ISSN 1341-562X

JOURNAL OF FOREST PLANNING

Vol. 11 No. 2

March, 2006

Japan Society of Forest Planning

JOURNAL OF FOREST PLANNING

Submission of Manuscripts

Manuscripts should be submitted to following Editorial Office.

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Subscription Information

JOURNAL OF FOREST PLANNING is pubished halfyearly. The subscription for 2003 is 5,000 yen and the single issue price is 2,500 yen. Subscription orders can be sent to following office.

Toho Shoten
343 Yamabuki-cho
Shinjuku-ku, Tokyo 162-0801, Japan
Phone: +81-3-3269-2131, Fax: +81-3-3269-8655
http://www.toho-shoten.co.jp

JOURNAL OF FOREST PLANNING is published by
Japan Society of Forest Planning
Iwate University, 3-18-8 Ueda, Morioka, Iwate 020-8550, Japan

JOURNAL OF

FOREST PLANNING

Vol.11, No.2 March, 2006

Japan Society of Forest Planning

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Article

Contemporary Indigenous Resources Management and Behavior Change -A Case Study of Yak Poey Community Forest in Ratanakiri, Cambodia*1-

Krishna Han*2 and Tatsuhito Ueki*3

ABSTRACT

Ratanakiri is a province in the northeast of Cambodia. It has a total land area of 12,500 square kilometers, in which forestland is estimated to be 70-80%, making it an area of great economic potential on account of its natural resources. This region, where the majority of populations are indigenous, traditional swidden agriculture and Non-Timber Forest Products (NTFPs) collection is practiced widely. However, without survey data associated with environmental and social monitoring, much of the level practice may be unsustainable either from the view of a traditional conservation based perspective or modern technique of sustainable practice, since much of the social, economic and political climate is changing. As a result, updating and understanding the contemporary traditional resource management and the trends in both human behavior and practice is crucial, because that understanding is among the important aspects that might be central to the success of traditional community forest management. This study revealed that indigenous populations are practicing resource management instinctively. Moreover, the research showed that recent changes in the social, physical and economic environment affected indigenous people's ability and their behavior from the way they perceive their current livelihood situation to the way they use their natural surroundings. From the fieldwork data, we finally identified strengths, weaknesses, threats and opportunities in the current local knowledge and behavioral change in Yak Poey

Keywords: traditional local knowledge, development impacts, behavior change, indigenous, Cambodia

INTRODUCTION

Ratanakiri is located about 600km from Phnom Penh in an upland area in the northeast of Cambodia. The total area of Ratanakiri is approximately 12,500 square kilometers. The province has abundant forest, wildlife and other natural resources. In the period 1953 and 1996, the forest covered around 77% of the total provincial area (Fox, 2000). People living in Ratanakiri are mostly indigenous, whose current literacy rate is as low as 32% for males and 15.3% for females (MOP[1], 1998). They live largely within the limit of their own local ecosystem and scattered throughout the province, with two systems of major importance to their subsistence economy: The swidden agriculture system and the forest ecosystem (RUTH, 1996), where the "Basic Needs" of households are required through non-monetary strategies such as self-production, gathering from the common, or barter exchanges (TIMOTHY, 1999). Over the recent past, forest resources in the province have declined dramatically both in quality and quantity. The decline is caused by various factors including logging, clearing forestland for shifting and intensive cultivation as well as increasing needs for land by people living in the area (RUA/CEDAC, 2001). According to Esa Puustjarvi, 130% of Ratanakiri's land area has been allocated to concession companies, implying that all customary forest and agriculture land used by local people fall within concession area. The government is hoping to establish a significant tourist industry in the province, making it the last destination of development

*1 Part of this paper was presented at the Shinrin Chubu Taikai in United Graduated School of Agricultural Science, Gifu University in 2002

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1) Ministry of Planning of Cambodia: 1998 Population Census of Cambodia

in Cambodia. The increase of development activities around the area is attracting immigration of lowland Khmers seeking land. The consequences of these environmental and social factors and changes on indigenous knowledge of practicing resource management, and behavior are yet to be studied, as is their impact on the environment. Therefore, the objective of this study is to better understand the local knowledge of sustainable resource use, resource-use behavior and its changing trends if it is in order to identify strengths, weaknesses, threads and opportunities which would contribute to a meaningful future intervention in traditional community forest management.

