Original article

Natural Watershed Recovery Estimation after 40 Years of Forest Rehabilitation in Khun Khong Watershed Research Station, Chiang Mai, Thailand

Vanchai Viranant **Thammanon Kaewaumput**
Suphot Charoensuk **Parichart Buajung**

National Park, Wildlife and Plant Conservation Department, Chatuchak, Bangkok 10900 Thailand.
E-mail: Viranant_Vanchai@Yahoo.com

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ABSTRACT

The cumulative effects of previous massive deforestation can have catastrophic consequences, particularly flash floods and landslides in every rainy season from May to October. Without any restoration, abandoned land will never develop into forest. To recover degraded land, fast-growing native tree species like pine (*Pinus kesiya*) have been widely planted in the *Imperata* grasslands at the head of the watersheds in the northern part of Thailand. Therefore, this study aimed to investigate: (i) the floristic composition after 40 years of forest watershed rehabilitation, and (ii) the recovery period for forest watershed rehabilitation. The data were gathered through vegetation surveys conducted at various ages in pine (*Pinus kesiya*) reforestation stands and the nearby natural hill evergreen forest as a control area. Non-linear trend analysis was applied to forecast the natural watershed recovery period.

After 40 years, the tree parameters in terms of species richness, Shannon-Wiener diversity index, total basal area, tree density and IVI were highly variable. The planted stands had no clear age-structure distribution and most of the planted trees were found in the 14.5-24.5 and 24.5-34.5 cm DBH classes. Native tree species had established in the lowest class of 4.5-14.5 cm DBH within the clumped distribution of Raunkier class A and class B. The period required for the rehabilitation of degraded land through natural watershed recovery was estimated to be about at least 84-153 years.

Keywords: degraded forest, watershed rehabilitation, floristic composition, non-linear trend analysis, recovery period

INTRODUCTION

The recovery of a natural forested watershed needs quite a long period. Furthermore, this requirement does not coincide with the five-year periods used in Thailandû s National Social and Economic Development Plan, as ecological processes need to be fully restored over a long time span. The short-term recovery of ecosystem functions usually will not be apparent, except for the physical appearance of newly planted trees on the degraded land. The long-term recovery of natural watersheds will be a challenge to ensure securing quality of life for every citizen of the Kingdom. The reduction in natural forested watershed, due to an endless cycle of poverty or for whatever reason, has given rise to ever-greater ecological instability through: increasing soil erosion and desertification; a growing water-shortage; the extinction of plant and animal species; climatic changes; and other severe discontinuities that are rapidly making Thailand less habitable. These cumulative effects of earlier massive deforestation have catastrophic consequences in every rainy season from May to October. Recently, on September 20, the Minister of Public Health announced that 14 people had been swept away by flash floods that had hit 36 provinces in Thailand over the previous nine days (Associated Press, 2008). It was also reported that 839,000 people were affected by consequential flooding at a cost of 353 million baht. Agricultural areas and fisheries were devastated with about 50,000 rai (8,000 ha) and 9,023 rai (1,444 ha), respectively, affected, costing approximately 600 million baht and 55 million baht respectively (Khaosod, 2008).

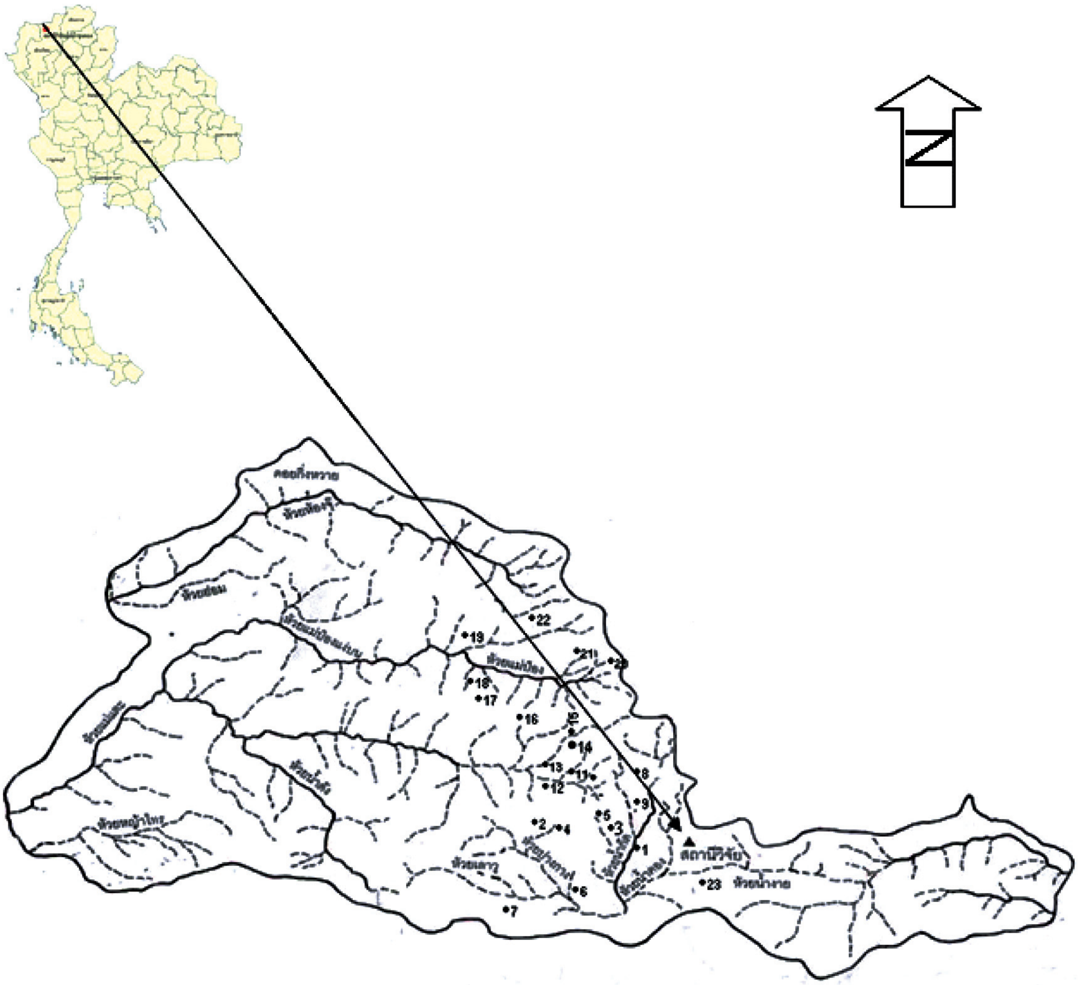
In late successional forests, small-scale disturbance, caused by tree falling, provides gaps in which early successional species (pioneer species) can fulfill their growth cycle. At the other extreme, fire, clear cutting and shifting cultivation usually result in much larger areas of degraded land. In addition, if disturbance is frequent through continued human interference, the land will consist solely of *Imperata* grasses. (Mackinnon *et al*., 1996; Richards, 1996). Such abandoned grassland might also recover from disturbance, but only after human pressure has ceased and after a long period of time (Mackinnon *et al*., 1996; Finegan, 1996).

