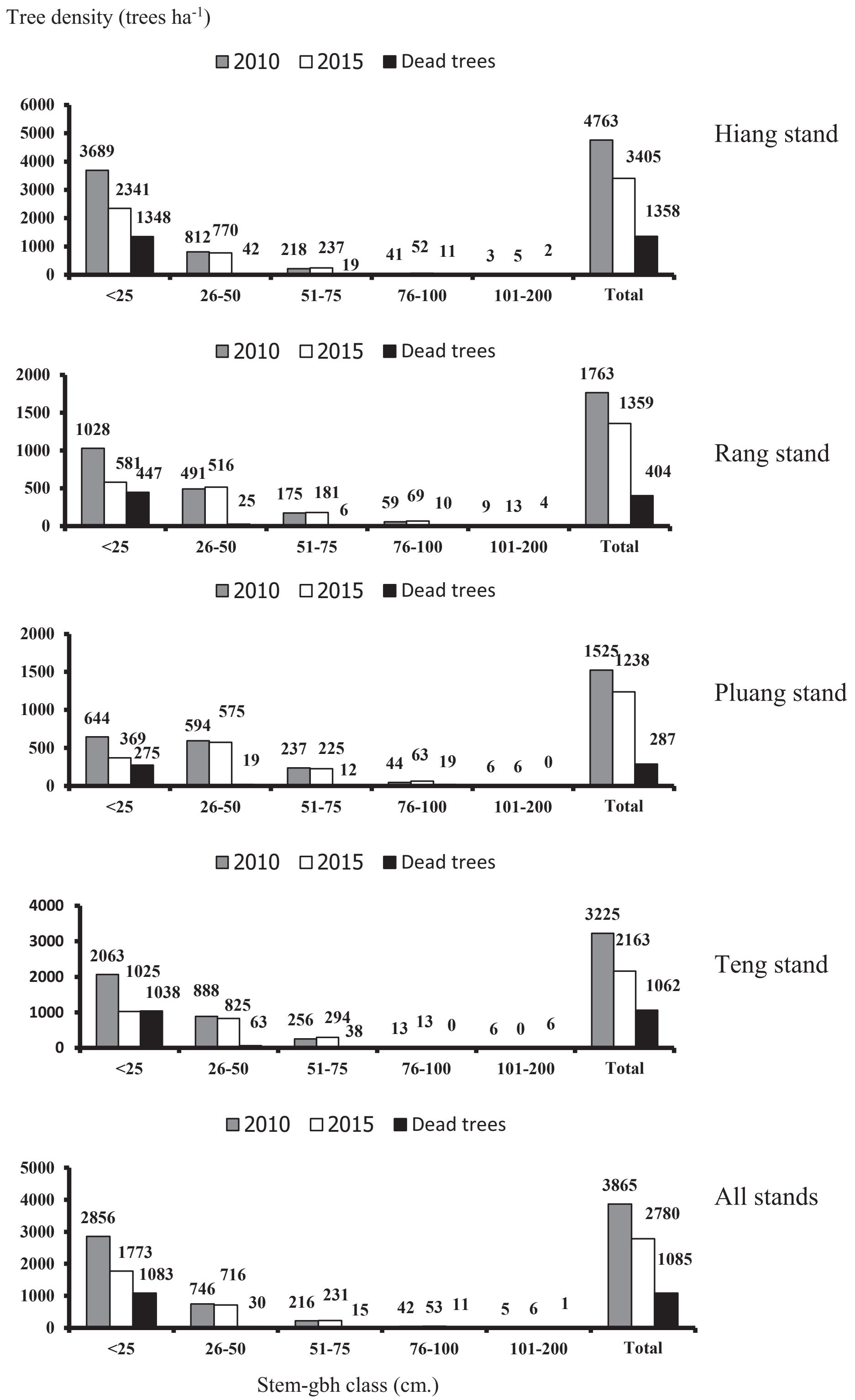

Figure 1 Changes in plant population based on stem-gbh classes in 4 stands in 2010 and 2015. (Positive and negative values of dead trees are given in Table 4)

