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Measures of Change in Projected Landscape Conditions

Pete Bettinger*

ABSTRACT

A new perspective on measuring the change associated with landscape conditions, when projected through forest plans, is presented. Traditionally, results of forest plans have consisted of various measures of the net amount (or change) of landscape conditions, such as suitable wildlife habitat. Numerous examples exist of how the net amount of habitat has been used as either an objective or a constraint in forest planning. Here, methods are presented to measure the transition of a landscape condition in terms familiar to those used in the modeling of the growth and yield of forests. The measures include the net change, the gross increment, and the net increment of a landscape condition, using such terms as ingrowth, mortality, and harvest (cut). The level of ingrowth, mortality, and cut relative to some current condition of the landscape, and relative to the total landscape area are also proposed as measures of interest to planners. Finally, the percent of a landscape in each category (ingrowth, mortality, and cut) during each planning period are suggested as conditions of interest to planners. Two examples, one hypothetical, and another a realistic scenario for a large watershed, are used to illustrate the measures of landscape change. This work suggests a new way for managers to evaluate, and perhaps control, projected landscape conditions by examining both the rate of change and the type of change projected to occur across a landscape when managed according to a particular forest plan.

Keywords: forest planning, harvest scheduling, landscape modeling

INTRODUCTION

State and federal land use regulations in the United States have dramatically changed the context of forest-level planning over the past 30 years, particularly on publicly-managed lands. The objectives, constraints, and measures associated with forest-level planning are becoming quite complex, as ecological and social goals have arguably become as important as economic goals to many organizations. Therefore, forest management planning efforts now often attempt to achieve multiple resource goals, and increasingly use spatial algorithms to measure landscape condition or to constrain the selection of management activities. Forest planning thus plays a significant role in decision-making today (Jørgensen, 2000). In addition to timber volumes reported by product class, and acres treated by various silvicultural methods, forest planning methods are increasingly able to provide decision-makers with estimates of projected landscape conditions. However, decision-makers, when interested in ecological aspects of forest plans, tend to focus mainly on the net change in conditions from one period of time to the next. For example, current (or projected) landscape conditions are typically reported, and may be used as constraints to control the allocation of activities across a landscape.

A number of recent examples of the integration of methods for wildlife habitat estimation and forest planning can be found in the forestry literature. For example, Arthaud and Rose (1996) integrate planning and a ruffed grouse (*Bonasa umbellus*) habitat model. Bettinger *et al.* (1997) integrate planning and a Rocky Mountain elk (*Cervus elaphus nelsoni*) model, and later a Roosevelt elk (*Cervus elaphus roosevelti*) habitat effectiveness index model (Bettinger *et al.*, 1999). Finally, Bettinger *et al.* (2003) and Sessions *et al.* (1998) both integrate planning with northern spotted owl (*Strix occidentalis caurina*) habitat models. In general, suitable habitat projected by forest plans is allowed to move around a landscape over time, and the literature describes how the total level of habitat can be controlled during forest plan development. A thorough investigation of the rate and type of transition of landscape conditions, however, has generally been avoided.

Many of these planning efforts have ignored the fact that wildlife species utilize landscape conditions at many spatial scales, and that each species has their own spatial and

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temporal population dynamics. For example, birds can react to short-term changes in habitat by quickly moving from one place to another, a reaction not as easily performed by small amphibians. In order to persist, species that cannot easily adjust to fluctuations in habitat availability must develop some resistance to the change (VIROLA *et al.*, 2001), or disperse along corridors to other available suitable habitat. The juxtaposition and relative quality of habitat will vary through time and space, due to natural disturbances or management activities, and therefore may have an impact on the immigration and dispersal of certain species. Measuring habitat quality across a landscape is a necessary first step towards modeling wildlife population dynamics, however, how landscape conditions are projected to transition through time is also implicitly important.

When considering the biological growth dynamics of individual forested stands, one might use measures of the increment, ingrowth, mortality, and harvest of individual trees to describe how stands transition through time. Beers (1962) presented a number of measures to describe the dynamics of change in ways other than simply reporting the current (or projected) status of a stand. Similar measures are presented here to describe transitions in landscape condition, with a focus on the development and maintenance of suitable wildlife habitat for a single species. The concepts of ingrowth, mortality, and harvest of trees within a stand are extended to the ingrowth, mortality, and harvest of suitable wildlife habitat. In addition to understanding the amount of suitable habitat through time, the rate of change and type of change provided by these measures of landscape conditions may be of interest to wildlife biologists or forest managers. This paper therefore focuses on the methods for measuring other types of change other than simple net change in landscape condition, using "suitable wildlife habitat" as the example landscape condition.

MEASURES OF CHANGE IN PROJECTED LANDSCAPE CONDITIONS

Landscape condition can be measured with a number of models, such as the numerous land classification systems that are available, the recreation opportunity spectrum, or the multitude of wildlife habitat suitability models that have been developed in the last two decades. The focus of this paper is on using one example of wildlife habitat suitability to illustrate measures of change in landscape condition. Wildlife habitat suitability is usually expressed as a single value between 0 (poor) and 1 (optimal) for a stand, analysis area, watershed, or landscape (U.S. FISH and WILDLIFE SERVICE, 1981). However, the point along the 0-1 scale at which land becomes suitable habitat is usually determined by researchers or practicing biologists. Decision-makers and managers have generally either been interested in the amount of suitable habitat projected through time, the periodic net change, or the periodic percent change. It is proposed here that the rate and type of transition of habitat are also important and should be considered.

If one were to classify a landscape into two broad classes (suitable and unsuitable wildlife habitat), the change in suitable habitat between two periods of time ($\Delta SH_{t \rightarrow t+1}$) can be expressed simply as:

$$\Delta SH_{t \rightarrow t+1} = SH_{t+1} - SH_t \qquad \forall t; t = 1,2,\ldots T-1 \qquad [1]$$

Where:
t = a time period
T = the total number of time periods
SH_t = amount of suitable habitat available during time period t

Measures of increment used to describe changes in forest inventories can also be applied to projected characteristics of landscape conditions (e.g., suitable wildlife habitat) from forest plans, to enable one to more thoroughly measure the rate and type of transition through time. Several terms are that are commonly used to describe forest growth and yield estimates (i.e., ingrowth, morality, and harvest) are extended to describe landscape transition. Ingrowth, for example, typically refers to the number or volume of new trees growing into the smallest trees size class measured between two measurement periods. When extended to describe landscape transition, ingrowth may refer to the movement of land from an unsuitable habitat class to a suitable habitat class between two time periods in a planning horizon. Mortality generally refers to the number or volume of measurable trees that have died between two measurement periods. When extended to describe landscape transition, mortality may refer to the movement of land out of a suitable habitat class to an unsuitable habitat class between two time periods. It is proposed here that mortality of habitat may occur either as an indirect result of management activity or due to natural causes. Finally, harvest (cut) generally refers to the number or volume of trees removed through management activity between two measurement periods. When extended to describe landscape transition, one might consider cut to be the movement of land from a suitable habitat class to an unsuitable habitat class between two time periods, as a direct result of management activity. Symbolically, one can represent these three components as:

$I_{t \rightarrow t+1}$ = area of land moving into a suitable habitat class from an unsuitable habitat class between measurement periods t and $t+1$

$M_{t \rightarrow t+1}$ = area of land naturally moving out of a suitable habitat class from a suitable habitat class between measurement periods t and $t+1$ either as an indirect result of management activity or due to natural causes

$C_{t \rightarrow t+1}$ = area of land moving out of a suitable habitat class from a suitable habitat class between measurement periods t and $t+1$ due to management activity

To express potential landscape transition of SH_t as a series of mathematical equations, assume that SH_t represents the level (area) of suitable habitat at the beginning of a planning period, SH_{t+1} represents the level of suitable habitat at the end of a planning period, and assume some time period length (e.g., one year, five years, a decade). SH_{t+1} includes additions of $I_{t\rightarrow t+1}$ to SH_t, and deletions of $M_{t\rightarrow t+1}$ and $C_{t\rightarrow t+1}$.

$$SH_{t+1} = SH_t + I_{t\rightarrow t+1} - M_{t\rightarrow t+1} - C_{t\rightarrow t+1} \qquad [2]$$

Substituting SH_{t+1} into equation 1, we can now express the change in suitable habitat between two planning periods as,

$$\Delta SH_{t\rightarrow t+1} = SH_t + I_{t\rightarrow t+1} - M_{t\rightarrow t+1} - C_{t\rightarrow t+1} - SH_t \qquad [3]$$

Equation 3 then reduces to:

$$\Delta SH_{t\rightarrow t+1} = I_{t\rightarrow t+1} - M_{t\rightarrow t+1} - C_{t\rightarrow t+1} \qquad [4]$$

What is different here from that presented by Beers (1962) is that there is no increment (growth) of suitable habitat in one stand from one time period to the next. When describing the dynamics of change in a timber stand, a growth term (G) is used to illustrate the fact that individual trees get larger with time. This is the increment of the trees. However, the size of a stand of suitable habitat fails to grow in size; it simply remains "suitable," and the size (area) remains the same. So the increment (change) in habitat between two periods of time reduces to ingrowth of habitat minus mortality and cut of habitat. The gross increment of suitable habitat, including ingrowth, can be expressed as:

$$\textit{Gross increment of } SH_t \textit{ including ingrowth} = SH_{t+1} + M_{t\rightarrow t+1} + C_{t\rightarrow t+1} - SH_t \qquad [5]$$

And the net increment of SH_t, including ingrowth, can be expressed as:

$$\textit{Net increment of } SH_t \textit{ including ingrowth} = SH_{t+1} + C_{t\rightarrow t+1} - SH_t \qquad [6]$$

If one were interested in simply understanding how the initial area of suitable habitat (SH_0) changes through time, one would calculate the gross increment of SH_0 which implies estimating how much SH_0 remains in each subsequent time period, since SH_0 does not grow on its own from one time period to the next. This problem is slightly more complex than measuring the change in SH_t from one period to the next, as one needs to identify the suitable habitat areas that exist at the beginning of the forest plan and track how they are lost with each successive time period projection.

$$SH_{0t} = SH_{0t-1} - M_{0t\rightarrow t+1} - C_{0t\rightarrow t+1} \qquad \forall t; t = 1,2,\ldots T \qquad [7]$$

Where:

$M_{0t\rightarrow t+1}$ = area of land that was identified as suitable habitat at the beginning of the forest plan, and naturally moves out of the suitable habitat class between measurement periods *t* and *t+1*, either as an indirect result of management activity or due to natural causes

$C_{0t\rightarrow t+1}$ = area of land that was identified as suitable habitat at the beginning of the forest plan, and moves out of the suitable habitat class between measurement periods *t* and *t+1* due to management activity

Ingrowth of suitable habitat is not considered here, because we are solely interested how the area of land classified as suitable habitat at the onset of a forest plan changes, thus the changes in SH_{0t} will only be a function of mortality or cut. From another perspective, one can measure the increment of areas deemed suitable habitat at the beginning of each time period, thus ignoring ingrowth. The gross increment of the SH_t, ignoring ingrowth, at the beginning of a time period can be expressed as:

$$\textit{Gross increment of } SH_t \textit{ ignoring ingrowth} = SH_{t+1} + M_{t\rightarrow t+1} + C_{t\rightarrow t+1} - I_{t\rightarrow t+1} - SH_t \qquad [8]$$

And the net increment of SH_t at the beginning of a time period, ignoring ingrowth, can be expressed as:

$$\textit{Net increment of } SH_t \textit{ ignoring ingrowth} = SH_{t+1} + C_{t\rightarrow t+1} - I_{t\rightarrow t+1} - SH_t \qquad [9]$$

If one were interested in a thorough examination of the level of mortality, ingrowth, and harvest of suitable habitat from one time period to the next, one would express these changes perhaps as being relative to the SH_t levels at the beginning of the measurement period (for mortality and cut), at the end of a measurement period (for ingrowth), or as a percentage of the total landscape area. For example, mortality of SH_t during the period of time from *t* to *t+1* can be expressed as either the percentage of the land area that was considered suitable habitat at the beginning of the measurement period, or as a percentage of the landscape.

$$\textit{mortality as a percentage of } SH_t = \left[\frac{M_{t\rightarrow t+1}}{SH_t}\right]100 \qquad [10]$$

$$\textit{mortality as a percentage of the landscape} = \left[\frac{M_{t\rightarrow t+1}}{LS}\right]100 \qquad [11]$$

where:

LS = total area of the landscape

The harvest (cut) of SH_t during the period of time from *t* to *t+1* can also be expressed as either the percentage of the land area that was considered SH_t at the beginning of the measurement period, or as a percentage of the landscape.

$$cut\ as\ a\ percentage\ of\ SH_t = \left[\frac{C_{t\rightarrow t+1}}{SH_t}\right]100 \quad [12]$$

$$cut\ as\ a\ percentage\ of\ the\ landscape = \left[\frac{C_{t\rightarrow t+1}}{LS}\right]100 \quad [13]$$

Finally, ingrowth of SH_t during the period of time between t and $t+1$ may be best expressed as a percentage of SH_{t+1} rather than SH_t, and can also be expressed as a percentage of the landscape area.

$$ingrowth\ as\ a\ percentage\ of\ SH_{t+1} = \left[\frac{I_{t\rightarrow t+1}}{SH_{t+1}}\right]100 \quad [14]$$

$$ingrowth\ as\ a\ percentage\ of\ the\ landscape = \left[\frac{I_{t\rightarrow t+1}}{LS}\right]100 \quad [15]$$

HYPOTHETICAL EXAMPLE USE OF MEASURES OF CHANGE IN PROJECTED LANDSCAPE CONDITIONS

To illustrate the measures of change when applied to projected landscape conditions, consider a hypothetical 1,000 ha forest where the initial area of land considered to be suitable habitat (prior to implementing a forest plan) is 250ha (Table 1). With each decade comes planned activities, yet the area of suitable habitat in this hypothetical example is projected to increase to 730ha by the fifth decade. The change in suitable habitat ($\Delta SH_{t\rightarrow t+1}$) is simply the projected difference in suitable habitat from one decade to the next. This change is brought about by ingrowth of forested areas into the suitable habitat class, removal (mortality) of forested area from the suitable habitat class, and harvest (cut) of some of the suitable habitat areas. For example, between the initiation of the forest plan and the end of the first decade (or whichever point, for planning purposes, a decade's worth of activities are assumed to occur) 100ha will grow into suitable habitat, but 20ha will fall out, and 30ha will be cut, resulting in a net change of 50ha. In this hypothetical example, the mortality of suitable habitat ranges from about 3 to 8% of SH_t per decade, or about 1.5 to 4% of the landscape. The harvest of suitable habitat ranges from 5 to 12% of SH_t per decade, or 2 to 5% of the landscape (Table 2). Finally, the percent ingrowth of suitable habitat ranges from about 27 to 33% of SH_{t+1}, or 10 to 20% of the landscape.

The gross increment of SH_t, including ingrowth, at the end of each time period t (using eq. 5) actually reduces to ingrowth, thus is not especially of value. For example, the gross increment of SH_t, including ingrowth, between time periods 1 and 2 is 125ha (375ha + 25ha + 25ha - 300ha). The net increment of SH_t, including ingrowth, at the end of each time period t (using eq. 6) is also of limited value. For example, between time periods 1 and 2, the net increment is

Table 1 Hypothetical data describing land classified as suitable habitat, ingrowth into the suitable habitat class, and mortality and harvest from the suitable habitat class

Decade (t)	SH_t (ha)	$\Delta SH_{t\rightarrow t+1}$ (ha)	$I_{t\rightarrow t+1}$ (ha)	$M_{t\rightarrow t+1}$ (ha)	$C_{t\rightarrow t+1}$ (ha)
0 (initial)	250				
		50	100	20	30
1	300				
		75	125	25	25
2	375				
		105	140	15	20
3	480				
		110	200	40	50
4	590				
		140	200	20	40
5	730				

Table 2 Dynamics of mortality, cut, and ingrowth of land classified as suitable habitat in a hypothetical landscape

Decade (t)	$M_{t\rightarrow t+1}$ of SH_t (%)	$M_{t\rightarrow t+1}$ of LS (%)	$C_{t\rightarrow t+1}$ of SH_t (%)	$C_{t\rightarrow t+1}$ of LS (%)	$I_{t\rightarrow t+1}$ in SH_{t+1} (%)	$I_{t\rightarrow t+1}$ of LS (%)
1	8.00	2.00	12.00	3.00	33.33	10.00
2	8.33	2.50	8.33	2.50	33.33	12.50
3	4.00	1.50	5.33	2.00	29.17	14.00
4	8.33	4.00	10.42	5.00	33.90	20.00
5	3.39	2.00	6.78	4.00	26.67	20.00

LS = Landscape

100ha (375ha + 25ha - 300ha). The net increment may provide insight into how much habitat is actually being produced prior to harvest, however levels of SH_t are influenced by losses due to mortality, which may be influenced by nearby harvests. Therefore, the net increment does not necessarily indicate how much habitat is being produced prior to harvest if the landscape condition model being used includes spatial algorithms that could cause nearby, pre-harvest, suitable habitat areas to be counted as mortality.

The area of SH_0 also changes with each passing decade (Table 3) due to mortality and cut processes. Ingrowth of new habitat is not considered here, only the loss of original (pre-plan) habitat. One finds the change of SH_{0t} is -50ha between the start of the plan and the end of the first decade. After this point, the change of SH_{0t} is less clear, and requires additional information to determine. For example, one needs to understand, from Table 1, whether mortality (25ha) and cut (25ha) between the end of the first and the end of the second

Table 3 Hypothetical data describing land classified as initial (pre-plan) suitable habitat, and mortality and harvest from the initial suitable habitat class

Decade (t)	SH_{0t} (ha)	$\Delta SH_{0t\rightarrow t+1}$ (ha)	$M_{0t\rightarrow t+1}$ (ha)	$C_{0t\rightarrow t+1}$ (ha)
0 (initial)	250			
		-50	20	30
1	200			
		-40	20	20
2	160			
		-30	10	20
3	130			
		-70	40	30
4	60			
		-50	20	30
5	10			

decades arises from SH_{0t} areas or arises from ingrowth that occurred during the first decade (100ha).

The gross increment of SH_t at the beginning of a time period, ignoring ingrowth (using eq. 8) always reduces to a value of 0. For example, between time periods 1 and 2, the gross increment ignoring ingrowth is 375ha + 25ha + 25ha - 125ha - 300ha, or 0ha. This equation simply represents the balance of landscape transition from one period of time to another, since the level of SH_t at the beginning of a time period does not "grow" through time on its own, like individual trees may grow from one period of time to another. The net increment of SH_t at the beginning of a time period, ignoring ingrowth (using eq. 9) reduces to the amount of mortality of habitat between two time periods. For example, between time periods 1 and 2, the net increment is -25ha (375ha + 25ha - 125ha - 300ha). Therefore, the measures of gross and net increment of SH_t at the beginning of a time period, ignoring ingrowth, are also of limited value when examining the rate and type of change in landscape conditions.

CASE STUDY EXAMPLE FOR A MANAGEMENT SCENARIO OF AN ACTUAL WATERSHED

Using the scheduling model and planning problem described in BETTINGER and DRAKE (2005), we now apply the measures of change in landscape conditions to a forest planning scenario that was developed for a 49,000ha watershed in western Oregon. The study area is comprised of a mixture of ownerships, however the majority of the area is controlled by several forest industry companies as well as the State of Oregon. The dominant tree species grown in this area are Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), although hardwoods (mainly red alder [*Alnus rubra*]) are common in the riparian areas. The average

Table 4 Data describing land classified as suitable habitat, ingrowth into the suitable (high quality) habitat class, and mortality and harvest from the suitable habitat class for a 49,000ha watershed in western Oregon

5-year period (t)	SH_t (ha)	$\Delta SH_{t\rightarrow t+1}$ (ha)	$I_{t\rightarrow t+1}$ (ha)	$M_{t\rightarrow t+1}$ (ha)	$C_{t\rightarrow t+1}$ (ha)
0 (initial)	52.8				
		-1.7	12.2	13.9	0.0
1	51.1				
		13.6	34.7	21.0	0.1
2	64.7				
		38.9	55.9	17.0	0.0
3	103.6				
		61.9	65.7	3.8	0.0
4	165.5				
		13.1	34.8	21.7	0.0
5	178.6				
		117.4	124.6	7.2	0.0
6	296.0				
		268.8	323.8	55.0	0.0
7	564.8				
		344.7	418.8	74.1	0.0
8	909.5				

rotation age for conifer species in this area is about 45-50 years, and the dominant management action prescribed is clearcutting.

In this case study, the objective was to develop a plan that maximized even-flow of timber harvest volume from the watershed, while measuring the habitat capability index described in MCCOMB *et al.* (2002) for the northern spotted owl. Northern spotted owl nests are generally found in clumps of larger conifers (≥ 75cm) with a high level of canopy heterogeneity, and in areas with sufficient landscape heterogeneity to provide adequate foraging and roosting habitat (MCCOMB *et al.*, 2002). The current rate of ingrowth, mortality, and cut of suitable habitat in the watershed is uncertain, since a historical analysis was not performed. However, the current level of suitable habitat is 0.1% of the watershed (about 53ha). If one used the measures of change projected over the first 5 years of the plan (Table 4) as an estimate of the current rates of habitat change, one would infer that ingrowth (12ha) and mortality (14ha) were relatively even, and harvest of suitable habitat was negligible.

Suitable habitat was calculated for the study area using a raster vegetation GIS database that has associated with it a tree list for every pixel. The database was created using a gradient nearest neighbor approach to classification that facilitated the association between the grid cells and the tree lists (OHMANN and GREGORY, 1999). A tree list is simply a list of trees used to represent the forested conditions within each pixel, and they were derived from the U.S. Forest Service's Forest Inventory and Analysis program, the U.S. Forest Service's Continuous Vegetation Survey program, and research plots. More detailed information regarding the classification approach and assignment of tree lists to pixels in the GIS database can be found in OHMANN and GREGORY (1999). A second GIS database that represented management units was overlaid on the vegetation database to assist in determining the HCI. Using the tree lists assigned to each pixel, the variables required for the HCI computations were developed for each pixel in each time period in the planning horizon, then aggregated up to the management unit level to arrive at a single HCI value for each unit. Since the management units were assigned scheduled activities, HCI was calculated at this scale. Subsequent summaries involve computing the area of management units whose HCI values are above 0.37, which MCCOMB *et al.* (2002) suggest is the value above which suitable (high quality) habitat is obtained.

Again, the only activities allowed in the plan for the 49,000 ha watershed were clearcuts, and the planning horizon was 40 years, divided into eight 5-year planning periods. A heuristic planning technique, threshold accepting, was used to develop the plan. In the scenario modeled, clearcut sizes were limited to 24.3ha (60ac), with a 5-year green-up imposed on adjacent clearcut blocks.

The amount of suitable habitat ($\Delta SH_{t \rightarrow t+1}$), which is brought about by ingrowth of forested areas into the suitable habitat class, removal (mortality) of forested area from the suitable habitat class, and harvest (cut) of some of the suitable habitat areas, is relatively low (Table 4), but not unexpected, since only about 5% of this region is currently considered suitable (high quality) habitat (MCCOMB *et al.*, 2002). Over time, under the scenario that was modeled for the watershed, suitable habitat increases considerably, but only to about 2% of the watershed. And there is a delay in the increase due to the harvesting that occurs in the first two time periods. As a result, the mortality of suitable habitat is not offset much by the ingrowth of suitable habitat. The mortality of suitable habitat, in fact, ranges from about 30% of SH_t per time period in the first two time periods, to about 10% in the final two time periods (Table 5). As a percentage of the landscape, the morality of SH_t is quite low, however, but since it is in short supply, it may be a concern to planners. The harvest of suitable habitat in the watershed is almost non-existent, and the percent ingrowth of suitable habitat ranges from about 20 to 57% of SH_{t+1}, or 0.02 to almost 1% of the landscape.

The area of SH_0 also declines during the first two time periods (Table 6) mainly due to mortality processes (areas harvested near suitable habitat force some areas of suitable habitat to become unsuitable). What might be further controlled in a forest plan is the net change in suitable habitat (perhaps keeping it above 0 in Table 4), the amount of mortality as a percentage of the suitable habitat or landscape (Table 5), or the rate of decrease in initial suitable habitat as a result of management activities (Table 6). The analysis provided in Table 4-6 is more revealing than the maps describing habitat values through time (Fig. 1-8) might suggest.

