CHAPTER 4

Economic Valuation of Wood Production, Carbon and Nutrient Storages in Ecosystems of Pine Plantations, Adjacent Fragmented Forests and Climax Montane Forest

Abstract

Economic valuation in forest ecosystems of different age pine plantations and adjacent fragmented forests at Boakaew Watershed Management Station, and the climax montane forest at Doi Inthanon national park, Chiang Mai province, were taken including three parts; wood production, carbon and nutrient storages in plant biomass, soil and forest floor. The economic analysis was adopted by market valuation and replacement cost approach (RCA). The total value of wood production in 21 age-class (14-34 year old) of *Pinus kesiya* plantations varied between 70,544-341,800 baht ha^{-1}. This included the economic value of succession trees in pine plantations with contributed from 17% to 94.36%. The fifteen adjacent fragmented forests had the value of varied 94,009 to 236,791 baht ha^{-1}, in average 152,396 baht ha^{-1}. The total value of wood production in the climax montane forest was 243,883 baht ha^{-1}. For ecosystem approach, The total values of five year old plantation (17-33 year old) was calculated as 626,512-921,985 bath ha^{-1} (100,241-147,527 bath rai^{-1}), separated to those of wood production, carbon on voluntary market and nutrients as 91,474-234,568 bath ha^{-1}; 601-847 bath ha^{-1}; and 391,343-755,031 bath ha^{-1}, respectively. If the carbon was calculated on carbon market, the value was increased to 59,962-84,738 bath ha^{-1}. The total ecosystem value was changed to 685,873-1,001,718 bath ha^{-1} (109,739-160,274 bath rai^{-1}). In five adjacent fragmented forests, the total value of ecosystems was calculated as 516,429-815,074 bath ha^{-1} (82,628-130,411 bath rai^{-1}), separated to those of wood production, carbon on voluntary market and nutrients as 111,142-180,621 bath ha^{-1}; 599-1,110 bath ha^{-1}; and 368,152-703,154 bath ha^{-1}, respectively. If the carbon was calculated on carbon market, the value was increased to 59,864-111,130 bath ha^{-1}. The total ecosystem value was changed to 575,694-892,268 bath ha^{-1} (92,111-142,762 bath rai^{-1}). For climax montane forest, the total value was 874,784 bath ha^{-1} (139,965 bath rai^{-1}), separated to those of wood production, carbon on voluntary market and nutrients as 243,883 bath ha^{-1}; 965 bath ha^{-1}; and 243,883 bath ha^{-1}, respectively. If the carbon was calculated on carbon market, the value was increased to 96,473 bath ha^{-1}. The total ecosystem value was changed to 970,293 bath ha^{-1} (155,246 bath rai^{-1}).

4.1 Introduction

In recent years, human population growth, migration and industrialisation, and other socio-economic changes have a dramatic impact on the world's forest resources. Deforestation in tropical regions is widely acknowledged as a global problem, as is the decline in so-called "old-growth" forests in all countries (Brown and Pearce, 1994; Dudley *et al.*, 1995). The recent increase in secondary forests in temperate regions, while less well-known, will also have a profound effect on the future supply of forest goods and services (Arnold, 1991; Sedjo and Lyon, 1990). Meanwhile, human demands on forests are changing rapidly, as we become more aware of the important environmental benefits they provide. For example, biodiversity conservation, water purification and soil stabilization, carbon sequestration benefits, in addition to various recreational benefits; for a general discussion of costs and benefits in relation to forests (Pearce and Moran, 1994).

Economic benefits can usually be valued in monetary terms but the forest ecosystem services are more difficult to measure and can vary considerably among countries, depending on their traditions and level of development. Maintaining and enhancing these functions is a part of sustainable forest management. To help government policy-makers make more informed decisions about activities with significant environmental impacts, economists have devoted considerable effort in recent years to developing and applying methods for valuing non-market benefits in monetary terms (Freeman, 2003). A variety of methods has been applied in order to compare outcomes from different methods on a given issue (Van den Bergh *et al.*, 1997 and Florax *et al.*, 2002). For example, when using the travel cost method, researchers estimate the economic value of recreational sites by looking at the generalized travel costs of visiting these sites (Bockstael *et al.*, 1991). Conversely, practitioners of the hedonic price method estimate the economic value of an environmental commodity, say, clean air by studying the relation between house prices and air quality (Palmquist, 1991). The averting behavior or production cost function methods is characterized by exploring the relationship of the environmental commodity through a generalized cost function (Cropper and Freeman, 1991). For instance, improvement of air quality can be assessed on the basis of expenditures made to avert or mitigate the adverse effects of air pollution. Avoided cost damage costs, preventive expenditures, repair costs (or restoration), compensation costs, replacement costs, and relocation costs are specific instances of this method. Replacement cost approach has been the most commonly applied in the economic evaluation of soil services, especially as related to developing countries (Grohs, 1994; Enters, 2000; Bojö, 1996) and it uses of a wide array of valuation techniques as developed by the environmental economics literature (Dixon *et al.*, 1994; Organization for Economic Cooperation and Development, 1995).

In Thailand, these forest ecosystem benefits are less considered here, largely because of the difficulty of obtaining suitable values. Consequently, this study focuses on recent applies in the economic valuation methods for the assessment of forest restoration ecosystem and, in particular, for direct-use values include revenues from timber and fulewood and indirect-use values or "functional" values relate to the ecological functions performed by forests, such as carbon and nutrient storage. Valuing non-market forest benefits in monetary terms can assist the development of forest policy and management systems.

4.2 Materials and Methods

The economic evaluation of forest restoration ecosystem was considered in three parts; in term value of wood production, value of carbon and nutrient stocks in plant and value of carbon and nutrient stocks in soil. The economics analysis was adopted by market valuation and replacement cost approach (RCA). It uses of a wide array of valuation techniques as developed by the environmental economics literature (Dixon *et al.*, 1994; Organization for Economic Cooperation and Development, 1995).

4.2.1 Evaluation of Wood Production

Estimating the value of timber trees was based on the value of the products that can be made from them. This was dictated by size (height and stem diameter), species, and quality of the wood. Product classes were generally expressed in terms of stem diameter measured at breast height (DBH), 1.3 m aboveground. Wood productions were considered in fuelwood and timber products. The values of wood production equal the total of wood production per volume unit multiplied by the price of wood production.

(1) Pine Wood

Pine wood was expressed in terms of industrial coniferous sawntimber. Price of timber applied from market price by the Customs Department, Thailand (2012). The coniferous sawntimber price was 470 baht per cubic metre. Sawntimber prices were based upon a 30 cm Girth-at-Breast-Height (GBH) log size.

(2) Broad-leaved Wood

The estimation used the quantities traded on the market and the market price for each type of product. The broad-leave woods were considered as fuelwood and timber products. The price of fuelwood was 600 baht per cubic metre. The timber products were classified in terms of stem-girth at breast height (GBH) including 30-50 cm, 50-100 cm, >100 cm. The prices were 1,000; 3,000; and 5,000 baht per cubic metre, respectively. These prices were recommended in the market price by Chiangmai Suksawad, LP (2011).

4.2.2 Evaluation of Biomass Carbon and Nutrient Stocks

Total values of carbon and nutrients storage were considered in three parts; forest biomass, organic layers on forest floor and soil. Biomass carbon stock could be calculated from carbon contents and biomass. Nutrient contents in various organs of tree species followed the data of Tsutsumi *et al.* (1983) in dry evergreen forest. The mean contents in stem, branch, leaf and root were different : 49.9, 48.7, 48.3 and 48.2% for carbon; 0.53, 0.53, 1.59 and 0.53% for nitrogen; 0.08, 0.10, 0.13 and 0.02% for phosphorus; 0.37, 0.40, 1.10 and 0.27% for potassium; 0.76, 0.80, 1.50 and 0.88% for calcium; and 0.17, 0.20, 0.90 and 0.10% for magnesium, respectively.

Carbon stock values were adopted by market valuation and cost replacement method (Witthawatchutikul and Thitirojanawat, 2009). The value of carbon stocks equaled the total of carbon stocks per unit multiplied by carbon price. The price of carbon sequestration could be assumed to be positive; although any exact or core estimates are impossible to determine at present (Price and Willis, 1993; Niskanen *et al.*, 1996). These study, the carbon price were applied two scenario (1) the price for carbon flows US$ 0.10 $Mg.C^{-1}$ on voluntary carbon market; VCM. (Katherine *et al.*, 2008). This value was recommended in the policy paper by Chicago Climate Exchange; CCX. (Molly *et al.*, 2011). The carbon price was 3.049 baht $Mg.C^{-1}$ (Thai official exchange rate, 30.49 baht per US$ from Bank of Thailand, 2012) and (2) the price for carbon flows US$ 10 MgC^{-1} on carbon market, was similar to the value recommended in Zhang (2000). The carbon price was 304.9 baht $Mg.C^{-1}$.

To value nutrients via fertilizer prices requires either a translation of the lost nutrients into marketed fertilizer types or an expression of fertilizers in nutrient units, calculations were based on the costs of nutrient units. This simplified the comparison with the already estimated nutrient losses. So, valuing nutrients equals the total value of nutrient amounts per unit multiplied by the prices of fertilizer.