METHODOLOGY

In January and November 2002, field research was conducted in Kameng and Kanchhoeung [2] village of Poey commune in Ratanakiri province, Cambodia. The total population of both villages is 204 and 269 respectively. We made appointments with various stakeholders such as villagers, head of tribe, head of households and local NGOs. 50 heads of household were selected randomly from Kanchhoeung and Kameng villages for interview. The questionnaire design was discussed and revised with academic advisors and local NGOs staff prior to actual field survey to ensure its applicability in the local context. Various literature reviews of the developmental events in the study site were made to better understand the effects and changes of traditional local knowledge of managing resources and current perception, as well as behavior of indigenous population. However, it is worth noting that in this study, we focused only on Kroeung indigenous in Kameng and Kanchhoeung village and their livelihood, as well as behavior in using resources. In the future, we also think a discussion beyond different communes and indigenous groups to look at the way, in which communities and indigenous groups are components in larger ecological, economic and political systems, is needed. When dealing with ecosystem and livelihood management, we believe that the whole picture cannot be captured completely by study focusing only upon the village and its immediate surroundings. It is hard to defend an approach which stresses the locality as a small world which contains the mass different groups as a boundary of social horizon, as a more or less autonomous circuit which dynamic, as far as it was present, could be explained only from the internal mechanism. Therefore, this study which only describes a village and its condition in detail runs a risk of implying that social-economic and resources relation in the village is typical, when broadly representative would be a more modest and more realistic claim.

[2] Kameng and Kanchhoeung are the two villages among the ten villages in Yak Poey commune that is practicing traditional community forest management.

RESULT AND DISCUSSION

The characteristic of respondents are presented in table 1. All respondent were farmers, 95-100% of whom rely on subsistence farming, derived from swidden farming and forest products. As to educational levels, 4% of respondents were educated up to grade four of primary school, 56% up to grade 2 of primary school and the remainders are illiterate. Traditionally, Kroeung indigenous believe in Animism.

The Historical Perspective: Recent Development Activities and Their Impacts

Ratanakiri only became a province in 1959. Before that, the area was administratively under the control of the Stung Treng province of Cambodia. Then the province was divided into districts and villages, engulfing villages and proceeding to strengthen links between villages and the center. Since then the grant titles and salaries were given to indigenous (Hjorleifur, 1992). A summary review of historical events and different regimes in the region has been made by Jeremy Ironside, who shows that within the last 50 years, there have been changes in political regimes 6 times. The last change was in 1993 after the 1st national election was held. Cambodia has increasingly been moving toward economic development and exploitation of natural resources during which various orders has been introduced to the region such as logging concessions, cashew and coffee plantations, International Development Agencies...etc. Ratanakiri-with its rich volcanic soil, pristine rivers, abundant hardwood forests, and relatively low population-has become the frontier for proposed industrial plantation, hydrological projects, and logging concessions (AMRC, 2002). For instance, 1.2 million hectares (Well cover the total of Ratanakiri land area) had been allocated to logging concession companies (Global Witness, 1999), during which illegal timber harvest and export volume in this province in

Table 1 Characteristic of respondents

Characteristics (F=50)		%
Age	18-50	62
	51-63	38
Education	None	40
	1-2 (Primary Level)	56
	3-4 (Primary Level)	4
Occupation	Farmer	100
Ethnicity	Kroeung Indigenous	100
Economic Status	Subsistence	100
Belief	Animism	100

Source: Field Survey

1997 alone was 311,100m³ (DAI, 1998). And according to Ratanakiri Land Title Office, in addition to the existing industrial plantation areas, more than a dozen projects of industrial plantations with sizes ranging from 100-20,000ha are pending. Due to these present opportunities, small scale land speculation and encroachment on fellow swidden and customary land is on the increase. The interview with NGO staff during the fieldwork revealed another problem that community faces in the effect of outsiders in which they would buy the land for USD50 per hectare from villagers. This phenomenon has two main causes. First, there is the problem of intimidation from speculators and the fear of losing land to outsiders including the government, without getting anything. Another obvious impact of the development activities in the region is population growth. The total population of indigenous in the province observed in 1993 was about 54,217, which represent over 75% of the total population of the province, while the rest (About 18,070 people) were non-indigenous. The 1998 National Population Census showed the total indigenous population in Ratanakiri was 64,037 (67.9%) of the 94,243 total population in the province. This implies that within 5 years the indigenous population grew by only 18%; while non-indigenous grew by 67%. According to Berg in 2000, 26% of immigrants come to Ratanakiri to farm and it is noticed that most of the immigrants are living better than they were before they came to Ratanakiri (BERG, 2000). This prospect is believed to be one factor that attracts more immigrants to farm in the region. In almost all cases, according to local NGO staff, this has led to threatening livelihood, cultural repression and environmental degradation as the new comers tend not to respect or understand the local indigenous communities and local traditions. Indigenous people, especially the poor, have very little or even lost access to their agricultural land and their traditional lifestyle disturbed (CDRI, 2001). The migration of lowland Khmer in search of land in the highland is the main reason for population growth phenomenon and will remain as such in the years ahead. The impact of development activities can be seen in the reduction of swidden production and cycle period (KRISHNA, 2002), which is placing uncertainty and unpredictability on both changing social value and ecological events that affect ecosystem sustainability including the forest.