Table 5 Dynamics of mortality, cut, and ingrowth of land classified as suitable (high quality) habitat in a 49,000 ha landscape in western Oregon

5-year period (t)	$M_{t \rightarrow t+1}$ of SH_t (%)	$M_{t \rightarrow t+1}$ of LS (%)	$C_{t \rightarrow t+1}$ of SH_t (%)	$C_{t \rightarrow t+1}$ of LS (%)	$I_{t \rightarrow t+1}$ in SH_{t+1} (%)	$I_{t \rightarrow t+1}$ of LS (%)
1	27.20	0.03	0.00	0.00	23.87	0.02
2	32.46	0.04	0.15	0.00	53.63	0.07
3	16.41	0.03	0.00	0.00	53.96	0.11
4	2.30	0.01	0.00	0.00	39.70	0.13
5	12.15	0.04	0.00	0.00	19.48	0.07
6	2.43	0.01	0.00	0.00	42.09	0.25
7	9.74	0.11	0.00	0.00	57.33	0.66
8	8.15	0.15	0.00	0.00	46.05	0.85

Table 6 Data describing land classified as initial (pre-plan) suitable (high quality) habitat, and mortality and harvest from the initial suitable habitat class for a 49,000ha watershed in western Oregon

5-year period (t)	SH_{0t} (ha)	$\Delta SH_{0t \rightarrow t+1}$ (ha)	$M_{0t \rightarrow t+1}$ (ha)	$C_{0t \rightarrow t+1}$ (ha)
0 (initial)	52.76			
		13.88	13.88	0.00
1	38.88			
		12.94	12.88	0.06
2	25.94			
		0.00	0.00	0.00
3	25.94			
		0.00	0.00	0.00
4	25.94			
		0.00	0.00	0.00
5	25.94			
		0.00	0.00	0.00
6	25.94			
		0.00	0.00	0.00
7	25.94			
		3.31	3.31	0.00
8	22.63			

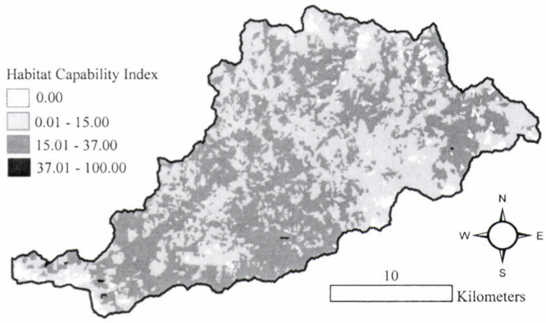

Fig. 1 Spatial distribution of habitat capability indices for the spotted owl in a 49,000ha watershed in western Oregon, time period 1

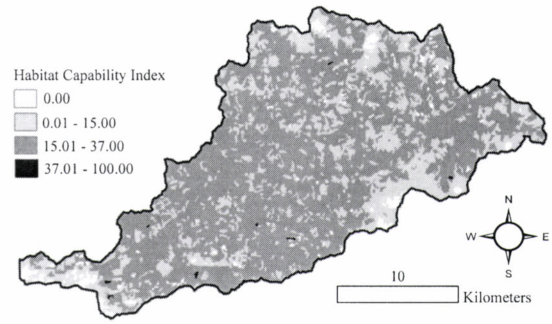

Fig. 2 Spatial distribution of habitat capability indices for the spotted owl in a 49,000ha watershed in western Oregon, time period 2

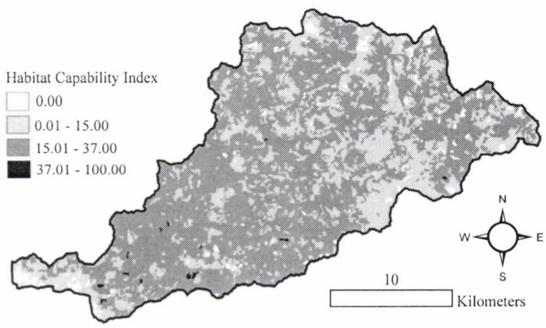

Fig. 3 Spatial distribution of habitat capability indices for the spotted owl in a 49,000ha watershed in western Oregon, time period 3

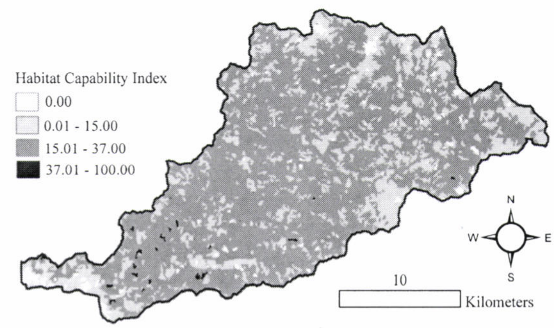

Fig. 4 Spatial distribution of habitat capability indices for the spotted owl in a 49,000ha watershed in western Oregon, time period 4

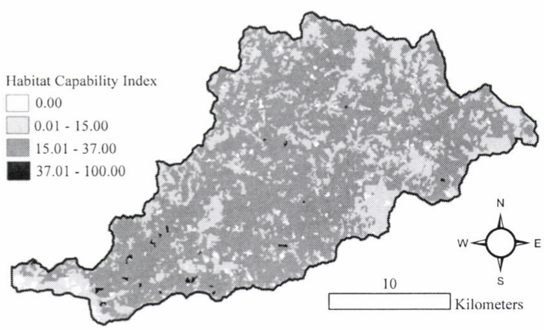

Fig. 5 Spatial distribution of habitat capability indices for the spotted owl in a 49,000ha watershed in western Oregon, time period 5

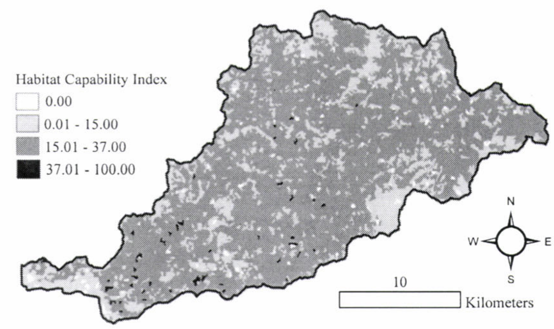

Fig. 6 Spatial distribution of habitat capability indices for the spotted owl in a 49,000ha watershed in western Oregon, time period 6

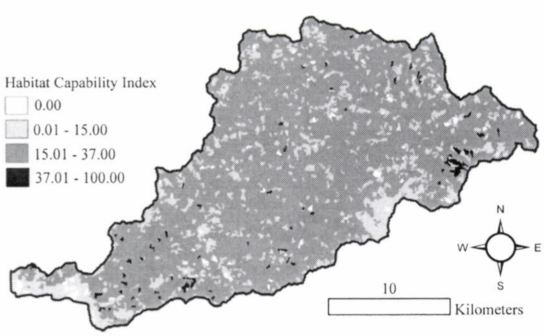

Fig. 7 Spatial distribution of habitat capability indices for the spotted owl in a 49,000ha watershed in western Oregon, time period 7

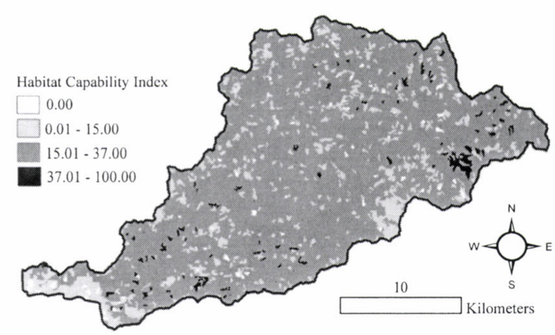

Fig. 8 Spatial distribution of habitat capability indices for the spotted owl in a 49,000ha watershed in western Oregon, time period 8

DISCUSSION

Models that facilitate the estimation of landscape conditions range in complexity from those that utilize simple linear relationships (e.g., early habitat suitability index models) to those containing spatial and non-linear relationships (e.g. McComb *et al.*, 2002). How these models are integrated within forest planning processes (i.e., used to develop coefficients related to decision variables, used to measure habitat suitability simultaneous with decision choices, or used as a posterior evaluation of a forest plan) is problematic to the issue at hand: the change in habitat characteristics over time can be determined using the concepts of ingrowth, mortality, and harvest (cut). These concepts are viable whether one uses integer or continuous decision variables, since the amount of area moving into or out of a landscape condition is known. Measures of landscape transition can also be examined in association with other natural resource models (e.g. recreation opportunity spectrum, land classification) whose determination is also influenced by land management decisions. The relationships provided by Beers (1962) are of limited value when examining the rate and type of transition of landscape conditions, however, presented here are other methods to facilitate an understanding of the transition of a landscape condition (suitable habitat) through time. Theoretically, these measures can be controlled in forest landscape planning or harvest scheduling efforts.

Wildlife habitat models evolve as new theories regarding the use of the landscape by various species are presented, the appropriate data are collected, and species-habitat relationships modeled. Many of the more recently developed models contain complex, spatial, non-linear relationships, making the integration of these models with forest planning difficult, if not impossible, depending on the forest planning model used. In the past, the integration of wildlife models with forest planning efforts concentrated on simplistic analyses of changes in "habitat" through time. Based on practical experience, the author has noted that biologists also contemplate how the characteristics of habitat change over time, and whether these changes (rate or type) in landscape condition are acceptable.

The uncertainty associated with landscape (habitat) assessment models has been avoided in this conversation, although it may be a fairly important consideration if decisions are based on the landscape condition values. The examples presented here assumed a strict threshold above which one has obtained "suitable habitat" and below which one has "unsuitable habitat." The interpretation of the threshold is therefore unyielding: land is either suitable or unsuitable habitat. In practice, a number of areas of land may have landscape condition values slightly above or below suitable habitat thresholds. Thus the inherent uncertainty in forest structure projections and in geographic descriptions of the landscape suggest a fuzzy threshold might be considered. Further, one might be interested in statistical measures of variability associated with estimates of habitat classification values. These areas of insight are left for others to pursue.

Diamond and May (1977) suggest that to examine the effect of habitat on the turnover of species in a landscape, one needs to use a temporal scale appropriate for each species, which for birds they recommend one year intervals. The dispersal characteristics of different wildlife species may influence their population size and presence in recently developed suitable habitat areas, as may the availability, distribution, and size of suitable habitat and the number of other species competing for the habitat (Merriam *et al.*, 1991). The timing of reproduction and dispersal of species and the timing of the availability and quality of habitat are therefore important. Since forest planning efforts generally utilize a single time step (1, 2, 5, 10 years) to describe the collection of activities and associated effects, the influence of habitat changes on wildlife species presence within a landscape may be masked. Biologists are called upon to help managers understand how species might match their life cycle dynamics to the fluctuations of resources they require for survival, and a key issue for managers and planners alike is to understand the spatio-temporal distribution of resources that are available for a species survival.

What was not modeled here is the spatial aspect of changes in landscape condition. We have suggested ways to measure how suitable habitat may change over time, but where these changes specifically occur, how quickly they occur, and what landscape pattern results, may also be of concern to different species of wildlife. The spatial change in suitable habitat may not be gradual, as some suitable habitat is developed through ingrowth, and some is lost through mortality and harvest. The spatio-temporal shift in suitable habitat may suggest that some local (e.g., watershed-level) measure of pattern might need to be measured and controlled. For example, the geographic center of all suitable habitat in a watershed could be computed and controlled during forest plan development, only allowing it (the geographic center of all suitable habitat) to drift a certain distance over a certain period of time.

Tracking the transitions in landscape condition through time allows one to evaluate the risks associated with changes in land use at a landscape scale. Modeling landscape dynamics can be incorporated into forest planning efforts, if it is assumed that the rate and type of change are important. However, controlling the transition is more easily made through control of the cut of suitable habitat, rather than through control of the mortality and ingrowth of suitable habitat, as these latter two may be influenced by the rate of growth (or mortality) of structural conditions across the landscape. The equations presented here, however, can be formulated as constraints in linear programming, integer programming, heuristic, or simulation models.

CONCLUSION

Forest plans and subsequent analyses generally report the net change in suitable habitat for various wildlife species over time, and across broad landscapes. Managers, biologists, and others may be interested in further understanding the rate and type of change in landscape conditions, according to the direction provided by forest plans. A number of landscape transition equations were presented to enable one to evaluate both the rate of change, and the type of contribution (or loss) of habitat through processes (ingrowth, mortality, and cut) that are familiar to those who utilize or develop forest growth and yield models. The integration of wildlife habitat models (or other landscape condition models) with forest planning models continues to evolve as both types of models evolve. However, a habitat evaluation that requires spatial or non-linear relationships to be recognized may be difficult to integrate with forest planning models, forcing a compromise or advancement in one or the other model. Some uncertainty in landscape condition (e.g., habitat) estimates should be expected, and may temper the assessment of landscape dynamics. Given recent advances in forest planning techniques, computer systems, and geographic information systems, future assessments of forest plans may be able to accommodate a more detailed examination of landscape condition transition, in addition to assessments of the net change in landscape condition, the volumes to be expected, and acres to be treated with various silvicultural methods.

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Article

Topographic Correction Effect on Sugi (*Cryptomeria japonica* D.Don) Stand Volume Estimation using Multi Temporal Landsat TM and ASTER Satellite Images in Mountainous Tsugawa Region, Niigata Prefecture

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ABSTRACT

Five images of Landsat Thematic Mapper (TM) and one image of ASTER data at different years were taken to determine the topographic correction effects in the mountainous area in Tsugawa region, Niigata. *An automatic scattergram-controlled regression* approach was applied for radiometric normalization correction using sequence images obtained using the Landsat TM. The forest was classified as either a deciduous, low-middle volume sugi or high volume sugi forest based on its characteristics and volume by separability analysis. We examined four topographic correction methods to reduce the slope-aspect effect in each forest class compared. In order to elucidate the effect of the applied correction method, we also analyzed the correlation between the digital number and ground measurement. The results showed that the specific forest class type should be considered as input when applying a topographic correction method in satellite images analysis. The *two-stage topographic normalization* proposed by Civco (1989) and *statistic-empirical* methods appeared to be the best for statistical analyses but were unsuccessful regarding actual correlation for analysis of sugi stand volume. The results indicated that, the *C-correction* for visible bands and Minnaert correction methods for infrared band are adequate methods for improving the correlation accuracy between derived digital number and sugi stand volume in the Tsugawa region.

Keywords: topographic correction; Landsat TM/ASTER satellite images; sugi

INTRODUCTION

Covered with many mountains, almost all regions in Japan have a steep mountainous terrain and consequently the slope and aspect cause a different illumination condition for evaluating forest cover and has proved to be difficult for image processing analysis. For more than 25 years, topographic effects have been major problems in image processing but have remained unsolved satisfactory. To correct the remotely sensed image due to the illumination effect, many authors have proposed various methods: those based on band ratios and those requiring the digital elevation model (DEM). The former is simple but rarely used due to lack of changes in each spectral band for diffuse irradiance, whereas the latter (using DEM) has proved useful to minimize effectively the topographic effect.

The first result achieved on topographic correction was a simple normalization based on cosine law. In this approach, the surface is assumed to have Lambertian behavior, but resulting in over-correction especially in weak illuminated regions due to disproportional brightening effect (Civco, 1989; Colby, 1991; Meyer *et al.*, 1993). Several published algorithms have been demonstrated useful for correcting the topographic effect based on the non-Lambertian method such as: Minnaert correction (Smith *et al.* 1980; Colby 1991; Ekstrand 1996), Running Minnaert correction (Ekstrand, 1996), C-correction (Teillet *et al.*, 1982; Meyer *et al.*, 1993), modified C-correction (Riano *et al.*, 2003), using digital terrain models (Conese *et al*, 1993) and models for high spatial resolution imagery (Richter, 1997). Other methods such as the two-stage topographic normalization proposed by Civco (1989) and statistical-empirical method (Teillet *et al.*, 1982; Meyer *et al.*, 1993) also proved to be appropriate methods for reducing the topographic effect based on slope-aspect correction. Moreo-

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ver, for topographic correction on forest images, GU and GILLESPIE (1998) developed a Sun-Canopy-Sensor (SCS) terrain correction model based on the interaction between solar radiation and forest canopy elements. It is necessary to examine the utility of topographic correction methods among many scientific literatures.

Much of regions in Niigata Prefecture contain high topographic relief where sugi as main forest grows. SMITH *et al* (1980) suggested that topographic correction method is inherent to a land cover type. TEILLET *et al* (1982) found that slope-aspect correction in forestry applications must be class-specific and that no correction formula is general enough to accommodate the various forest types by itself, meanwhile HOLBEN and JUSTICE (1980) and LEPRIEUR *et al* (1988) showed that different types of vegetation respond differently. The effect of topography on sugi forest remains unknowable due to the lack on illumination correction information of sugi stand in image analysis especially for estimating its volume. Therefore, the topographic correction effect need to examine for sugi stand in order to achieve better understanding on its implementation and higher accuracy in sugi stand volume estimation.

The objectives of this study were to: (a) examine existing topographic correction methods and suggest the best correction method for topographic correction in mountainous region particularly for sugi forest using Landsat TM and ASTER images; and (b) evaluate of applying topographic correction methods to the accuracy of image analysis in estimating sugi stand volume.

MATERIAL AND METHODS

The study area site is located in the Tsugawa region, Niigata Prefecture, covering approximately 43,200 ha (Latitude 37°38'50" - 37°44'35" N; Longitude 139°26'13" - 139°36'05" E). Tsugawa is covered by forests with a secondary forest consisting of sugi (*Cryptomeria japonica*); as the main coniferous plantation trees and deciduous broad-leaved trees species, such as Buna (*Fagus crenata*) Mizunara oak (*Quercus crispula* Blume), Konara-oak (*Quercus serrata*), Maple species, and Wingnut (*Pterocarya rhoifolia*). The study area in the Tsugawa region is a hilly and mountainous area with elevation ranging from 41 to 1,031m.

Primary image data sets used in this study were obtained from Landsat-5 Thematic Mapper data imagery in the summer season (June) due to its clear and abundant information for reflecting land cover characteristics to image. The 800-lines by 600-columns (432km^2) sub-scene of the Tsugawa region derived from 5-sequence scene images of year 1986, 1989, 1997, 1999 and 2001 of Landsat TM and the 1600-lines by 1200-columns pixels of ASTER image. Digital Elevation Model (DEM) was derived from a 50-meter grid elevation scale made by the Japan Geographical Survey Institute geometrically matched the Landsat TM pixel size (30m) and ASTER image pixel size (15m) for geometric registration. ERDAS IMAGINE version 8.7 was used for image processing. The geometric correction was performed by selecting more than 45 ground control points for each image in the sub-scene image with a root-mean square error (RMSE) of less than 0.5 pixel in the transverse mercator coordinate system.

From ground field measurements, about 50 plots were investigated from 2001 to 2003, based on the Niigata Prefecture Forestry Division. In approximately 0.03 - 0.04 ha per plot (generally used 20 × 20 m), we measured tree diameter at breast height (DBH) and tree height on every plot taken. Radiometric normalization correction was applied to Landsat TM sequence images based on the *An automatic scattergram-controlled regression* approach (ELVIDGE *et al.*, 1995). The effectiveness of radiometric correction was evaluated by visual inspection and calculated using root mean square error (RMSE) in the sample area chosen in order to avoid clouds for the 1997 image.

Forest was classified by the *maximum likelihood classification* method into 3 recognized categories; i.e. "deciduous forest", "low-middle volume sugi forest" with a volume of 0 - 450m^3 and "high volume sugi forest" with a volume of more than 450m^3 (the decision of volume class depends on separability analysis). Training sites for the classes mentioned above were determined by gathering information from the ground plots investigated (50 plots) and the contextual information provided by satellite image scenes. Mostly 3 × 3 pixel kernels were extracted in each plot as training data areas to divide forest covers especially in sugi forest whereas in some cases only a few neighbor pixels in

Table 1 Satellite acquisition metadata

No.	Satellite	Date	Sun Elevation	Sun Azimuth
1	Landsat	06/10/1986	61	112
2	Landsat	06/02/1989	62	116
3	Landsat	06/24/1997	63	112
4	Landsat	06/14/1999	64	115
5	Landsat	06/03/2001	64	118
6	ASTER	06/02/2005	70	134

plots were used.

Since topographic normalization involves several theoretical and practical considerations, we examined four different topographic normalization methods in mountainous region to reduce slope-aspect effect in Landsat TM and ASTER image data sets regarding the difference of vegetation types: *statistical-empirical* correction method, *a traditional MINNAERT* correction, *C-correction* method and *two- stage topographic normalization* proposed by CIVCO (1989). Many authors have applied these models to forest cover with different degrees of success in application (SMITH *et al.*, 1980; TEILLET *et al.*, 1982; CIVCO, 1989; COLBY, 1991; MEYER *et al.*, 1993; EKSTRAND, 1996 ; MURAKAMI *et al.*, 1998).

Four methods have been applied to accurately assess the results of topographic normalization; The first method involves direct visual evaluation using bands 2, 4 and 5 in which images ideally appear to be flat and both slope facing the sun and that facing away from the sun reflect the same colors. The second method compares the effect of solar incidence angle before and after correction by using the slope of regression (inclination) and the correlation coefficient (r), whereas slope of the regression line is close to zero (flat slope) and a low (zero) correlation showed that illumination correction has no effect on the images and significantly reduced the topographic effect. In the third method standard deviation (SD), preferably for each forest cover type should be reduced, meaning that a greater interclass homogeneity has been achieved. In the fourth method, by comparing the average digital number of the slope facing away from the sun with that of the slope facing the sun after correction, which should be similar. The digital number for both uncorrected and post-corrected data were imported to SPSS software after converting to ASCII format and analyzed independently for the above purposes.

Sugi Stand Volume Analysis

Regression analysis was applied to *single band images*, *NDVI*, *simple ratio* and *vegetation indices* bands to evaluate the regression line between estimated sugi stand volume and original digital number as well as derived corrected images using different topographic correction methods on 1999 and 2001 of Landsat TM images including 2005 ASTER image. Thus in order to compare the average sugi stand volume from prediction and volume from ground investigation, the root mean squared error (RMSE) was applied. The smaller RMSE gives a better regression and is related to a more accurate model.

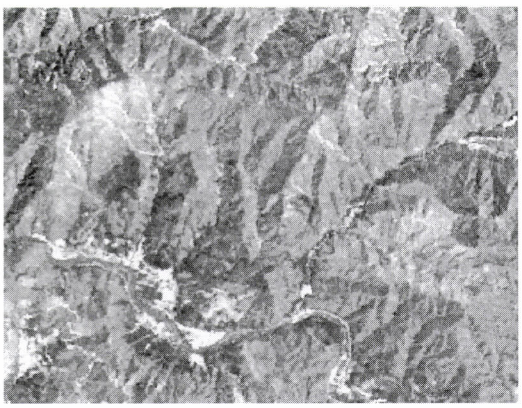
$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(ground\ volume - estimated\ volume)^2}{n}}$$

RESULTS AND DISCUSSION

Topographic Correction Approaches

Using transformed divergence analysis (JENSEN, 1986), the accuracies of classification was high for all images in distinguishing among land covers into 7 covers: water (5,308 pixel; 1.11%, based on the 2001 image classification), deciduous forest (286,273 pixels; 59.64%), low-middle volume sugi forest (108,912 pixels; 22.69%), high volume sugi forest (27,504 pixels; 5.73%), agriculture/paddy field (4,257 pixels; 0.89%), resident/building area (36,492 pixels; 7.60%) and open area/bare land (11,272 pixels; 2.35%). The overall accuracy for more than 95% has been resulted for all images operating 5 band combinations (bands 1, 2, 3, 4, and 7) on Landsat images and full bands (bands 1, 2 and 3) on ASTER image.

Visually, images resulted from different topographic correction methods show significant improvements (see its comparison in Fig. 1). In band 1, the MINNAERT correction appears to be overcorrection in all examined images especially in the area of the slope facing the sun whereas it becomes darken. Three other methods were evaluated in the same ways and show slightly similar results in all bands by showing relatively uniform vegetation brightness. Using visual interpretation, the effects of applying topographic correction



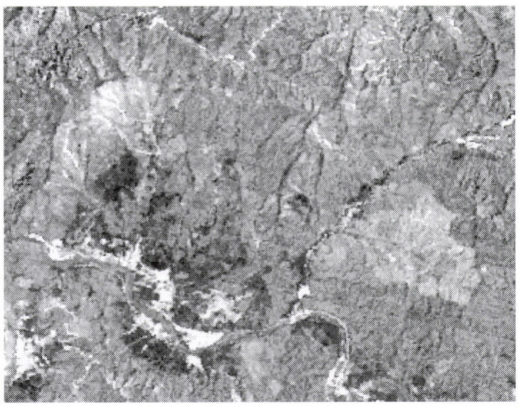


Fig. 1 Uncorrected band 2 (left) and statistic-empirical corrected band 2 on 2001 Landsat image, Tsugawa test site (right)

based on specific forest types can be considered improve the images than those in one single forest type.