Nitrogen (N) was estimated by urea (46%N), this price are 50 kilogram per 600 baht. Phosphorous (P) was estimated by tripple super phosphate (46% P_2O_5), this price are 50 kilogram per 600 baht. Potassium (K) was estimated by Potassium chloride (60% K_2O), the price was 50 kilogram per 400 baht. Calcium (Ca) and magnesium (Mg) were estimated by dolomite (31% CaO, 21%MgO), the price was 1 tone per 1,500 baht. Sodium (Na) was estimated by sodium chloride (39% Na), the price was 1 tone per 923.45 baht (Department of Internal Trade of Thailand, 2011). The nutrient costs could then also be calculated for N (26.09 baht kg^{-1}), P (26.09 baht kg^{-1}), K (13.33 baht kg^{-1}), Ca (5.77 baht kg^{-1}), Mg (5.77 baht kg^{-1}), and Na (2.37 baht kg^{-1}) (Table 4-1)

Table 4-1 Unit costs of fertilizers in Thailand, 2011

Fertilizer	Nutrient Content (%)		Market Price	Cost (Baht $kg.^{-1}$)
Urea (46%N)	N	46	600 Baht/ 50 kg.	26.09
Tripple super phosphate (46% P_2O_5)	P	46	600 Baht/ 50 kg.	26.09
Potassium chloride (60% K_2O)	K	60	400 Baht/ 50 kg.	13.33
Dolomite (31% CaO, 21%MgO)	Ca	31	1,500 Baht/ton	5.77
	Mg	21		
Sodium chloride (39% Na)	Na	39	923.45 Baht/ton	2.37

4.3 Results

The evaluation of forest ecosystem benefit was considered in term of wood production, carbon and nutrient storages in ecosystems of *Pinus kesiya* plantations, adjacent fragmented forests and climax montane forest.

4.3.1 Valuation of Wood Production

Estimation of wood production value was based on value of the products that can be made from them, including fulewood and timber.

4.3.1.1 *Pinus kesiya* Plantations

The value of pine wood was estimated by benefit for sawntimber. The values were varied between 9,926-94,290 baht ha^{-1}. In 33-year-old plantation, the value was the highest (200.62 m^3ha^{-1}) and the lowest in 17-year-old plantation (19.93 m^3ha^{-1}). In addition, the values of succession broad-leaved trees were considered as fuelwood and timber products. The values were varied 19,135-289,862 baht ha^{-1}. It was the highest in 31-year-old plantation and the lowest in 20-year-old plantation. The total value of wood production in *Pinus kesiya* plantations varied from 70,544 to 341,800 baht ha^{-1} (11,287-54,688 baht rai^{-1}) (Table 4-2 to 4-4).

Table 4-2 Value of wood production of *Pinus kesiya* with different stem-girth classes in 21 age-class plantations

Age	Timber with different stem-girth classes								Total
	30-50 cm		50-100 cm		100-150 cm		>150 cm		Value
(year)	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(B ha^{-1})
14	-	-	19.39	9,111	30.84	14,495	-	-	23,607
15	-	-	10.19	4,789	10.93	5,137	-	-	9,926
16	0.09	42	71.36	33,540	37.42	17,586	-	-	51,168
17	-	-	16.25	7,635	3.69	1,732	-	-	9,368
18	0.21	99	46.78	21,984	42.50	19,976	-	-	42,059
19	0.66	308	89.27	41,959	26.51	12,461	-	-	54,728
20	0.98	462	92.33	43,394	33.84	15,905	-	-	59,761
21	0.65	306	88.63	41,658	62.14	29,205	-	-	71,168
22	0.95	448	66.01	31,024	27.94	13,134	-	-	44,606
23	-	-	40.67	19,114	20.68	9,720	-	-	28,834
24	-	-	76.79	36,090	10.34	4,860	-	-	40,951
25	-	-	92.76	43,597	17.61	8,277	-	-	51,874
26	0.11	52	77.28	36,320	96.28	45,251	-	-	81,623
27	0.73	343	70.62	33,192	34.81	16,360	-	-	49,894
28	-	-	22.18	10,422	80.91	38,027	-	-	48,450
29	-	-	27.52	12,934	39.78	18,698	-	-	31,632
30	-	-	37.81	17,769	79.30	37,272	-	-	55,041
31	-	-	14.25	6,698	54.12	25,437	-	-	32,135
32	-	-	47.53	22,337	106.94	50,263	-	-	72,600
33	-	-	32.94	15,482	158.96	74,710	8.72	4,098	94,290
34	-	-	27.10	12,739	58.24	27,375	5.91	2,778	42,892

Table 4-3 Value of wood production of succession trees with different timber quality and stem-girth classes in 21 age-class plantations

Age	Fulewood		Timber with different stem-girth classes								Total Value
			30-50 cm		50-100 cm		100-150 cm		>150 cm		
(year)	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(B ha^{-1})
14	32.15	19,291	4.73	4,732	11.34	34,007	8.16	40,777	1.25	6,235	105,041
15	30.44	18,262	3.24	3,239	9.59	28,769	8.64	43,179	4.43	22,158	115,607
16	6.26	3,758	0.95	953	4.89	14,665	-	-	-	-	19,376
17	37.41	22,447	6.93	6,926	13.91	41,722	6.43	32,127	10.71	53,558	156,781
18	30.67	18,400	8.54	8,543	16.56	49,674	5.81	29,073	-	-	105,691
19	19.24	11,543	5.74	5,736	12.61	37,832	2.51	12,546	4.05	20,243	87,899
20	5.17	3,100	1.23	1,230	3.49	10,483	0.45	2,233	-	-	17,047
21	41.38	24,827	6.79	6,785	18.00	54,010	6.57	32,857	8.98	44,921	163,400
22	29.47	17,682	12.13	12,132	10.18	30,527	4.09	20,475	-	-	80,815
23	28.91	17,347	6.74	6,741	12.75	38,243	7.36	36,810	1.79	8,955	108,097
24	42.56	25,535	2.83	2,826	14.39	43,183	4.32	21,610	27.60	138,000	231,154
25	22.76	13,653	4.82	4,821	10.41	31,216	3.53	17,627	9.95	49,745	117,063
26	36.79	22,072	3.25	3,247	11.47	34,400	7.86	39,309	32.23	161,149	260,177
27	41.48	24,888	6.59	6,587	29.61	88,821	7.41	37,031	-	-	157,327
28	13.95	8,372	1.07	1,068	10.06	30,189	5.44	27,218	-	-	66,847
29	12.18	7,308	1.75	1,753	5.89	17,677	4.42	22,119	2.20	10,986	59,843
30	32.35	19,410	4.37	4,372	19.84	59,515	2.82	14,118	12.18	60,897	158,313
31	57.43	34,459	8.64	8,645	23.14	69,430	15.87	79,342	19.60	97,987	289,862
32	42.04	25,223	1.08	1,081	13.25	39,743	16.12	80,609	14.36	71,793	218,449
33	3.36	2,015	0.11	106	1.53	4,593	2.52	12,600	-	-	19,315
34	45.42	27,253	4.61	4,611	17.93	53,778	16.50	82,509	16.75	83,765	251,916

Table 4-4 Total value of wood production in 21 age-class pine plantations.

Age (year)	Value of wood production				Total Value
	Pinus kesiya		Succession trees		
	(B ha^{-1})	%	(B ha^{-1})	%	
14	23,607	18.35	105,041	81.65	128,648
15	9,926	7.91	115,607	92.09	125,533
16	51,168	72.53	19,376	27.47	70,544
17	9,368	5.64	156,781	94.36	166,148
18	42,059	28.47	105,691	71.53	147,750
19	54,728	38.37	87,899	61.63	142,628
20	59,761	77.81	17,047	22.19	76,808
21	71,168	30.34	163,400	69.66	234,568
22	44,606	35.57	80,815	64.43	125,422
23	28,834	21.06	108,097	78.94	136,931
24	40,951	15.05	231,154	84.95	272,105
25	51,874	30.71	117,063	69.29	168,937
26	81,623	23.88	260,177	76.12	341,800
27	49,894	24.08	157,327	75.92	207,221
28	48,450	42.02	66,847	57.98	115,297
29	31,632	34.58	59,843	65.42	91,474
30	55,041	25.80	158,313	74.20	213,353
31	32,135	9.98	289,862	90.02	321,997
32	72,600	24.94	218,449	75.06	291,048
33	94,290	83.00	19,315	17.00	113,605
34	42,892	14.55	251,916	85.45	294,808

4.3.1.2 Adjacent Fragmented Forests

The wood of succession trees were considered including fuelwood and timber products. The price of fuelwood was 600 baht per cubic metre. The timber products were classified into different stem-girth at classes (GBH), 30-50 cm, 50-100 cm and >100 cm. The prices were 1,000; 3,000; and 5,000 baht per cubic metre, respectively. The values of fuelwood were varied from 9,529 to 24,185 baht ha^{-1}, and the average total value was 17,729 baht ha^{-1}. It was the highest in FF12 and the lowest in FF10. For timber production, the values were varied between 84,480 to 219,141 baht ha^{-1} and the average total value was 134,667 baht ha^{-1}. It was the highest in FF1 and the lowest in FF10. The total values of wood production in adjacent fragmented forests were varied, 94,009-236,791 baht ha^{-1}. The average total value was calculated as 152,396 baht ha^{-1} (24,383 baht rai^{-1}) (Table 4-5).