Kroeung Traditional Knowledge of Resource Management

Kroeung indigenous people live largely within the limits of their own local ecosystem, with two systems of major importance to their subsistence economy. They are the swidden agriculture and the forest ecosystem which refers to the collection of NTFPs.

A. The Swidden Agriculture:

Swidden agriculture, the foundation of indigenous people's livelihood, is the main cultivation practice in the region. In the swidden farm, rice is the main crop planted along with other crop such as vegetables and fruit tree. As many as 20 to 40 varieties of crops are cultivated for 2 to 4 years, and then left uncultivated to allow the forest to regenerate and allow the soil to regain its fertility. In the research villages, over 20 species crops were identified (Table 2). At the present time, Kroeung do not use either fertilizer or compost to enhance the soil fertility beside the conversion of vegetation to ash once at the beginning of farming. As a result, the productivity from the swidden farm dramatically decreases from one year to the next.

The process of swidden farming and its changes is closely connected to the fate of the forest in Yak Poey, because both are the ecosystem on which Kroeung depend on for their lifestyle and livelihood. The less the production from the swidden, the more dependent Kroeung will be on the old growth forest and its products. The shorter the circle is the more and faster forest plots will be cleared for cultivation. In Yak Poey, a lot of land after clearing can support farming for three to four years depending on slope erosion and soil fertility. We were told that in the last 15 years or so, people moved at least within eight to ten fallow. However, at the present time, each family moves within four to five fallow and sometimes even within three fallow. A villager showed us the place he wants to clear. We learned that he had farmed the same plot six years earlier. However, because it is difficult to find new plots, this area of 6 year-old regenerated forests will definitely be cleared. The impact of a limited land base and increasing population on swidden agriculture has been well documented. Stout, reports that degradation of soil and vegetation usually occurs when the population density exceeds

Table 2 Crops often found growing in indigenous swidden field in research area

Crops often found growing in swidden field of Kroeung indigenous			
Rice	Bean	Lemongrass	Jackfruit*
Eggplant	Pineapple	Potato	Taro
Cashew**	Tobacco	Sesame	Maize
Banana	Sponge gourd	Cassava	Water melon
Mango*	Pumpkin	Sugarcane	Corn
Winter melon	Garlic and Chilly	Bitter gourd	Papaya

Source: Field Survey
Note: * Fruit tree, ** Commercial crop

one person/4 ha. Traditional swidden system in other parts of Ratanakiri has been found to sustainably support 1 person/3 ha according to Fox. In Yak Poey, based on the annually average active swidden farmland in 1996 of 419ha x 4 fallow, divided by the total population in the commune, would translate to 1 person per approximately 1,8 ha. People expressed their concern about the inevitable change to their lifestyle and livelihood, as theirs is extensive system. Complicating the issue, currently, there are some incentives from certain development agencies including government to plant cashew trees on their farms to improve living conditions and reduce poverty. The Kroeung people themselves have shown enthusiasm about this as it is provide them with cash income and ensures a better diet. With this trend, some part of their farms will be planted with cashew, thus leaving even less land for traditional swidden activities of Kroeung. However, how the cashew plantation affects the livelihood and ecosystem is an issue that needs further research.

B. Collection of NTFPs

Six selected items, namely Bamboo, Rattan, Fuelwood, Malva, Medicine and Animal (Table 3) are very important to the existence of Kroeung traditional livelihood and culture. Information regarding these products and harvesting technique were sought from the research subjects, and can be summarized as follows:

Bamboo: There are more than 10 species of bamboo in the Yak Poey community forest. However, 4 species are commonly harvested and used. They are Russey Phor, Russey Prey (Bobousia arundinaceae), Russey Pok and Russey Srok. These bamboos can be collected in the conservation forest, in the mountains, and along the streams, which range 1-8km in distance from the village. Kroeung harvesting technique is very traditional and instinctive. They normally select the largest bamboo plant they happen to see during collecting. However, small plants are also collected based on specific uses. Some villagers in Kanchhoeung said the travel distance to the place they can harvest bamboo is becoming greater. As a result, some families are starting to grow bamboo in their farm for their own use.