Slope (*m*), intercept (*b*) and correlation coefficient (*r*) of the various correlations were evaluated for each band in all images before and after corrections were applied. High slope angle of regressions show that the deciduous cover were strongly influenced by the topographic effect, followed by the low-middle volume sugi cover and the high volume sugi cover (Tables 2 and 3). LEPRIEUR *et al.* (1988) observed that coniferous stands are more dependent on the solar position than the deciduous stand, particularly for near infrared and infrared bands. Using statistical tests, only deciduous forest cover showed a strongly significant correlation; meanwhile both sugi covers generally show significant correlations for visible bands but low correlations for near infrared and short-wave infrared bands. A lower slope angle of regression was

Table 2 Regression analyses between uncorrected digital number and solar incidence angle (*cos i*) on 2001 on forest cover types in all years of Landsat TM (inclination/slope *m*, intercept *b* and correlation coefficient *r*)

Year of Landsat	Mean *Cos i*	Band 1			Band 2			Band 3			Band 4			Band 5			Band 7		
		m	*b*	*r*	*m*	*b*	*r*	*m*	*b*	*r*	*m*	*b*	*r*	*m*	*b*	*r*	*m*	*b*	*r*
General forest cover (n = 422,671)																			
1986	0.809	10.5	69.2	0.465*	11.8	22.3	0.500*	9.5	16.9	0.429*	96.4	52.4	0.453*	60.2	69.8	0.486*	20.8	7.5	0.486*
1989	0.818	7.3	71.5	0.396*	8.7	24.4	0.482*	7.3	18.0	0.414*	88.8	56.8	0.409*	60.2	34.0	0.435*	15.6	10.9	0.430*
1997	0.822	6.5	72.3	0.311*	6.6	25.9	0.396*	6.8	14.5	0.366*	78.4	63.3	0.322*	49.9	39.8	0.330*	13.4	12.0	0.333*
1999	0.832	5.9	72.5	0.268*	5.2	27.2	0.391*	5.1	20.1	0.300*	79.9	62.8	0.333*	48.3	41.9	0.327*	11.9	13.6	0.336*
2001	0.832	7.8	70.9	0.371*	7.6	25.2	0.401*	6.4	18.7	0.336*	69.7	68.3	0.290*	46.0	42.7	0.307*	12.5	12.9	0.324*
Deciduous forest cover (n = 286,273)																			
1986	0.807	9.6	69.3	0.562*	11.2	22.7	0.606*	7.9	17.7	0.593*	108.7	53.5	0.678*	72.8	29.9	0.679*	20.2	8.6	0.660*
1989	0.813	6.7	71.5	0.442*	8.5	24.5	0.593*	6.5	18.1	0.567*	104.9	54.9	0.642*	65.5	34.3	0.629*	15.9	11.3	0.598*
1997	0.820	7.3	71.2	0.373*	7.4	25.4	0.497*	7.3	17.9	0.567*	104.2	56.7	0.587*	64.3	35.9	0.580*	16.5	11.2	0.545*
1999	0.836	6.2	71.7	0.311*	5.6	26.8	0.469*	4.8	20.1	0.407*	96.9	62.8	0.569*	57.4	42.5	0.554*	13.5	13.9	0.538*
2001	0.833	7.7	70.9	0.466*	8.1	25.2	0.529*	6.0	19.0	0.493*	89.0	67.6	0.568*	57.6	40.8	0.544*	14.6	12.7	0.539*
Low-middle volume sugi forest (n = 108,893)																			
1986	0.829	10.8	71.1	0.359*	12.2	23.2	0.379*	12.7	16.6	0.363*	70.6	57.9	0.338*	63.4	28.3	0.359*	21.8	7.2	0.358*
1989	0.842	6.8	73.4	0.281*	7.1	26.9	0.298*	6.76	20.4	0.266*	57.9	66.2	0.253*	47.2	40.7	0.265*	13.7	13.1	0.259*
1997	0.831	2.9	76.6	0.145	3.3	29.6	0.212*	4.7	21.6	0.210*	16.5	99.9	0.089	15.5	62.4	0.122	5.9	17.7	0.152
1999	0.823	6.9	73.2	0.274*	4.5	28.1	0.298*	7.2	19.4	0.281*	16.3	90.1	0.114	14.9	56.4	0.141	6.8	15.8	0.192
2001	0.830	8.6	71.2	0.308*	7.1	25.4	0.308*	8.1	18.1	0.277*	23.1	81.9	0.145	19.5	54.3	0.145	8.6	14.5	0.202*
High volume sugi forest (n = 27,505)																			
1986	0.758	4.7	71.3	0.373*	2.7	24.7	0.305*	2.1	19.6	0.266*	-5.7	77.0	0.063	-2.6	46.2	0.045	-0.2	13.6	0.000
1989	0.772	3.9	73.0	0.305*	1.8	26.3	0.276*	1.0	20.6	0.187	-9.1	79.6	0.114	-6.2	50.9	0.118	-1.0	15.4	0.063
1997	0.805	4.8	72.0	0.277*	4.5	25.1	0.351*	3.6	18.6	0.308*	1.9	68.7	0.032	-2.0	44.9	0.045	0.0	13.4	0.000
1999	0.829	3.5	74.1	0.202*	2.1	27.9	0.268*	1.5	21.6	0.200*	4.5	67.7	0.055	2.5	41.3	0.055	0.5	13.9	0.032
2001	0.832	4.4	71.3	0.279*	2.9	25.5	0.324*	2.7	19.2	0.283*	4.5	61.4	0.071	3.2	39.0	0.063	1.2	12.4	0.089

*Significant at the 0.05 level;

Table 3 Regression analyses between uncorrected digital number and solar incidence angle (*cos i*) on 2005 ASTER Image (inclination/slope *m*, intercept *b* and correlation coefficient *r*)

Year of ASTER	Mean *Cos i*	Band 1			Band 2			Band 3		
		m	*b*	*r*	*m*	*b*	*r*	*m*	*b*	*r*
General forest cover (n = 1,692,036)										
2005	0.845	6.9	41.0	0.371*	3.7	18.9	0.401*	14.9	84.3	0.336*
Deciduous forest cover (n = 1,164,485)										
2005	0.841	8.3	40.6	0.391*	4.3	18.5	0.411*	29.8	81.7	0.407*
Low-middle volume sugi forest (n = 406,329)										
2005	0.846	6.6	40.7	0.249*	3.7	19.4	0.200*	2.8	77.5	0.032
High volume sugi forest (n = 121,222)										
2005	0.873	3.6	38.9	0.288*	2.0	18.3	0.295*	3.7	54.3	0.095

*Significant at the 0.05 level;

seen in high volume sugi cover than low-middle volume sugi cover for near infrared and infrared bands (band 4, band 5 and band 7, respectively), it show that reflectance value decrease when sugi stand volume increases. The same result was also obtained by LEPRIEUR *et al.* (1988) using stand age analysis.

As has often been noticed before (HOLBEN and JUSTICE, 1980; LEPRIEUR *et al.*, 1988; TEILLET *et al.*, 1982), the present results showed that using corrected images derived from specific forest types were more effective than those using the forest in general. LEPRIEUR *et al* (1988) believed that these differences based on different properties of the biological materials (such as: photosynthetic pigments, cell wall materials, water concentrations, etc) and of foliage geometry (leaf and branch shape roughness, internal anatomy, leaf and branch zenith angles, etc).

The relation between mean incidence angle (*cos i*) and correlation coefficient (*r*) for regressions derived from the sequences obtained with Landsat TM also showed that a lower mean incidence angle (local solar incident angle) on forest type, the higher the topographic effect to the forest. In the comparison between low-middle volume sugi cover and high volume sugi cover, the apparent reflectance effect due to topography decreased with the increase in the volume of sugi stand tree, particularly for bands 4, 5 and 7.

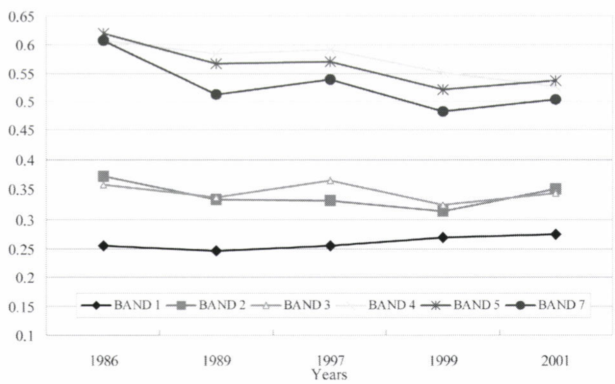


Fig. 2 MINNAERT constant values (*k*) on deciduous forest type

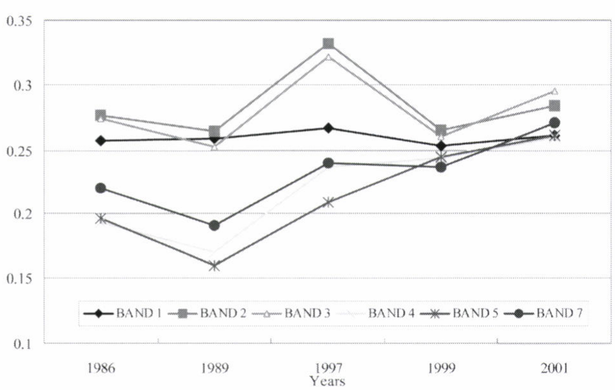


Fig. 3 MINNAERT constant values (*k*) on high volume sugi forest type

In addition, MINNAERT constant values gained from one image varied from those constants gained from other images, and no one fixed value was adequate for all images (see Fig. 2 and 3); a similar result was also obtained for cover type, there being no single fixed value for all cover type which may be highly variable. COLBY (1991) also suggested that the MINNAERT constant gained from sample areas was more accurate than MINNAERT constant gained from corresponding entire scenes.

Tables 4 and 5 show that in most corrected images, slope angle of regression and correlation coefficient was reduced to zero although the topographic effect was nearly completely removed. MURAKAMI *et al* (1988) reported that no correlation was found after MINNAERT correction and C-correction methods were applied to bands 4 and 5 of Landsat TM data. The best result was obtained by statistic empirical correction and two-stage topographic normalization whiles the worst result was obtained by MINNAERT correction, which clearly can be seen in visible bands.

In an effort to determine the variants among images after corrections, the standard deviation (SD) was analyzed. Ideally, SD was reduced for successful corrected images since both opposite slopes (slope facing away from the sun and that facing the sun) have similar mean digital numbers. In a deciduous forest type, the decrease of standard deviations showed that all methods were effective and could be defined as suitable methods to correct the illumination effect even though in MINNAERT correction there was less improvement or overcorrection for visible bands. In comparison, the result using a sugi forest type was different, whereas both for low-middle volume sugi cover and high volume sugi cover, there was less improvement; even in the same cases, the correction approach increased its standard deviation. The mean values for both slope facing away from the sun and slope facing the sun were tested statistically. All topographic correction gave significantly reduced the digital numbers on the slope facing the sun and increased digital numbers on the slope facing away from the sun (Table 6).

For the entire analysis of topographic correction, traditional MINNAERT correction was failed to improve topographic correction statistically due to its inconsistencies particularly in visible bands. Other methods showed marked improvements especially the two-stage topographic normalization proposed by CIVCO (1989), but there was only a slight difference among the others as demonstrated by statistical analysis.

Table 4 Standard deviation (SD) and correlation parameters of original image and corrected image in 2001 Landsat TM image (ideally SD for the corrected is lower than uncorrected, slope and *r* data is close to zero)

Bands	Correction methods	Deciduous forest (n = 286,273)				Low-middle volume sugi forest (n = 108,893)				High volume sugi forest (n = 27,505)			
		SD	*m*	*b*	*r*	SD	*m*	*b*	*r*	SD	*m*	*b*	*r*
Band 1	**Uncorrected**	**2.19**	**7.77**	**70.89**	**0.466***	**3.55**	**8.59**	**71.21**	**0.308***	**1.70**	**4.36**	**71.32**	**0.279***
	Statistic Empirical	1.96	-0.21	77.02	0.000	3.39	-0.15	77.95	0.000	1.65	-0.36	74.73	0.032
	Minnaert Correction	4.05	-9.36	83.81	0.303	4.27	-5.01	83.55	0.148	2.54	-4.52	79.62	0.192
	C-Correction	2.00	1.29	76.42	0.084	3.46	2.65	76.63	0.100	1.68	1.61	73.65	0.105
	Topographic Normalization (Civco)	1.96	-0.25	77.03	0.000	3.39	-0.50	78.23	0.000	1.68	-0.30	74.58	0.000
Band 2	**Uncorrected**	**2.00**	**8.05**	**25.22**	**0.529***	**2.94**	**7.11**	**25.38**	**0.308***	**0.89**	**2.90**	**25.45**	**0.324***
	Statistic Empirical	1.72	-0.25	31.62	0.000	2.81	0.09	30.72	0.000	0.89	-1.10	28.23	0.134
	Minnaert Correction	1.98	-2.64	33.94	0.176	2.96	-1.25	32.89	0.055	1.10	-1.48	29.27	0.145
	C-Correction	1.72	1.35	30.97	0.105	2.87	2.08	29.88	0.095	0.88	1.80	26.30	0.221
	Topographic Normalization (Civco)	1.71	-0.32	31.64	0.032	2.78	-0.46	31.14	0.000	0.89	-1.13	28.25	0.138
Band 3	**Uncorrected**	**1.59**	**5.96**	**18.96**	**0.493***	**3.70**	**8.05**	**18.09**	**0.277***	**0.93**	**2.70**	**19.22**	**0.283***
	Statistic Empirical	1.42	0.65	22.95	0.063	3.57	-0.11	24.37	0.009	0.93	-1.23	21.94	0.145
	Minnaert Correction	1.56	-1.82	25.12	0.152	3.72	-0.55	25.89	0.046	1.06	-1.43	22.74	0.046
	C-Correction	1.40	1.03	23.05	0.095	3.69	2.45	23.18	0.084	0.93	1.78	19.92	0.036
	Topographic Normalization (Civco)	1.38	-0.11	23.5	0.004	3.54	-0.97	25.03	0.033	0.94	-1.28	21.99	0.002
Band 4	**Uncorrected**	**20.53**	**88.97**	**67.62**	**0.568***	**20.33**	**23.13**	**81.91**	**0.145**	**6.96**	**4.50**	**61.39**	**0.071**
	Statistic Empirical	16.90	0.02	141.20	0.000	20.12	0.03	100.59	0.000	6.95	-0.29	64.85	0.045
	Minnaert Correction	16.80	5.60	144.78	0.045	20.09	2.92	100.45	0.000	7.11	-3.10	68.37	0.000
	C-Correction	16.70	13.5	137.04	0.105	20.37	6.73	97.66	0.045	7.02	1.69	63.78	0.032
	Topographic Normalization (Civco)	16.61	0.682	139.64	0.000	19.93	1.69	99.13	0.000	6.98	-1.01	65.48	0.000
Band 5	**Uncorrected**	**13.89**	**57.59**	**40.80**	**0.544***	**16.98**	**19.51**	**54.29**	**0.145**	**5.24**	**3.2**	**39.01**	**0.063**
	Statistic Empirical	11.66	-0.02	88.28	0.000	16.79	-0.02	70.01	0.000	5.24	-0.89	41.87	0.000
	Minnaert Correction	11.74	4.09	90.28	0.045	16.80	4.27	68.17	0.032	5.36	-1.73	43.37	0.032
	C-Correction	11.63	8.76	85.56	0.100	17.07	5.57	67.58	0.045	5.25	1.76	40.16	0.032
	Topographic Normalization (Civco)	11.51	0.28	87.35	0.000	16.63	0.05	69.86	0.000	5.26	-1.38	42.29	0.032
Band 7	**Uncorrected**	**3.55**	**14.56**	**12.72**	**0.539***	**5.43**	**8.59**	**14.54**	**0.202***	**1.42**	**1.19**	**12.43**	**0.084**
	Statistic Empirical	3.00	-0.14	24.45	0.000	5.33	-0.15	21.29	0.009	1.46	-2.24	14.72	0.167
	Minnaert Correction	2.97	0.732	25.65	0.032	5.46	1.15	21.21	0.028	1.44	-0.20	13.38	0.002
	C-Correction	2.97	2.24	23.65	0.105	5.48	2.53	20.06	0.055	1.42	0.40	13.02	0.031
	Topographic Normalization (Civco)	2.96	-0.45	24.57	0.001	5.24	-0.66	21.66	0.003	1.46	-2.29	14.76	0.170

* Significant at the 0.05 level;

Table 5 Standard deviation (SD) and correlation parameters of uncorrected image and corrected image in 2005 ASTER image (ideally SD for the corrected is lower than uncorrected, slope and *r* data is close to zero)

Bands	Correction methods	Deciduous forest (n = 1,164,185)				Low-middle volume sugi forest (n = 406,329)				High volume sugi forest (n = 212,222)			
		SD	*m*	*b*	*r*	SD	*m*	*b*	*r*	SD	*m*	*b*	*r*
Band 1	**Uncorrected**	**2.73**	**8.31**	**40.56**	**0.391***	**3.60**	**6.58**	**40.66**	**0.249***	**1.03**	**3.59**	**38.92**	**0.288***
	Statistic Empirical	2.53	0.00	47.55	0.000	3.50	0.01	46.23	0.000	1.01	-0.03	42.09	0.000
	Minnaert Correction	3.01	-4.71	51.39	0.200*	3.72	-2.40	48.87	0.089	1.43	-2.93	45.06	0.207*
	C-Correction	2.50	2.75	45.61	0.141	3.52	2.91	44.23	0.045	1.02	1.25	41.23	0.122
	Topographic Normalization (Civco)	2.51	-0.17	47.67	0.000	3.48	-0.19	46.37	0.000	0.97	0.11	41.96	0.000
Band 2	**Uncorrected**	**1.33**	**4.25**	**18.48**	**0.411***	**2.48**	**3.66**	**19.42**	**0.200***	**0.68**	**1.98**	**18.255**	**0.295***
	Statistic Empirical	1.26	0.11	21.96	0.000	2.47	0.05	22.45	0.000	0.72	-0.02	19.95	0.000
	Minnaert Correction	1.41	-1.81	23.54	0.164	2.50	-0.94	23.63	0.055	0.81	-1.29	21.34	0.161
	C-Correction	1.24	1.53	20.96	0.158	2.49	1.67	21.34	0.032	0.73	0.69	19.47	0.095
	Topographic Normalization (Civco)	1.21	-0.12	22.15	0.000	2.43	-0.18	22.65	0.000	0.648	-0.06	20.04	0.000
Band 3	**Uncorrected**	**9.40**	**29.79**	**81.72**	**0.407***	**12.21**	**2.77**	**77.54**	**0.032**	**4.01**	**3.79**	**54.32**	**0.095**
	Statistic Empirical	8.58	-0.01	106.78	0.000	12.21	0.00	79.88	0.000	4.00	-0.01	57.63	0.000
	Minnaert Correction	8.74	-6.79	113.51	0.100	11.92	-1.62	80.62	0.000	4.05	-2.70	60.29	0.071
	C-Correction	8.48	9.9	99.78	0.152	12.20	1.23	79.04	0.000	4.00	1.33	56.75	0.032
	Topographic Normalization (Civco)	8.60	0.97	105.84	0.000	12.20	1.38	78.72	0.000	3.99	-0.15	57.76	0.000

*Significant at the 0.05 level;

Table 6 Comparison of mean DN value on different slopes in 2001 Landsat image (ideally DN values for both of facing away from the sun/shaded side and facing to the sun/sunny side are similar)

Bands	Correction methods	Deciduous forest (n = 286,273)		Low-middle volume sugi forest (n = 406,329)		High volume sugi forest (n = 121,222)	
		Facing away from the sun	Facing to the sun	Facing away from the sun	Facing to the sun	Facing away from the sun	Facing to the sun
Band 1	**Uncorrected**	**76.39**	**78.11**	**77.26**	**79.11**	**74.56**	**75.28**
	Statistic Empirical	76.91	76.79	77.84	77.82	74.63	74.28
	MINNAERT Correction	77.34	75.00	80.11	78.88	76.56	75.29
	C-Correction	77.38	77.60	78.50	79.06	74.79	75.16
	Topographic Normalization (CIVCO)	76.90	76.77	77.87	77.77	74.62	74.28
Band 2	**Uncorrected**	**30.92**	**32.71**	**30.38**	**31.93**	**27.58**	**28.09**
	Statistic Empirical	31.46	31.36	30.79	30.81	27.59	27.09
	MINNAERT Correction	32.09	31.46	31.98	31.77	28.28	27.85
	C-Correction	31.95	32.20	31.38	31.77	27.60	27.97
	Topographic Normalization (CIVCO)	31.45	31.31	30.82	30.71	27.59	27.09
Band 3	**Uncorrected**	**23.16**	**24.52**	**23.71**	**25.54**	**21.21**	**21.68**
	Statistic Empirical	23.46	23.51	24.23	24.31	21.22	20.68
	MINNAERT Correction	23.83	23.43	25.39	25.47	21.78	21.37
	C-Correction	23.79	24.01	24.86	25.45	21.21	21.56
	Topographic Normalization (CIVCO)	23.48	23.37	24.29	24.17	21.22	20.68
Band 4	**Uncorrected**	**130.54**	**150.33**	**98.50**	**102.95**	**64.62**	**65.55**
	Statistic Empirical	141.01	141.37	100.76	100.51	64.68	64.55
	MINNAERT Correction	148.58	150.11	102.89	102.85	66.21	65.46
	C-Correction	146.79	149.51	102.72	103.62	64.89	65.42
	Topographic Normalization (CIVCO)	140.21	140.20	100.52	100.53	64.76	64.54
Band 5	**Uncorrected**	**81.52**	**94.35**	**68.13**	**72.16**	**41.30**	**41.97**
	Statistic Empirical	88.13	88.36	69.96	70.00	41.31	40.97
	MINNAERT Correction	93.05	94.17	71.30	72.01	42.15	41.76
	C-Correction	91.86	93.62	71.59	72.63	41.34	41.85
	Topographic Normalization (CIVCO)	87.61	87.56	69.90	69.89	41.35	40.97
Band 7	**Uncorrected**	**23.01**	**26.28**	**20.57**	**22.46**	**13.28**	**13.54**
	Statistic Empirical	24.33	24.34	21.15	21.18	13.23	12.54
	MINNAERT Correction	25.50	25.73	21.97	22.30	13.21	13.21
	C-Correction	25.25	25.72	21.83	22.39	13.28	13.41
	Topographic Normalization (CIVCO)	24.27	24.13	21.19	21.06	13.26	12.54

The Effect of Applying Topographic Correction Methods on Sugi Stand Volume Analysis

Correlations between DN and ground characteristic information (volume) were analyzed. Regression results obtained from original digital number and observed sugi stand volume on both Landsat TM and ASTER images were found to be generally high with band 2 showing the highest correlation (r = 0.798). In 2001 Landsat TM, NDVI calculated from this regression almost similarly resulted with simple ratio bands (r = 0.467 and r = 0.491, respectively) but weaker than the correlation resulting from vegetation indices (r = 0.688). Even though it shows a lower correlation in ASTER images, the same tendency in correlation was found. The strong correlation seen in this study showed that Landsat TM and ASTER images proved to be trustable images for predicting sugi stand volume (see Fig. 4 and Fig. 5).

Almost all band correlations showed that correction using forest type in general resulted in a lower correlation than operating fixed forest types. As expected, the MINNAERT method in band 1 gave the lowest value to volume by decreasing its correlation. In Landsat TM image, both the statistic-empirical method and two-stage topographic normalization proposed by CIVCO (1989) previously gave statistically better value, resulting a correlation in contrast correlation to sugi volumes (see complete result on Table 7). For visible and near-infrared bands, a better correlation was achieved using C-correction (with band 2 as the highest, r = 0.802), meanwhile MINNAERT method for shortwave infrared bands. Slightly different results were obtained from the ASTER image, whereas original DN is better than using corrected DN, mainly for near infrared bands (band 3).

The root mean square error (RMSE) was obtained, The RMS error gained from C-correction showed the smallest value for visible bands (RMSE = 193.71), in contrast to the infrared bands resulting from MINNAERT correction (Table 8). This result indicated that for sugi stand volume analysis, C-correction is the best for visible bands and near infrared band while MINNAERT correction is best for short-wave infrared bands.