In general, natural succession in abandoned pastureland is a very slow process (Aide *et al*., 1995; Chapman and Chapman, 1996). Natural succession in deforested and abandoned land is dependent on the previous land use pattern (Uhl *et al*., 1988, Aide and Cavelier, 1994), soil seed-bank depletion due to repeated burning (Nepstad *et al*,. 1991) and the non-attraction of frugivores, which bring the seeds of native, tropical rainforest species to these areas (Duncan and Chapman, 1999). Natural succession may occur in a few instances due to changes in microenvironment (Brown and Lugo, 1994). Without any restoration, abandoned land will never develop into forest. To recover the degraded land, forest rehabilitation using fast-growing, native, pioneer species like *Pinus kesiya* has been widely practiced in the degraded watersheds of northern Thailand. Therefore, research on the recovery period of a natural watershed after forest rehabilitation in the highlands would provide extremely valuable information for future land management and conservation, especially in tropical areas, like Thailand, where the mountainous, forested watershed functions as a water tower supply to all sectors of the nation. The objectives of this study were to investigate: (i) the floristic composition after 14 to 40 years of forest watershed rehabilitation in northern Thailand; and (ii) the recovery period of forest watershed rehabilitation. It is expected that the research findings will provide some lessons to help address the challenge of watershed development and its long term restoration.

MATERIALS AND METHODS

Study Site

The Khun Khong Watershed Research Station is located between longitude 98°43′ and 98°54′E and latitude 19°20′-19°38′ N in Chiang Mai province, Thailand



1. Pine plantation planted in 1965
2. Pine plantation planted in 1966
3. Pine plantation planted in 1969
4. Pine plantation planted in 1970
5. Pine plantation planted in 1972
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8. Pine plantation planted in 1976
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14. Pine plantation planted in 1983
15. Pine plantation planted in 1984
16. Pine plantation planted in 1985
17. Pine plantation planted in 1986
18. Pine plantation planted in 1987
19. Pine plantation planted in 1988
20. Pine plantation planted in 1989
21. Pine plantation planted in 1990
22. Pine plantation planted in 1991
23. Natural hill evergreen forest

Figure 1 The study sites in Khun Khong Watershed Research Station, Chiang Dao district, Chiang Mai province, northern Thailand.

(Figure 1.). Elevation ranges from 1200 to 1700 m amsl. The mean annual rainfall is 1985 mm mainly occurring during May to October. The mean annual temperature, relative humidity and evaporation is 19.48°C, 87.38% and 1,729.92 mm, respectively. Physical soil properties in terms of bulk density, particle density, porosity and maximum water holding capacity are 0.86-1.07 gm/cm^3, 2.45-2.59 gm/cm^3 36.44-58.38%, and 49-55.01%, respectively. The chemical soil properties are highly acidic with very high organic matter, high potassium, low-middle calcium and low-middle magnesium levels of 3.55-6.43%, 147-283 ppm, 197-1,215 ppm and 96-284 ppm, respectively.

Vegetation

Originally, the study site was covered with hill evergreen forest but was cleared approximately more than 50 years previously, to provide land for cultivation of upland rice, vegetables, maize, potatoes and other cash crops. The quantitative characteristics in the least-undisturbed hill evergreen forest at a similar elevation near the study site in terms of tree density, species richness ,Shannon-Wiener diversity index, basal area and the average canopy height were: 1,017 trees/ha, 48 species, 5.19, 0.27% and 12.41 m, respectively. The dominant tree species were: *Schima wallichii, Ternstroemia gymnanthera, Castanopsis acuminatissima,* and *Melicia* spp.. The forest canopy was divided in to four height classes: class 1 (> 29 m);class 2 (21.7-29 m); class 3 (2.3-21.1 m) and class 4 (<2.3 m) (Pukjarune and Kaewaumput, 1993).

Method

Based on similar aspect and slope steepness, during November-December, 2005, reforestation stands of pine (*Pinus kesiya*) planted at a spacing of 4 m x 4 m (100 trees/rai or 625 trees/ha) from 1965 to 1991 were selected for investigation (Table 1). Each age of the rehabilitated stands had three replicates; thus, 66 sampling plots representing 22 different ages from 14 to 40 years were located along the slope length at the top, middle and lower part of the study sites. For the purposes of comparison, another three sample replicates as a control were also placed in the same manner nearby the least undisturbed natural hill evergreen forest stand. The research procedures were designed as follows.

Sample Plot

Sample plots with equal size of 40 m x 40 m were then divided into 16 (10 m x 10 m) subplots. Within these subplots, 16 (4 m x 4 m) plots and 16 (1 m x 1 m) plots were placed in the upper right corner of each subplot as depicted in Figure 2.

Data Collection

Vegetation inventories in each age of rehabilitated stand and natural hill evergreen forest were conducted during the winter season from November to February 2005. The vegetation was stratified into trees, saplings and seedlings according to diameter growth at 1.3 meter height (DBH) and total height. In each sample plot, 16 subplots with quadrat sizes of (10 m x 10 m), (4 m x 4 m) and (1 m x 1 m) (Figure 2) were employed to identify the vegetative characteristic composition in terms of: trees (DBH > 4.5 cm and height > 1.3 m); saplings (DBH < 4.5 cm and height >1.3 m); and seedlings (DBH < 4.5 cm and height < 1.3 m), respectively.