Rattan: As with bamboo, there are not less then ten species of Rattan in Yak Poey community forest. To employ local nomenclature, they are Kantoykandal, Sum, Chhvang, Dambourng, Amborn, Trosorng, Anchor, Habak, Thomada, and Taaseuy. Rattan is normally found growing in old growth forest or spirit forest. The distance to the collection area ranges from 5-10km. The way Kroeung harvest rattan is the same as the method of bamboo harvest. However, Kroeung also collect the bud of Rattan for food, which tends to disturb the growth of rattan.

Fuelwood: Fuelwood is the only NTFP that is easy to find in abundance in Yak Poey. Villagers can collect fuelwood nearby their village, in the old farm, or the fence of their abandoned farm. In Yak Poey, Kroeung collect the branch of tree; some trees grow in their fallow land such as Poplear (Grewia paniculata) and dead branches are used as fuelwood.

Malva: Malva nuts are the most important fruit for villager income. It is also the most obvious commercial forest product in Yak Poey. These popular forest fruits are used in soup or as a dessert. They are very good for energy as well as kidney medicine according to traditional healers. Malva have an irregular and seasoning fruiting cycle. It is only bears a bumper crop once every seven years for a two month period,

Table 3 Selected 6 NTFPs harvesting technique, harvesting area

Items	Collected areas	N. of species Collected	Ave. distance and travel time	Harvesting techniques
Bamboo	Conservation forest, mountains, and along streams.	More than 4	1km - 8km	Selected the biggest available plant for cutting
Rattan	Conservation forest and mountains.	Around 10	5km - 10km	Select the biggest and longest available for cutting
Fuelwood	Around village, old farms.	Around 20	100m - 500m	Cut tree, cut branches, and dead branches.
Malva nut	Conservation forest and mountains.	1	5km - 12km	Trees are cut to collect the fruit in May, but by June fruits have fallen, so can be collected from the ground
Medicine	Conservation forest, old farm, and mountains	Various	1km - 10km	Cut or pick based on the type of plants
Animal	Conservation forest, swidden farm, old farm, and mountains	Over 20	1km - 15km	Trap and arrow
Other	Ornamental plants, edible plants…etc			

Source: Field Survey

according to villagers we interviewed. For the duration in between this cycle, only a few kilograms of malva nuts can be collected. Malva nut can be collected in the conservation forest and on the mountain from about 5-12km away from the village. Villagers collect the fruit by collecting the fallen fruits from the ground in June. Because this fruit is commercially expensive, sometime they do not wait till June, but cut the tree to get the fruit in May. This harvesting technique through cutting the mother trees is very unsustainable. Therefore, education and awareness about the sustainability must be an immediate focus.

Medicine: Medicine is normally collected by the traditional herbal men in the village. However, some common traditional medicines are also collected by ordinary villagers. A herbal man told us that medicinal plants can be collected from the forest whenever necessary. However, it is sometime necessary to travel to far away place in the forest to find an appropriate product and it might take him half a day to one day. The collection technique depends upon the type of medicines and plants. Some plants are picked, or cut, or tapped for resin.

Animals: Kroeung hunt in the conservation forest and on the mountains. Some animals such as wild pigs and birds can also be hunted in the farm or old fallow. Kroeung collect animal products by using traditional hunting equipments such as traps, poisonous arrows. It is very rare to see guns used in hunting.

Current Perceptions and Behavioral Change

The increasing physical pressure of development on land, community and community mentality is beginning to have a visible and invisible impact on the traditional society. To access the impacts of the changes of people perceptions, we investigated dynamics such as reasons for participation in the community forest activities, view of advantage of participation, view of forest advantages to their livelihood, perception of current situation of livelihood and natural surrounding resources, affect of deforestation, confidence and needs and approaches toward forest protection (Table 4)

The survey data show that Kroeung people perceive their current livelihood and education as poor and uneducated. However, they are also aware of certain "creature comforts" available to villagers such as bicycles, motorbikes, and more

Table 4 Current perception of Kroeung indigenous people in Yak Poey

Perceived situation	Low (poor)	Middle	High					
Education	100%							
Living standard	100%							
Perceived situation	Decrease	Stable	Increase	Do not know				
Natural resources	90%			10%				
Perceived advantage	Ecological	Livelihood	Commercial	Culture				
Advantage of forest	43.3%	73.4%	56%	32%				
Perceived affects of deforestation	Food	Fuelwood	SE	F	D	S	SCM	RI
	100%	90%	64%	4%	94%	76%	92%	62%
Perceived confidence	confident	Less confident	No confidence					
	28%	30%	42%					
Needs for forest protection	Stop encroachment	Provide knowledge	PIGS	IRR				
	86%	92%	84%	12%				
Approach to forest protection	People management	Joint Management						
	20%	80%						
Reasons for group participation	Benefit of society & community	Individual and that of society	Individual benefit only					
	32%	46%	22%					
Advantage of participation	Knowledge	Community cooperation	No advantage					
	84%	90%	2%					