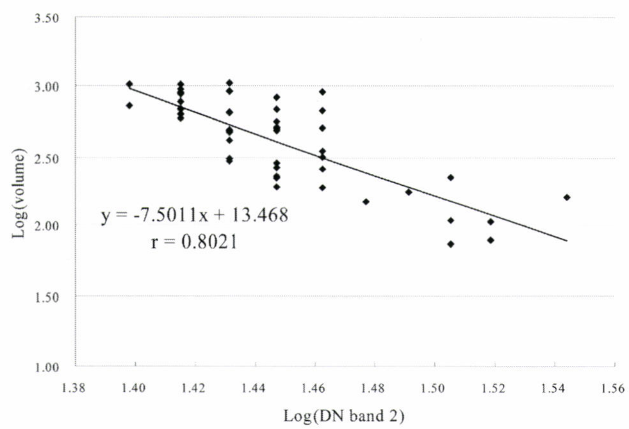


Fig. 4 Regression between digital number derived from C-correction method (band 2) and observed sugi stand volume on 2001 image

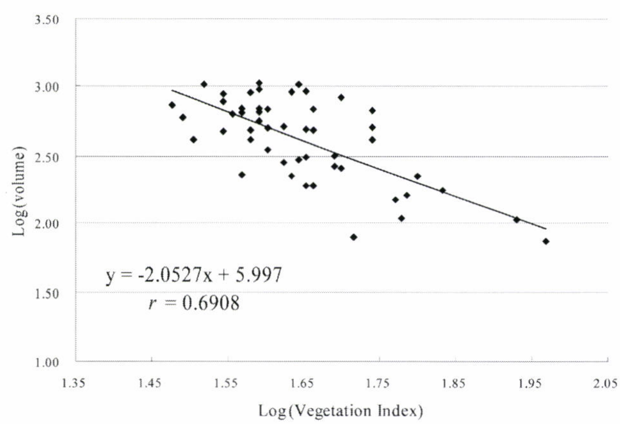


Fig. 5 Regression between digital number derived from C-correction method (Vegetation Index) and observed sugi stand volume on 2001 image

Table 7 Comparison of correlation coefficient (r) between topographic correction methods and sugi stand volume on 2001 Landsat TM image (n = 50)

Correction methods	Bands								
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7	NDVI	Vegetation Indices	Simple Ratio
Uncorrected	**0.671***	**0.798***	**0.738***	**0.738***	**0.754***	**0.791***	**0.467***	**0.688***	**0.491***
Statistic Empirical	0.596*	0.774*	0.713*	0.727*	0.751*	0.772*	0.466*	0.680*	0.491*
MINNAERT Correction	0.477*	0.779*	0.703*	0.735*	0.766*	0.797*	0.443*	0.683*	0.468*
C-Correction	0.652*	0.802*	0.742*	0.740*	0.762*	0.781*	0.459*	0.691*	0.486*
Topographic Normalization (CIVCO)	0.604*	0.768*	0.713*	0.728*	0.752*	0.774*	0.468*	0.682*	0.494*

Table 8 Comparison of Root Mean Square Error (RMSE) using multi bands in estimating sugi stand volume (n = 50)

Correction methods	**Bands**								
	Band 1	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 7**	**NDVI**	**Vegetation Indices**	**Simple Ratio**
Uncorrected	**240.39**	**193.37**	**213.40**	**228.20**	**215.67**	**219.94**	**273.88**	**241.55**	**270.81**
Statistic Empirical	261.85	211.16	225.66	230.60	217.89	223.56	273.90	243.66	270.47
MINNAERT Correction	280.94	213.09	230.63	228.76	212.95	215.39	275.17	241.65	272.21
C-Correction	247.03	193.71	212.66	228.07	214.19	220.34	275.73	241.75	272.20
Topographic Normalization (CIVCO)	258.55	211.72	225.63	230.40	217.48	222.87	273.58	243.46	270.08

Pattern curve of solar incidence angle and digital number from original and DN derived from various methods were also analyzed. DN derived from statistic-empirical correction and two-stage topographic normalization (CIVCO, 1989) was concentrated only on the sunny side (slope facing the sun), while on the dark side (slope facing away from the sun) it was unchanged. Contrasting changes were obtained by MINNAERT correction, whereas for visible bands it showed dynamic changes, even overcorrection in band 1 but slightly for infrared bands. The inconsistency of the results of application of the MINNAERT method and C-correction methods is well known and has been mentioned by many authors (MEYER *et al*, 1993; GU and GILLESPIE, 1998) but considering the high positive correlation and slight-selective changes for all bands, it shows that both MINNAERT method and C-correction are adequate methods for sugi stand volume estimation analysis even though for different bands.

CONCLUSION

The present study examined the methods for topographic correction of measured value: statistical analysis post-correction and its relation to sugi stand volume estimation. The specific major forest class type should be considered as input when applying a topographic correction method in satellite images analysis. The influence of sugi stand volume on the apparent reflectance distribution appeared as a result: reflectance globally decreased with the increase in stand volume. All topographic correction methods applied in this study were effective for reducing the topographic effect and were suitable for correcting the illumination effect except for MINNAERT correction for visible bands (especially in band 1). Post-corrected statistical analysis is not reliable for determining degree of success until the real effect of applying correction methods on a forest is known.

Topographic effects are scene-dependent and there is no single parameter or model adequate for all scenes and forest types. The two-stage topographic normalization proposed by CIVCO (1989) and statistic-empirical method appeared to be the best for statistical analysis but were unsuccessful regarding actual correlation to sugi stand volume. The present results indicate that using C-correction for visible bands and MINNAERT correction for short-wave infrared band are adequate methods for increasing the correlation accuracy between derived digital number and sugi stand volume in the Tsugawa region. Further studies using appropriate ground field data are needed at a lower sun elevation angle (*cos i*) since only a few of the plots had poor illumination conditions. In this study, we found a strong indication of the illumination effect on deciduous forest cover, but further analyses are needed to verify our hypothesis.

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Article

Monitoring the Forest Resources and Management of Private Landowners in Nagano, Japan*

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ABSTRACT

Approximately 80% of Japan's wood demand is currently met with imported wood. Although private forestry is the most important factor in domestic wood production, more and more private forest landowners have reduced their management activity, resulting in a general deterioration of the private plantation forests in Japan and heavy pressure on the forest resources of supplier countries. An integrated private forest management planning system is needed to reinvigorate private forestry in Japan. This research assessed the information management of forest owners' associations and some of the negative effects of parcelization on landowners' forest management activities. The research was done to provide answers to the question of how such an integrated private forest management system might be organized. We learned through questionnaires that the majority of the associations in Nagano Prefecture, who could be the foundation of an integrated management system, do not have the necessary information about their members' forest resources and management activity. Comprehensive directives are needed to establish standards for the associations on how to collect, maintain and update such information. On the other hand, the results of our investigation of forest landowners' behavior suggests that, without the right incentives for the landowners to implement cooperative forest management, an integrated planning system probably will not be successful. It appears that the current level of silvicultural activity and the proportion of owners having a management plan tend to be higher on larger forest properties. We also found that timber production was more likely to be a primary goal of ownership for owners of larger tracts. Cooperative forest management may provide a way to ameliorate the problem associated with small-scale ownerships and reduce the costs of management. Combined with more competitive prices, such cooperation could help Japanese private forestry reduce the country's reliance on imported timber.

Keywords: private forestry in Japan, parcelization, cross-boundary forest management, landowner attitudes, monitoring

INTRODUCTION

Japan is one of the largest wood consumers in the world. Because of its economic affluence and the liberalization of its timber-trade in the early 1960s, Japan has become a strong timber importing country (NOMURA, 1978; MURASHIMA, 1997; YOSHIMOTO *et al.*, 1998; NAGASHIMA *et al.*, 1999). Due to soaring forest management and labor costs, domestic wood production has not been able to compete against foreign timber industries (YUKUTAKE *et al.*, 1998). The principal reasons for the high costs are an expensive and scarce labor force, difficult terrain, and small-scale, fragmented ownerships. It is no wonder that the last three decades have witnessed a gradual stagnation of

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domestic private forestry - the most important factor in wood production in the country (private forests currently account for 74% of the forest products produced in Japan). As a result of the lower level of silvicultural treatments, the general condition of private forest resources - mostly plantation forests - has been deteriorating.

However, the sluggish domestic forest industry is only one of the negative outcomes of Japan's low self-sufficiency rate in timber production. Currently, roughly 80% of the country's total wood demand is supplied by import timber (approx. 90 million m^3 annually), 41% of which comes from Canada and the U.S., 22% from Russia, 18% from South-Pacific Asia, 9% from New Zealand, and 10% from other sources (Ministry of Agriculture, Forestry and Fisheries 2000). Furthermore, the forest resources of many supplier countries are under severe harvesting pressure. Forest overexploitation had forced the Philippines (in the late 1960s), Indonesia (in 1985), Sabah (in 1993) and Sarawak (in 1995) to ban their log exports completely (TACHIBANA, 2000).

If domestic timber prices were competitive, the current annual increment of plantation forests (91 million m^3 in 1995), 65% of which are private, could satisfy a significantly larger share of its demand for wood. Japan must revitalize its private forestry. Doing so would, on the one hand, solve the problem of untended plantation forests, and it would also relieve the supplier countries of the burden on their own forest resources. Revitalizing private forestry would, in addition, provide job opportunities for people wishing to live and work in the countryside and, at the same time, contribute to efforts to stop, or at least decelerate, the dispiriting process by which rural Japan is becoming depopulated.

What can be done to increase Japan's self-sufficiency rate in timber production? As the parcelization of private forestland is one of the major factors that contribute to high management costs, we believe an integrated forest management planning system that would promote cooperative forest management could be effective in increasing the profitability of domestic timber production. The already existing forest owners' associations (FOA) could be the foundation of such a system. There are three reasons why they would be well suited for this role: 1) most private forest owners are members of the FOAs (70-75% in terms of forest area); 2) the FOAs have the most direct relationship with the landowners (Fig. 1); and 3) the FOAs were legally established, by government initiatives, with this purpose in mind throughout the country.

The present paper analyzes whether the forest owners' associations are in possession of the information about their member owners' forest resources and management activity that would be essential to implement integrated forest management planning. We researched what data are available and what additional information needs to be collected in the future. The second part of the paper addresses the parcelization problem. The investigation focused on the relationship between the size of forestland and the attitudes of landowners in relation to forest management issues, such as management activity, having a forest management plan, and ownership objectives.

METHODS

FOA Survey

One objective of this study was to assess the amount, type and currency of the information held by the FOAs regarding their members and their activities. The first phase of this research focused on the 33 FOAs in Nagano Prefecture in 2001. The scope of administration of these FOAs ranged from 793ha to 64,721ha. The overall forest area administered by the FOAs totals 507,984ha, of which 367,353 ha (72%) are owned privately and 140,631 ha (28%) is public property (e.g., municipal and property ward forests). The 367,353ha of private forests under the administration of the FOAs is 72% of the total area of private forests in Nagano Prefecture (512,903ha). Given their legal role in private forestry, one would expect the associations to have up-to-date, reliable information on the forest resources and silvicultural activities of their members.

In order to assess the FOAs' information management, we sent a questionnaire to each of the associations in the prefecture. The FOAs were asked whether they had the following data: 1) the names, addresses, and type of forest ownership (independent, communal, etc.) of their members; 2) the location of their members' forestland; 3) the acreage (area) of forestland owned by each member; 4) the area of artificial and natural forests; 5) the growing stock on artificial and natural forests; 6) the distribution of area by the primary tree species; 7) the distribution of growing stock by the primary tree species; 8) the age-class distribution by area; 9) the age-class distribution by volume for the primary tree species; and 10) records of silvicultural operations. We considered this information to be the minimal prerequisite for effective management planning. The FOAs were also requested to clarify whether the data were available for individual members or only as a total for their entire administrative area.

Landowner Survey

In order to address the problem of forest management inactivity, charting the attitudes, needs and constraints of landowners is essential. We administered a second questionnaire with the objective of obtaining the following information from the landowners: 1) land ownership size category (<5ha; 5-10ha; 10-20ha; >20ha); 2) the number of silvicultural operations that were carried out in the last 5 years; 3) whether they have a forest management plan or not; and 4) forestland ownership objectives. A basic question was whether the size of a forestland ownership affects silvicultural activities, planning, or ownership objectives.

The private, individual owners who are members of Kami

Ina Forest Owners' Association (Kami Ina FOA) were the target population of this questionnaire. The total area of forestland owned by the members of the association is 57,332ha, of which 45,947ha are owned by individual private forest landowners. This represents 87% of all private forests in the district. There are 16,522 private forest landowners in Kami Ina Administrative District, of which 12,772 (77%) are members of the FOA. Information (address, location of forest property etc.) concerning non-members was not available. Contact information for member owners (address, telephone number, forest area etc) was obtained from Kami Ina FOA's files.

A mailed questionnaire, followed by postcard reminders, was used to collect the data. The questionnaires were sent to all of the owners with at least 20ha of forestland (there were 87 of them), to 100 owners with 0-5ha, to 102 owners with 5-10ha, and to 107 owners with 10-20ha of forestland. Attention was paid to maintaining the geographical distribution of the landowners chosen in the district. Because the number of owners in each category was roughly the same, the proportion in the total number of owners represented in the sample is different in each group. The data were stratified because information and statistics concerning Japanese private forestry are usually reported in this four forestland-size category format. The response rates in the four property size categories of 0-5ha, 5-10ha, 10-20ha, and >20ha were 41.7%, 52.5%, 55.3% and 55.5%, respectively.

The survey instrument included the following questions: 1) How many of each of the main silvicultural operations (afforestation, weeding, pruning, clearing, improvement thinning, commercial thinning and final cutting) have you carried out during the last 5 years (1996-2001)? 2) Do you have a forest management plan? 3) Why did you choose to own forestland (A: Timber production; B: Charcoal, Shiitake-, Matsutake-mushroom or other secondary forest products; C: Recreation, sport, tourism, etc.; C: Inherited land, no specific reason for ownership; D: Other reasons)? Evidence was sought to test the following hypotheses.

1) The level of silvicultural activity tends to be higher on larger forest lots.
2) The likelihood that owners have a management plan is greater for the larger tracts than for the smaller ones.
3) Timber production is more likely to be the main goal of ownership for larger forest ownerships than for the smaller ones.

Two-sample t-tests were run for each combination of forestland size categories ('0-5ha' vs. '5-10ha', '5-10ha' vs. '10-20ha', etc) to test the first hypothesis (MINITAB Statistical Software, 1999). A Mantel-Haenszel Chi-square test was used to determine whether or not having a management plan depends on the size of forestland parcel (SAS, 1989). To test the third hypothesis, 95% confidence intervals were calculated for the cells corresponding to each response category.

RESULTS

Twenty-three associations (70%) completed the FOA questionnaire. Four FOAs had all ten sets of data in hand. By contrast, one FOA did not even have basic information on the name, address, and type of ownership of its members. More than half of the associations maintain the first 5 categories of data at the owner level and the first 8 categories of data at the level of their total administrative area. Area and volume data broken down by main tree species and age-classes at the owners' level are only available for one third of the associations. Only 43% of the associations maintain data regarding the silvicultural operations implemented in their member owners' forests.

The responses to the three questions are summarized in Table 1, 2, and 3, respectively. Tests regarding the hypotheses addressed by the second questionnaire provided the following results. The average number of silvicultural operations was significantly higher in the '5-10ha' and the '10-20ha' groups than in the '0-5ha' group (the P-values in these comparisons were 0.015 and 0.024, respectively). The difference between the 'Over 20ha' and '0-5ha' groups was significant only at the 0.084 level. For the three larger ownership classes, the smallest class, 5-10ha, had the most actions per ownership and the largest class had the lowest. However, none of these differences were statistically significant (Table 1). The results of the Mantel-Haenszel test indicated that there is a positive

Table 1 Forest management activity

Type of action	Number of actions			
	0-5ha	**5-10ha**	**10-20ha**	**Over 20ha**
Afforestation, planting	9	23	23	16
Weeding	20	31	31	18
Pruning	24	34	36	28
Clearing	15	30	35	24
Improvement thinning	11	26	35	24
Commercial thimming	8	18	18	11
Final cutting	5	10	5	5
Total	**92**	**172**	**183**	**126**
Average # of actions	**2.30**	**3.31**	**3.21**	**3.00**
Number of ownerships	40	52	57	42

Table 2 Forestry based on forest management plans

	0-5ha		**5-10ha**		**10-20ha**		**Over 20ha**	
	#	%	#	%	#	%	#	%
Owners w/ for. man. plan	7	17.5	15	28.8	17	29.8	16	38.1
Number of ownerships	40		52		57		45	

Table 3 Aim of forest ownership

	0-5ha		5-10ha		10-20ha		Over 20ha	
	#	%	#	%	#	%	#	%
Timber production	12	30.0	27	51.9	39	68.4	27	60.0
	C.I. (15.8, 44.2)		C.I. (38.3, 65.5)		C.I. (56.3, 80.5)		C.I. (45.7, 74.3)	
Charcoal, Shiitake, etc.	10	25.0	20	38.5	29	50.9	19	42.2
Recreation	3	7.5	3	5.8	2	3.5	3	6.7
Inherited land, no specific reason for ownership	25	62.5	29	55.8	20	35.1	13	28.9
	C.I. (47.5, 77.5)		C.I. (42.3, 69.3)		C.I. (22.7, 47.5)		C.I. (15.7, 42.1)	
Other reasons	2	5.0	5	9.6	1	1.8	1	2.2
Number of ownerships	40		52		57		45	

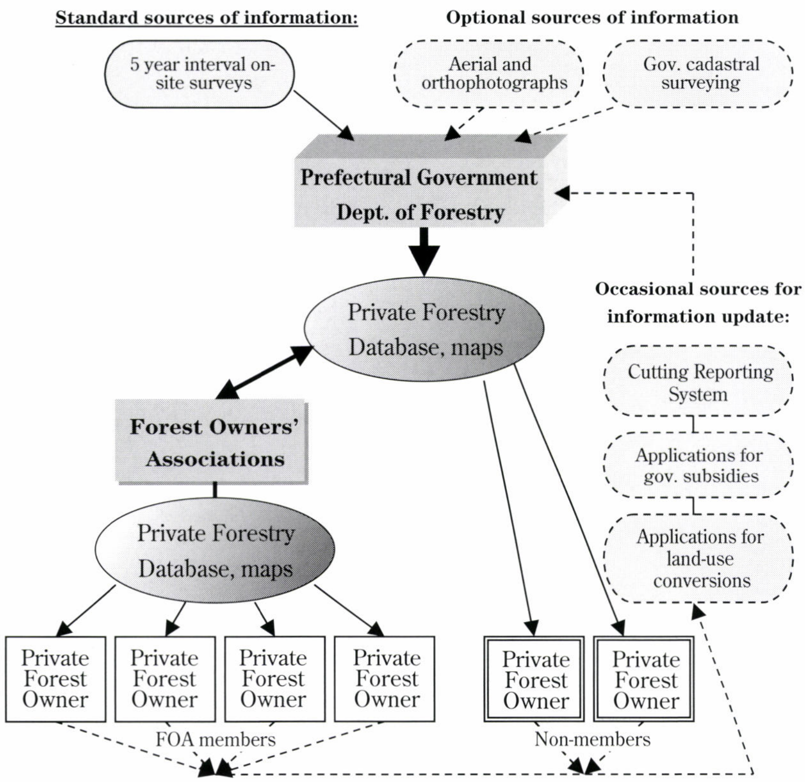

Fig. 1 Information flow in private forests in Japan

relationship between the size of forest property and having a management plan only at the 8% level of significance (Table 2). As for the primary objectives of forestland ownership, 'Timber production' was cited significantly more often in the '10-20ha' and 'over 20ha' categories than in the '0-5ha' category. The difference between the '5-10ha' ownerships and the other three categories was not significant at the 0.05 level, however. For 'Inherited land...', significant differences were found between the '0-5ha' size class and the larger two categories, and between the '5-10ha' and the 'Over 20ha' size classes (Table 3).

DISCUSSION

The results of the FOA survey imply that there is apparently no consistency in the information management of the associations. This is in spite of the fact that the Department of Forestry (Prefectural Government) theoretically provides each association with a private forestry database (updated by field surveys in every 5 years), accompanied by maps indicating the forest ownerships. One must assume that the quality of the data is dependent upon the FOAs' individual policies. It seems that there are no common guidelines or fixed criteria for the FOAs' data policies, even within the prefecture. Obviously, this makes it extremely difficult to monitor the ongoing processes in the private sector's forest resources and forest management activity.

Fig. 1 may provide some additional hints of why the FOAs' information management is so ineffective. Although the Prefectural Government is supposed to provide the forest owners' associations with inventory and ownership data and the landowners themselves may also acquire this information from them, there is no regular feedback from the grassroots level in relation to the accuracy of information or the changes that took place on the owners' lands in the meantime. The majority of the landowners are not even aware of the existence of the database (Matsushita, 1996). The optional cutting reports and the applications for government subsidies and land-use conversions may provide useful but only occasional information.

Good information management is a necessary but not sufficient condition for reinvigorating the private forestry sector in Japan. The results of our investigation regarding forest landowners' behavior may provide some clues why the promotion of cooperative management must also be incorporated into an integrated forest management planning system. The results indicate that the level of silvicultural activity and the probability of having a management plan tend to be higher on larger forest properties. The results also indicate that the role of timber production as an ownership objective was significantly greater in the larger tracts than in the smaller ones. Obviously, tendencies of forest ownership parcelization do not favor domestic timber production in Japan. Using the same forest roads, machinery, management plan and administrative procedures (such as the applications for government subsidies) would significantly reduce management costs. This is, however, not the only benefit of cooperative forest management. Since a larger forest area usually has a better age-class distribution than a smaller one, and, in general, there tends to be a higher diversity of assets in a larger area, cooperative management may provide landowners with a more balanced and diverse flux of timber or other forest products. This may serve as an incentive for the landowners to think about their forestland as a potential and reliable source of income.

CONCLUSION

Monitoring the forest resources and forestry activities on private forests is a prerequisite for finding effective measures for integrating, orienting and reinvigorating the sector's role in supplying the Japanese population with the various forest products they demand. Forest owners' associations could act as the principal organizations to fulfill these tasks. However, considering the above results regarding the FOAs' data management policies, radical changes would be needed for them to fulfill this role. Comprehensive directives or guidelines should be established to encourage the associations to collect, maintain, update and utilize the information that would be minimally necessary for management planning at both the regional and at the owners' level. It is the responsibility of the prefectural governments to determine the quality of the information required to enable effective management planning.

In summary, we propose the following action plan: Step 1 is to construct a practical monitoring and information management system for private forests. Step 2 would address the parcelization problem by promoting cooperative management by the FOAs, in collaboration with the prefectural and municipal forestry offices. Finally, Step 3 requires a radical change in the government's incentive policies in order to realize the above "movements." Without adequate subsidies of silvicultural operations, cooperative management, and preparation of management plans, the landowners will not be encouraged to act, as the stagnant domestic wood-market currently does not provide them with sufficient profits to cover management costs.

There are many other timber importing countries like Japan where a substantial portion of timberland is held by inactive, small-scale private ownerships. South Korea, the United States, and to a lesser extent, Spain, Italy, France and Germany all share the same situation. The relatively low self-sufficiency rate of these countries in timber production might be increased by directing attention to those owners who have, or might have, the intention but, due to their small scale, lack the resources to manage their forests for timber production. Cooperative forest management is an important option for overcoming this problem. The potential of this segment of landowners can only be evaluated and capitalized on by maintaining a permanent and comprehensive monitoring system that not only keeps track of these forest resources but also charts the current needs and constraints of the landowners. Although the establishment and maintenance costs of such a system might be high, these developed countries are the ones that should take the lead in developing landscape-level, cross-boundary forest management schemes. Success in these efforts will reduce the burden these countries place on the resources of the timber supplier countries. We are not suggesting the eradication of the international timber trade. However, by achieving a more balanced import ratio in these countries, the suppliers could focus on a more sustainable level of production of higher quality forest products.

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Article

Estimating Sunny Crown Length using Stand Density, Total Height, and Height Increment in Even-Aged Closed Hinoki Cypress Stands

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ABSTRACT

Estimating the sunny crown volume or surface area requires the sunny crown length, as well as the crown profile defined as a change in crown radius from the tree apex toward the ground, because sunny crown volume or surface area can be obtained by rotating the crown profile from the apex to the base of the sunny crown. In this study, we presented a model to estimate sunny crown length in even-aged closed hinoki cypress (*Chamaecyparis obtusa* ENDL.) stands. The model requires only three attributes: stand density, total height, and height increment of individual trees. To evaluate the model, it was applied to a 36-year-old hinoki cypress stand in which three plots of various stand density were established. The model provided accurate and precise sunny crown length estimates. Combining the model with a total height growth model allows us to estimate sunny crown length because stand density is generally a known variable.