4.3.1.3 Climax Montane Forest

The wood production in this forest was considered as fuelwood and timber products. The price of fuelwood was 600 baht per cubic metre. The timber products were classified into different stem-girth at classes, including 30-50 cm, 50-100 cm and >100 cm. The prices were 1,000; 3,000; and 5,000 baht per cubic metre, respectively. The average value of fuelwood was 27,669 baht ha^{-1}. The average value of timber production was calculated as 216,214 baht ha^{-1}. The total value of wood production in the climax montane forest was 243,883 baht ha^{-1} (39,021 baht rai^{-1}) (Table 4-6).

4.3.2 Valuation of Carbon and Nutrient Storages

Total values of carbon and nutrient storages were considered in terms of forest biomass, organic layers on forest floor and soil.

4.3.2.1 *Pinus kesiya* Plantations

The valuation of carbon and other nutrients as well as their allocation in different tree organs, organic layers on forest floor and soil in 21 age-class pine plantations were shown in Table 4-7 to 4-9.

(1) Valuation of carbon and nutrient storages in plant biomass

The value of biomass carbon in a series of 21 age-class pine plantations included stored carbon in pine trees and succession broad-leaved trees. The amounts did not increase with stand ages, and varied from 140-428 baht ha^{-1} based on voluntary market. The lowest amount was found in the 15-year-old stand, whereas the largest amount was occurred in the 26-year-old stand. Same as other nutrients, the value of nitrogen accumulation in biomass of pine plantations varied between 9,852-25,176 baht ha^{-1}. For the value of phosphorus, potassium, calcium, and magnesium accumulation in forest biomass varied between 1,140-3,294; 3,506-9,071; 2,767-7,666 and 431-1,609 baht ha^{-1}, respectively. All lowest value was found in the 20-year-old stand, whereas the highest value was occurred in the 26 and 31-year-old stand. The total values of carbon and nutrient storages in plant biomass varied 17,707 to 47,088 baht ha^{-1} (2,833-7,534 baht rai^{-1}) (Table 4-7).

Table 4-5 Value of wood production with different timber quality and stem-girth classes in fifteen adjacent fragmented forests

FF	Fuelwood		Timber with different stem-girth classes									Total Value
			30-50 cm		50-100 cm		100-150 cm		>150 cm		Total	
	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(B ha^{-1})	(B ha^{-1})
1	29.42	17,650	1.97	1,973	9.00	26,988	31.00	155,000	7.04	35,179	219,141	236,791
2	21.72	13,031	3.73	3,733	11.16	33,488	15.76	78,809	-	-	116,031	129,062
3	31.53	18,916	4.32	4,316	16.15	48,440	15.83	79,169	5.96	29,777	161,705	180,621
4	26.75	16,050	0.68	680	8.58	25,750	11.85	59,251	22.97	114,854	200,536	216,586
5	29.67	17,803	3.02	3,022	13.00	39,013	8.31	41,539	9.26	46,300	129,875	147,678
6	26.38	15,827	1.18	1,179	7.82	23,471	8.21	41,047	17.72	88,584	154,283	170,111
7	23.64	14,185	2.22	2,217	6.02	18,052	7.58	37,916	11.23	56,142	114,329	128,514
8	26.38	15,827	1.62	1,621	5.16	15,490	10.25	51,230	11.74	58,712	127,055	142,882
9	28.93	17,359	2.22	2,218	6.76	20,275	6.39	31,931	15.16	75,816	130,240	147,600
10	15.88	9,529	1.74	1,736	5.05	15,154	5.89	29,450	7.63	38,138	84,480	94,009
11	37.49	22,496	3.87	3,867	13.18	39,530	6.13	30,631	2.92	14,616	88,646	111,142
12	40.31	24,185	3.21	3,206	10.86	32,583	6.21	31,044	14.23	71,139	137,974	162,159
13	36.16	21,698	1.98	1,976	7.82	23,452	3.61	18,045	23.74	18,685	162,159	183,858
14	33.89	20,336	2.94	2,944	8.45	25,349	8.36	41,818	7.32	36,595	106,709	127,045
15	35.07	21,041	1.36	1,362	11.24	33,716	5.17	25,866	5.18	25,894	86,839	107,880
Average	**29.55**	**17,729**	**2.40**	**2,404**	**9.35**	**28,051**	**10.04**	**50,183**	**10.81**	**54,029**	**134,667**	**152,396**

Table 4-6 Value of wood production with different timber quality and stem-girth classes in climax montane forest

Plot	Fuelwood		Timber with different stem-girth classes									Total Value
			30-50 cm		50-100 cm		100-150 cm		>150 cm		Total	
	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(m^3 ha^{-1})	(B ha^{-1})	(B ha^{-1})	(B ha^{-1})
1	57.98	34,790	1.75	1,750	7.10	21,312	12.51	62,529	45.39	226,963	312,554	347,345
2	47.94	28,762	1.30	1,300	5.22	15,651	7.17	35,865	35.19	175,965	228,782	257,543
3	47.02	28,215	2.45	2,448	13.00	38,988	10.08	50,391	22.14	110,682	202,509	230,724
4	32.97	19,783	3.22	3,218	11.61	34,823	8.39	41,935	12.79	63,953	143,929	163,712
5	44.66	26,794	2.59	2,589	8.60	25,815	11.26	56,281	21.72	108,611	193,297	220,091
Average	**46.11**	**27,669**	**2.26**	**2,261**	**9.11**	**27,318**	**9.88**	**49,400**	**27.45**	**137,235**	**216,214**	**243,883**

Table 4-7 Valuation of biomass carbon and nutrient storages in pine and succession tree of pine plantations

Age (yrs)	C	Total Amounts (kg.ha^{-1})					Total Value
	(Mg/ha)	N	P	K	Ca	Mg	(Baht/ha)
14 yrs							
Nutrient Storages	62.20	499.65	65.70	346.37	700.20	142.25	
Value (Baht ha^{-1})	**189.66**	**13,034.38**	**1,713.85**	**4,618.28**	**4,039.63**	**820.68**	**24,416.48**
15 yrs							
Nutrient Storages	46.02	435.40	59.08	299.19	622.32	133.84	
Value (Baht ha^{-1})	**140.31**	**11,358.31**	**1,541.17**	**3,989.21**	**3,590.32**	**772.15**	**21,391.46**
16 yrs							
Nutrient Storages	70.20	377.68	45.52	269.65	495.52	79.86	
Value (Baht ha^{-1})	**214.04**	**9,852.59**	**1,187.40**	**3,595.33**	**2,858.79**	**460.72**	**18,168.87**
17 yrs							
Nutrient Storages	56.37	551.10	74.41	377.23	788.86	171.62	
Value (Baht ha^{-1})	**171.87**	**14,376.61**	**1,941.07**	**5,029.72**	**4,551.12**	**990.10**	**27,060.48**
18 yrs							
Nutrient Storages	84.69	645.71	83.24	447.75	896.50	178.61	
Value (Baht ha^{-1})	**258.22**	**16,844.52**	**2,171.52**	**5,969.97**	**5,172.14**	**1,030.42**	**31,446.79**
19 yrs							
Nutrient Storages	85.45	574.29	72.49	400.81	782.53	146.60	
Value (Baht ha^{-1})	**260.53**	**14,981.36**	**1,891.15**	**5,344.15**	**4,514.61**	**845.77**	**27,837.58**
20 yrs							
Nutrient Storages	71.31	369.67	43.73	263.02	479.67	74.82	
Value (Baht ha^{-1})	**217.43**	**9,643.61**	**1,140.73**	**3,506.87**	**2,767.33**	**431.64**	**17,707.60**
21 yrs							
Nutrient Storages	114.45	834.90	108.08	581.56	1,154.16	225.15	
Value (Baht ha^{-1})	**348.94**	**21,779.96**	**2,819.39**	**7,754.14**	**6,658.63**	**1,298.97**	**40,660.04**
22yrs							
Nutrient Storages	85.62	672.93	85.68	463.28	934.32	189.13	
Value (Baht ha^{-1})	**261.07**	**17,554.67**	**2,235.07**	**6,177.02**	**5,390.32**	**1,091.12**	**32,709.26**
23 yrs							
Nutrient Storages	70.64	562.36	72.95	388.33	784.82	159.21	
Value (Baht ha^{-1})	**215.38**	**14,670.26**	**1,902.99**	**5,177.71**	**4,527.80**	**918.54**	**27,412.68**
24 yrs							
Nutrient Storages	92.70	747.30	100.44	518.60	1,049.89	213.51	
Value (Baht ha^{-1})	**282.65**	**19,494.88**	**2,620.30**	**6,914.67**	**6,057.07**	**1,231.79**	**36,601.38**
25 yrs							
Nutrient Storages	86.12	594.57	75.84	414.39	814.05	154.66	
Value (Baht ha^{-1})	**262.57**	**15,510.55**	**1,978.35**	**5,525.25**	**4,696.43**	**892.25**	**28,865.39**
26 yrs							
Nutrient Storages	140.40	965.11	126.31	680.39	1,328.86	251.39	
Value (Baht ha^{-1})	**428.09**	**25,176.91**	**3,294.93**	**9,071.85**	**7,666.49**	**1,450.32**	**47,088.59**
27 yrs							
Nutrient Storages	104.46	802.57	104.78	557.85	1,118.17	223.05	
Value (Baht ha-1)	**318.49**	**20,936.52**	**2,733.43**	**7,437.98**	**6,450.97**	**1,286.85**	**39,164.24**
28 yrs							
Nutrient Storages	80.93	484.64	61.17	346.31	652.83	113.79	
Value (Baht ha-1)	**246.76**	**12,642.78**	**1,595.66**	**4,617.47**	**3,766.31**	**656.46**	**23,525.45**