Source: Field Survey
Note: SE=Soil Erosion, F=Flood, D=Drought, S=Storm, SCM=Shortage of Construction Material, RI=Reduce Income, PIGS=Provide Income Generation Skills, IRR=Improved Rules and Regulations

modern medicine. Respondents repeatedly expressed their desire to be “as smart as” and better off like lowland Khmer. 90% perceived the current natural resources as decreasing in volume, while the other 10% said they do not know. Regarding the perceived advantages gained from the forest, Kroeung perceived livelihood advantage as the most important to them; with the percentage of such responses being 73.4%. Virtually, respondents expressed its concern about their food security and living condition. In responding to this concern, they tend to resort to commercial trade to generate cash income as additional source of improving their living condition. 56% of respondents perceived that commercial advantage could be gained from the forest. The ecological advantage is of third importance (43.3%), while cultural advantage account for 32%. As to their confidence in self resource management, 28% of respondents expressed confidence; 30% and 42% said less confident and no confidence, respectively. Respondents who fell into the less confident category expressed themselves little idea and feel that they cannot undertake forestry related activities without support from government agencies and NGOs; while the last category said they have absolutely no confidence at all and realize that their own current activities and practices are bringing about certain unsustainable outcomes. People said they feel this trend as a result of experiences in their everyday life and experiences such as hunting, and the difficulty to find NTFP and suitable fallow. The trend of losing confidence, thus, might in one way lie in the Kroeung own unintentional overexploitation of the resources capability to regenerate, which in turn reduces resource availability. Therefore, it is worth pointing out here that even the level of exploitation for subsistence use of forest resources should not be underestimated. Plus, according to the comparative research conducted by UNG (1996) in the southern part of Cambodia, people tend to lose confidence in managing forest resources when the forest resources are becoming scarcer. Concerning the current resource use activities, the perceived of deforestation was asked. The hypothesis is that because the indigenous populations do not know the potential consequences of deforestation on their natural environment and livelihood, do they continue exploiting their resources in an unsustainable manner. This was tested by using coefficient of concordance. The result was significant. People do understand well the consequences of deforestation. They know their situation, such as what is important to them, and also know what will happen if forest is destroyed. But they repeatedly stressed the lack of alternatives to current method of forest resources use. Indigenous people depend on forest mostly for food, construction material and fuelwood and other products as the percentage of this accounted for 100%, 92% and 90% respectively. According to our interview, if forest is destroyed, the first natural disaster that is likely to happen in the area is drought (94%), storm (76%) and followed by soil erosion (64%). People are even aware of the nearly non-existent risk of flood in their area. The respondents' view about needs and approaches to forest protection were also investigated. 20% of respondents believe in people management. They think people can manage the resources by their own initiative; while 80% think joint management is the best approach toward forest protection. To protect the forest, 92% of respondents said education is needed, 86% said encroachment should be stopped, and 84% said providing income generation and skills to reduce poverty is important. At the present time, 46% of respondents participate in community activities for the individual benefit and that of society, 32% for the social and community benefit, and the remaining 22% participate for individual benefit. The perceived advantages from participation show that 90% of respondents participate in community forest activities in order to strengthen community cooperation; 84% participate because they expect to learn and gain more knowledge; information and understanding, and only 2% do not think it is worth participating.

Analysis from the Perspective of Indigenous Belief

Kroeung people believe in Animism. The Animist beliefs influence all aspects of life, in the forests, in the swidden farms and villages domain. Each domain has a strong connection with the spirit. It is believed that if the spirit is angry, the spirit will send a tiger to maul the guilty party, or inflict them with malaria. The surrounding natural ecosystem belongs to no one, but the spirit. Such system of tenure leaves little room for greed, because it requires a balance between the humans and ecosystem which is occupied by the spirit. The indigenous population follows this system partly through fear and partly for economic reasons, thus maintaining a balance. It is a balance based on the ongoing tension between fear of hunger and fear of the spirits. Hunger equates with the need to clear forestland and cultivate the soil, while the demand of the spirits equate with the long term need of society. However, this is a fragile balance when it is confronted with the pressure of social changes due to the government's policy of economic development and new opportunities that open to the Kroeung. For example, the availability of modern medicine is currently undermining the authority of the spirit as more people who can afford it are using it in preference to the ritual sacrifices.