Keywords: sunny crown length, even-aged closed hinoki cypress stand, stand density, total height, height increment

INTRODUCTION

Given that the crown of a tree supports the foliage quantitatively and spatially, crown dimensions are often incorporated in growth and yield models as part of the information used to estimate tree growth (AVERY and BURKHART, 2002). In particular, sunny crown volume or surface area is an effective predictor of stem volume growth (INOSE, 1982; KAJIHARA, 1985). Therefore, the estimating sunny crown volume or surface area is useful for providing inputs for use in a growth model.

Estimating the sunny crown volume or surface area requires the crown profile, defined as a change in crown radius from the tree apex toward the ground, as well as the sunny crown length, because sunny crown volume or surface area can be obtained by rotating the crown profile from the apex to the base of the sunny crown. Previously, WAGUCHI and UEDA (2005) proposed an equation to represent the sunny crown profile of hinoki cypress (*Chamaecyparis obtusa* ENDL.) using the total height increment. If a model for estimating the sunny crown length using the total height increment were available, the integration of the sunny crown length estimation model and the sunny crown profile equation proposed by WAGUCHI and UEDA (2005) into a total height growth model would enable the estimation of the sunny crown volume and surface area in hinoki cypress. Although many total height growth models have been proposed (*e.g.*, BIGING and DOBBERTIN, 1992; COLE and LORIMER, 1994; KOBAYASHI, 1978; OTTORINI, 1991; VALENTINE, 1985; WENSEL *et al.* 1987), a model for estimating sunny crown length using the total height increment has not yet been reported. Therefore, the objective of this study was to present a sunny crown length estimation model using the total height increment for even-aged closed hinoki cypress stands.

MODEL FOR ESTIMATING SUNNY CROWN LENGTH

The crown profile is given by the relationship between the crown radius r at a point on the stem axis and the distance z from the apex to this point. The following equation is often used for conifers:

$$r = az^b \tag{1}$$

where a and b are parameters. Equation (1) fits sunny crown profiles for todo fir (*Abies sachalinensis* MAST.) (INOSE, 1982), Japanese cedar (*Cryptomeria japonica* D. DON) (MIZUNAGA, 1992; 1998), hinoki cypress (MIZUNAGA, 1998), and black

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spruce (*Picea mariana* BSP) (RAULIER *et al.*, 1996) well. WAGUCHI (2004) showed that parameter b in eq. (1) was invariant among hinoki cypress trees. Moreover, WAGUCHI and UEDA (2005) confirmed that the relationship between the parameter a in eq. (1) and the annual total height increment (HI) for hinoki cypress tree could be described using eq. (2), and obtained eq. (3) to represent the difference in the sunny crown profile using HI:

$$a = c\mathrm{HI}^d \quad (2)$$

$$r = c\mathrm{HI}^d z^b \quad (3)$$

where c and d are constants. Thus, once the values of HI and constants b, c, and d are available, sunny crown length is determined using the crown radius at the base of the sunny crown (*i.e.*, sunny crown radius, SCR).

To obtain the SCR for individual tree, the sum of the sunny crown basal area per unit stand area (SCBA) was adopted in the model. The sunny crown basal area is defined as the area of the crown cross section, which is assumed to be a circle, at the base of the sunny crown. In even-aged closed stands, sum of growing space for each crown is limited by stand area, while average of growing space increases as stand density decreases. Therefore, SCBA in even-aged closed stands may have a definite amount regardless of stand density. If this is true, SCBA can be obtained from SCBA measurements in even-aged closed hinoki cypress stands. On the other hand, even if SCBA depends on stand density, once a functional relationship between stand density and SCBA has been determined, the SCBA of a given stand can be estimated from the stand density which can be measured easily. After obtaining SCBA, distributing the SCBA among trees in the stand appropriately enables us to estimate the SCR of each tree.

To distribute SCBA among every tree in a given stand, we assume that the height to the base of the sunny crown is invariant among trees in the given stand. The SCR of the i-th tree, SCR_i (m) (i = 1, 2, ..., n), is given by

$$\begin{aligned}\mathrm{SCR}_i &= c\mathrm{HI}_i^d\mathrm{SCR}_i^b \\ &= c\mathrm{HI}_i^d(\mathrm{TH}_i - \mathrm{H_{SCB}})^b\end{aligned} \quad (4)$$

where HI_i (m/year), SCL_i (m), and TH_i (m) are the annual total height increment, the sunny crown length, and the total height of the i-th tree, and $\mathrm{H_{SCB}}$ (m) is the height to the base of the sunny crown, which is assumed to be invariant among trees in the stand. The relation between these variables is depicted in Fig. 1. The SCBA ($\mathrm{m^2/ha}$) of the stand is given by

$$\begin{aligned}\mathrm{SCBA} &= \frac{\rho}{n}\sum_{i=1}^{n}\pi\mathrm{SCR}_i^2 \\ &= \frac{\rho}{n}\sum_{i=1}^{n}\pi\left[c\mathrm{HI}_i^d(\mathrm{TH}_i-\mathrm{H_{SCB}})^b\right]^2\end{aligned} \quad (5)$$

where ρ (stems/ha) represents the stand density. Therefore, $\mathrm{H_{SCB}}$ can be calculated by substituting SCBA obtained using a ρ-SCBA relationship in eq. (5), and SCL_i can be calculated by subtracting $\mathrm{H_{SCB}}$ estimate from THi.

RELATIONSHIP BETWEEN ρ AND SCBA

To examine the relationship between ρ and SCBA, ρ and SCBA were measured for seven even-aged closed stands of hinoki cypress in Nara, Japan. Characteristics of these stands are summarized in Table 1. For each stand, a plot was established to include at least 30 trees. The crown diameter at the base of the sunny crown of every tree in the seven plots was measured using a wide-scale Spiegel relascope (KAJIHARA, 1974). The sunny crown basal area for each tree was calculated using the crown diameter measurement. The base of the sunny crown was averaged visually to find the point representing the average height to the top point of the crown contact in the direction of the contour. The SCBA for each plot was calculated by dividing the sum of the sunny crown basal area by the plot area.

Fig. 2 shows the change in SCBA with ρ for the seven even-aged hinoki cypress stands. The SCBA increased with

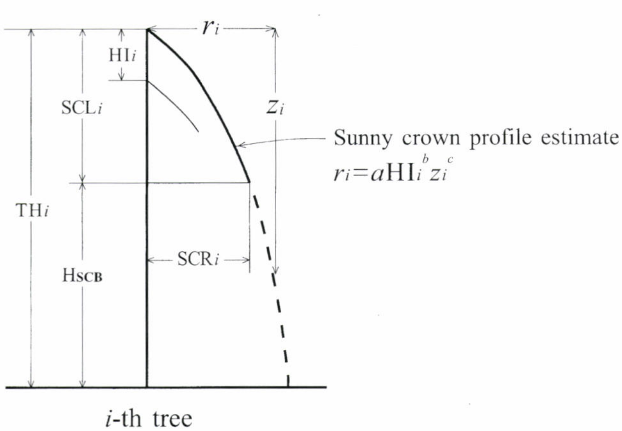

Fig. 1 Relationships among variables in the sunny crown length estimation model

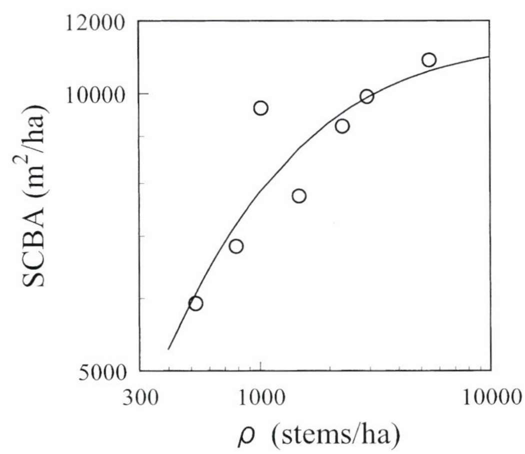

Fig. 2 Relationship between ρ and SCBA
The solid line indicates the fitted regression equation (6).

Table 1 Summary of seven stands in which the relationship between ρ and SCBA was examined

Stand	Age (year)	Density ρ (stems/ha)	Number of measured trees (stems)	Mean diameter at breast height (cm)	Mean total height (m)
1	14	5446	37	8.6	6.5
2	30	2284	36	18.0	18.0
3	40	2928	37	16.2	15.3
4	55	1475	35	18.4	17.9
5	62	1010	37	27.5	21.8
6	75	783	44	33.3	22.3
7	100	522	68	38.9	24.5

increasing ρ. This result indicates that the assumption that SCBA is constant regardless of ρ will produce overestimates in H_{SCB} for denser stand, and underestimates for thinner stand. Therefore, in this study, assuming that SCBA depends on ρ, the relationship between ρ and SCBA was described by the following reciprocal equation, which represents between ρ and amount per unit stand area well (ANDO, 1968),

$$\frac{1}{SCBA}=\frac{0.0407687}{\rho}=0.0000873. \quad (6)$$

The regression equation was statistically significant ($r^2 = 0.767$, $F = 16.459$, $p < 0.01$). Although further studies will be required to clarify the relationship of SCBA to ρ, SCBA substituted in eq. (5) was estimated using eq. (6) in this study.

MODEL EVALUATION

To evaluate the model, it was applied to a 36-year-old hinoki cypress stand in Nara. In this stand, three plots of various stand density were established. Descriptions of these plots are provided in Table 2. In each plot, the total height of every tree has been measured for seven years annually. The height to the base of the sunny crown of every tree in the plots was measured. The sunny crown length was calculated by subtracting the height to the base of the sunny crown from the total height. The annual total height increment was calculated by subtracting the previous-year total height measurement from that of the current year. The measurement error of the annual total height increment would be small because the total height has been measured annually with attention to earlier measurements. For each tree, crown cross-sectional areas, assumed to be a circle, at 0.01-m height intervals from the ground to the apex were calculated from the crown radius estimated using eq. (3). The constants b, c, and d in eq. (3) were set at 0.686, 0.401, and -0.299 (WAGUCHI and UEDA, 2005), indicating that trees with smaller HI have more obtuse sunny crowns than those with larger HI because the value of the constant d is negative. For each plot, the sum of the crown cross-sectional areas at each height was calculated and converted into the area per hectare. The height at which the sum of the crown cross-sectional area was the same area as

Table 2 Summary of three plots in a 36-year-old hinoki cypress stand to which the sunny crown length estimation model was applied

Plot	Density ρ (stems/ha)	Number of measured trees (stems)	Mean diameter at breast height (cm)	Mean total height (m)
A	4983	15	12.8	13.3
B	2523	15	14.9	14.6
C	1483	15	17.1	16.1

SCBA, which was estimated using eq. (6), was selected as H_{SCB}. The sunny crown length was calculated by subtracting the H_{SCB} estimate from the total height.

The model was evaluated by comparing the estimated to observed sunny crown lengths for each plot using a paired *t*-test to detect bias and a correlation analysis to measure model precision.

RESULTS AND DISCUSSION

The average ± standard deviation values of observed sunny crown length were 1.61 ± 0.76 m for plot A, 2.78 ± 0.61 m for plot B, and 3.59 ± 0.82 m for plot C, indicating that trees in thinner plot had longer sunny crown lengths than those in denser plot. Fig. 3 shows the relationship between the observed and estimated sunny crown lengths. For every plot, the dispersion observed around the line $y = x$ for sunny crown length values was well balanced, and no significant difference in the average value between observed and estimated sunny crown lengths was found ($t = 0.939$, $p > 0.20$ for plot A; $t = -1.477$, $p > 0.10$ for plot B; $t = -1.756$, $p > 0.10$ for plot C). This result indicates the effectiveness of eq. (6) because the bias in sunny crown length estimate is caused by the error in SCBA estimated using eq. (6).

Although the model was derived under the assumption that the height to the base of the sunny crown was invariant among trees in a given stand, the height to the base of the sunny crown varies from tree to tree in actual even-aged

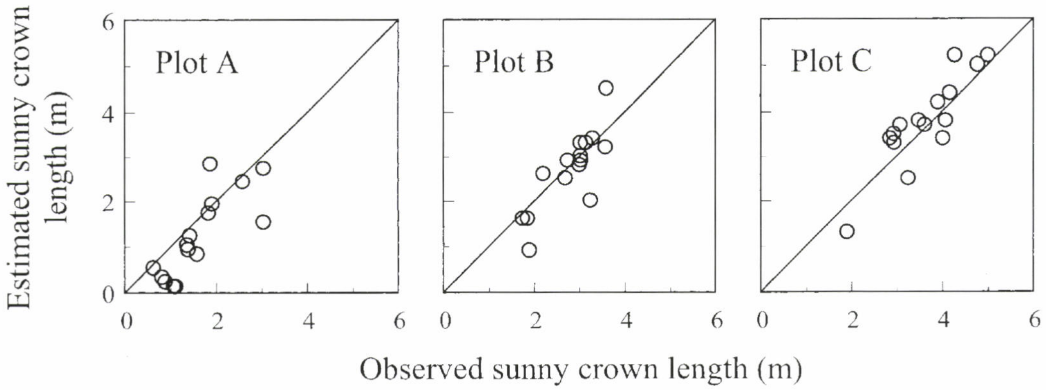

Fig. 3 Relationship between estimated and observed sunny crown lengths
The line $y = x$ is shown for comparison.

stands. Therefore, the assumption obviously causes error in sunny crown length estimate. However, in this study, statistically significant correlations between the observed and estimated sunny crown lengths were found in all plots ($r = 0.798$, $p < 0.01$ for plot A; $r = 0.822$, $p < 0.01$ for plot B; $r = 0.877$, $p < 0.01$ for plot C), indicating that the error in sunny crown length estimate which was caused by the assumption might be negligible in terms of the precision of sunny crown estimate. FUJIMORI (1970) and FUJIMORI *et al.* (1984) reported that there were no correlations between total height and height to the base of crown in even-aged young Japanese cedar and hinoki cypress stands. Furthermore, TAKEUCHI (2005) showed that no correlations were found between diameter at breast height and height to the base of crown in even-aged old Japanese cedar stands. On the other hand, KAJIHARA (1976) showed that shaded crown length was invariant among trees in even-aged Japanese cedar stands in Oita, Japan. The results of these studies indicate that height to the base of sunny crown has no relation to tree size because the height to the base of the sunny crown is the sum of the height to the base of the crown and the shaded crown length. Therefore, if no factor can explain differences in height to the base of sunny crown, the assumption of H_{SCB} may be applicable to the model presented here.

CONCLUSION

In this study, we presented a model to estimate sunny crown length in even-aged closed hinoki cypress stands and applied it to a 36-year-old hinoki cypress stand. The model provided accurate and precise sunny crown length estimates. For most growth and yield simulations, crown size information is usually not a readily available input parameter (LIU *et al.*, 1995). The model presented here requires only three attributes: stand density, total height, and height increment of individual trees. Therefore, combining the model with a total height growth model allows us to estimate sunny crown length, because stand density is generally a known variable, and can be incorporated in to the growth model. Furthermore, because the sunny crown profile estimation is obtained in the process of estimating sunny crown length, the sunny crown volume and surface area can be estimated using these attributes. In conclusion, the sunny crown length estimation model presented here is useful for estimating sunny crown size information (*i.e.*, sunny crown length, volume, and surface area) of a tree in even-aged closed hinoki cypress stands.

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Article

An Estimate of Full Density Curves for Branches on Standing Trees: A Case Study of the Evergreen Broadleaf Tree, *Quercus acuta*, in the Tokyo University Forest in Chiba, Japan

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ABSTRACT

The purpose of this study was to determine the full density curves of branches on standing trees. Sixty sample trees of *Quercus acuta* in a single stand were selectively cut in the Tokyo University Forest in Chiba, and then diameters and lengths of those branches with more than 2cm diameter that were at a length between 3.3m and 9.3m above ground were measured at one meter intervals along their stems and branches. To derive the full density curve of branches, the number of branches at a specific length and the maximum average volumes of branches above that length were selected to be independent and dependent variables, respectively in reference to the pipe model theory. The linear relationships between these variables were investigated on a log-log scale. The result showed that the regression estimates were significant for lengths from 4.3m to 8.3m, and that the full density curves for these significant lengths were considered to have a common slope parameter of -0.9801. This implied that the -3/2 power law of self-thinning is effective for branches on standing trees that are similar to the standing trees in forest stands. Further research was required, however, to investigate whether this slope is applicable not only to *Quercus acuta* but also to other species.

Keywords: -3/2 power law, branch, broadleaf tree, full density curve, self-thinning

INTRODUCTION

A full density curve represents the relationship between the mass and number per unit area in overcrowded plant communities (SHIDEI, 1956; KIRA, 1957a, b; TADAKI, 1963). When the average weights of plants among overcrowded communities are plotted against their densities on a log-log scale, the relationship between the two variables will follow a single line. The slope of this line is generally around -3/2 regardless of species, age, initial density and soil fertility level; this has become known as the -3/2 power law of self-thinning (YODA *et al.*, 1963).

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The full density curve is expressed as follows:

$$\bar{v}_m = a_0 N^{-a_1} \quad [1]$$

or

$$\log\bar{v}_m = a_2 - a_1 \log N, \quad [2]$$

where $\bar{v}_m$ is the maximum attainable average volume of plants, N is the number or density of plants per unit area, a_0 or a_2 (= log a_0) is the intercept of the line and a_1 is its slope (SMITH and HANN, 1984).

The reason why the slope of the full density curve, a_1, becomes -3/2 is allometrically explained as follows, referring to WHITE (1981) and ZEIDE (1987). Given that the number of plants in a given space, N, raised to some power is proportional to their average horizontal width, $\bar{w}$, under fully occupied condition, this relation is expressed using the coefficient α by

$$\bar{w} \propto N^{-\frac{1}{\alpha}}. \quad [3]$$

Furthermore, the average width of plants is assumed to be proportional to their average vertical length, $\bar{l}$, on condition that plants of the same species are geometrically similar regardless of age and habitat conditions. Therefore,

$$\bar{l} \propto \bar{w}^{\beta}. \quad [4]$$

where β is a coefficient. Since the average volume of plants can be assumed to be proportional to the product of length and the power of the width, $\bar{v}$ is represented using the coefficient γ by

$$\bar{v} \propto \bar{w}^{\gamma}\bar{l} \propto \bar{w}^{\beta+\gamma} \propto N^{-\frac{\beta+\gamma}{\alpha}}. \quad [5]$$

YODA et al. (1963) considered that if each plant is completely closed, the coefficient α becomes two, and that if the forms of plants are completely similar, the parameters β and γ become one and two, respectively. Thus, the power of N in Eq. 5 becomes -3/2, which is derived from the geometrical manner in which the plants are packed together in a given space.

The slope parameter of the curve, however, is not exactly -3/2 in actual situations, which only exist in the ideal or virtual condition of $(\alpha, \beta, \gamma) = (2, 1, 2)$. For instance, SAKAGUCHI (1961) revealed that the slopes of full density curves on a log-log scale vary with planted tree species such as Japanese cedar, Japanese cypress and red pine in even-aged pure stands. WESTOBY and HOWELL (1986) and WELLER (1987) estimated hundreds of full density curves using both published data and temporal plot data from forest stands and concluded that the slopes were significantly different depending on the species, the site index and the tolerance. NISHIZONO *et al.* (2002) also supported WESTOBY, HOWELL and WELLER's conclusion, employing thousands of actual plot data from Japanese cedar and Japanese cypress planted stands.

Although the slope parameter of a full density curve is not exactly -3/2, it is a universal law among living creatures that the *N-v* plot is bounded by a specific curve. For instance, LONSDALE and WATKINSON (1983) showed that this law basically fits well with most plants such as monocotyledonous grass and dicotyledonous herbs. WATANABE (1985) discovered that even bamboo populations follow this law. The law is true not only among plants but also animals such as grasshoppers (BEGON *et al.*, 1986), seashells (HUGHES and GRIFFITHS, 1988) and sea trout (ELLIOT, 1993) if some experimental supports like constant food inputs are given to the target population.

Thus, the previous studies have proved the universality of the law mainly among different species and additionally among different ages, site conditions and so on. Here, from another point of view, since this law is intrinsically derived from the simple geometrical manner as shown in Eqs. 3 - 5, its universality seems to expand on different spatial scales: This law can be effective on an individual scale as well as on a community or population scale that have been reported in previous studies. As for forests, these scale relations are interpreted as standing trees for an individual scale and forest stands for a community scale, namely that the -3/2 power law seems effective for branches on standing trees that are similar to the standing trees in forest stands. Needless to say, there are ecologically, or physiologically, differences between the two scales: The self-thinning in a standing tree deals with new branch production according to height growth and translocation of photosynthates from a stem to branches (SPRUGEL, 2002) while the self-thinning in forest stands generally deals with no ingrowing tree. But at the same time, there are points in common between the two scales like a spatial competition for survival and resulting mortality according to a lack of sunlight, which make us expect the validity of the law on an individual scale as well. However, this kind of -3/2 power law among overcrowded branches has not been investigated until now.

Thus, in this study we direct our attention to the self-thinning, or to be exact, self-pruning in the following, occurring among branches on a standing tree. The purpose of this study is to determine the full density curve of branches, especially in regard to the relationship between the number of branches on standing trees and their average volume.

MATERIALS AND METHODS

Collection and Measurement of Samples

We collected data on the number of branches and their volumes from 60 samples of *Quercus acuta*, an evergreen broadleaf tree, in a single stand with a mixture of *Quercus acuta* and *Castanopsis sieboldii* in the Tokyo University Forest in Chiba. The university forest is located in the southern Boso peninsular, Kanto region, Japan. *Quercus acuta* is typical of the natural forests in this area. The sample trees were selectively cut to produce fuel woods, which compose the dominant trees in the subject stand. The basic statistics of the sample trees were as follows: The mean and standard deviation of stem diameters at a length (see detail in the following paragraph) of 1.3m were 17.43cm and 3.070cm; the same figures regarding tree length were 12.28m and 1.125m, respectively. Thus, the standard deviations of diameter and length were relatively low because the dominant trees were intentionally selected for fuel woods.

In each sample tree, diameters of those branches with more than 2cm diameter that were at a length between 3.3m to 9.3m above ground were measured at one meter intervals along the stem and branches. Note that the "length" of trees along a stem and branches is employed instead of the vertical "height" of trees in this measurement. The starting length of 3.3m represents the minimum length (or height) at which all sample trees have at least one branch, and the ending length of 9.3m represents the length that does not exceed the minimum sample tree length of 9.9m. In addition, the length of each branch was also measured. Furthermore, the volumes of branches were calculated by summing up the circular truncated cones, as defined by the following equation:

$$v = \frac{l}{3}\left(g_1 + g_2 + \sqrt{g_1 g_2}\right), \quad [6]$$

where v is the volume of a circular truncated cone that forms part of a branch, l is the length of the cone (basically one meter except at the top of branch), and g_1 and g_2 are the top and bottom basal areas of the cone, respectively, as calculated from corresponding diameters.

Selection of the Variables of the Density N and Average Volume $\bar{v}$

To derive a full density curve, the number of branches at a specific length per tree and the average volume of branches that are above a specific length per tree are selected as density N and average volume $\bar{v}$, respectively. The variable $\bar{v}$ is expressed by the total volume of branches above a specific length divided by the number of branches at a specific length on a single tree. For instance, let us think of a tree like Fig. 1a, where branches are colored black only to show them clearly. In the case of a 4.3m length (Fig. 1b), where the white lines represent the length along a stem and the branches above ground, the number of branches at that length, $N_{4.3}$, is two, and the corresponding total branch volume is expressed by $(v1_{4.3} + v2_{4.3} + v3_{4.3} + v4_{4.3})$. Consequently, $\bar{v}_{4.3}$ is $(v1_{4.3} + v2_{4.3} + v3_{4.3} + v4_{4.3})/2$. Similarly, in the case of a 5.3m length (Fig. 1c), the number of branches at that length, $N_{5.3}$, is four, and the corresponding total branch volume is expressed by $(v1_{5.3} + v2_{5.3} + v3_{5.3} + v4_{5.3} + v5_{5.3} + v6_{5.3})$. Consequently, $\bar{v}_{5.3}$ is $(v1_{5.3} + v2_{5.3} + v3_{5.3} + v4_{5.3} + v5_{5.3} + v6_{5.3})/4$.