Data Analysis

Vegetation Analysis

The vegetative characteristics in terms of species richness, Shannon-Wiener diversity index, importance value index (IVI) and tree density were analyzed to investigate the structural changes in the pine rehabilitation stands at

Table 1 Pine reforestation during 1965-1991, Khun Khong Watershed Development Unit and Watershed Research Station, Chiang Dao district, Chiang Mai province, northern Thailand.

Year	Forest rehabilitation stand			
	Age	*Species*	*Area* (rai)	*Area* (ha)
1991	14	*Pinus kesiya*	600	96
1990	15	*Pinus kesiya*	900	144
1989	16	*Pinus kesiya*	428	68.48
1988	17	*Pinus kesiya*	550	88
1987	18	*Pinus kesiya*	550	88
1986	19	*Pinus kesiya*	600	96
1985	20	*Pinus kesiya*	650	104
1984	21	*Pinus kesiya*	775	124
1983	22	*Pinus kesiya*	450	72
1982	23	*Pinus kesiya*	800	128
1981	24	*Pinus kesiya*	1 130	180.8
1980	25	*Pinus kesiya*	1 300	208
1979	26	*Pinus kesiya*	1 300	208
1978	27	*Pinus kesiya*	1 430	228.8
1976	29	*Pinus kesiya*	500	80
1974	31	*Pinus kesiya*	950	152
1973	32	*Pinus kesiya*	500	80
1972	33	*Pinus kesiya*	1 500	240
1970	35	*Pinus kesiya*	1 000	160
1969	36	*Pinus kesiya*	1 500	240
1966	39	*Pinus kesiya*	500	80
1965	40	*Pinus kesiya*	500	80
Total			18 413	2 946.08

Note 1. The study was conducted during November to February, 2005.
2. 1 ha = 6.25 rai.
3. Spacing of planted trees = 4 mx4 m, thus stocking = 100 trees/rai or 625 trees/ha.

each age. The various tree species in each stand were grouped into one of five frequency classes: 1-20% (Class A), 21-40% (Class B), 41-60% (Class C), 61-80% (Class D) and 81-100% (Class E), according to Raunkier's law of frequency. The above parameters were also used to estimate the recovery-trend period after rehabilitation of the forest watershed as described in the next section.

Trend Analysis

Variation in climate change was considered to affect consistency in the plant communities in the pine rehabilitation stands at each age. Therefore, the nonlinear trend was modified using a nonlinear smoothing equation (Levin *et al*., 1992) to estimate the recovery period in a natural watershed. The nonlinear trend can be generated by Equations 1, 2 and 3:

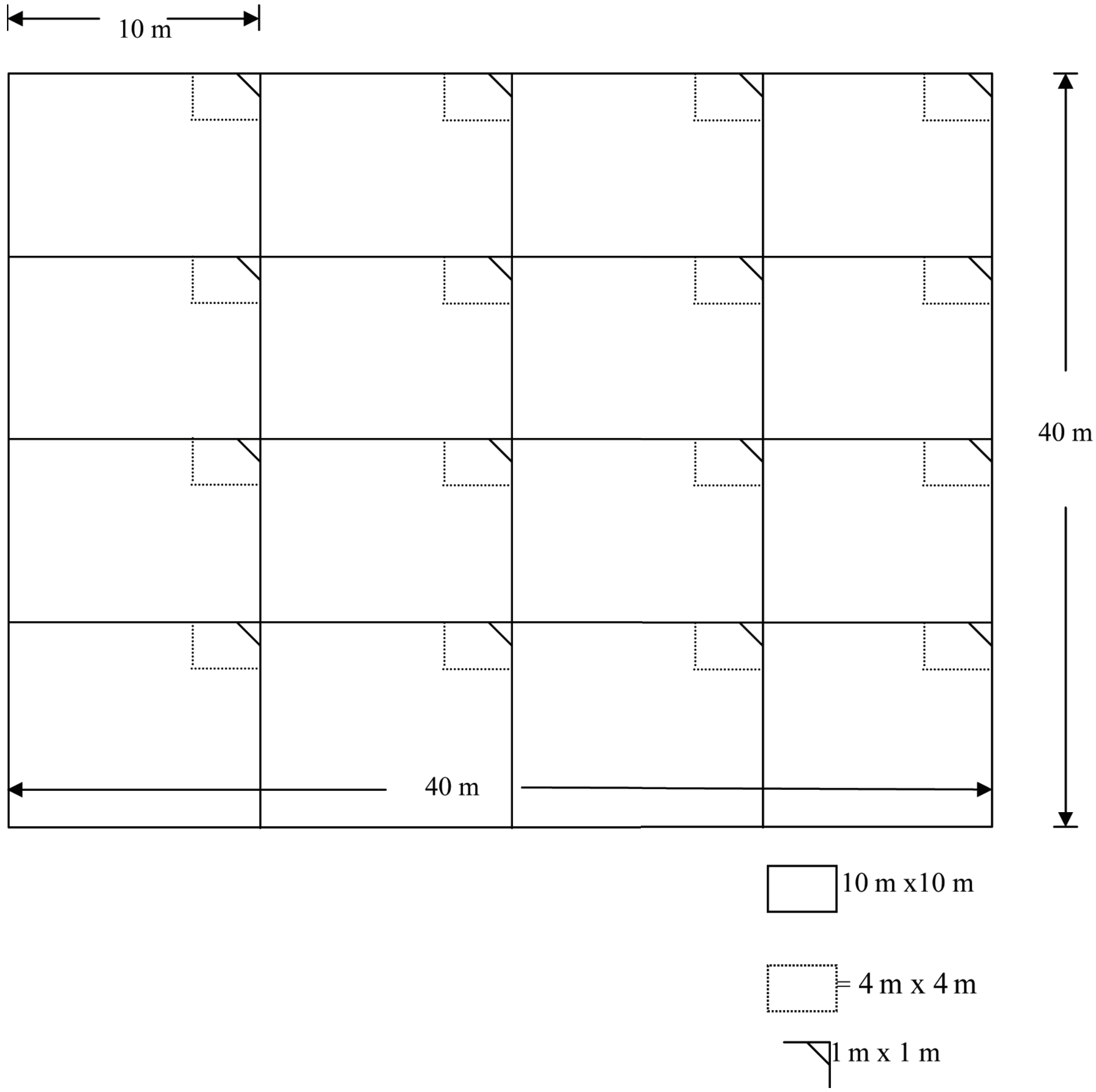

Figure 2. Layout of a sample plot of 40 m x 40 m. The 16 (10 m x 10 m), (4 m x 4 m) and (1 m x 1 m) subplots were designated for the respective measurement of trees, saplings and seedlings.