Table 4-7 (Continued)

Age (yrs)	C (Mg/ha)	Total Amounts (kg.ha^{-1}) N	P	K	Ca	Mg	Total Value (Baht/ha)
29 yrs							
Nutrient Storages	57.24	408.18	52.55	284.53	562.30	108.46	
Value (Baht ha^{-1})	**174.54**	**10,648.16**	**1,370.97**	**3,793.69**	**3,244.04**	**625.75**	**19,857.15**
30 yrs							
Nutrient Storages	102.00	722.46	94.61	508.45	998.98	191.85	
Value (Baht ha^{-1})	**311.01**	**18,846.69**	**2,468.05**	**6,779.27**	**5,763.33**	**1,106.84**	**35,275.18**
31 yrs							
Nutrient Storages	105.47	933.31	126.71	646.71	1,327.83	279.06	
Value (Baht ha^{-1})	**321.57**	**24,347.18**	**3,305.59**	**8,622.77**	**7,660.56**	**1,609.94**	**45,867.60**
32 yrs							
Nutrient Storages	118.09	843.93	111.47	593.66	1,169.28	225.43	
Value (Baht ha^{-1})	**360.06**	**22,015.68**	**2,907.96**	**7,915.48**	**6,745.87**	**1,300.56**	**41,245.61**
33 yrs							
Nutrient Storages	113.02	564.07	68.15	411.80	734.14	110.35	
Value (Baht ha^{-1})	**344.59**	**14,714.74**	**1,777.77**	**5,490.67**	**4,235.40**	**636.65**	**27,199.82**
34 yrs							
Nutrient Storages	107.28	874.55	117.08	608.68	1,231.79	251.32	
Value (Baht ha^{-1})	**327.10**	**22,814.27**	**3,054.33**	**8,115.79**	**7,106.48**	**1,449.94**	**42,867.90**

(2) Valuation of carbon and nutrient storages in forest floor

The value of carbon and nutrient storages in litter on forest floor were considered under five age- class pine plantations (17, 21, 25, 29 and 33- year-old stand). The values of carbon storages were varied between 5.09-9.60 baht ha^{-1} based on voluntary market. For the value of nitrogen, phosphorus, potassium, calcium, and magnesium accumulation in forest floor varied between 755.22-1,823.22; 5.74-12; 28.27-103.07; 13.38-32.88 and 2.42-5.48 baht ha^{-1}, respectively. It was highest in 17-year-old stand and the lowest in 25-year-old stand. The total values of carbon and nutrient storages in forest floor were varied between 810.12-1,986.25 baht ha^{-1} (129.62-317.80 baht rai^{-1}) (Table 4-8).

(3) Valuation of carbon and nutrient storages in soil

The value of carbon and nutrient accumulations within 160 cm depth soils under five age-class pine plantations include carbon and nitrogen, available phosphorus, extractable potassium, calcium, magnesium and sodium (Table 4-9).

The value of carbon accumulations within 160 cm depth soils were varied, 243-652 baht ha^{-1} on voluntary market. The highest was in 17-year-old stand as same the carbon storage in litter on forest floor but lowest in 21-year-old stand. The value of nitrogen, phosphorus, potassium, calcium, magnesium and sodium accumulation in soil of five age-class pine plantation varied between 264,652-643,800; 730-2,643; 58,973-80,280; 2,440-47,296; 2,036-6,986 and 795-1,067 baht ha^{-1}, respectively. The result shown that the highest value of carbon, nitrogen and phosphorus were in 17-year-old stand, were as the value of calcium, magnesium and sodium were in 33-year-old stand. The total values of carbon and nutrient storages within 160 cm depth soils under five age-class pine plantations varied between 350,142-726,790 baht ha^{-1}(56,022-116,286 baht rai^{-1}).

Table 4-8 Valuation of carbon and nutrient storages in forest floor of pine plantations

Age (year)	C ($Mg.ha^{-1}$)	Total Amounts ($kg.ha^{-1}$) N	P	K	Ca	Mg	Total Value ($Baht\ ha^{-1}$)
17 yrs							
Nutrient Storages	3.15	69.89	0.46	7.73	5.70	0.95	
Value ($Baht\ ha^{-1}$)	**9.60**	**1,823.22**	**12.00**	**103.07**	**32.88**	**5.48**	**1,986.25**
21 yrs							
Nutrient Storages	2.66	40.92	0.31	2.56	3.53	0.63	
Value ($Baht\ ha^{-1}$)	**8.11**	**1,067.48**	**8.09**	**34.13**	**20.37**	**3.63**	**1,141.81**
25 yrs							
Nutrient Storages	1.67	28.95	0.22	2.12	2.32	0.42	
Value ($Baht\ ha^{-1}$)	**5.09**	**755.22**	**5.74**	**28.27**	**13.38**	**2.42**	**810.12**
29 yrs							
Nutrient Storages	2.62	49.71	0.35	4.59	4.16	0.71	
Value ($Baht\ ha^{-1}$)	**7.99**	**1,296.78**	**9.13**	**61.20**	**24.00**	**4.10**	**1,403.20**
33 yrs							
Nutrient Storages	2.92	42.39	0.33	2.20	3.74	0.69	
Value ($Baht\ ha^{-1}$)	**8.90**	**1,105.83**	**8.61**	**29.33**	**21.58**	**3.98**	**1,178.23**

Table 4-9 Valuation of carbon and nutrient storages in 1.60 meter soil profiles of pine plantations

Age (year)	C ($Mg.ha^{-1}$)	Total Amounts ($kg.\ ha^{-1}$) N	P	K	Ca	Mg	Na	Total Value ($Baht\ ha^{-1}$)
17 yrs								
Nutrient Storages	205	24,679	101	4,423	2,852	608	336	
Value ($Baht\ ha^{-1}$)	**625.05**	**643,800.00**	**2,634.78**	**58,973.33**	**16,453.85**	**3,507.69**	**795.59**	**726,790.29**
21 yrs								
Nutrient Storages	80	10,145	28	5,942	423	353	343	
Value ($Baht\ ha^{-1}$)	**243.92**	**264,652.17**	**730.43**	**79,226.67**	**2,440.38**	**2,036.54**	**812.16**	**350,142.28**
25 yrs								
Nutrient Storages	166	18,935	31	6,021	1,255	462	406	
Value ($Baht\ ha^{-1}$)	**506.13**	**493,956.52**	**808.70**	**80,280.00**	**7,240.38**	**2,665.38**	**961.34**	**586,418.46**
29 yrs								
Nutrient Storages	178	17,658	46	5,582	4,256	1,064	410	
Value ($Baht\ ha^{-1}$)	**542.72**	**460,643.48**	**1,200.00**	**74,426.67**	**24,553.85**	**6,138.46**	**970.81**	**568,475.98**
33 yrs								
Nutrient Storages	162	14,856	85	4,828	8,198	1,211	451	
Value ($Baht\ ha^{-1}$)	**493.94**	**387,547.83**	**2,217.39**	**64,373.33**	**47,296.15**	**6,986.54**	**1,067.89**	**509,983.07**

4.3.2.2 Adjacent Fragmented Forests

The valuation of carbon and other nutrients as well as their allocation in different tree organs, on forest floor and soil in fifteen adjacent fragmented forests were shown in Table 4-10 to 4-12.

(1) Valuation of carbon and nutrient storages in plant biomass

The value of biomass carbon in fifteen adjacent fragmented forests varied between 176-381 baht ha^{-1}based on voluntary market. The value of nitrogen, phosphorus, potassium, calcium, and magnesium storage in forest biomass, they varied between 16,784-36,105; 2,341-5,082; 5,862-12,637; 5,396-11,626; and 1,211-2,602 baht ha^{-1}, respectively. The lowest amount was found in FF10 and the largest amount in FF1. Total values of nutrient storages in plant biomass were varied between 31,773-68,435 baht ha^{-1} (5,083-10,949 baht rai^{-1}). (Table 4-10).