Though other variables such as the total number of branches per tree and their average volume may instead be conceivable for N and $\bar{v}$, N_i and $\bar{v}_i$ as defined above seem to represent the full density curve of branches in the most effective way based on the concept of the pipe model theory (SHINOZAKI *et al.*, 1964). The theory expresses the linearly proportional relationship between the total basal area at a specific height and the total biomass above the specific height in a plant body, that can be represented in the case of this study as follows;

$$\frac{\sum_j v_{ji}}{N_i} = \bar{v}_i \propto \frac{\sum_j g_{ji}}{N_i} = \bar{g}_i \ (\because \sum_j v_{ji} \propto \sum_j g_{ji}) \qquad [7]$$

where g_{ji} represents the basal area of the jth branches at length i and $\bar{g}_i$ is their average. Though $\bar{v}_i$ excludes the photosynthetic organ of leaves above the length i while SHINOZAKI *et al.* (1964) includes them, Eq. 7 seems practically valid considering the proportion of leaves is relatively low compared with $\sum_j v_{ji}$. Note that the pipe model theory for branches assumed in Eq. 7 corresponds to the geometrical similarity of plants assumed in Eq. 4. Moreover, if it is assumed that the number of branches in a given space is proportional to their average diameter, so that the number of branches raised to some power is proportional to their average basal area, under fully occupied condition as same as assumed in Eq. 3, then

$$\bar{g}_i \propto N_i^{\delta}, \qquad [8]$$

which indicates that the above-defined $\bar{v}_i$ is proportional to the above-defined N_i raised to some power, δ, on a single tree;

$$\bar{v}_i \propto \bar{g}_i \propto N_i^{\delta}. \qquad [9]$$

The power index, δ, can be analyzed into more specific indices like $(\beta + \gamma)/\alpha$ in Eq. 5.

As shown in the cases of Fig. 1, since the variables N_i and $\bar{v}_i$ change with length i, it is furthermore necessary to investigate what length is appropriate for determining the full density curve between N_i and $\bar{v}_i$; self-pruning does not necessarily work at the height where the density of branches is relatively low.

Thus, N_is and $\bar{v}_i$s are calculated at a length of i (=3.3, 4.3, 5.3, 6.3, 7.3, 8.3 and 9.3m) for all 60 sample trees. After this calculation, $\bar{v}_i$s are arranged in order of corresponding N_is at each length i, and then the maximum $\bar{v}_{m_i}$s are identified for Eq. 2 among the $\bar{v}_i$s that have the same value of N_is for each length i (see details in the next section). Finally, the parameters of a_{1_i} and a_{2_i} in Eq. 2 are estimated by the ordinary least squares method for each length i, and the differences of the parameter

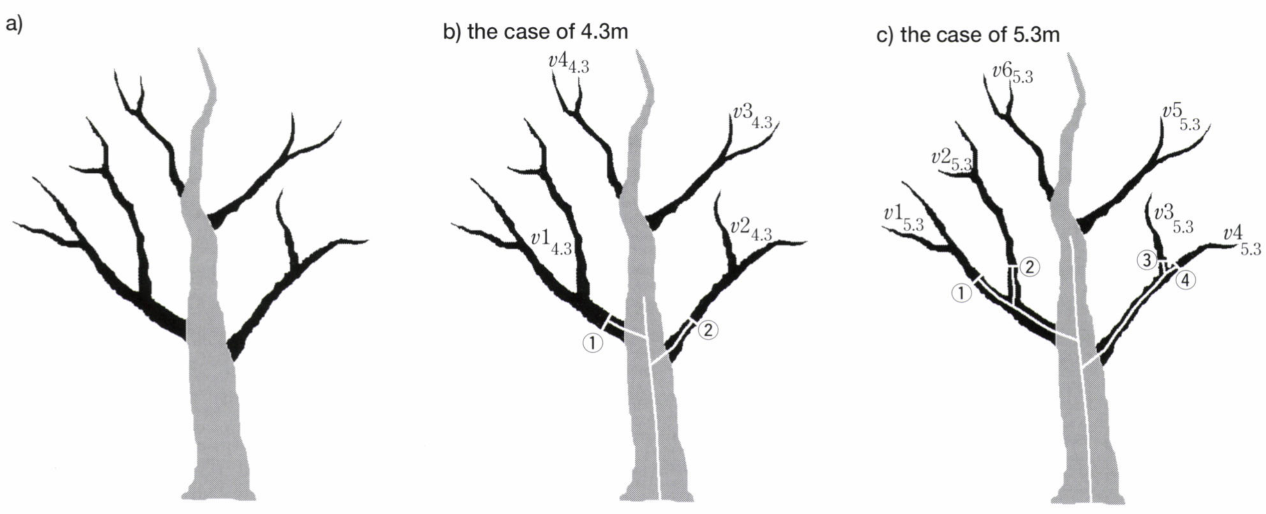

Fig. 1 Illustration of the way to identify the variables for a full density curve: a) A sample tree having branches colored black, b) the identified number of branches and branch volumes at and above a length of 4.3m, and c) similar to b but above a length of 5.3m

values for the lengths are statistically analyzed.

RESULTS AND DISCUSSION

Variable Values

Table 1 shows the variables obtained from 60 sample

Table 1 Variables obtained from 60 sample trees

Tree No.	3.3m		4.3m		5.3m		6.3m		7.3m		8.3m		9.3m	
	$N_{3.3}$	$\Sigma v_{3.3}$	$N_{4.3}$	$\Sigma v_{4.3}$	$N_{5.3}$	$\Sigma v_{5.3}$	$N_{6.3}$	$\Sigma v_{6.3}$	$N_{7.3}$	$\Sigma v_{7.3}$	$N_{8.3}$	$\Sigma v_{8.3}$	$N_{9.3}$	$\Sigma v_{9.3}$
1	1	0.0620	2	0.0494	2	0.0365	2	0.0252	2	0.0154	4	0.0086	2	0.0024
2	1	0.0610	1	0.0490	1	0.0379	2	0.0276	3	0.0188	6	0.0106	2	0.0026
3	1	0.0613	3	0.0495	3	0.0362	6	0.0233	5	0.0109	3	0.0031		
4	1	0.0452	2	0.0350	2	0.0253	2	0.0167	4	0.0088	2	0.0024		
5	3	0.0424	5	0.0297	2	0.0188	5	0.0102	3	0.0039	1	0.0007		
6	2	0.0467	2	0.0349	2	0.0250	5	0.0154	4	0.0063	1	0.0011		
7	1	0.0692	1	0.0559	1	0.0441	1	0.0336	2	0.0241	4	0.0153	3	0.0048
8	2	0.0821	3	0.0634	3	0.0458	5	0.0315	5	0.0180	6	0.0084	3	0.0017
9	1	0.0556	2	0.0444	2	0.0337	3	0.0251	4	0.0169	3	0.0101	3	0.0046
10	1	0.0781	1	0.0643	2	0.0508	2	0.0397	4	0.0280	6	0.0155	5	0.0047
11	1	0.0649	1	0.0513	1	0.0382	3	0.0263	3	0.0162	3	0.0062	2	0.0008
12	1	0.0666	1	0.0536	1	0.0430	1	0.0341	2	0.0242	3	0.0158	4	0.0083
13	1	0.0863	2	0.0701	4	0.0524	6	0.0369	5	0.0229	7	0.0100	2	0.0017
14	1	0.0926	1	0.0769	2	0.0616	2	0.0485	4	0.0349	6	0.0222	3	0.0124
15	1	0.0676	1	0.0540	1	0.0422	1	0.0330	2	0.0244	4	0.0154	3	0.0067
16	1	0.0868	1	0.0732	1	0.0613	1	0.0495	1	0.0394	2	0.0299	4	0.0193
17	1	0.0589	1	0.0481	1	0.0394	2	0.0292	3	0.0209	3	0.0117	3	0.0065
18	1	0.1008	1	0.0877	1	0.0762	2	0.0634	2	0.0506	3	0.0373	5	0.0245
19	1	0.0931	1	0.0774	1	0.0638	2	0.0497	2	0.0367	3	0.0236	4	0.0149
20	1	0.1130	2	0.0942	2	0.0754	2	0.0588	5	0.0400	7	0.0238	5	0.0086
21	1	0.0967	1	0.0811	1	0.0656	1	0.0518	3	0.0394	3	0.0250	4	0.0152
22	1	0.0989	1	0.0851	2	0.0689	2	0.0549	2	0.0422	4	0.0296	3	0.0178
23	1	0.0923	1	0.0783	1	0.0651	2	0.0519	3	0.0385	3	0.0258	5	0.0126
24	1	0.1102	1	0.0947	1	0.0791	2	0.0636	2	0.0498	3	0.0363	3	0.0251
25	1	0.0950	2	0.0770	2	0.0614	3	0.0469	4	0.0336	5	0.0213	3	0.0116
26	1	0.0843	1	0.0685	1	0.0553	2	0.0427	3	0.0293	3	0.0171	3	0.0082
27	3	0.0747	4	0.0558	6	0.0406	4	0.0236	5	0.0124	3	0.0025	1	0.0001
28	1	0.0955	1	0.0801	1	0.0669	2	0.0541	3	0.0405	3	0.0280	4	0.0175
29	1	0.0630	1	0.0499	1	0.0401	2	0.0313	2	0.0206	2	0.0121	3	0.0060
30	3	0.0950	4	0.0713	4	0.0526	5	0.0375	9	0.0228	5	0.0079	3	0.0016
31	1	0.1091	2	0.0912	3	0.0706	6	0.0497	8	0.0287	7	0.0114	3	0.0014
32	1	0.1109	1	0.0929	1	0.0764	1	0.0614	2	0.0475	2	0.0350	4	0.0234
33	1	0.0874	3	0.0717	3	0.0551	3	0.0417	3	0.0311	4	0.0185	3	0.0091
34	1	0.0809	1	0.0662	1	0.0530	1	0.0409	2	0.0291	4	0.0177	3	0.0074
35	1	0.1211	1	0.1022	1	0.0849	3	0.0679	5	0.0468	6	0.0269	7	0.0130
36	2	0.1724	3	0.1504	3	0.1294	4	0.1078	2	0.0896	3	0.0726	5	0.0552
37	1	0.0976	1	0.0800	1	0.0669	1	0.0546	1	0.0438	1	0.0348	2	0.0262
38	1	0.1225	1	0.1061	2	0.0920	2	0.0742	4	0.0582	8	0.0430	7	0.0261
39	2	0.1286	2	0.1056	4	0.0807	6	0.0575	6	0.0379	8	0.0207	6	0.0056
40	2	0.1538	2	0.1257	2	0.1010	2	0.0793	3	0.0594	4	0.0423	4	0.0255
41	2	0.1390	3	0.1164	3	0.0940	5	0.0691	7	0.0455	10	0.0226	4	0.0047
42	1	0.1051	2	0.0832	2	0.0629	3	0.0459	2	0.0304	5	0.0188	7	0.0074
43	1	0.1084	1	0.0891	2	0.0706	4	0.0543	6	0.0375	7	0.0206	3	0.0071
44	1	0.0643	2	0.0425	2	0.0287	3	0.0178	3	0.0095	3	0.0028		
45	1	0.1303	2	0.1088	2	0.0845	3	0.0619	3	0.0438	5	0.0272	7	0.0121
46	1	0.1510	1	0.1272	1	0.1064	2	0.0878	2	0.0667	6	0.0467	8	0.0285
47	3	0.0920	3	0.0707	3	0.0539	6	0.0393	7	0.0230	4	0.0088	3	0.0016
48	2	0.1042	4	0.0821	4	0.0611	4	0.0449	5	0.0288	8	0.0144	6	0.0034
49	1	0.1351	1	0.1153	1	0.0962	1	0.0789	2	0.0623	4	0.0452	7	0.0278
50	1	0.1245	1	0.1039	2	0.0828	3	0.0611	6	0.0419	8	0.0244	5	0.0049
51	2	0.1844	3	0.1493	5	0.1168	6	0.0862	11	0.0582	10	0.0320	8	0.0122
52	1	0.0997	2	0.0775	3	0.0574	6	0.0417	8	0.0258	6	0.0123	1	0.0032
53	1	0.1091	1	0.0908	1	0.0748	1	0.0609	5	0.0448	5	0.0280	7	0.0136
54	1	0.2151	2	0.1874	2	0.1535	4	0.1250	8	0.0957	7	0.0623	8	0.0379
55	5	0.2350	7	0.1824	7	0.1416	10	0.1026	11	0.0671	8	0.0380	7	0.0159
56	3	0.1506	4	0.1079	6	0.0714	9	0.0408	11	0.0150	2	0.0014		
57	3	0.1651	7	0.1297	14	0.0882	12	0.0511	15	0.0206	4	0.0023		
58	3	0.2304	3	0.1792	5	0.1370	10	0.0994	11	0.0622	9	0.0319	9	0.0134
59	2	0.1065	3	0.0796	4	0.0547	3	0.0373	4	0.0219	7	0.0091	3	0.0019
60	2	0.1755	3	0.1367	4	0.1052	5	0.0759	6	0.0511	5	0.0312	8	0.0142

Notes. N_i: the number of branches at the length i; Σv_i: the cumulative branch volumes above the length i (m^3)

trees; these are the numbers of branches for the length i, N_is, and the cumulative branch volumes above the length i, Σv_is, as calculated by Eq. 6. The sample trees are listed in order of their stem diameter for the 1.3m length, so that the cumulative volumes roughly increase as the sample tree number increases for each length. The cumulative volume of branches decreases as the length increases for each same sample tree; in several trees there was no countable branch at a length of 9.3m.

Table 2 shows the variables N_i and $\bar{v}_i$. As mentioned

Table 2 The variables of N_i and $\bar{v}_i$ at the length i

3.3m		4.3m		5.3m		6.3m		7.3m		8.3m		9.3m	
$N_{3.3}$	$\bar{v}_{3.3}$	$N_{4.3}$	$\bar{v}_{4.3}$	$N_{5.3}$	$\bar{v}_{5.3}$	$N_{6.3}$	$\bar{v}_{6.3}$	$N_{7.3}$	$\bar{v}_{7.3}$	$N_{8.3}$	$\bar{v}_{8.3}$	$N_{9.3}$	$\bar{v}_{9.3}$
1	0.0452	1	0.0481	1	0.0379	1	0.0330	1	0.0394	1	0.0007	1	0.0001
1	0.0556	1	0.0490	1	0.0382	1	0.0336	1	0.0438	1	0.0011	1	0.0032
1	0.0589	1	0.0499	1	0.0394	1	0.0341	2	0.0077	1	0.0348	2	0.0004
1	0.0610	1	0.0513	1	0.0401	1	0.0409	2	0.0103	2	0.0007	2	0.0009
1	0.0613	1	0.0536	1	0.0422	1	0.0495	2	0.0121	2	0.0012	2	0.0012
1	0.0620	1	0.0540	1	0.0430	1	0.0518	2	0.0121	2	0.0061	2	0.0013
1	0.0630	1	0.0559	1	0.0441	1	0.0546	2	0.0122	2	0.0149	2	0.0131
1	0.0643	1	0.0643	1	0.0530	1	0.0609	2	0.0145	2	0.0175	3	0.0005
1	0.0649	1	0.0662	1	0.0553	1	0.0614	2	0.0152	3	0.0008	3	0.0005
1	0.0666	1	0.0685	1	0.0613	1	0.0789	2	0.0184	3	0.0009	3	0.0005
1	0.0676	1	0.0732	1	0.0638	2	0.0083	2	0.0211	3	0.0010	3	0.0006
1	0.0692	1	0.0769	1	0.0651	2	0.0126	2	0.0238	3	0.0021	3	0.0006
1	0.0781	1	0.0774	1	0.0656	2	0.0138	2	0.0249	3	0.0034	3	0.0015
1	0.0809	1	0.0783	1	0.0669	2	0.0146	2	0.0253	3	0.0039	3	0.0016
1	0.0843	1	0.0800	1	0.0669	2	0.0156	2	0.0312	3	0.0053	3	0.0020
1	0.0863	1	0.0801	1	0.0748	2	0.0198	2	0.0333	3	0.0057	3	0.0022
1	0.0868	1	0.0811	1	0.0762	2	0.0214	2	0.0448	3	0.0079	3	0.0022
1	0.0874	1	0.0851	1	0.0764	2	0.0242	3	0.0013	3	0.0083	3	0.0024
1	0.0923	1	0.0877	1	0.0791	2	0.0248	3	0.0032	3	0.0086	3	0.0025
1	0.0926	1	0.0891	1	0.0849	2	0.0259	3	0.0054	3	0.0093	3	0.0027
1	0.0931	1	0.0908	1	0.0962	2	0.0270	3	0.0063	3	0.0121	3	0.0030
1	0.0950	1	0.0929	1	0.1064	2	0.0275	3	0.0070	3	0.0124	3	0.0039
1	0.0955	1	0.0947	2	0.0094	2	0.0294	3	0.0098	3	0.0242	3	0.0041
1	0.0967	1	0.1022	2	0.0125	2	0.0317	3	0.0104	4	0.0006	3	0.0059
1	0.0976	1	0.1039	2	0.0127	2	0.0318	3	0.0128	4	0.0021	3	0.0084
1	0.0989	1	0.1061	2	0.0144	2	0.0371	3	0.0131	4	0.0022	4	0.0012
1	0.0997	1	0.1153	2	0.0168	2	0.0396	3	0.0135	4	0.0038	4	0.0021
1	0.1008	1	0.1272	2	0.0183	2	0.0439	3	0.0146	4	0.0038	4	0.0037
1	0.1051	2	0.0175	2	0.0254	3	0.0059	3	0.0198	4	0.0044	4	0.0038
1	0.1084	2	0.0175	2	0.0307	3	0.0084	4	0.0016	4	0.0046	4	0.0044
1	0.1091	2	0.0213	2	0.0308	3	0.0088	4	0.0022	4	0.0074	4	0.0048
1	0.1091	2	0.0222	2	0.0315	3	0.0124	4	0.0042	4	0.0106	4	0.0058
1	0.1102	2	0.0247	2	0.0344	3	0.0139	4	0.0055	4	0.0113	4	0.0064
1	0.1109	2	0.0350	2	0.0353	3	0.0153	4	0.0070	5	0.0016	5	0.0009
1	0.1130	2	0.0385	2	0.0377	3	0.0156	4	0.0084	5	0.0038	5	0.0010
1	0.1211	2	0.0387	2	0.0414	3	0.0204	4	0.0087	5	0.0043	5	0.0017
1	0.1225	2	0.0416	2	0.0422	3	0.0206	4	0.0145	5	0.0054	5	0.0025
1	0.1245	2	0.0456	2	0.0460	3	0.0226	5	0.0022	5	0.0056	5	0.0049
1	0.1303	2	0.0471	2	0.0505	4	0.0059	5	0.0025	5	0.0062	5	0.0110
1	0.1351	2	0.0528	2	0.0768	4	0.0112	5	0.0036	6	0.0014	6	0.0006
1	0.1510	2	0.0544	3	0.0121	4	0.0136	5	0.0046	6	0.0018	6	0.0009
1	0.2151	2	0.0628	3	0.0153	4	0.0269	5	0.0058	6	0.0020	7	0.0011
2	0.0233	2	0.0937	3	0.0180	4	0.0312	5	0.0080	6	0.0026	7	0.0017
2	0.0411	3	0.0165	3	0.0184	5	0.0020	5	0.0090	6	0.0037	7	0.0019
2	0.0521	3	0.0211	3	0.0191	5	0.0031	5	0.0094	6	0.0045	7	0.0019
2	0.0533	3	0.0236	3	0.0235	5	0.0063	6	0.0063	6	0.0078	7	0.0023
2	0.0643	3	0.0239	3	0.0313	5	0.0075	6	0.0063	7	0.0013	7	0.0037
2	0.0695	3	0.0265	3	0.0431	5	0.0138	6	0.0070	7	0.0014	7	0.0040
2	0.0769	3	0.0388	4	0.0131	5	0.0152	6	0.0085	7	0.0016	8	0.0015
2	0.0862	3	0.0456	4	0.0132	6	0.0039	7	0.0033	7	0.0029	8	0.0018
2	0.0878	3	0.0498	4	0.0137	6	0.0062	7	0.0065	7	0.0034	8	0.0036
2	0.0922	3	0.0501	4	0.0153	6	0.0065	8	0.0032	7	0.0089	8	0.0047
3	0.0141	3	0.0597	4	0.0202	6	0.0069	8	0.0036	8	0.0018	(9)	(0.0015)
3	0.0249	4	0.0140	4	0.0263	6	0.0083	8	0.0120	8	0.0026		
3	0.0307	4	0.0178	5	0.0234	6	0.0096	(9)	(0.0025)	8	0.0031		
3	0.0317	4	0.0205	5	0.0274	6	0.0144	11	0.0014	8	0.0047		
3	0.0502	4	0.0270	6	0.0068	(9)	(0.0045)	11	0.0053	8	0.0054		
3	0.0550	(5)	(0.0059)	6	0.0119	10	0.0099	11	0.0057	(9)	(0.0035)		
3	0.0768	7	0.0185	(7)	(0.0202)	10	0.0103	11	0.0061	10	0.0023		
(5)	(0.0470)	7	0.0261	(14)	(0.0063)	(12)	(0.0043)	(15)	(0.0014)	10	0.0032		

Notes. The underlined $\bar{v}_i$s represent the maximum average volume of branches, $\bar{v}_{m_i}$s (m^3). The $\bar{v}_{m_i}$s in parentheses represent branches having a single sample for the corresponding N_is.

Table 3 The variables of N_i and $\bar{v}_{m_i}$ at the length i for the full density curve estimates

3.3m		4.3m		5.3m		6.3m		7.3m		8.3m		9.3m	
$N_{3.3}$	$\bar{v}_{m_{3.3}}$	$N_{4.3}$	$\bar{v}_{m_{4.3}}$	$N_{5.3}$	$\bar{v}_{m_{5.3}}$	$N_{6.3}$	$\bar{v}_{m_{6.3}}$	$N_{7.3}$	$\bar{v}_{m_{7.3}}$	$N_{8.3}$	$\bar{v}_{m_{8.3}}$	$N_{9.3}$	$\bar{v}_{m_{9.3}}$
1	0.2151	1	0.1272	1	0.1064	1	0.0789	1	0.0438	1	0.0348	1	0.0032
2	0.0922	2	0.0937	2	0.0768	2	0.0439	2	0.0448	2	0.0175	2	0.0131
3	0.0768	3	0.0597	3	0.0431	3	0.0226	3	0.0198	3	0.0242	3	0.0084
		4	0.0270	4	0.0263	4	0.0312	4	0.0145	4	0.0113	4	0.0064
		7	0.0261	5	0.0274	5	0.0152	5	0.0094	5	0.0062	5	0.0110
				6	0.0119	6	0.0144	6	0.0085	6	0.0078	6	0.0009
						10	0.0103	7	0.0065	7	0.0089	7	0.0040
								8	0.0120	8	0.0054	8	0.0047
								11	0.0061	10	0.0032		

Table 4 Parameter estimates of full density curves in lengths from 3.3m to 9.3m

Length	Parameter	Estimates[a]	t	p	
3.3	$a_{1_{3.3}}$	−0.9684 (−3.548, 1.611)	−4.770	0.1316	
	$a_{2_{3.3}}$	−0.6879 (−1.528, 0.1523)	−10.40	0.0610	
4.3	$a_{1_{4.3}}$	−0.9208 (−1.535, −0.3064)	−4.769	0.0175	*
	$a_{2_{4.3}}$	−0.8504 (−1.175, −0.5258)	−8.339	0.0036	**
5.3	$a_{1_{5.3}}$	−1.150 (−1.470, −0.8296)	−9.228	0.0003	**
	$a_{2_{5.3}}$	−0.8738 (−1.087, −0.661)	−10.56	0.0001	**
6.3	$a_{1_{6.3}}$	−0.9065 (−1.196, −0.6175)	−8.062	0.0005	**
	$a_{2_{6.3}}$	−1.109 (−1.291, −0.9273)	−15.67	0.0000	**
7.3	$a_{1_{7.3}}$	−0.9270 (−1.262, −0.5916)	−6.535	0.0003	**
	$a_{2_{7.3}}$	−1.271 (−1.505, −1.036)	−12.83	0.0000	**
8.3	$a_{1_{8.3}}$	−0.9566 (−1.314, −0.5987)	−6.320	0.0004	**
	$a_{2_{8.3}}$	−1.394 (−1.641, −1.146)	−13.32	0.0000	**
9.3	$a_{1_{9.3}}$	−0.2523 (−1.423, 0.918)	−0.5276	0.6167	
	$a_{2_{9.3}}$	−2.150 (−2.902, −1.398)	−6.994	0.0004	**

Notes. a) 95% confidence bounds of coefficients are given in parentheses.
α_{1_i}: the slope parameter at length i; α_{1_i}: the intercept parameter at length i.

above, $\bar{v}_i$ is calculated by $\Sigma v_i / N_i$ for each length in each sample tree, and then the $\bar{v}_i$s are sorted depending on their N_is and arranged in order of volume. Thus, in Table 2 the underlined $\bar{v}_i$s represent the maximum average volume of branches, $\bar{v}_{m_i}$s, for the corresponding N_is for each length i. Note that the N_is and $\bar{v}_{m_i}$s in parentheses have only one sample under the corresponding N_i, so that they are excluded from the following full density curve estimate because of their inability to have a maximum attainable value. To summarize, the variable values for the estimate are shown in Table 3.