$$S_t = F_t + a_1 e_1 \quad (1)$$

$$T_t = \phi\, T_{t-1} + a_2 e_1 \quad (2)$$

$$F_{t+1} = S_t + \phi\, T_t \quad (3)$$

where

S_t = the smoothed level or an intercept
T_t = the smoothed trend or slope
a_1 = smoothing parameter for the level
a_2 = smoothing parameter for the trend
ϕ = the trend-modification parameter

The least square method (LSD) was applied to obtain the intercept (a) and slope (b) of the linear regression. These values are always used as the initial values of S and T (Levin *et al.*, 1992). Then the least mean square error (MSE) was taken as a basic principle to determine the best fitting parameter. An application in Excel using Visual Basic was formulated to reduce the burden of calculation. The best fitting parameters of a_1, a_2 and ϕ were identified for smoothing the non-linear trend of each tree parameter. Thus, values in Equation (3) can be obtained by substituting the values of (a) and (b) and derived parameters in Equations (1) and (2).

Equations 1, 2 and 3 only forecast for one period (t+1). However, at any time, forecasts can be made for a longer time horizon, by using the general forecast equation for exponential smoothing of a nonlinear trend (Equation 4):

$$F_{t+m} = S_t + \sum_{i=1}^{m} \phi^i T_t \qquad (4)$$

where m = the number of periods in the future that want to forecast.

From Equation 4, if the chosen ϕ parameters coincide in each derived non-linear trend and the future period (m) is projected far enough into the future, eventually growth will disappear altogether. The point at which growth stops is called an éasymptoteé. This point was assumed to be the mature or climax stage that would indicate the end of the recovery period for forest watershed rehabilitation.

RESULTS AND DISCUSSION

Species Richness and Forest Structure

The species richness of plant life forms in terms of trees, saplings and seedlings varied highly between respective values of 7–47, 5-45 and 1-22 species. On the contrary, life forms of shrubs and graminoids were almost similar to the control site within the range of 1-7 and 3-10 species, respectively. Analysis by Raunkierûs frequency classes revealed that almost 80% of the tree species in all ages of planting, including the control site had a similar pattern of low frequency in classes A and B. This demonstrated that the higher the tree frequency, the lower the number of the tree species. This feature is typical of species abundance distribution in tropical forests (Kumar *et al*., 2006). It was also found that the planted trees of *Pinus kesiya* and *Schima walllichii* were in class E, having the most regular distribution (low species number and high frequency) throughout all ages. *Schima wallichii, Prismatomeris tetrandra, Diospyros glandulosa, Engelthardtia spicata, Ternstroemia gymnanathera, Michelia floribunda, Catanopsis acuminatissima,* and *Markhamia stipulata* were found in all stands and had the most clumped distribution (high species number and low frequency) within Classes A and B (Table 2).

The highest species richness, diversity index and total basal area with respective values of 58 species, 4.99, and 19.29 m^2/ha were found in the natural hill evergreen forest (control area), whereas the 25-year-old plantation had the lowest values of 7 species and 0.36 for both species richness and diversity index, respectively, while the 14-year-old stand had the lowest basal area of 7.49 m^2/ha (Table 3). In general, the successional stage can be assessed by comparing the rehabilitated land to the nearby undisturbed forest. The main objective of this watershed rehabilitation was to restore to the original natural forest condition or as close as possible. Thus, this process would be considered successful when the plant communities in the natural forest and the rehabilitated stands were equal or had almost reached the same values for natural tree parameters.

In this study, the diversity index has been used as an indicator of the stage of succession. A late successional stage is commonly implied by high values of plant diversity, while the early stage is indicated by lower values (Odum, 1971). Therefore, the control site was judged to be in the late successional stage or close to the mature stage

Table 2 Some plant life forms and Raunkier's frequency for various ages of pine plantations and hill evergreen forest at Khun Khong Watershed Research Station, Chiang Mai, Thailand.

Year	Age	# Species			Understorey		Raunkier Classification (%No. of Species)				
		Tree	Sapling	Seedling	Shrubs	Graminoids	A(0-20%)[1/]	B(21-40%)[1/]	C(41-60%)	D(61-80%)	E(81-100%)[2/]
1991	14	25	9	-	5	5	76	20	-	-	4
1990	15	25	9	-	1	4	92	4	-	-	4
1989	16	24	8	-	6	3	88	8	-	-	4
1988	17	27	29	1	4	8	85	11	-	-	4
1987	18	32	38	1	7	9	88	6	-	3	3
1986	19	20	33	1	3	5	80	10	5	-	5
1985	20	13	21	-	4	7	77	8	8	-	8
1984	21	24	9	3	3	4	83	13	-	-	4
1983	22	36	11	14	6	5	81	14	3	-	3
1982	23	31	19	7	3	7	84	13	-	-	3
1981	24	17	31	2	5	10	94	-	-	-	6
1980	25	7	19	1	2	5	86	-	-	-	14
1979	26	16	32	1	3	6	94	-	-	-	6
1978	27	24	45	1	9	7	79	17	-	-	4
1976	29	10	5	3	4	8	90	-	-	-	10
1974	31	35	12	3	2	5	80	17	-	-	3
1973	32	33	38	6	6	7	88	9	-	-	3
1972	33	40	13	9	6	9	80	15	3	-	3
1970	35	23	9	3	2	4	87	9	-	-	4
1969	36	42	18	7	6	9	86	12	-	2	-
1966	39	36	32	18	5	4	75	11	8	-	6
1965	40	47	37	22	3	4	87	6	4	-	2
Hill evergreen	-	58	20	5	3	6	86	12	2	-	-

Note [1/]: Clumped distribution: *Albizia odoratissima, Castanopsis acuminatissima, Castanopsis diversifolia, Clause na excavata, Dalbergia dongnaiensis, Diospyros glandulosa, Engelhardtia spicata, Eriolaena candollei, Fernandoa adenophylla, Glochidion kerrii, Helicia nilagirica, Lannea coromandelica, Michelia floribunda, Prismatomeris tetrandra, Quercus kingiana, Schima wallichii, Ternstroemia gymnanthera*

[2/]: Regular distribution: *Pinus kesiya* (only found in all reforestation stands), and *Schima wallichii*

Table 3 Quantitative characteristics in stands 14 to 40 years old of pine (*Pinus kesiya*) plantations at Khun Khong Watershed Research Station, Chiang Mai, Thailand.