A major disturbance to dry dipterocarp forest in Thailand in the past was caused by the selective cutting of big and intermediate trees as a result of forest concession activity and illegal cutting, and most forest at the present has changed as a result into secondary forest at different stages of condition depending on the level of disturbance. Therefore, most of the DDF in the country is secondary forest. In conservation forest such as national park, the forest is protected from tree cutting, and in such areas, the forest is considered to be recovery forest. In contrast, in national preserved forest, where illegal cutting is still occurring, the forest is considered to be degrading. Temporal changes in forest structure and function usually vary with the forest type or stand (Oliver and Larson, 1996; Waring and Running, 1998). Since the DDF covers xeric sites having poor soil and subject to frequent forest fires, natural regeneration is generally very slow, particularly from seed germination to seedlings. However, sprouting from stumps and roots is a features of most plant species in the DDF especially dipterocarps such as Teng, Rang, Hiang, and Pluang. Therefore, the tree density in this forest in 2010 was high, at 3,864 trees ha^{-1} (618 trees per plot). The death of many individual trees, especially those in the stem-gbh class below 25 cm was observed in 2015 caused by competition for environmental factors. There were no impacts from forest fire and timber harvesting in this protected forest, and competition for space, moisture, light, and nutrients were thought to be the main factors. A few species with a very low initial density and frequency therefore disappeared, and this resulted in a reduction in the species richness. The remaining tree species appeared to grow slowly in the forest. Thus, these are the main causes of the changes in species richness, composition, and forest structure in the DDF.

Very few data are available on the temporal changes in biomass production in Thailand's forests. The death of many tree individuals resulted in a reduction in the biomass in this secondary forest. However, the remaining trees could grow slowly and this resulted in little net increase in the plant biomass in the forest. The net increase between 2010 and 2015 was 6.91 Mg ha^{-1}, or 1.38 Mg ha^{-1} yr^{-1}. The slow growth rate of plants in the forest was influenced by the combined effects of the poor soil and dry site. Khamyong *et al.* (2011) reported that soil under DDF on sandstone was very poor, shallow to moderately deep, and contained many fragmented rocks and gravels. The amounts of soil carbon varied between 8.50 Mg ha^{-1} and 13.0 Mg ha^{-1}. The slow growth rate of plant species further affected biomass production. Sahunalu (1994) studied 52 stands classified into six sub-type communities of DDF in Thailand and reported that the average gross primary production of the forest was 11.252 ± 2.504 Mg ha^{-1} yr^{-1}, divided into net primary production (NPP) of 5.772 ± 1.162 Mg ha^{-1} yr^{-1} (51.30%) and respiration loss of 5.480 ± 1.424 Mg ha^{-1} yr^{-1} (48.70%). The NPP included the net increment of plant biomass, dead trees, litterfall, and grazing loss. The data indicated that most of the primary production was lost from the DDF ecosystem, and the net increment of plant biomass was very small. In the present study, a small increase in the carbon stored as plant biomass was observed, with a net increase of 3.20 Mg ha^{-1}, and the annual increase was only 0.64 Mg ha^{-1}. This research implied that DDF on sandstone had a slow rate of carbon accumulation in plant biomass during stand development.

CONCLUSION

The five-year monitoring study (2010-2015) of plant communities and carbon storage in DDF on sandstone identified changes in the plant species composition, species diversity, forest condition, biomass, and carbon storage, which can be summarized as follows:

1. The species richness decreased during the period by seven species from seven genera and four families resulting in little change in the species composition. The SWI of species diversity reduced from 3.17 to 3.06. The tree density decreased from 3,865 trees ha^{-1} to 2,780 trees ha^{-1}, and the death of many individual trees in the forest was the main cause of the plant community changes. However, a small net increase in biomass production in the forest was found caused by the slow growth of the remaining tree species.

2. The average amount of plant biomass in the forest increased from 83.74$\pm$12.35 Mg ha^{-1} in 2010 to 90.65$\pm$11.36 Mg ha^{-1} in 2015, with a net increase of 6.91 Mg ha^{-1} or only 1.38 Mg ha^{-1} yr^{-1}. Thus, the carbon amount stored as plant biomass increased from 41.59$\pm$6.26 Mg ha^{-1} in 2010 to 44.79$\pm$5.61 Mg ha^{-1} in 2015, with a net increase of 3.20 Mg ha^{-1}. The annual increment of carbon storage in this forest was only 0.64 Mg ha^{-1}, which was 1.5% higher than the stored amount in 2010.

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