Full Density Curves

Table 4 shows the parameter estimates for a_{1_i} and a_{2_i} in Eq. 2 for each length i; the estimated full density curves are illustrated in Fig. 2 on a log-log scale. The estimates are based on the logarithmic variables of Table 3 using the ordinary least squares method. The result shows that the parameter estimates for lengths of 3.3m and 9.3m are not significant. The reason for their insignificance at 3.3m lies in a lack of data: There are only three plots for the parameter estimate, which implies that the length of 3.3m is too short to contain an adequate number of branches. The reason for their insignificance at 9.3m lies in an absence of competition: At that length it seems that branches get thinner towards the tips and do not cause self-pruning any longer.

Moreover, the homogeneity of these significant slope parameters, a_{1_i}s from 4.3m to 8.3m, is tested based on the concept of the Chow test (Chow, 1960). The resulting ANOVA table is given in Table 5. In the table, the sum of squares (SS) between- and within-groups are represented by

$$SS_{bg} = \sum_{j=1}^{k}\sum_{i=1}^{nj}(Y_{ij} - \bar{Y}_j)^2 - \frac{\left\{\sum_{j=1}^{k}\sum_{i=1}^{nj}(X_{ij} - \bar{X}_j)(Y_{ij} - \bar{Y}_j)\right\}^2}{\sum_{j=1}^{k}\sum_{i=1}^{nj}(X_{ij} - \bar{X}_j)^2} - \sum_{j=1}^{k}\sum_{i=1}^{nj}\{Y_{ij} - (a_{1j}X_{ij} + a_{2j})\}^2 \quad [10]$$

and

$$SS_{wg} = \sum_{j=1}^{k}\sum_{i=1}^{nj}\{Y_{ij} - (a_{1j}X_{ij} + a_{2j})\}^2, \quad [11]$$

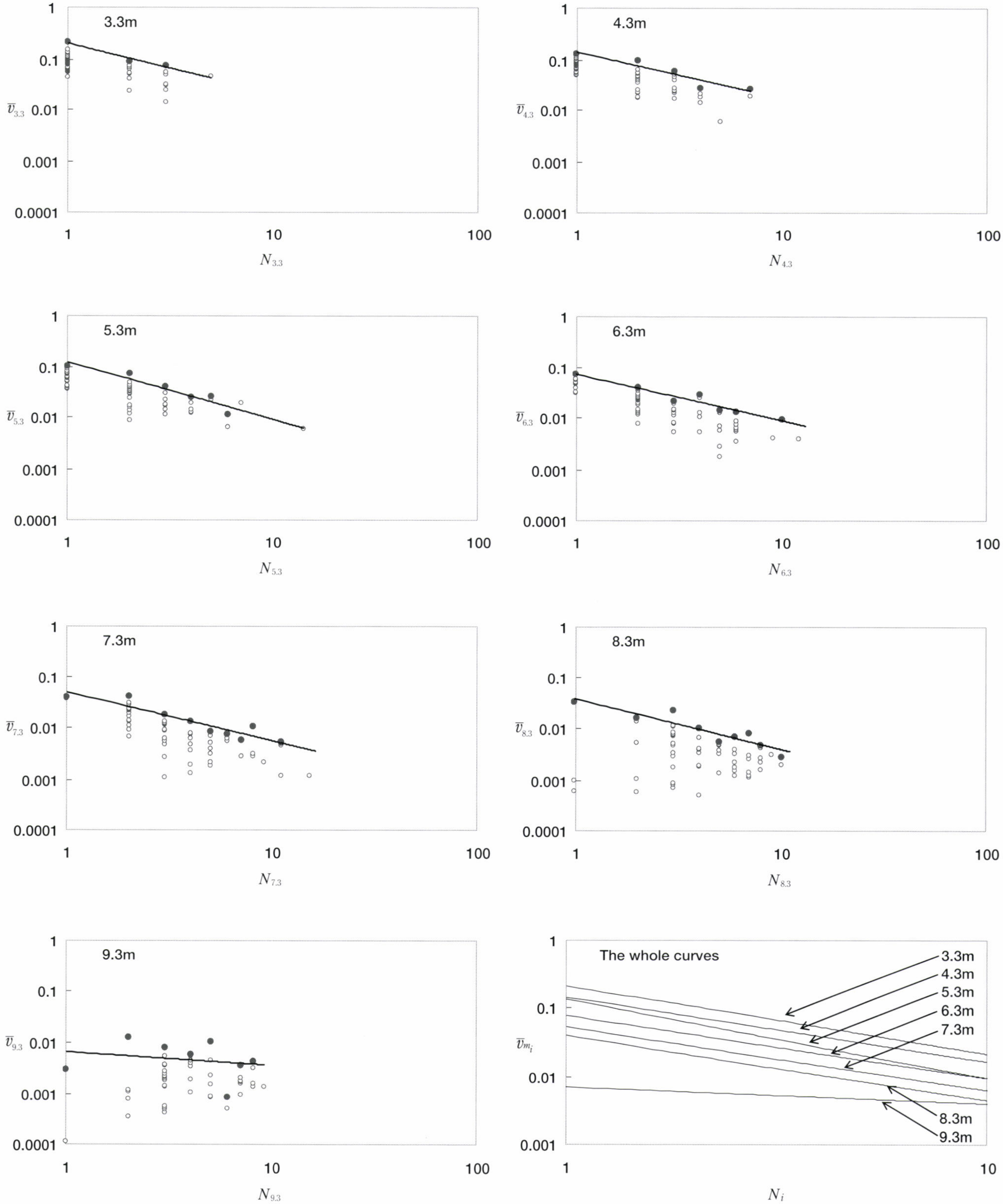

Fig. 2 Estimated full density curves at lengths between 3.3m and 9.3m on a log-log scale
The solid lines represent the full density curves, the small circles represent the average volumes of branches, and the small solid circles represent the maximum average volumes of branches, all of which are employed for the full density curve estimates. The figure on the bottom right represents the comparison between the whole estimated curves.

Table 5 ANOVA table for testing the homogeneity of the slope parameters

Sources	*SS*	*df*	*MS*	*F*	*p*
Bet. Groups	0.0308	4	0.0077	0.5229	0.7197
Within Groups	0.3979	27	0.0147		
Total	0.4287	31			

where X is the independent variable, Y is the dependent variable, k is the number of groups, n is the sample size, and a_1 and a_2 are the estimates of regression slope and intercept, respectively. For each variable, the subscripts i and j represent the sample number and group index, respectively, e.g., X_{ij} corresponds to the ith sample of N_j at a length of j, and Y_{ij} to the ith sample of $\overline{v}_{mj}$ at a length of j in this study. The degrees of freedom (df) corresponding to SS_{bg} and SS_{wg} are (k-1) and (n-2k), respectively. Thus, the F value is calculated using the mean squares (MS) between- and within-groups under the null hypothesis of equal slopes. The result shows no evidence of violating the equal slopes hypothesis; the F value is 0.5229, with a significance level of 0.7197. In this case, the regression coefficient estimate, $\hat{a}_1$, expresses the common slope among the groups, which is calculated by

$$\hat{a}_1 = \frac{\sum_{j=1}^{k}\sum_{i=1}^{n_j}(X_{ij}-\overline{X}_j)(Y_{ij}-\overline{Y}_j)}{\sum_{j=1}^{k}\sum_{i=1}^{n_j}(X_{ij}-\overline{X}_j)^2}. \qquad [12]$$

As for the sample trees, this estimate is -0.9801. This implies that the full density curves of the branches are represented by lines having a common slope of -0.9801 while having different interceptions corresponding to lengths between 4.3m and 8.3m on a log-log scale. The reason why $\hat{a}_1$ takes -0.9801 is explained as follows: In the stand scale full density curve, the power index of N_i in Eq. 5, $(\beta+\gamma)/\alpha$, takes -3/2 under the ideal condition of $(\alpha, \beta, \gamma) = (2, 1, 2)$. Among these parameters, particularly the numerator of the index, $\beta+\gamma = 3$, means that the average volume of individuals is proportional to the third power of their average width. But in the branch full density curve, the average volume of branches above a specific height is linearly proportional to their average basal area according to Eq. 7, which means the average volume is proportional to the second power of their average diameter. Thus, the parameter value of β is zero in this case with result that the power index of N_i in Eq. 9, δ, takes -1 under the ideal condition of $(\alpha, \beta, \gamma) = (2, 0, 2)$. In the actual situations, however, the index does not take exactly -1, so that $\hat{a}_1$ and corresponding $\hat{a}_{1i}$s slightly differed from -1.

Unfortunately, we could not investigate the difference in the slopes between species owing to a lack of *Castanopsis sieboldii* sample trees, which were mixed with *Quercus acuta* in the subject stand.

CONCLUSIONS

The purpose of this study was to determine the full density curves of branches on standing trees. The 60 sample trees of *Quercus acuta* in a single stand were selectively cut, and then diameters and lengths of those branches with more than 2cm diameter that were at a height between 3.3m and 9.3m were measured at one meter intervals along their stems and branches. To derive the full density curve of the branches, the number of branches at a specific length and the maximum average volumes of branches above that length were selected to be the independent and dependent variables, respectively based on the pipe model theory. The linear relationships between these variables were investigated on a log-log scale, with the consequence that the regression estimates were significant at lengths between 4.3m and 8.3m. Furthermore, the full density curves for these lengths were considered to have a common slope parameter of -0.9801. Further research is required, however, to investigate whether this slope is applicable not only to *Quercus acuta* but also to other species.

This study discovered that the -3/2 power law of self-thinning is effective for branches on standing trees that are similar to the standing trees in forest stands. In a future study we will examine ways to make good use of the full density curve for branches, such as being able to estimate the obtainable charcoal size for fuel wood production.

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Short communication

How is Short-wave Infrared (SWIR) Useful to Discrimination and Classification of Forest Types in Warm Temperate Region?

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ABSTRACT

This study confirmed the usefulness of short wavelength infrared (SWIR) in the discrimination and classification of evergreen forest types. A forested area near Hisayama and Sasaguri in Fukuoka Prefecture, Japan, served as the study area. Warm-temperate forest vegetation dominates the study site vegetation. Coniferous plantation forest, natural broad-leaved forest, and bamboo forest were analyzed using LANDSAT5/TM and SPOT4/HRVIR remote sensing data. Samples were extracted for the three forest types, and reflectance factors were compared for each band. Kappa coefficients of various band combinations were also compared by classification accuracy. For the LANDSAT5/TM data observed in April, October, and November, Bands 5 and 7 showed significant differences between bamboo, broad-leaved, and coniferous forests. The same significant difference was not recognized in the visible or near-infrared regions. Classification accuracy, determined by supervised classification, indicated distinct improvements in band combinations with SWIR, as compared to those without SWIR. Similar results were found for both LANDSAT5/TM and SPOT4/HRVIR data. This study identified obvious advantages in using SWIR data in forest-type discrimination and classification.

Keywords: SWIR, LANDSAT5/TM, SPOT4/HRVIR, evergreen forest, bamboo forest

INTRODUCTION

There are advantages to using short-wave infrared (SWIR) for forest monitoring. Atmospheric effects are less in the SWIR region (SCHOWENGERDT, 1997; REES, 2001), and SWIR can also be used to detect soil or canopy water contents (TUCKER, 1980; BARET *et al.*, 1988; MUSICK and PELLETIER, 1988; WHITING *et al.*, 2004). Spaceborne sensors, such as LANDSAT/TM, LANDSAT7/ETM+, SPOT4/HRVIR, SPOT5/HRG, and TERRA/ASTER, cover the SWIR wavelengths. SPOT2/HRV and IKONOS, however, are limited to visible and near-infrared wavelengths. Despite the higher spatial resolution of SPOT2/HRV, research has shown that LANDSAT/TM produces classifications that are more accurate in forested areas (GODARD *et al.*, 1990; MICHELE BASHAM MAY *et al.*, 1997). These results are largely due to the LANDSAT/TM Bands 5 and 7 (the SWIR band). SWIR band can provide valuable information for discriminating vegetation types and monitoring change in agricultural and forested environments (NELSON *et al.*, 1984; BARET *et al.*, 1988; PANIGRAHY and PIRIHAR, 1992; NEMANI *et al.*, 1993).

Evergreen forests have less seasonal change in canopy reflectance than deciduous forests (XIAO *et al.*, 2002; BOLES *et al.*, 2004). Using multi-temporal SPOT2/HRV data, MURAKAMI (2000) determined seasonal changes in reflectance factors for various forest types in northern Kyushu, Japan. Because evergreen forest dominates in that region, the range of reflectance factor change was relatively low. Although SPOT2/HRV covers the visible and near-infrared (NIR), the combination of different observation dates can be useful in discriminating forest types (MURAKAMI, 2000). Moreover, MURAKAMI (2004) indicated one example that a classification with SWIR band achieved better accuracy in this area. However, the effectiveness of using a single scene (especially a single scene with SWIR data) has not sufficiently been evaluated in this area. If adding SWIR makes a single scene as effective as scene combinations, single-scene imagery with SWIR will improve forest monitoring, since single scenes are easier to acquire than multiple scenes.

This study examined how SWIR addition affected the discrimination and classification of forest types. Using LANDSAT5/TM and SPOT4/HRVIR data, the reflectance factor for each forest type in the SWIR and non-SWIR bands

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was compared. Supervised classification was also applied to band combinations with and without SWIR, and classification accuracies were compared.

STUDY AREA

The study area is a forested area located near Hisayama (3,743 ha) and Sasaguri, (3,890 ha) in Fukuoka Prefecture, Japan. The area includes the Kyushu University Forest (482 ha). Hisayama has 2,412 ha of forest, and Sasaguri has 2,313 ha. Coniferous plantation forest makes up 74% of the forest area in Hisayama and 80% in Sasaguri. The area ranges in altitude from 20 to 670m asl. The natural vegetation is warm-temperate evergreen broad-leaved forest.

This study focused on three forest types for classification: natural broad-leaved forest, coniferous plantation forest, and bamboo forest. The natural broad-leaved forest has the following tall species, identified from ongoing plot research in the university forest: *Cinnamomum camphora, Neolitsea sericea, Machilus thunbergii, Castanopsis sieboldii, Quercus serrata, Quercus glauca, Quercus acuta, Quercus salicina, Myrica rubra, Symplocos prunifolia,* and *Carpinus laxiflora.* Except for *Quercus serrata and Carpinus laxiflora,* the dominant broad-leaved trees are evergreen species. *Cryptomeria japonica* and *Chamaecyparis obutusa* dominate nearly all of the coniferous plantation forest. The bamboo forest is composed mainly of *Phyllostachys pubescens* (*Phyllostachys heterocycala*), but also contains some *Phyllostachys bambusoides.*

MATERIALS AND METHODS

Data and Pre-processing

Table 1 lists the LANDSAT5/TM and SPOT4/ HRVIR observation dates used in this study. SPOT4/HRVIR has four bands (multispectral mode): Band 1 (visible green, 500-590nm), Band 2 (visible red, 610-680nm), Band 3 (near-infrared, 790-890nm), and Band 4 (short-wave infrared, 1580-1750nm). Its spatial resolution is 20 m. LANDSAT/TM has seven bands, but Band 6 was excluded from this study: Band 1 (visible blue, 450-520nm), Band 2 (visible green, 520-600nm), Band 3 (visible red, 630-690nm), Band 4 (near infrared, 760-900nm), Band 5 (short wavelength infrared, 1,550-1,750nm), Band 6 (thermal infrared, 10,400-12,500nm), and Band 7 (short wavelength infrared, 2,080-2,350nm). The spatial resolution of LANDSAT/TM is 30m.

Aerial photographs obtained in July 1995 were used to acquire classification training data and for verification. A Digital Map 50-m grid, published by the Geographical Survey Institute of Japan, was used for the digital elevation model (DEM). A Digital Map 25000 (map image), produced by the Geographical Survey Institute, was used for geometric registration.

All analyses were executed on ERDAS IMAGINE Version 8.6. All imagery data were geometrically registered on a Universal Transverse Mercator projection, zone 52, using ground-control points on the Digital Map 25000. The LANDSAT or SPOT model of ERDAS IMAGINE, one of the specific rectification modules, was applied to correct topographic distortion from the central projection and oblique viewing. Aerial photographs were orthorectified using ERDAS IMAGINE OrthoBASE. All images were atmospherically corrected and converted into reflectance factors using ATCOR2.

Table 1 Data set used for this study

Sensor	Observation Date	Path-Row
LANDSAT5/TM	24 Apr. 1997	113-37
LANDSAT5/TM	17 Oct. 1997	113-37
LANDSAT5/TM	7 Nov. 1997	113-37
SPOT4/HRVIR	17 Sep. 2001	313-283

Supervised Classification

As mentioned above, natural broad-leaved, coniferous plantation, and bamboo forest types were chosen for supervised classification. Training data for the three forest classes were collected by dividing the slope aspect from 45 to 224 degrees and from 225 to 44 degrees. The acquired training data were executed on the orthorectified aerial photographs. A total of six initial classes were set (three forest-type classes and two slope-aspect classes). Images in which a cloud or cloud shadow covered the training area were excluded in advance. The maximum likelihood method was used for supervised classification. After classification, the slope aspect classes were merged, creating a classified image with three classes. Training data for accuracy assessment were prepared independently. Both training data sets for each forest type were determined on dense forests with canopy closure.

Accuracy Assessment

Kappa analysis (CONGALTON *et al.*, 1983; CONGALTON, 1991) was applied to evaluate error matrices derived from the supervised classification. In this study, Kappa coefficients were calculated as a measure of classification accuracy. Using *z*-tests (CONGALTON *et al.*, 1983; CONGALTON, 1991), the Kappa statistic and its variance were used to statistically compare the classification accuracies among forest types.

RESULTS

Comparison of Reflectance Factors

Fig. 1 shows the reflectance factor for each forest type.

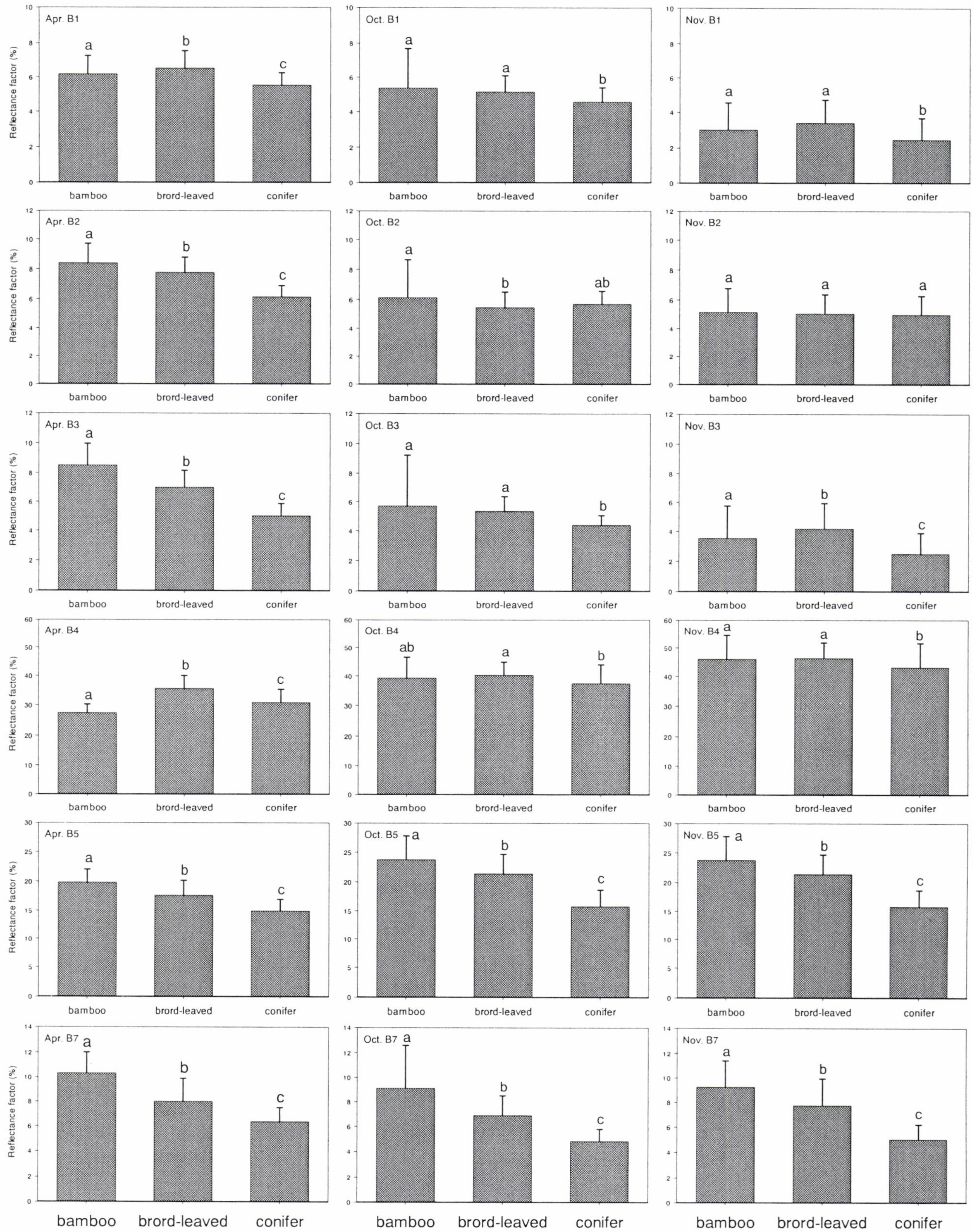

Fig. 1 The reflectance factor of each forest type by band and observation date
Error bars show the standard deviation. The characters indicate ANOVA post hoc test groupings (Tukey HSD).

ANOVA post hoc tests of Bands 5 and 7 data from April, October, and November, indicated significant differences among the three forest types. Some other band or scene data, however, showed no difference between three forest types. The reflectance factor order for each forest type differed between SWIR (Bands 5 and 7) and other visible and near-infrared band data. For all Bands 5 and 7 scenes, bamboo showed the highest reflectance, followed by the broad-leaved forest, and then the coniferous plantation forest.

Comparison of Classification Accuracy (with SWIR vs. without SWIR)

Fig. 2 shows classification accuracy comparisons of LANDSAT5/TM band combinations. The classification accuracy of a Band 2, 3, 4, and 5 combination was compared with that of a Band 2, 3, and 4 combination, for each scene. No significant difference was found for these band combinations using the April data. However, for the October and November data, the Band 2, 3, 4, and 5 combination was significantly more accurate than the Band 2, 3, and 4 combination. At this time of year, the addition of SWIR improved the classification accuracy.

Comparison of classification accuracy measured by different SPOT4/HRVIR band combinations is shown in Figure 3. The Kappa coefficients of the full band and the combination of Bands 1, 2, and 3 were 0.844 and 0.609, respectively. The full band showed significantly higher classification accuracy than the combination of Bands 1, 2, and 3.

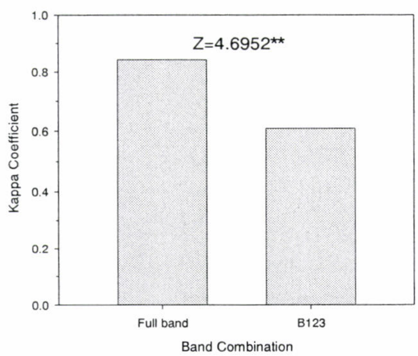

Fig. 3 Classification accuracy measured by different band combinations of SPOT4/HRVIR
Band combinations are the full band and Bands 1, 2, and 3. When the absolute value of "z value" is more than 2.45, it means significant different at 0.01 level.