Year	Age	# Species	Diversity	%IVI[1/]	Basal area (m^2/ha)	Density (trees/ha)		% No.of trees by DBH class[2/] (cm)							Total (No.of trees)
						Pine	Tree	4.5-14.5	14.5-24.5	24.5-34.5	34.5-44.5	44.5-54.5	54.5-64.5	>64.5	
1991	14	25	2.72	269.02	7.49	408.3	735.42	52.14	44.73	2.56	0.28	-	-	0.28	351
1990	15	25	2.32	265.88	8.64	470.8	714.58	40.43	52.16	5.56	0.62	0.31	-	0.93	324
1989	16	24	2.29	274.64	12.23	472.9	731.25	38.42	53.95	7.06	-	-	-	0.56	354
1988	17	27	2.48	268.88	7.96	420.8	675	50.93	40.68	6.83	0.93	-	-	0.62	322
1987	18	32	2.52	260.22	11.52	508.3	820.83	42.57	42.57	13.35	0.25	0.25	0.50	0.50	397
1986	19	20	2.45	280.1	10.27	447.9	810.42	45.10	41.49	12.11	0.77	-	-	0.52	388
1985	20	13	1.62	296.46	10.13	497.9	791.67	46.61	35.68	16.41	0.78	0.26	-	0.26	384
1984	21	24	2.39	273.11	12.69	472.9	756.25	35.91	33.15	29.28	1.10	-	-	0.55	362
1983	22	36	3.11	251.59	14.62	414.6	812.5	38.30	25.45	33.16	2.31	-	0.51	0.26	389
1982	23	31	3.08	253.56	18.73	416.7	829.17	49.83	34.55	13.95	1.00	0.33	-	0.33	301
1981	24	17	1.49	285.33	12.78	393.8	500	15.29	22.73	54.55	7.44	-	-	-	242
1980	25	7	0.36	300	15.03	452.1	472.92	8.33	17.54	57.89	16.23	-	-	-	228
1979	26	16	0.71	290.06	16.01	631.3	687.5	10.13	36.39	47.15	6.33	-	-	-	316
1978	27	24	2.24	279.34	15.47	518.8	800	28.01	32.20	35.86	3.93	-	-	-	382
1976	29	10	1.26	300	13.99	306.3	385.42	8.65	14.05	50.81	22.16	2.70	1.08	0.54	185
1974	31	35	4.11	234.95	13.25	152.1	635.42	49.65	20.83	14.58	11.11	1.39	1.04	1.39	288
1973	32	33	2.96	251.5	13.5	420.8	764.58	43.49	15.38	33.14	7.40	0.59	-	-	338
1972	33	40	3.63	239.77	15.85	337.5	887.5	48.02	18.41	27.27	5.13	0.23	0.47	0.47	429
1970	35	23	2.07	276.04	16.72	331.3	491.67	19.23	21.37	29.91	25.21	1.71	1.28	1.28	234
1969	36	42	4	237.56	16.28	214.6	712.5	50.00	12.99	14.97	15.25	1.13	4.24	1.41	354
1966	39	36	3.97	237.7	16.66	290.6	1159.38	61.43	14.86	13.14	8.86	1.71	-	-	350
1965	40	47	4.19	225.02	14.76	233.3	891.67	61.34	13.19	11.34	11.81	2.31	-	-	432
Hill evergreen		58	4.99	161.34	19.29	-	760.42	49.86	23.04	16.80	4.61	1.90	1.63	2.17	369

Note [1/]: Some dominant trees species were found in stands of all ages, such as: *Schima wallichii, Prismatomeristetrandra, Castanopsis diversifolia, Lannea coromandelica ,Castanopsis acuminatissima, Albizia odoratissima, Ternstroemia gymnanthera, Engelhardtia spicata, Michelia floribunda,* and *Helicia nilagirica.*

[2/]: Tree species widely distributed in 4.5-14.5 DBH classes: *Schima wallichii, Lannea coromandelica, Prismatomeris tetrandra, Catanopsis diversifolia, Chukrasia tabularis, Quercus kingiana, Engelthardtia spicata,Markhamia stipulata, Fernandoa adenophylla, Helicia vestita,* and *Diospyros glandulosa* of a climax community, as demonstrated by its high diversity of 4.99 (Table 3). This value is close to 5.19 reported by Pukjarune and Kaewaumput (1993).

Tree density was highly variable in stands from 24 years old up to 40 years old. The highest and lowest values were 1,159 trees/ha and 385 trees/ha in the 39-year-old and 29-year-old stands, respectively. After a period of 14 to 40 years, when compared to the original pine stocking of 625 trees/ha, it was found that stocking varied between 152-631 trees/ha or 24.32-100.96% of the initial planting, while the overall tree density ranged from 473-1159 trees/ha or 76-185%. The discrepancy between both tree densities reflected the addition of native trees, with a density of up to 52-85% of the initial tree planting. This implies that after the Imperata grassland had been rehabilitated by light-demanding or pioneer species like *Pinus kesiya,* the microenvironment improved until it was suitable for the other new native tree species. On the other hand, the highest IVI of 300% was found both in the 25-year-old and 29-year-old stands, while the natural forest had the lowest IVI of 161.36%. The inverse relationship between species richness and the IVI value was clearly observed as shown by a lower species number of 7 and 10, respectively. This feature is always found due to the nature of IVI values. Planted Pinus kesiya were still the dominant trees found in all aged stands, except for the natural forest. The other dominant tree species in all plots were: *Schima wallichii, Prismatomeris tetrandra, Castanopsis diversifolia, Lannea coromandelica, Castanopsis acuminatissima, Albizia odoratissima, Ternstroemia gymnanthera, Engelhardtia spicata, Elaecocarpa floribundus, Michelia floribunda* and *Helicia nilagirica* (Table 3).