(2) Valuation of carbon and nutrient storages in forest floor

The value of carbon and nutrient storages in forest floor was studied in five sites of adjacent fragmented forests (FF3, FF5, FF11, FF13 and FF14). The values of carbon storages varied between 6.52-8.32 baht ha^{-1} based on voluntary market. The value of nitrogen, phosphorus, potassium, calcium, and magnesium storage in forest floor varied between 1,110.52-1,810.17; 7.83-10.70; 49.07-120.67; 21-33.69and 3.69-5.25 baht ha^{-1}, respectively. The total values of carbon and nutrient storages were varied between 1,199.24-1,988.80 baht ha^{-1} (191.88-318.20 baht rai^{-1}). It was the highest in FF11 and the lowest in FF5 (Table 4-11).

(3) Valuation of carbon and nutrient storages in soil

The value of carbon and nutrient storages within 160 cm depth soils under five sites of adjacent fragmented forests involved carbon and nitrogen, available phosphorus, extractable potassium, calcium, magnesium and sodium (Table 4-12).

The value of carbon accumulations within 160 cm depth soils was varied, 257-804 baht ha^{-1}. The highest was occurred in FF14 and the lowest in FF3. The value of nitrogen, phosphorus, potassium, calcium, magnesium and sodium accumulation in soil of five sites of adjacent fragmented forests varied between 220,207-484,766; 1,051-1,492; 46,350-105,500; 7,680-40,220; 3,439-12,294 and 929-1,096 baht ha^{-1}, respectively. The highest value of nitrogen, phosphorus, potassium, calcium, magnesium and sodium was in FF11.

The total values of carbon and nutrient storage within 160 cm depth soils in the five adjacent fragmented forests were varied between 312,126-645,961 baht ha^{-1} (49,940-103,353 baht rai^{-1}).

Table 4-10 Valuation of biomass carbon and nutrients in adjacent fragmented forests

FF	C ($Mg.ha^{-1}$)	Total Amounts ($kg.ha^{-1}$) N	P	K	Ca	Mg	Total Value ($Baht\ ha^{-1}$)
FF1							
Nutrient Storages	125.17	1,384.03	194.84	947.79	2,015.18	451.17	
Value (Baht ha^{-1})	**381.63**	**36,105.21**	**5,082.80**	**12,637.26**	**11,626.01**	**2,602.90**	**68,435.82**
FF2							
Nutrient Storages	83.98	936.79	129.21	638.39	1,360.19	305.80	
Value (Baht ha^{-1})	**256.07**	**24,438.08**	**3,370.66**	**8,511.90**	**7,847.23**	**1,764.23**	**46,188.17**
FF3							
Nutrient Storages	118.04	1,311.71	182.43	895.62	1,906.93	427.81	
Value (Baht ha^{-1})	**359.90**	**34,218.57**	**4,759.07**	**11,941.53**	**11,001.49**	**2,468.16**	**64,748.73**
FF4							
Nutrient Storages	113.00	1,247.41	176.38	855.18	1,817.22	406.61	
Value (Baht ha^{-1})	**344.55**	**32,541.26**	**4,601.29**	**11,402.34**	**10,483.96**	**2,345.84**	**61,719.22**
FF5							
Nutrient Storages	101.17	1,122.03	156.84	767.07	1,632.15	365.93	
Value (Baht ha^{-1})	**308.46**	**29,270.35**	**4,091.60**	**10,227.55**	**9,416.25**	**2,111.14**	**55,425.35**
FF6							
Nutrient Storages	97.83	1,079.28	152.90	740.28	1,572.56	351.86	
Value (Baht ha^{-1})	**298.29**	**28,155.14**	**3,988.61**	**9,870.33**	**9,072.49**	**2,029.94**	**53,414.79**
FF7							
Nutrient Storages	81.07	899.05	125.79	614.80	1,307.75	293.31	
Value (Baht ha^{-1})	**247.18**	**23,453.38**	**3,281.48**	**8,197.33**	**7,544.69**	**1,692.18**	**44,416.25**
FF8							
Nutrient Storages	88.11	974.94	137.13	667.55	1,419.19	317.95	
Value (Baht ha^{-1})	**268.66**	**25,433.22**	**3,577.40**	**8,900.61**	**8,187.64**	**1,834.34**	**48,201.86**
FF9							
Nutrient Storages	95.06	1,051.38	148.16	720.27	1,530.56	343.03	
Value (Baht ha^{-1})	**289.84**	**27,427.30**	**3,865.05**	**9,603.56**	**8,830.16**	**1,979.03**	**51,994.94**
FF10							
Nutrient Storages	57.94	643.41	89.76	439.69	935.48	209.99	
Value (Baht ha^{-1})	**176.66**	**16,784.57**	**2,341.57**	**5,862.51**	**5,396.97**	**1,211.46**	**31,773.74**
FF11							
Nutrient Storages	101.88	1,135.07	156.93	773.92	1,648.75	370.38	
Value (Baht ha^{-1})	**310.63**	**29,610.42**	**4,093.74**	**10,318.87**	**9,512.00**	**2,136.78**	**55,982.45**
FF12							
Nutrient Storages	119.60	1,326.47	185.41	906.81	1,929.57	432.57	
Value (Baht ha^{-1})	**364.67**	**34,603.55**	**4,836.82**	**12,090.75**	**11,132.11**	**2,495.60**	**65,523.52**
FF13							
Nutrient Storages	117.07	1,292.53	182.84	886.26	1,882.75	421.52	
Value (Baht ha^{-1})	**356.95**	**33,718.23**	**4,769.67**	**11,816.79**	**10,862.01**	**2,431.86**	**63,955.51**
FF14							
Nutrient Storages	97.51	1,082.67	150.93	739.67	1,574.37	353.12	
Value (Baht ha^{-1})	**297.32**	**28,243.65**	**3,937.41**	**9,862.25**	**9,082.89**	**2,037.21**	**53,460.74**
FF15							
Nutrient Storages	92.62	1,025.62	143.77	701.57	1,492.74	334.25	
Value (Baht ha^{-1})	**282.39**	**26,755.42**	**3,750.45**	**9,354.29**	**8,611.99**	**1,928.35**	**50,682.89**

Table 4-11 Valuation of carbon and nutrient storages in forest floor of adjacent fragmented forests

FF	C (Mg.ha^{-1})	Total Amounts (kg. ha^{-1})					Total Value (Baht/ha)
		N	P	K	Ca	Mg	
FF 3							
Nutrient Storages	2.15	50.62	0.31	6.17	4.31	0.69	
Value (Baht ha^{-1})	**6.56**	**1,320.52**	**8.09**	**82.27**	**24.87**	**3.98**	**1,446.28**
FF 5							
Nutrient Storages	2.34	42.57	0.3	3.68	3.64	0.64	
Value (Baht ha^{-1})	**7.13**	**1,110.52**	**7.83**	**49.07**	**21.00**	**3.69**	**1,199.24**
FF 11							
Nutrient Storages	2.73	69.39	0.41	9.05	5.84	0.91	
Value (Baht ha^{-1})	**8.32**	**1,810.17**	**10.70**	**120.67**	**33.69**	**5.25**	**1,988.80**
FF 13							
Nutrient Storages	2.14	49.39	0.3	5.97	4.25	0.68	
Value (Baht ha^{-1})	**6.52**	**1,288.43**	**7.83**	**79.60**	**24.52**	**3.92**	**1,410.83**
FF 14							
Nutrient Storages	2.48	60.34	0.36	7.62	5.14	0.81	
Value (Baht ha^{-1})	**7.56**	**1,574.09**	**9.39**	**101.60**	**29.65**	**4.67**	**1,726.97**

Table 4-12 Valuation of carbon and nutrient storages in 1.60 meter soil profiles of adjacent fragmented forests

FF	C (Mg.ha^{-1})	Total Amounts (kg. ha^{-1})						Total Value (Baht/ha)
		N	P	K	Ca	Mg	Na	
FF 3								
Nutrient Storages	84.3	9,364.20	54.2	3,472.90	4,645.70	1,069.80	392.4	
Value (Baht ha^{-1})	**257.03**	**244,283.48**	**1,413.91**	**46,305.33**	**26,802.12**	**6,171.92**	**929.13**	**326,162.93**
FF 5								
Nutrient Storages	93.1	8,441.30	40.3	5,001.40	2,815.30	1,165.00	394.8	
Value (Baht ha^{-1})	**283.86**	**220,207.83**	**1,051.30**	**66,685.33**	**16,242.12**	**6,721.15**	**934.82**	**312,126.41**
FF 11								
Nutrient Storages	150.8	18,582.70	62.3	7,912.50	6,971.50	2,131.00	463	
Value (Baht ha^{-1})	**459.79**	**484,766.09**	**1,625.22**	**105,500.00**	**40,220.19**	**12,294.23**	**1,096.30**	**645,961.82**
FF 13								
Nutrient Storages	108	17,896.80	45.8	5,433.10	1,331.20	596.2	404.8	
Value (Baht ha^{-1})	**329.29**	**466,873.04**	**1,194.78**	**72,441.33**	**7,680.00**	**3,439.62**	**958.49**	**552,916.56**
FF 14								
Nutrient Storages	263.9	18,574.00	57.2	4,512.80	2,421.70	692.6	404.8	
Value (Baht ha^{-1})	**804.63**	**484,539.13**	**1,492.17**	**60,170.67**	**13,971.35**	**3,995.77**	**958.49**	**565,932.21**

4.3.2.3 Climax Montane Forest

The valuation of carbon and other nutrients as well as their allocation in different tree organs, forest floor and soil in climax montane forest were shown in Table 4-13 to 4-15**.**

(1) Valuation of carbon and nutrient storages in plant biomass

The value of biomass carbon in the climax montane forest was 569.54 baht ha^{-1}based on voluntary market. The value of nitrogen, phosphorus, potassium, calcium, and magnesium storage in biomass was 53,699.20; 7,266.28; 18,536.87; 17,319.47 and 3,766.50 baht ha^{-1}, respectively. The total value of carbon and nutrient storages in biomass was calculated as 101,127.87 baht ha^{-1} (16,180.46 baht rai^{-1}) (Table 4-13).