Summary of SWOT Analysis[3)]

Table 5 SWOT Analysis of Swidden Farming Practice

Swidden Farming Practice			
STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
-Not much capital required. -Kroeung knows how to do it, as this is way it has always been. -Agro-biodiversity -Produce chemical free products -Reciprocity labor system	-Low yield -Fast soil erosion and degradation. -Requires a lot of labor, thus affects education of children and women. -Fragile to collapse in response to changes	-Improvement on existing knowledge. -Preserving indigenous identities. -Maintain community solidarity. -Change for more research about the traditional system.	-Population growth and land speculation will continue. -System depends completely on nature. -Risk of forest fires. -Inevitable presence of new social, political and economic orders in the region.

Table 6 SWOT Analysis of NTFPs Collection Practice

NTFPs Collection Practice			
STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
-Still use traditional gears. -Harvest different species at different times of the year.	-Instinctively conducted. -Cutting the mother tree to collect Malva. -Cutting the bud of rattan disturbs full growth.	-Availability of NTFPs is still high, thus opening the opportunity for "trial and error" in management planning. -Improve managerial skills of indigenous people. -Chance to work collectively with indigenous to achieve better resource management and environmental awareness.	-Facing risk since stock may not be known with accuracy, thus minimum viable size of the stock perceived by indigenous people could be markedly higher than reality. -More risk when there is NTFPs strong market dynamic presence, while manageable market system has not been established yet.

Table 7 SWOT Analysis of Current Perception of People

Current Perception of People			
STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
-Willing to integrate themselves into joint management. -Understand the consequences of deforestation. -Willing to learn not only formal education, but also skills and technologies. -Plant bamboo to meet own needs	-Losing confidence. -Losing belief in spirit -Passive and expect funding from outside sources as a drive of change. -Selling land to outsiders. -Trend of exploitive and materialistic behavior.	-Promote Joint Forest Management with people through active participation. -Easy to initiate small enterprises, financial service and macro-credit, and to inform about market information since people are more familiar with cash. -Increase literacy rate	-Loss of Kroeung identity and culture. -Spur more ambition and greed as more opportunities are opened -Exploitive behavior will lead to overuse of resources. -The perceived commercial advantage currently is high.

CONCLUSION

The contemporary role of local knowledge and change in perception and behavior of using ecological surrounding suggests to us that Kroeung traditional resource management, which is congruent with conservation only if practice in moderation needs to be qualified and elaborated. The weak governance of the recent past development policy, the aim of which to develop economic growth has already created new dynamics, new physical conditions, perception and behavior-which are the products of population growth, modernization, materialism, and so forth. These presences of opportunities in new social, political and economic orders carry their own ideology, which turns previous traditional community and time into an era lacking of these elements. In order words,

[3)] The result of this analysis was the answers we found from our point of view and the view of other people involved such as villagers and NGOs staffs during fieldwork, as well as from the fieldwork data.

population growth, economic dynamics, and institutional parameters that social, political and economical opportunities presented have created a situation where exploitative behavior is rewarded and traditional sustainable behavior is discouraged, even when recent ideologies proclaim the opposite. However, it is no denying that this change is natural, because the sense of a "Good Life" entails does not separate subsistence from other needs. In short, the change in physical, social, political and economic environment leave Kroeung traditional knowledge of practicing resource management no more a sustainable method in the sense understood today. The key implication is that the current community forest practice could be a real contributor to sustainable forest management and rural development unless additional method (not an alternative) are added to the existing traditional knowledge to improve the practice in order to meet both environmental and socio-economic objectives and creating a sustainable behavior in the community.

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(Received 24 September 2004)
(Accepted 28 February 2005)

Article

Estimation of Carbon Stock in *Fagus crenata* Secondary Forest using X-ray Densitometry

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ABSTRACT

Global warming due to increase in the atmospheric carbon dioxide level is a matter of growing concern and the carbon-absorbing function of the forest is now an issue gathering public attention. Under such conditions, it is necessary to calculate carbon stock in tree stems, and understand the details of the bulk density of stems. The aim of this study is to estimate the carbon stock in the forest with guaranteed accuracy by stem analysis and soft X-ray densitometry, using a Stem Density Analyzer (SDA). Samples of beech (*Fagus crenata*) were collected at Kaminagawa Experimental Forest, Yamagata University. Ten trees were selected from the standing trees in the investigation area. The wood disks were obtained from the stem at a 1-m interval starting from the height of 0.2m. From each disk, four blocks were cut out in the four directions, and a 1.4-mm-thick strip was prepared from each block using a double-toothed circular saw. Annual ring width and bulk density were measured by soft X-ray densitometry. Each 1-m-long stem segment was regarded as a cone trapezoid, and using the average of annual ring widths in four directions, wood volume for each year was calculated. The calculated value was multiplied by average of bulk density to obtain wood dry weight for each year, and it was converted to carbon stock by multiplying by the rate of carbon. SDA was used for these calculations. The distribution of bulk density in the stem was variable in the same individual, and even the average bulk density of each individual varied with the individual, even though the bulk density was measured for the individuals with similar ages and under similar environmental conditions. These results indicate that the examination of bulk density is important for the calculation of carbon stocks. The diameter at breast height (DBH) of trees was found to have a close correlation with the carbon stock. Therefore, we estimated carbon stock per unit area using the correlation formula between DBH and carbon stock in each tree in the investigation area. The estimated carbon stock per unit area in the stand was 44% greater than that estimated by the method currently proposed by IPCC method. Carbon stock can be estimated with high accuracy using the correlation formula between DBH and carbon stock.