The recovery of a forest ecosystem is marked by changes in microclimatic conditions that provide favorable conditions to facilitate the establishment of native tree species from nearby natural forest (Richards,1996). This describes the successional process after land rehabilitation with planted pine (*Pinus kesiya*). In Nepal, this process was reported by Gilmour *et al*., (1990), with three waves of regeneration after planting with chir pine (*Pinus roxburghii*). The first wave developed as coppice from stumps, which were remnants from the original forest. The second wave consisted of seedling regeneration, which germinated about five years after plantation establishment. The dominant species in the first and second waves was *Schima wallichii*. Within 12 years, the canopy had closed and the third wave of regeneration occurred, including a large number of species from the nearby forest.

The recovery and maturity processes were also shown by the ability of forest to regenerate. Another characteristic of mature or climax forest is its ability to maintain stability by its tree regeneration mechanism. Thus, the successional stage can also be identified by the tree age structure. Lortz *et al*., (1997) and Bender (1999) reported that the mature, climax stage showed an age structure approaching a (reverse J) distribution pattern. In this investigation, the age structure of the tree component was investigated through diameter distribution analysis. In the natural forest, the pattern approached a (reverse J) or (L-shaped) distribution, which indicates an uneven aged structure (Figure 3b). This pattern is usually found in the climax stage of mixed forest, e.g. the mixed forest at Sepunggur Jambi, Sumatra (Ketterings *et al*., 2001). The largest proportion of trees on this site was found in the smallest DBH class consisting of small trees. The species of small trees found in this site would later become the dominant species. The frequency of trees in each age class tended to reduce as the diameter class increased.

Although the diameter distribution of the 31-year-old stand was similar to the natural forest (Figure 3a), it was comprised of 63% of planted trees, while the natural forest had a diverse range of other native trees species. However, there were no clear age structure patterns for the remaining age stands. In all aged stands, most of the planted trees were found in the 14.5–24.5 and 24.5–34.5 cm DBH classes. Almost all of the native tree species were established in the 4.5-14.5 cm DBH class, including: *Schima wallichii, Lannea coromandelica, Prismatomeris tetrandra, Catanopsis diversifolia, Chukrasia tabularis, Quercus kingiana, Engelthardtia spicata, Markhamia stipulata, Fernandoa adenophylla, Helicia vestita,* and *Diospyros glandulosa* (Table 3). A few remnants of forest trees within the 34.5-44.5 cm DBH class up to the >64.5 cm DBH class were found in the stands aged 14 to 23 years, 31years, and 33 years to 36 years. There were no large trees left in the stands aged 24 years to 29 years, 32 years, and 39 years to 40 years. The remnant of forest implied the surviving trees had been there since the beginning of planting period. On the other hand, planted stands where there were no existing remnant trees indicated there had been periods of long cultivation with short fallow periods. Alternatively, there had been conversion to continuous cultivation until the crop yields had declined and then the *Imperata* grassland took over, as the area was left in search of a new forest area, in the manner of shifting cultivation practices.

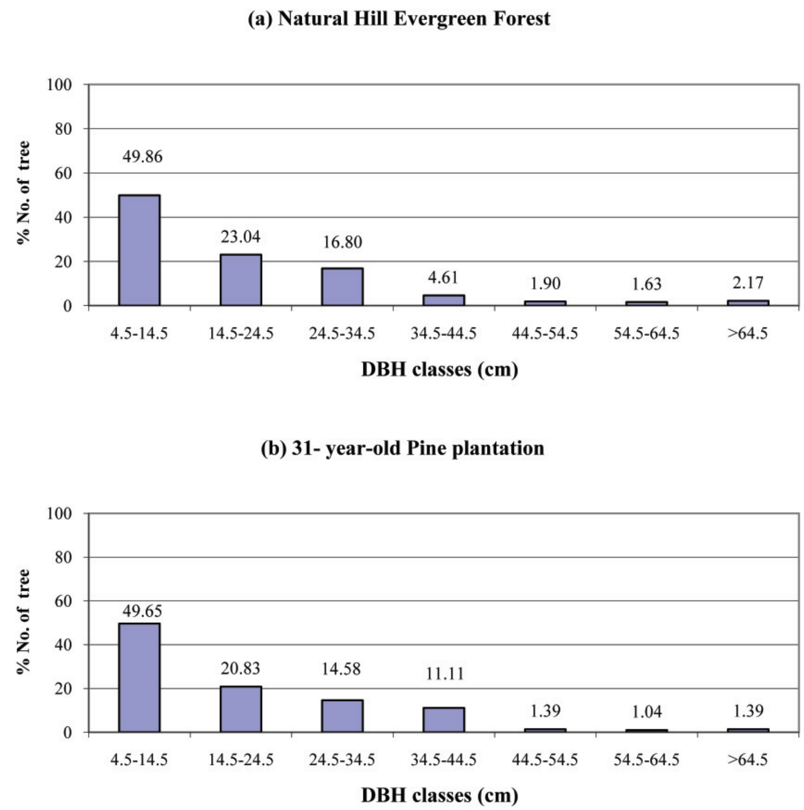

Figure 3 A “reverse J” or “L-shaped” distribution of (a) natural hill evergreen forest; and (b) 31-year-old pine plantation at Khun Khong Watershed Research Station, Chiang Mai, Thailand.

Watershed Recovery Period

Depending on the LSD method, the coefficients for the intercept and slope were obtained from the linear relationship between each tree parameter and the age of the planted stand. The derived intercept and slope of species richness, diversity index, IVI and tree density with the mean square error (MSE) are shown in Table 4. These values were used as the initial values for the trend analysis involving smoothed level (S_t) and smoothed trend (T_t) in Equations 1 and 2 earlier in the paper.

Table 4 Values for a (intercept) and b (slope) from the linear relationship between each tree parameter and planting period, used to derive the best suitable values of α_1, α_2, and ϕ using the Excel application written in Visual Basic.