(2) Valuation of carbon and nutrient storages in forest floor

The value of carbon storage was 14.46 baht ha^{-1} based on voluntary market. The value of nitrogen, phosphorus, potassium, calcium, and magnesium storage in forest floor was 5,360.74; 14.04, 25.26, 114.39 and 14.35 baht ha^{-1}, respectively. The total value of carbon and nutrient storages in forest floor was 5,543.24 baht ha^{-1} (886.92 baht rai^{-1}) (Table 4-14).

(3) Valuation of carbon and nutrient storages in soil

The value of carbon and nutrient accumulations within 160 cm depth soils under different slope (upper, middle and lower) of the climax montane forest was calculated for carbon and nitrogen, available phosphorus, extractable potassium, calcium, magnesium and sodium.

The value of carbon storages within 160 cm depth soils were varied, 342.68-437.93 baht ha^{-1}based on voluntary market. The average value was 380.73 baht ha^{-1}. The average value of nitrogen, phosphorus, potassium, calcium, magnesium and sodium accumulation in soil were 460,222.26; 832.09; 57,937.78; 3,119.79; 650.58 and 1,087.09 baht ha^{-1}, respectively. The average total value of nutrients within 160 cm depth soils in the climax montane forest was 524,230.31 baht ha^{-1} (83,876.84 baht rai^{-1}) (Table 4-15).

Table 4-13 Valuation of biomass carbon and nutrient storages in climax montane forest

	C	Total Amounts (kg. ha^{-1})					Total Value
	(Mg.ha^{-1})	N	P	K	Ca	Mg	(Baht ha^{-1})
Nutrient Storages	186.80	2,057.32	278.54	1,390.26	3,002.04	652.86	
Value (Baht ha^{-1})	**569.54**	**53,669.20**	**7,266.28**	**18,536.87**	**17,319.47**	**3,766.50**	**101,127.87**

Table 4-14 Valuation of carbon and nutrient storages in forest floor of climax montane forest

	C	Total Amounts (kg. ha^{-1})					Total Value
	(Mg.ha^{-1})	N	P	K	Ca	Mg	(Baht ha^{-1})
Nutrient Storages	4.74	205.50	0.54	1.89	19.83	2.49	
Value (Baht/ha)	**14.46**	**5,360.74**	**14.04**	**25.26**	**114.39**	**14.35**	**5,543.24**

Table 4-15 Valuation of carbon and nutrient storages in 1.60 meter soil profiles of climax montane forest

	C	Total Amounts (kg. ha^{-1})						Total Value
	(Mg.ha^{-1})	N	P	K	Ca	Mg	Na	(Baht ha^{-1})
Upper slope								
Nutrient Storages	112.39	27,680.53	18.26	2,929.29	394.87	90.92	384.13	
Value (Baht ha^{-1})	342.68	722,100.78	476.35	39,057.20	2,278.10	524.54	909.55	765,689.19
Middle slope								
Nutrient Storages	143.63	13,553.29	28.47	5,492.50	877.47	168.61	482.38	
Value (Baht ha^{-1})	437.93	353,564.09	742.70	73,233.33	5,062.33	972.75	1,142.19	435,155.31
Lower slope								
Nutrient Storages	118.59	11,691.74	48.96	4,614.21	349.95	78.77	510.82	
Value (Baht ha^{-1})	361.58	305,001.91	1,277.22	61,522.80	2,018.94	454.44	1,209.53	371,846.43
Average Value	**380.73**	**460,222.26**	**832.09**	**57,937.78**	**3,119.79**	**650.58**	**1,087.09**	**524,230.31**

4.3.3 Valuation of Ecosystem Carbon and Nutrient Storages

(1) *Pinus kesiya* plantations

In the five age-class *Pinus kesiya* plantations, the value of carbon storages in pine plantation ecosystems including in plant, forest floor and soil compartments varied between 601-847 bath ha^{-1} based on voluntary market. The value of nutrients were different: nitrogen; 287,500-660,000 baht ha^{-1} (21,158-29,076 baht ha^{-1} based on available forms), phosphorus; 2,580-4,588 baht ha^{-1}, potassium; 64,106-87,015 baht ha^{-1}, calcium; 9,119-51,553 baht ha^{-1}, magnesium; 3,339-7,627 baht ha^{-1}, and sodium; 796-1,068 baht ha^{-1}. Total values of nutrient storages in pine plantation ecosystems varied in ranged of 391,595-755,837 baht ha^{-1} (62,655-120,933 baht rai^{-1}). The higher value was in soils (89.41-96.39%), followed by plants (3.37-10.29%) and forest floor (0.13-0.29%).

(2) Adjacent Fragmented Forests

In five adjacent fragmented forests, the value of carbon storages in plant, forest floor and soil compartments varied between 599-1,110 bath ha^{-1} based on voluntary market. The values of nutrients were different: nitrogen; 250,589-516,187 baht ha^{-1} (34,785-44,344 baht ha^{-1} based on available forms), phosphorus; 5,151-6,181 baht ha^{-1}, potassium; 58,329-115,940 baht ha^{-1}, calcium; 18,567-49,766 baht ha^{-1}, magnesium;5,875-14,436 baht ha^{-1}, and sodium 929-1,096 baht ha^{-1}. Total value of nutrient storages in adjacent fragmented forests ecosystems were varied, 368,751-703,933 baht ha^{-1} (59,000-112,629 baht rai^{-1}). The higher value was in soils (83.13-91.76%), followed by plants (7.95-16.50%) and forest floor (0.23-0.37%).

(3) Climax Montane Forest

In the climax montane forest at Doi Inthanon national park, the carbon stock in ecosystems including in plant, forest floor and soil compartments was 965 baht ha^{-1} based on voluntary market. The value for different nutrient was nitrogen; 519,252 baht ha^{-1} (68,234 baht ha^{-1} based on available forms), phosphorus; 8,112 baht ha^{-1}, potassium; 76,500 baht ha^{-1}, calcium; 20,554 baht ha^{-1}, magnesium; 4,431 baht ha^{-1}, and sodium; 1,087 baht ha^{-1}. Total value of nutrient storage in climax montane forest ecosystems was 630,901 baht ha^{-1}(100,944 baht rai^{-1}). The majority value was in soils (83.09%) followed by plants (16.03%), and forest floor (0.88%) (Table 4-16).

4.3.4 Total Ecosystems Economic Valuation

The total economic including the value of wood production, carbon and nutrient storages were shown in Table 4-17 to 4-18 and Figure 4-1 to 4-2.

(1) *Pinus kesiya* plantations

In the five age-class *Pinus kesiya* plantations, the economic value of ecosystems were different, wood production; 91,474-234,568 bath ha^{-1}, carbon based on voluntary market; 601-847 bath ha^{-1}, and nutrients; 391,343-755,031 bath ha^{-1}. The total economic value of ecosystems was calculated as 626,512-921,985 bath ha^{-1} (100,241-147,517 bath rai^{-1}). If the carbon was calculated on carbon market, the value was increased to 59,962-84,738 bath ha^{-1}. The total ecosystem value was changed to 685,873-1,001,718 bath ha^{-1} (109,739-160,274 bath rai^{-1}).

(2) Adjacent Fragmented Forests

In five adjacent fragmented forests, the economic value of ecosystems were different, wood production; 111,142-180,621 bath ha^{-1}, carbon based on voluntary market; 599-1,110 bath ha^{-1}, and nutrients; 368,152-703,154 bath ha^{-1}. The total economic value of ecosystems was calculated as 516,429-815,074 bath ha^{-1} (82,628-130,411 bath rai^{-1}). If the carbon was calculated on carbon market, the value was increased to 59,864-111,130 bath ha^{-1}. The total ecosystem value was changed to 575,694-892,268 bath ha^{-1} (92,111-142,762 bath rai^{-1}).