Keywords: X-ray densitometry, stem analysis, *Fagus crenata*, wood weight, carbon stock

INTRODUCTION

Among the many global environmental issues, global warning is now a particularly serious issue. Among the greenhouse gases, which are considered as the main causes of global warming, the abundance of atmospheric carbon dioxide abundant is considered to be the main cause. Carbon dioxide is generated by combustion of fossil fuel, burning of vegetation such as forest and grassland, and use of lime for cement production. Then, much attention is now being focused on the global warming-preventing function of forests. In December 1997, the third Conference of the Parties to the Convention on "the United Nations Framework Convention of Climate Change" was held and the Kyoto Protocol was adopted. Thereafter, absorption of carbon dioxide by forest management was approved as a measure to remove carbon dioxide by the Marrakech Accords. However, it was pointed out difficult to estimate accurately the amount of carbon absorbed by the

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forest. There is penal regulation for a defective report on the absorbed amount of carbon stock. According to the Kyoto Protocol, Article 3, paragraphs 3 and 4, carbon stocks fixed by forests should be reported taking into account "uncertainties", "transparency in reporting" and "verifiability". Therefore, it is very important to grasp the accurate amount of carbon stock in the forest, and clarify the method of estimation to solve the problem of global warming.

At present, carbon stock is calculated based on the IPCC guideline revised in 1996, and in Japan, carbon stock is estimated using forestry statistics (MATSUMOTO 2001a, 2001b, Forestry Agency of Japan 2003). In this method, carbon stock is calculated from the timber volume which was estimated using International Agriculture and Forestry Census, present conditions of forest reserves, and forestry statistics. For example, NIWA (2003) estimated the amount of fixed carbon in Iwata Prefecture using this method. The merit of this method is that the carbon stock is easily estimated using forest registers without any need for a new survey. However, this method is stubbornly provisional, and does not take into account the "uncertainties" prescribed in the Kyoto Protocol into consideration.

In this study, we tried to estimate the carbon stock paying attention to the "uncertainties" prescribed in the Kyoto Protocol. We examined stem volume and bulk density of individual trees in the forest, obtained stem weight, and tried to calculate carbon stock. The study area is a forest of a typical tree species in the Tohoku district, beech (*Fagus carenata*), and, we examined, in particular, the secondary stand of beech with vigorous timber volume growth.

We thank Dr. K. TAKADA and J. ZHU the Institute of Wood Technology, Akita Prefectural University

MATERIALS AND METHODS

Collection and Preparation of Samples

Samples were collected from compartment 2 of Kaminagawa Experimental Forest, Yamagata University, in Asahi Mura, Yamagata Prefecture. Topographically, the study area is a flat plateau about 700m above the sea level. In 1914, a natural forest of beech was cut down, and Japanese cypress (*Camaecypres obutusa*) was planted, but it was destroyed, and the area changed to a secondary stand consisted of a beech crown. According to the every timer cruising, the number of standing trees in the study area was 1475 trees/ha, average tree height 13.5m, average diameter at breast height (DBH) 18.2cm, timber volume 376.0m^3/ha, total basal area 48.28m^2/ha, and the rate of timber loss 0.43%.

The closing rate of the crown in the study area was 82% on the average, and horizontal relative luminous intensity at 1.4m height in the forest was 4%. Thus, this area is a typical secondary stand of beech. We set a 40m × 40m investigation plot in the center of this stand. Ten trees each with different DBH were selected from the standing trees in the study plot, and about 3-cm-thick disks were cut out from the trees at 1m interval starting from 0.2m height. The disks were oven-dried for 24 hours, about 2.5cm-wide blocks were cut out in the four directions from the center, and 1.4mm-thick samples were prepared with a twinsaw (Image 1, 2).

Soft X-ray Photographing

Soft X-ray densitometry was developed by POLGE (1970). In this method, the standard absorbent with a known bulk density is photographed with a soft X-ray together with the samples, and the bulk density is obtained from the density of the sample relative to that of the standard absorbent. For soft X-ray photographing, the sample strips and standard absorbent were dried absolutely, and stored in an airtight vessel. The standard absorbent was 10 pieces of 1-mm-thick plates of poplar (bulk density, 0.3517g / cm^3) piled up stepwise. The strips of the samples and standard absorbent were placed on

Image 1 The block taken out from the disk.