Tree parameter	Linear coefficient		MSE	Best Derived Parameters			MSE
	a	b		a_1	a_2	f	
Species richness	10.94	0.62	82.72	0.4	0.01	1	109.83
Shannon-Wiener Diversity Index	1.05	0.058	0.86	0.4	0.01	1	1.11
%IVI	301.83	-1.405	388.56	0.4	0.01	1	492.32
Tree density (tree/ha)	646.75	3.27	28 605.99	0.3	0.01	1.1	31 553.92

Values of α_1, α_2, and ϕ were within ranges of 0.1-0.9; 0.01-0.19; and 0.1-1.9 respectively (Table 4). Each value set of α_1, α_2, and ϕ was used in Equations 1, 2 and 3 to forecast each non-linear parameter of the planted stands. In order to facilitate the many cycles of the 12 996 (19x19x9x4) iterations, an application in Excel using Visual Basic was formulated to reduce the heavy burden of calculation. Thus, the value set (α_1, α_2 and ϕ) with the least MSE would be regarded as the best fit for forecasting the non-linear trend for each tree parameter.

The best derived parameters of α_1, α_2, and ϕ for the non-linear trend of species richness, diversity index, and IVI were the same values of 0.4, 0.01 and 1, while tree density had values of 0.3, 0.01 and 1.1 respectively (Table 4). It was noticeable that the first three values of ϕ were equal to 1, except for tree density, where the value was 1.1. This implies that a much longer period is needed to reach the mature stage.

Figure 4 shows the non-linear parameter trends for species richness, diversity index, IVI and tree density. Their ϕ values of 1 and 1.1 (Table 4), indicate that the growth rate for each parameter is still increasing according to a linear ($\phi = 1$) or exponential ($\phi > 1$) trend. In this fashion by means of natural succession, each trend line will continue to rise up far enough into the future, until eventually declining as it reaches a plateau. Thus, 14 to 40 years after planting, even though all stands of all ages have a mixture of other native dominant tree species, still longer time is needed to reach the climax stage. On the other hand, at least the minimum requirement period to rehabilitate a forest watershed stand can be estimated from Equation 4 by a damped trend to decrease the trend line of each parameter within the given ϕ values of 0.1, 0.5, 0.8 and 0.9, respectively.

Starting from an age of 40 years, it was found that the projected trend of ϕ equal to 0.9 coincided with every trend of the tree parameters (Figure 4). The recovery period is met, whenever the forecasting of each trend line reaches a plateau at the point at which it is numerically stable or the (asymptote)point. In this manner, the asymptotic age and the value for species richness, diversity index,

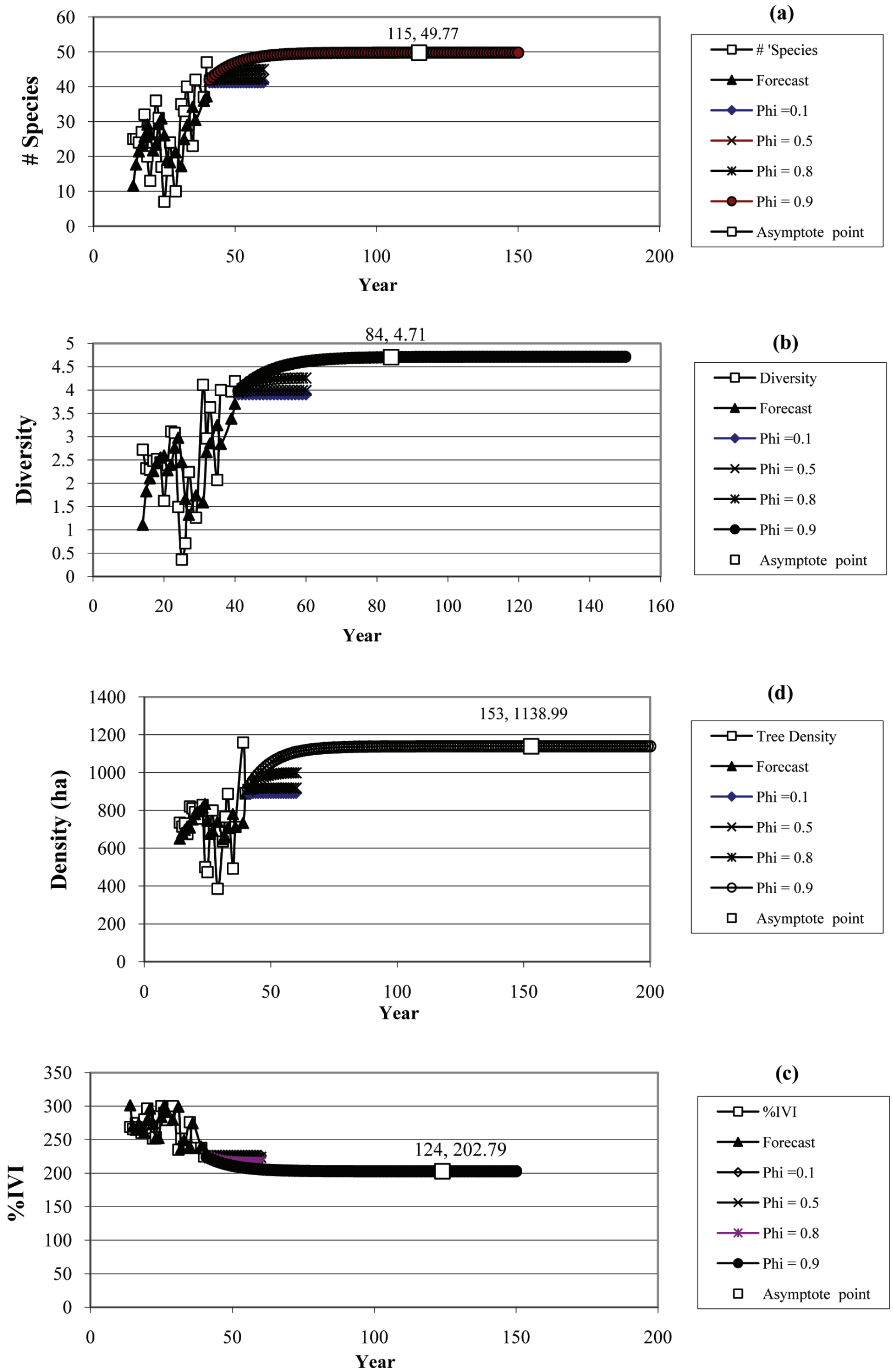

Figure 4 Estimation of natural head watershed recovery period for: (a) species richness, (b) diversity index, (c) IVI, and (d) tree density in Khun Khong Watershed Research Station, Chiang Mai, Thailand.