(3) Climax Montane Forest

The total ecosystems value of climax montane forest was calculated as 874,784 bath ha^{-1} (139,965 bath rai^{-1}), separated to those of wood production, carbon on voluntary market and nutrients as 243,883 bath ha^{-1}; 965 bath ha^{-1}; and 629,937 bath ha^{-1}, respectively. If the carbon was calculated on carbon market, the value was increased to 96,473 bath ha^{-1}. The total ecosystem value was changed to 970,293 bath ha^{-1} (155,246 bath rai^{-1}).

Table 4-16 Value of carbon and nutrient storages in ecosystems of pine plantations, adjacent fragmented forests and climax montane forest

Area	Plot	Component	Nutrient Value (Baht ha^{-1})							Total Value	%
			C	N	P	K	Ca	Mg	Na	(Baht ha^{-1})	
Pine Plantations	**17 yrs**	Plant	172	14,377	1,941	5,030	4,551	990	-	27,060	3.58
		Forest Floor	10	1,823	12	103	33	5	-	1,986	0.26
		Soil	625	643,800	2,635	58,973	16,454	3,508	796	726,790	96.16
		Total	**807**	**660,000**	**4,588**	**64,106**	**21,038**	**4,503**	**796**	**755,837**	**100.00**
	21 yrs	Plant	349	21,780	2,819	7,754	6,659	1,299	-	40,311.10	10.29
		Forest Floor	8	1,067	8	34	20	4	-	1,142	0.29
		Soil	244	264,652	730	79,227	2,440	2,037	812	350,142	89.41
		Total	**601**	**287,500**	**3,558**	**87,015**	**9,119**	**3,339**	**812**	**391,595**	**100.00**
	25 yrs	Plant	263	15,511	1,978	5,525	4,696	892	-	28,865	4.69
		Forest Floor	5	755	6	28	13	2	-	810	0.13
		Soil	506	493,957	809	80,280	7,240	2,665	961	586,418	95.18
		Total	**774**	**510,222**	**2,793**	**85,834**	**11,950**	**3,560**	**961**	**616,094**	**100.00**
	29 yrs	Plant	175	10,648	1,371	3,794	3,244	626	-	19,857	3.37
		Forest Floor	8	1,297	9	61	24	4	-	1,403	0.24
		Soil	543	460,643	1,200	74,427	24,554	6,138	971	568,476	96.39
		Total	**725**	**472,588**	**2,580**	**78,282**	**27,822**	**6,768**	**971**	**589,736**	**100.00**
	33 yrs	Plant	345	14,715	1,778	5,491	4,235	637	-	27,200	5.05
		Forest Floor	9	1,106	9	29	22	4	-	1,178	0.22
		Soil	494	387,548	2,217	64,373	47,296	6,987	1,068	509,983	94.73
		Total	**847**	**403,368**	**4,004**	**69,893**	**51,553**	**7,627**	**1,068**	**538,361**	**100.00**
Adjacent Natural Forests	**FF 3**	Plant	360	34,219	4,759	11,942	11,001	2,468	-	64,749	16.50
		Forest Floor	7	1,321	8	82	25	4	-	1,446	0.37
		Soil	257	244,283	1,414	46,305	26,802	6,172	929	326,163	83.13
		Total	**623**	**279,823**	**6,181**	**58,329**	**37,828**	**8,644**	**929**	**392,358**	**100.00**
	FF 5	Plant	308	29,270	4,092	10,228	9,416	2,111	-	55,425	15.03
		Forest Floor	7	1,111	8	49	21	4	-	1,199	0.33
		Soil	284	220,208	1,051	66,685	16,242	6,721	935	312,126	84.64
		Total	**599**	**250,589**	**5,151**	**76,962**	**25,679**	**8,836**	**935**	**368,751**	**100.00**
	FF 11	Plant	311	29,610	4,094	10,319	9,512	2,137	-	55,982	7.95
		Forest Floor	8	1,810	11	121	34	5	-	1,989	0.28
		Soil	460	484,766	1,625	105,500	40,220	12,294	1,096	645,962	91.76
		Total	**779**	**516,187**	**5,730**	**115,940**	**49,766**	**14,436**	**1,096**	**703,933**	**100.00**
	FF 13	Plant	357	33,718	4,770	11,817	10,862	2,432	-	63,956	10.34
		Forest Floor	7	1,288	8	80	25	4	-	1,411	0.23
		Soil	329	466,873	1,195	72,441	7,680	3,440	958	552,917	89.43
		Total	**693**	**501,880**	**5,972**	**84,338**	**18,567**	**5,875**	**958**	**618,283**	**100.00**
	FF 14	Plant	297	28,244	3,937	9,862	9,083	2,037	-	53,461	8.61
		Forest Floor	8	1,574	9	102	30	5	-	1,727	0.28
		Soil	805	484,539	1,492	60,171	13,971	3,996	958	565,932	91.11
		Total	**1,110**	**514,357**	**5,439**	**70,135**	**23,084**	**6,038**	**958**	**621,120**	**100.00**
Climax Montane Forest		Plant	570	53,669	7,266	18,537	17,319	3,766	-	101,128	16.03
		Forest Floor	14	5,361	14	25	114	14	-	5,543	0.88
		Soil	381	460,222	832	57,938	3,120	651	1,087	524,230	83.09
		Total	**965**	**519,252**	**8,112**	**76,500**	**20,554**	**4,431**	**1,087**	**630,901**	**100.00**

Table 4-17 Value of wood production, carbon (voluntary market) and nutrient storages in ecosystems of pine plantations, adjacent fragmented forests and climax montane forest

Plot	Wood production		Carbon		Nutrient		Total
	(baht ha^{-1})	%	(baht ha^{-1})	%	(baht ha^{-1})	%	(baht ha^{-1})
17 yrs	166,148	18.02	807	0.09	755,031	81.89	921,985
21 yrs	234,568	37.44	601	0.10	391,343	62.46	626,512
25 yrs	168,937	21.52	774	0.10	615,320	78.38	785,031
29 yrs	91,474	13.43	725	0.11	589,011	86.47	681,210
33 yrs	113,605	17.42	847	0.13	537,514	82.45	651,966
FF3	180,621	31.52	623	0.11	391,734	68.37	572,979
FF5	147,678	28.60	599	0.12	368,152	71.29	516,429
FF11	111,142	13.64	778	0.10	703,154	86.27	815,074
FF13	183,858	22.92	693	0.09	617,590	76.99	802,141
FF14	127,045	16.98	1,110	0.15	620,010	82.87	748,165
Climax	243,883	27.88	965	0.11	629,937	72.01	874,784

Table 4-18 Value of wood production, carbon (carbon market) and nutrient storages in ecosystems of pine plantations, adjacent fragmented forests and climax montane forest

Plot	Wood production		Carbon		Nutrient		Total
	(baht ha^{-1})	%	(baht ha^{-1})	%	(baht ha^{-1})	%	(baht ha^{-1})
17 yrs	166,148	16.59	80,539	8.04	755,031	75.37	1,001,718
21 yrs	234,568	34.20	59,962	8.74	391,343	57.06	685,873
25 yrs	168,937	19.61	77,344	8.98	615,320	71.42	861,601
29 yrs	91,474	12.15	72,450	9.62	589,011	78.23	752,935
33 yrs	113,605	15.44	84,738	11.52	537,514	73.05	735,856
FF3	180,621	28.46	62,245	9.81	391,734	61.73	634,601
FF5	147,678	25.65	59,864	10.40	368,152	63.95	575,694
FF11	111,142	12.46	77,972	8.74	703,154	78.81	892,268
FF13	183,858	21.12	69,255	7.95	617,590	70.93	870,703
FF14	127,045	14.80	111,130	12.95	620,010	72.25	858,185
Climax	243,883	25.13	96,473	9.94	629,937	64.92	970,293