DISCUSSION

Use of SWIR revealed significant differences among the three forest types (Fig. 1). This feature was not seen in other bands. Moreover, the addition of SWIR improved classification accuracy significantly (Figs. 2 and 3). This result suggests that SWIR is very important in the discrimination and classification of evergreen forest types.

This research has practical applications. For example, in recent years Japan has faced the problem of increasing bamboo forest (Okutomi *et al.*, 1996; Torii and Isagi, 1997; Isagi and Torii, 1998; Torii, 1998; Nishikawa *et al.*, 2005). The results of this study confirm that SWIR can be used to extract bamboo from other forest types in remotely sensed images. Although LANDSAT5/TM, SPOT4/HRVIR, SPOT5/HRG, and Terra/ASTER are suitable sensors, LANDSAT5/TM has the most substantial data archive. As archival data provide information on past forest conditions, LANDSAT5/TM data could be used for temporal change analysis of bamboo forest expansion. Recently, some researches have reported bamboo stand extraction using satellite data (Koizumi *et al.*, 2003; Fukui *et al.*, 2004). It was suggested that our research showed the effectiveness of the SWIR application to the detection of bamboo stand.

Atmospheric effects are weaker in the SWIR, because of its relatively longer wavelength (Schowengerdt, 1997; Rees, 2001). The SWIR can also detect soil or canopy water contents

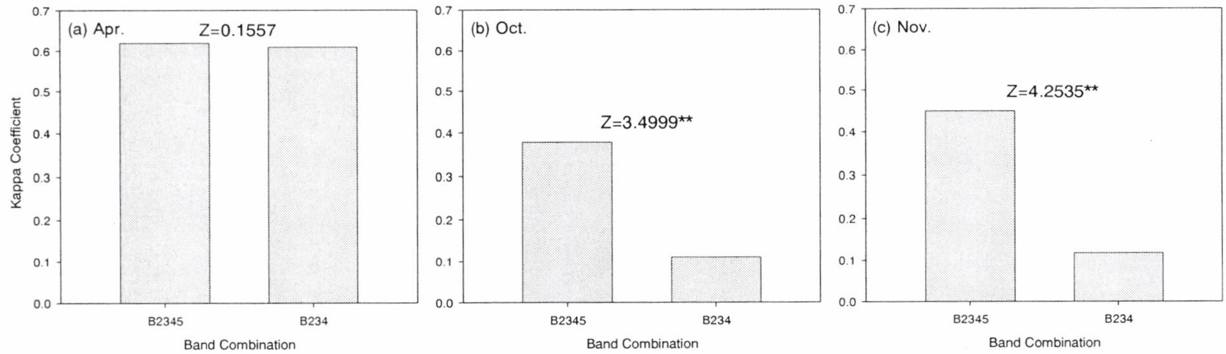

Fig. 2 Classification accuracy measured by different band combinations of LANDSAT5/TM
Combinations are Bands 2, 3, 4, and 5 and Bands 2, 3, and 4. When the absolute value of "z value" is more than 2.45, it means significant different at 0.01 level. (a) 24 April 1997 data, (b) 17 October 1997 data, (c) 7 November 1997 data.

and is effective in extracting cut areas. Given the usefulness of SWIR in forest-type discrimination and classification, SWIR has an important role to play in the remote sensing analysis of forests. SWIR is indispensable to forest remote sensing, and optical sensors for environmental monitoring should be equipped with this band.

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Short communication

An Introduction of Forest Resource Management in Cambodia since 1960

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ABSTRACT

This paper will introduce the history of forest resource management in Cambodia since the early 1960s. The integration of the country into the globalized capitalist economy has intensified since the end of the civil war in 1993. Such integration has not taken place naturally, but rather has been connected to political, social and economic process that has prompted Cambodia to exploit its forest resources and to emerge as a significant natural resource supplier country in the region. This leap, unfortunately, occurred during a time when Cambodia's physical and human capital had not yet recovered from 30 years of civil war. The resulting problems have negatively impacted a range of different areas, from biodiversity to people's livelihood. Currently, the community forestry (CF) practice is getting widespread attention as an alternative to forest management in Cambodia. Yet, little is known about the effectiveness of this emerging CF practices, thus further study is required.

Keywords: history, forest management, policy, Cambodia

INTRODUCTION

Cambodia has a total land area of 181,040 sq km (WORLD ATLAS, 2005), of which 58% is covered by forest (MRC, 1999). The total population is 13.4 million people of which 40% (CIA, 2004) live on less than $US0.45 per person per day (WORLD BANK, 2006). In 2000, the economy is a mix of agriculture (50%), manufacturing (15%), and services (35%) (CIA, 2002). Four years later, economy was roughly balanced between the three: manufacturing had grown (30%), while the share of agriculture (30%) and services (30%) had decreased (CIA, 2004). Forests are a major part of the natural resource base and in 2000 covered over half of the country's land mass. The importance of sustainable management of these forests has been the subject of much discussion recently, because the majority of the population lives in rural areas, and their livelihood depends on the forests and the surrounding ecology.

While Cambodia is a country blessed with abundant natural resources, it is also one of the countries in Southeast Asia with a debilitating recent history of murderous civil war and revolution. This caused an incalculable loss of human and physical capital, including the loss of professional knowledge about the ecologically sustainable utilization of natural resources. During the current period of accelerated economic development, Cambodia runs the risk of making economically and socially unsound decisions regarding the use of its natural resources on top of the fundamental recovery from the Khmer Rouge and the subsequent civil war.

In order to improve policymaking and provide instructive examples, the primary aim of this short communication is to introduce the history of forest management in Cambodia since 1960, and to understand the impetus behind earlier forest management schemes and policies to better prepare for future forest resource planning.

HISTORY OF FOREST MANAGEMENT AND POLICY IN CAMBODIA

Early 1960s

The first forest law after independence from France in 1953 was the Code Forestier (Forestry Code) passed in 1961. This law attempted to set up the basis for forest classification, with management focused primarily on the exploitation of forest resources. Forest areas were classified into 173 forest reserves and six wildlife protection areas. This covered 3.9 and 2.2 million ha, respectively (ASHWELL, 1996). From 1963,

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further forest policy development brought about two further primary objectives: conservation and amelioration (Loa, 1972). To achieve the former objective, the practices adopted were essentially measures against forest fires and illegal logging, while the latter objective involved practices of forest improvement. There were deficiencies in the implementation of this policy, because these concepts were new to both foresters and practitioners; there was no clear demarcation of different forest type and private or community property, which led to misuse of resources. Consequently, there were serious shortcomings and little conservation was actually achieved. It is understandable that the implementation of conservation of natural resources was hampered at that time because it was based on the original French ideology of economic growth coupled with social and cultural transformation. From what they termed their mission as *mise en valuer* (Development) and *mission civilization* (Civilizing Mission) of the overseas empire, it tells much about the attitude of colonial scientists and administrators to defining, controlling, developing and exploiting the forest resources in the region (see more in Mark, 2005). The other factor contributing to limited conservation success, in this period, is the relatively short time between adoption and the onset of the Vietnam War and its aftermath.

US Bombardment and Lon Nol Regime (1965-1975)

The forest policies during this period were the same as those of the early 1960s. The beginning of the Lon Nol Regime in 1965 saw the beginning of U.S. B-52 secret bombing along the eastern border of Cambodia. By 1968, at least 800 such missions had been conducted. During 1969 and 1970, 3,600 B-52 raids were conducted within Cambodia, and 53,000 tons of bombs were dropped (Kiernam, 1985). Significant tree destruction and crater damage occurred as a direct result of the bombing, with the crater damage contributing to soil erosion.

Of far greater importance to the forest environment was the spraying of an unknown amount of chemical defoliants; the most significant of which was Agents Orange I and II: 50% n-Butyl ester 2,4,-D and 50% n-butyl ester 2,4,5-T, and 50% n-Butyl ester 2,4-D and 50% isooctyl ester 2,4,5T respectively. This spraying occurred along the eastern border of the country with Vietnam in the area where the Ho Chi Min trail ran (Stellman, 2003). Ecosystems were destroyed, leaving wastelands dominated by worthless grasses and weeds; vegetation was stripped from the areas affected by spraying exposing the soil to wind and water erosion. In addition, dioxin residues remained in the ground, which endangered the local human and animal populations and contaminated rivers through rainfall runoff (Stockholm Declaration, 2002).

Forest exploitation activities for export, however, continued in accessible areas until 1969, while conservation and amelioration objectives had never actually been implemented due to social and political insecurity.

The Democratic Kampuchea (Pol Pot Regime, 1975-1979)

Little is known about forest management under the Pol Pot regime; we do know that the regime's agriculture policy merely focused on agricultural expansion. This period was one of social, cultural and political anarchy, where, among other things, there was a deliberate attempt to eradicate the written word and conventional institutions. Consequently, the legal infrastructure, documents and institutional knowledge was lost through the implementation of the regime's genocidal agrarian socialism. According to MacAndrews (1998), this has resulted in current lack of mature and experienced managers in the country, since the educated, managerial core were killed during this time.

After the Vietnamese invasion of 1979 toppled the Khmer Rouge, forest concessions were made along the Cambodian-Thai border. The area was logged in such a rapacious manner that the formerly pristine Sangke River turned into "a mud-laden slurry" whose sedimentary outpourings threatened the Tonle Sap lake and floodplain, the "ecological heart of the Cambodian nation" (Brauer, 2000; quoting Davies and Dunlop, 1994).

It is one of the great ironies, however, that the net effect of war and the civil disturbance of civil war was mixed: while widespread bombing caused immense environmental destruction, comparisons between war-torn countries in Southeast Asia, like Vietnam, Cambodia and Laos to relatively peaceful countries, such as Indonesia, Malaysia, Myanmar (Burma), and Thailand show that the natural environment in the latter set of countries is much more damaged than in the former (Brauer, 2000; quoting Audubon, 1991). The most likely reason is that war ultimately disrupts the human activities that destroy natural environments (Brauer, 2000). This effect is even more pronounced when considering the countless landmines sown by the Khmer Rouge, discouraged human activity in the areas they were planted.

State of Cambodia (1979-1992)

When refugees from the Khmer Rouge began returning to their homes in the early 1980s, about 2.5 million found their wooden houses completely destroyed. Replacement of these homes created a high demand for timber (UNDP/ETAP, 1999). Policy was made to fit the urgent social need for housing, and conservation and sustainable harvesting, by necessity, took second place.

The Forestry Department played a direct role in the exploitation of the forests by operating logging yards and saw mills in various forested provinces to meet domestic need (Grant, 1989). During this period, fifty-eight different policies were enacted both to protect and exploit the forest in response to a variety of social, economic and political circumstances. For example, the K-5 policy involved forest clearing to destroy potential cover for the Khmer Rouge. According to the Royal Government of Cambodia (RGC, 1998), annual log production was about 140,000 m^3 and about 2.4 million m^3 of fuelwood between 1981 and 1990. Since 1991, the volume of logging has increased, and problems associated with uncontrolled logging have begun to occur. The consequences of denuded lands on ordinary Cambodians are becoming grave, as flooding has increased during rainy seasons, follow by droughts during the dry seasons.

In 1992, the UNDP report estimated that the State of Cambodia exported approximately 320,000m^3 logs. To this amount should be added the illegal flow of 250,000m^3 to Vietnam, as well as 200,000m^3 to Thailand through Laos. The volume of timber logged by Khmer Rouge guerillas to fund their military struggle along the Cambodian-Thai border always went unreported. Besides exploitation to meet domestic needs, nothing had been done to implement protection or sustainable forest management during this period due to the widespread instability in the country. As a result, cumulative nationwide reforestation between 1985 and 2002 reached only 11,125 ha (DWF, 2003). Based on the forest inventories of the 1960s, we can conclude that there had been an average annual forest loss rate of 80,000 hectares from the early 1960s to the early 1990s (see Table 1).

Kingdom of Cambodia (1993 to present)

New Policy toward Natural Resources Management

Since the end of the civil war in 1993, the Royal Government of Cambodia (RGC) forest policy and priorities rest on four pillars: forest resource conservation, good governance, and poverty reduction which is closely related to the fourth goal, economic development.

This policy development was a direct result of policy changes after the first national election in 1993, when Cambodia made a concerted turn toward sustainable development. The Ministry of Environment (MoE) was created, and the RGC ratified several international conventions such as the Framework Convention on Climate Change, the Ramsar Convention, the Convention on International Trade in Endangered Species, the World Heritage Convention and the Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin, among others (UNDP, 2001). The RGC also established seven national parks, ten wildlife sanctuaries, three protected landscapes and three multiple-use areas, covering land areas of 742,250 ha, 2,030,000 ha, 97,000 ha and 403,950 ha, respectively; and a total land area of 2,866,297 ha. From 1996 to 2002, another nine protected forests were designated, covering a total land area of 1,346,225 ha (Table 2). All these designated areas are under the jurisdiction of the newly created MoE, which remains hampered by a lack of experienced personnel to accommodate its new managerial responsibilities.

Introduction of concession management and its failure

In addition to environmental protection, encouraging economic growth has also been a constant concern of the RGC; as a result achievement of the latter has often been at the expense of the former, since the two objectives have often been understood to be mutually exclusive rather than complimentary. Under assistance of the World Bank, the government introduced forest concessions as the primary instrument of forest management between 1994 and 1997, under the tutelage of the World Bank.

As a result, more than thirty concessions were granted,

Table 1 Forest cover data for Cambodia from 1964-1997

Year	1964[1]	1973[2]	1992/1993[3]	1997[4]
Forest cover (ha)	13,227,100	12,711,100	10,891,939	10,535,762
% of total land area	73.0%	70.2%	60.2%	58.2%

Source:
1. Report No. 2 of Ministry of Water, Forest and Hunting (1965) in Ung (1991).
2. FAO (1994) in World Bank, UNDP and FAO (1996).
3. Ministry of Agriculture, Forestry and Fishery (MAFF). (2001).
4. Mekong River Commission (MRC): Forest Cover Monitoring Project in World Bank (1999).

Table 2 Protected forests and areas

Categories		Number	Total Land Areas (ha)	Approved Year
Protected Forests		9	1,346,225	1996-2002
Protected Areas	National Parks	7	742,250	All in 1993
	Wildlife Sanctuaries	10	2,030,000	All in 1993
	Protected Landscapes	3	97,000	All in 1993
	Multiple Use Areas	3	403,950	All in 1993

Source: Department of Forestry and Wildlife (DFW), Cambodia, 2002.

covering an area of about 6.5 million ha. The required investment amounts varied widely from as low as $US5.5 million to as high as $US226.5 million. It is worth noting, however, that concessions were granted as a result of private negotiations between high-level officials and concessionaires, rather than through an open tender process. The lack of transparency resulted in ambiguous contracts strongly favorable to the concessionaire, and revealed growing corruption in the management of the forest sector among the national political and economic elite. According to the Mekong River Commission (MRC, 1999), this pattern is also reproduced at the local level where provincial, district or sub-district government officials may establish patronage ties to local businessmen. The Cambodian Development Review (CDR, 2001) noted that these grants have had a strong negative affect on rural livelihoods by reducing access to and use of forest resources.

In 1997 and 1998, the World Bank criticized the enormous problems with uncontrolled and illegal logging in and around concession areas, as well as the minimal revenue collection by the government. Even though commercial management of the forest in Cambodia is only feasible in less than 4 million ha of forest area (WORLD BANK, 1999), it is estimated that with proper management and control, the government could increase annual revenues from forest products to over $US100 million per year (CDR, 2002). Unfortunately, roughly 94% of timber production has been identified as illegal in 1997 (DAI, 1998), and based on the MINISTRY OF ECONOMIC AND FINANCE Report (2001), the government revenue from forest concession was only $US6 million in 1998 to $US10 million and $US11 million in 1999 and 2000 respectively.

Cambodia, consequently, has seen a rapid decline in its forest resources during the last decade and the relationship between economic growth and poverty reduction in the country had not been evident. Under pressure from the international community, the RGC cancelled twelve forest concession contracts in 1999 that violated the Investment Agreements. The cancellation involved ten companies and a total area of about 2.3 million ha (CDRI, 2002). Talam Resources Sdn Bhd later terminated their concession agreement voluntarily because of economic non-viability (FRASER, 2000). In most cases, unfortunately, these cancellations have not resulted in forest preservation because the concessions were largely logged before they were cancelled (CDRI, 2002). There are thirteen logging companies currently holding contracts for nineteen concessions, covering about 3.8 million ha (Table 3). The Cambodian Forest Concession Review found that through 2000, no forest concession in Cambodia had been managed sustainably. Despite that, the RGC did not recommend termination of any remaining concessions, though under the National Poverty Reduction Strategy, 2003-2005, it suspended some logging activities to promote conservation. At the same time there has been a strong desire on the part of the government to explore forest management alternatives to the concession system where concessionaires have failed to meet their commitments under Cambodian Law and as part of an initiative to combat poverty (CSD, 2002).

Table 3 Current forest concession companies and land areas

Companies	Country of Origin	Date Approved	Area (ha)
COLEXIM Enterprise	Cambodia / Japan	12-02-1996	147,187
CASOTIM Enterprise	Cambodia / Russia	09-04-1996	131,380
SL International Ltd (1)	Malaysia	11-08-1994	467,484
SL International Ltd (2)	Malaysia	11-08-1994	298,598
Mieng Ly Heng Investment Co. Ltd	Cambodia	27-02-1996	198,500
Pheapimex Fuchang Cambodia Co. Ltd (1)	Taiwan	15-03-1996	137,475
Pheapimex Fuchang Cambodia Co.Ltd (2)	Taiwan	15-03-1996	221,250
Pheapimex Fuchang Cambodia Co.Ltd (3)	Taiwan	08-04-1998	350,000
King Wood Industry Pte, Ltd	Taiwan	12-09-1995	301,200
Cambodia Chendar Plywood Mfg Co. Ltd	Taiwan	03-02-1996	103,300
Sam Rong Wood Industry Pte, Ltd	Cambodia	22-08-1996	200,050
Everbright CIG Wood Co. Ltd	China	08-08-1996	136,376
Super Wood IPEP Ltd	Malaysia	18-04-1996	94,418
Timas Resources Ltd (Hold 2 concessions)	Singapore	14-02-1996	161,450
Silveroad Wood Products Ltd (1)	China	08-04-1998	215,460
Siveroad Wood Products Ltd (2)	China	08-04-1998	100,000
You Rysaco Company	Cambodia	02-03-1998	214,000
TPP Cambodia Timber Product Pte, Ltd	Thailand	03-04-1998	395,900
Total Land Area			3,874,028

Source: DFW, Cambodia, 2002

Recent trends of forest management

Though the current system for concession management remains, Community Forestry (CF), a new term for traditional practices, has become an important policy mechanism to enhance the environment and livelihoods of the Cambodian rural poor.

With the support of various NGOs, domestic and international agencies, the first CF project commenced in 1995 in Takeo province. Since then, the number of CFs has increased to 237 in 2002, involving at least 416 villages and about 410,000 people (CDRI, 2002). The Cambodia National Forest Law of 2002 recognized and guaranteed the customary user rights of communities living within or in proximity to the Permanent Forest Reserve, as stipulated in Article 40 (ROYAL KRAM, 2002).

Until recently, however, little was known about the effectiveness of these recent efforts, as many projects were and in some cases still are in the planning stages or are seeking to establish CFs within existing concession areas. Moreover, other major issues surrounding community forestry development in Cambodia range from the lack of communal forestry knowledge, lack of a formally recognized CF development processes, lack of technical support for CF stakeholders to implement a formally recognized CF, and the lack of nationwide coordination between CF stakeholders. There is thus a strong need for further study about CF development and effectiveness in Cambodia. While the forest concession companies have made commitments towards establishing community forests within their concession areas, the GFA Consulting Group found in 2005 that implementation was defective and made detailed recommendations to rectify deficiencies (GFA, 2005).

NATURAL RESOURCE MANAGEMENT AND HUMAN RESOURCES (1965-2002)

This section discusses problems associated with the human resources necessary for effective forestry resource management, monitoring and the implementation of conservation and sustainable harvesting targets during the period of the widespread introduction of forest concession management. As mentioned earlier, schools were closed, schoolteachers and intellectuals were murdered, and the urban population was forced into rural labor camps during the Khmer Rouge era (1975-1979). It is estimated that only 15 percent of educated Cambodian survived this genocide (ULC, 1980; EVAN, 2002). No data exists on the exact number of skilled people who survived this era, making it difficult to accurately assess the full impact on the skilled and professional classes. The motto of the Ministry of Education of that time was the banal "Those who know a lot teach those who know little. And those who know little teach those who know nothing", the effect, of which, meant that no real education was conducted during that time save ideological indoctrination.

The effects of this era echo into the present day. The Department of Forestry and Wildlife (DFW), in the Ministry of Agriculture, Forestry and Fisheries is responsible for approximately 6.5 million ha of unprotected forest areas. The DFW found in 1997 that out of 696 officials, there was one master engineer, 234 engineers, 136 technicians, 87 skilled workers, and 238 non-certified staff. This number increased to 858 in 2002, with one doctor, 54 master engineers, 224 engineers, 141 technicians, 81 skilled workers and 357 non-certified (Table 4). There are 24 Provincial-Municipal Forest Offices with a further 993 members of staff, of which fewer than 200 have professional training. The MoE, formed in 1994 to manage 3.3 million ha of protected forest areas, is also severely hampered by a lack of trained staff, as well as funding problems.

CONCLUSION

From the above short description of the historical flow of forest resource management in Cambodia, we may conclude that Cambodia has experienced environmental changes on an unprecedented scale induced by continuous civil war as well as unsound social, economic and environment policymaking. At

Table 4 Number of officials, by qualification (1997-2002)

Year / Occupation	1965	1966	1967	1968	1969	1997	1998	1999	2000	2001	2002	
	Department of Forestry and Wildlife (DFW)										DFW	PFOs*
Doctor	N/A	N/A	N/A	N/A	N/A	0	1	1	1	1	1	0
Master	N/A	N/A	N/A	N/A	N/A	1	3	4	6	6	54	9
Engineer	N/A	N/A	N/A	N/A	N/A	234	256	265	269	268	224	161
Technician	N/A	N/A	N/A	N/A	N/A	136	131	137	136	134	141	169
Skilled-worker	N/A	N/A	N/A	N/A	N/A	87	88	86	79	78	81	214
Non-certificate	N/A	N/A	N/A	N/A	N/A	238	243	255	261	258	357	440
Total	665	667	658	611	703	696	722	748	752	745	858	993

*PFOs = Provincial Forestry Officials

Source: DFW, Cambodia, 2002

the heart of this process is the integration of the country into the globalized capitalist economy, initially commenced during the colonial era but with greater momentum in post-civil war time. Such integration has not taken place naturally but, rather, has been connected to both endogenous and exogenous political and economic processes and pressures that have marked the country's emergence as a significant natural forest resource supplier in the region.

Torn by war and civil war in its recent past, Cambodia is among the poorest in Asia and has suffered significant damage during the three decades of war. Its emergence from relative international isolation has coincided with a transition from a socialist to a market based economy, with a desperate need for international hard currency to pursue economic growth and remediation of its social fabric. The exploitation of natural resources has emerged as a promising introduction to international markets. So attractive was the prospect of exploiting "Green Gold" that as many as 30 forest concessions, covering an area of approximately 6.5 millions hectares, were granted for commercial logging with little or no critical examination of the cost benefit analysis and potential negative affects on both population and nature.

Various factors drove natural forest resources policies in Cambodia since 1960. Firstly, government funding and technical and human resource capability and capacity has been limited. Secondly, the long term concessions of forest management leases had the potential to attract the potential significant foreign and private sector investment capital in forest resources. This is especially true after 1993. Lastly, the forest concession system could have administratively unburdened the government and improved the overall level of forest stewardship. The size of the required capital investment, up to US$226 million, made the government somewhat overly optimistic that companies would be financially able to manage according to sustainable forest yield standards and contract conditions. This justification ignored the complicated nature of Cambodian politics and the long term social and economic effects the civil war caused to the institutional and technical ability of applying, performing and monitoring the formal natural resource use policy and the contracts with concessionaires. This mechanism created a weakness in consistent and coherent government policy and implementation, and encouraged corruption.

In addition, the spread of CF throughout Cambodia has been an *ad hoc*, reactive response to the negative impacts of concessionary forest management, rather than a systematically researched and developed policy and management change of direction. The effectiveness of this new practice is questionable, and must be examined in a critically constructive manner. One of the most important tasks to enable this to occur is to ensure development of a professional education and training infrastructure for government officials, forestry workers and forest communities, so that future forest policy and management becomes proactive rather than reactive. This will be the significant challenge facing the Cambodian people, their government and the forest management professionals in the twenty first century.

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