IVI, and tree density were: 115 years, 50 species; 84 years, 4.71; 124 years, 202.79% and 153 years, 1139 tree/ha, respectively. Compared with natural forest, these represent lower values for species richness and diversity, and higher values for IVI and tree density, These results imply there is a wide gap in the recovery period, thus a much longer period is needed to reach the climax stage.

Owing to the different nature of the aforementioned tree parameters, the estimated recovery period for watershed rehabilitation would take from 84 to 153 years. This period was shorter than in previous studies of succession in a mixed boreal forest in central Russia. In this fashion, Vladimir *et al*. (2001) have applied the Markov model and non-Markov effects to describe the course of succession through forest types after a tillage area was abandoned, leading eventually to the climax state, recognized as a polydominant spruce-broad-leaved forest. The model predicted an average period from 480 to 540 years for the ideal course of succession from the pioneer stage through to its climax stage, and less time from the later stages.

CONCLUSION AND RECOMMENDATION

In the early stage of forest watershed rehabilitation, fast-growing, native, pioneer species are needed to facilitate a better microenvironment favorable for other new, introduced, native tree species. After 40 years of rehabilitation, there was a declining trend in planted tree density, while there was an increase in the densities of other trees up to 52-85% of the initial planted stage. In all aged stands, planted trees were still the most dominant, while the other tree species had also established within a clumped distribution in class A and class B of the Raunkierû s law to form the dominant trees for future stages.

The tree parameters investigated were highly variable. The non-linear parameters tended to increase toward a future period. Thus, the recovery time for a completely rehabilitated forest watershed could be estimated to be at least about 84-153 years.

The rehabilitation of a natural watershed needs a long period that can only occur under the prolonged absence of human-induced disturbance. A challenging solution could be achieved from the collaboration of all stakeholders by taking all dimensions of a systems approach into consideration. The research findings focus only on floristic composition that could help rationalize the need for an ecologically sound recovery period. In fact, there is no standard analytical method for estimating the average time it would take to reach the mature state, but the results of nonlinear trend analysis can be seen in Figure 4. It is hoped that this technique could be applied to other reforested areas for better management of forest rehabilitation. However, further study is needed to clarify the dynamic changes of other structures that related to the services of the watershed ecosystem, such as the potential of the water yield/water budget/watershed hydrology after a period of watershed rehabilitation.

REFERENCES

Aide, T.M., and Caveller, J. 1994. Barriers to tropical lowland forest restoration in the Sierra Nevada de Santa Marta, Colombia. **Restoration Ecology.** 33 : 219-229

Aide, T.M., J.K. Zimmerman, L. Herrera, and M. Rosario. 1995. Forest recovery in abandoned tropical pasture in Puerto Rio. **Forest Ecology and Management** 77:77-86

Associated Press. 2008. Flooding in Thailand Kills 14, sicken over 53,000. Sep 21, 2008.

Bender, Jr. 1999. **Identifying Structural**

Differences in Mixed Mesophytic and Northern Hardwood Forests on the Monongahela National Forest using Remote Sensing Data. Thesis Masters of Arts in Geography The Eberly College of Arts and Sciences at West Virginia University Morgantown. West Virginia

Brown, A. and A.E. Lago. 1994. Rehabilitation of tropical lands : a key to sustaining development. **Restoration Ecology** 2 : 97-111.

Chapman, C.A. and L.J. Chapman. 1996. Exòtic tree plantations and the generation of natural forest in Kibale National Park. Uganda. **Biological. Conservation** 76 : 253-257.

Duncan, R.S. and C.A. Chapman. 1999. Seed dispersal and potential forest succession in abandoned agriculture in tropical Africa. **Ecological Applications** 9: 998-1008.

Finegan, B. 1996. Pattern and process in neotropical secondary rainforest: the 100 years of succession. **Trend in Ecology and Evolution.** 11 : 119-124

Gilmour, D.A., G.C. King, G.B. Applegate, and B. Mohns. 1990. Silviculture of plantation forests in central Nepal to maximize community benefits. **Forest Ecology and Management** 32: 173-186.

Kaosod. **2008. http://www.matichon.co.th/khaosod/view.news.php?** newsid=TUROtoFkyOHpNREk; TURrMUiR 29/9/2008

Ketterings, Q.M., R. Coe, M. Van Noorwidjik, Y. Ambagau, and C.A. Palm. 2001. Reducinguncertainty in the use of allometric biomass equations for predicting above ground tree biomass in mixed secondary forests. **Forest Ecology and Management,** 146 : 199 – 209.

Kumar, A., G. Bruce, Marcot and S. Ajai. 2006. Tree species diversity and distribution patterns in tropical forests of Garo Hills. **Current Science,** Vol. 91, No. 10, 25 November 2006.

Levin, R.I., D.S. Rubin, J.P. Stinson, and Jr.E.S. Gardner. 1992. **Quantitative Approaches to Management.** 8th ed. McGraw-Hill Inc.

Lortz, D., R. Kluender, W. Mc Coy, B. StoKes, and J. Klepac. 1997. Manual Felling Time and Productivity in Southern Pine Forest. **Forest Products Journal** 47 : 59-63.

Mackinnon, K., G. Hatta, H. Halim, and A. Mangalik. 1996. The ecology of Kalimantan. **The ecology of Indonesia** Series Vol.iii

Nepstad, D.C., C. Uhk, and E.A.S. Serrao. 1991. Recuperation of Degraded Amazonian Landscape :forest recovery and agricultural restoration. **Ambio** 20 : 248-255

Odum, B.P. 1971. **Fundamental of Ecology.** 3rd edition. W.B.Saunders : New York.

Pukjarune, W. and T. Kaewaumput. 1993. Floristic composition of Hill evergreen forest in Khun Khong watershed management unit. Watershed Group, Forest Environment and Research Development Section, Technical Forest Office, Royal Forest Department.

Richards, P.W. 1996. **The tropical rain forest.** Second Edition, Cambridge University Press, United Kingdom.

Uhl, C., R. Buschbacher, and E.A.S. Serrao. 1988. Abandoned pastures in eastern Amazonial. Patterns of plant Succession. **Journal of Ecology** 73 : 663-681

Vladimir, N.K, D.O. Logofe. and M. Loreau. 2001. Succession in mixed boreal forest of Russia Markov models and non-Markov effects. **Ecological Modeling** 142 (2001) 25-38. **www.elsevier.com/locate/ecolmodel.**