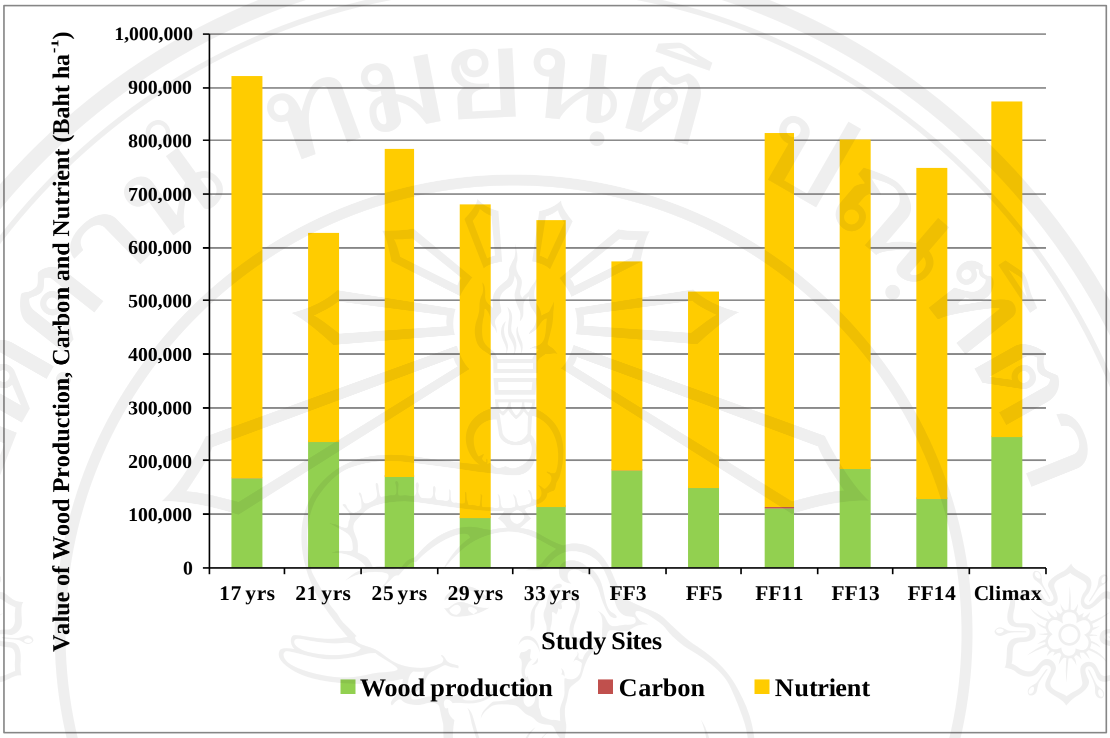

Figure 4-1 Value of wood production, carbon (voluntary market) and nutrient storages in forest ecosystems

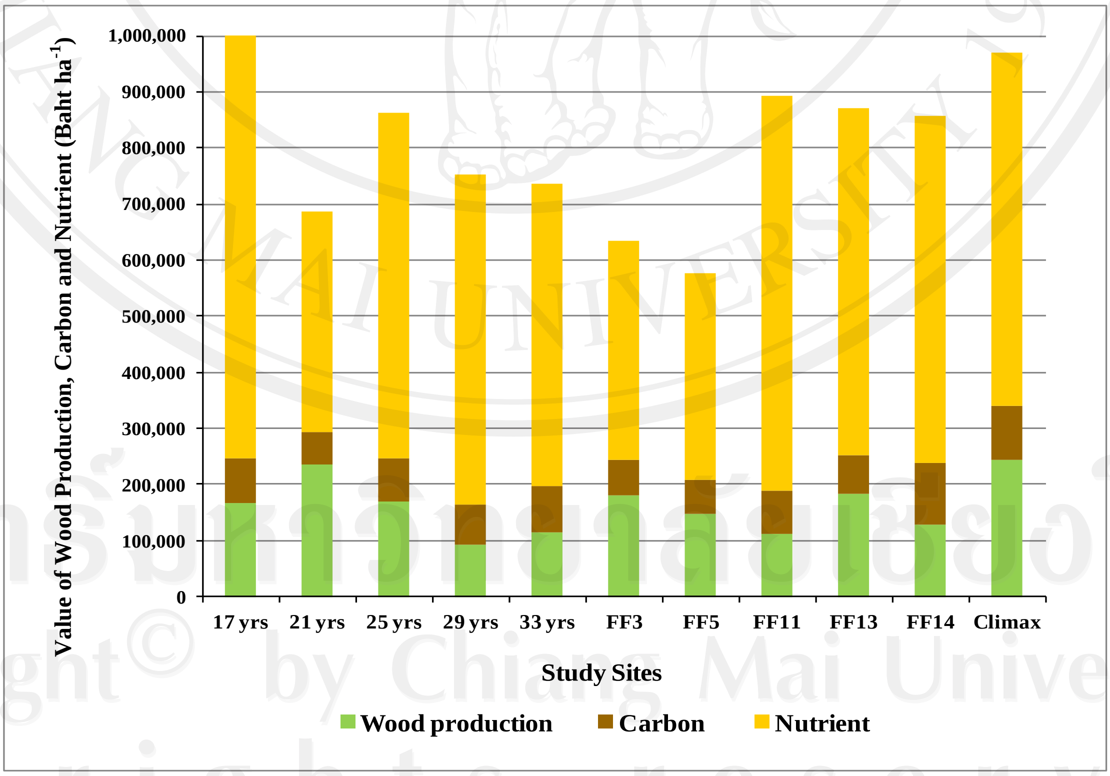

Figure 4-2 Value of wood production, carbon (carbon market) and nutrient storages in forest ecosystems

4.4 Discussion

Wood production in 21 age-class plantations were did not increase continuously with stand age. The high fluctuation of wood production was observed among the pine plantations caused by many factors such as 1) spacing of planting and tree densities; the difference in pine densities among these plantations is considered. The higher density was determining lower yield and resulted in lower value of wood production. 2) The forest fire occurred in some stands particularly on xeric sites might cause killing some pine individuals and resulted in lower tree density. 3) Plant succession affects on pine growth in older stands through competition and may results in standing dead of some individuals as the succession trees grow up to have the higher height and canopy. Succession tree is the most important factor for productivity and profit. This study, succession tress in 21 age-class pine plantation was productivity higher than 60-90% of wood production. 4) The site factor particularly soil fertility, soil moisture, altitude etc. These factors affected their growths and tree volume which resulted to value of wood production. The values of wood production in 21 age-class plantations were 70,544-341,800 baht ha^{-1} (11,287-54,688 baht rai^{-1}). In the fifteen adjacent fragmented forests, these values were 94,009-236,791 baht ha^{-1} (15,041-37,886 baht rai^{-1}) and in climax montane forest, the value was 243,883 baht ha^{-1} (39,021 baht rai^{-1}). Seeloy-ounkeaw (2011) investigated the valuation of Nong Tao community forest at Mae Wang district, Chiang Mai province, Thailand. Nong Tao community forest was divided into utilization and conservation forest. Most forest was montane and pine-montane forest. For utilization forest, there were 64 species and the timber volume was 13.14 m^3rai^{-1}. The pine wood was 5.67 m^3rai^{-1}. The total value of wood production was 28,580 baht rai^{-1}, value of pine wood; 15,142 baht rai^{-1}(53% of wood production value). In the conservation forest, there were 167 species and the timber volume was 26.13 m^3rai^{-1}. The pine wood was 5.71 m^3rai^{-1}. The total value of wood production was 63,872 baht rai^{-1}, separated to value of other broad-leave was 47,446 baht rai^{-1} (75% of wood production value) and value of pine wood; 16,426 baht rai^{-1} (75% of wood production value). So, in term of wood production, the values of wood production derived from forest plantation tend to be increasing to the value of adjacent fragmented forest and climax montane forest.

Further more, the storage of nutrient, especially nitrogen in trees biomass in a series of pine plantations did not increase with stand age, it depend on biomass allocation in pine trees and succession broad-leaved trees and soil nutrients. It was resulted in nutrient storage value. The values of nitrogen storages in five age-class plantations were separated in plant biomass; 10,648-21,780 baht ha^{-1} (1,703-3,484 baht rai^{-1}) and soil; 264,652-643,800 baht ha^{-1} (42,344-103,008 baht rai^{-1}). In the five adjacent fragmented forests, these values of nitrogen storages in plant biomass and soil were 28,244-34,219 baht ha^{-1} (4,519-5,475 baht rai^{-1}) and 220,208-484,766 baht ha^{-1} (35,233-77,562 baht rai^{-1}), respectively. For climax montane forest, the value of nitrogen storages in plant biomass was 53,669 baht ha^{-1} (8,587 baht rai^{-1}) and 460,222 baht ha^{-1} (73,635 baht rai^{-1}) in soli. The studies in Seeloy-ounkeaw (2011) shown that the value of nitrogen storages in the utilization forest was 9,103 baht ha^{-1} in plant biomass (1,456 baht rai^{-1}) and 15,523 baht ha^{-1} in soil (24,837 baht rai^{-1}). For the conservation forest, there was 29,617 baht ha^{-1} in plant biomass (4,738 baht rai^{-1}) and 451,096 baht ha^{-1} in soil (72,175 baht rai^{-1}).

Value for the carbon storage functions of forests, it is important to distinguish: in this case there is an economic value to the carbon stored and much of which value is lost if the forest is burned or logged, the results in these study show that the values of carbon storage in forest plantation were 601-847 baht ha^{-1} or US$ 19-27 ton C. In their review of cost estimates, Sedjo *et al*. (1995) show that estimates range from US$ 3-16 ton C for agro-forestry and US$ 3-60 ton C for plantations in tropical areas; US$ 1-50 ton C for plantations in temperate areas; and US$ 1-4 ton C for plantations in boreal areas. Tol *et al*. (2000) also review the studies and suggest that it is difficult to produce estimates of marginal damage above US$ 50 ton C. Taking US$ 34-50 ton C as the range produces very high estimates for the value of forests as carbon stores. In practical terms, however, a better guide to the value of carbon is what it is likely to be traded at in a 'carbon market'. Zhang (2000) suggests that, if there are no limitations placed on worldwide carbon trading, carbon credits will exchange at just under $10 per tC. If 'hot air' trading is excluded, the price will be US$ 13 ton C. Taking the US$ 10 ton C as a conservative estimate.