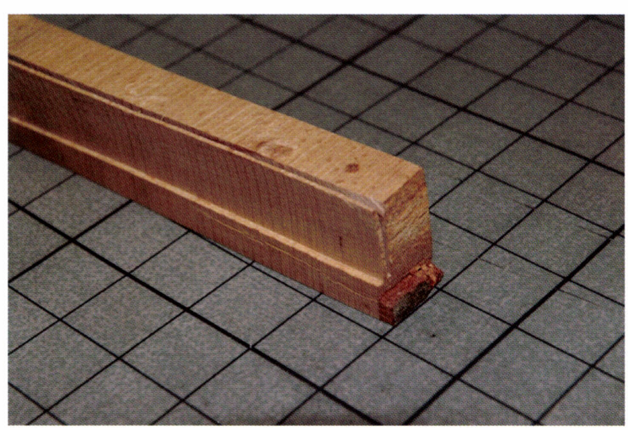

Image 2 A sliced sample.

Image 3 The samples on the X-ray film.

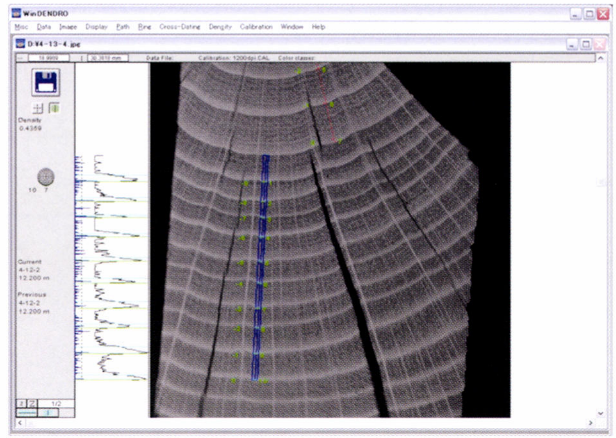

Image 4 A Operation screen of WinDendro.

photographing film (Fujifilm Industrial X-ray film IX FR) and photographed using soft X-ray photograph (Softex SR-1010 type, Softer Co.) equipped at Institute of Wood Technology, Akita Prefectural University (Image 3). Radiation distance was 2m, voltage 20 KV, current 14 mA and exposure time 3 min. The film after photographing was developed, stopped, fixed, washed and dried.

Measurement of Annual-ring Width and the Bulk Density

The image of the film was inputted to a personal computer using a scanner GT-7600 of Epson Co. and transparent copy unit. The input conditions were; resolution, 1,200 dpi; copy type, transparent copy positive film; image type, black and white. The shadow for each film was background of standard absorbent, ten high-light steps, and density correction linear. For measurement of annual ring width and intra-annual ring density, the software for annual-ring analysis, Win DENDRO (Density 20002a) of Regent Instrument Inc., was used (Image 4). Starting from the center, the sample strip was scanned using a 0.5-mm path width avoiding the radial tissue, which had a higher bulk density than the general cells. The width of each strip was measured to every 0.01mm using digital slide calipers (DIGIMATIC, Mitsutoyo Co.) and inputted to the computer for calculation of bulk density. Annual-ring components automatically measured by WinDENDRO were width of each annual ring, early-wood width, late-wood width, bulk density of each annual ring, bulk density of early wood, bulk density of late wood, minimum density of each annual ring, maximum density of each annual ring, proportion of early wood and proportion of late wood, 10 items in total. In this study, however, we used width of each annual ring and bulk density of each annual ring.

Calculation of Stem Weight and Conversion to Carbon Weight

Stem weight was obtained using Stem Density Analyzer (SDA) (NOBORI, 2004). For calculation of stem volume by SDA, either parabola, cone trapezoid or Neiloid is applicable, but cone trapezoid, which gives the medium value, was used in this study. In SDA, the weight of each part of stem was obtained by multiplying the average of the densities obtained from the top and bottom disks by the volume. Then, yearly weight growth and total weight growth were obtained by summing up the values for each part. Carbon content of stem is 50% of the dry weight according to the elemental composition of $C_{1.5}H_{2.1}O_{1.0}$ (UDA *et al.* 1968), and is therefore regarded as 0.5 in IPCC guide line (IPCC, 1996). In this study, we also multiplied the stem weight determined by SDA by 0.50.

RESULTS AND DISCUSSION

Distribution of Bulk Density in Stems

Fig. 1 shows the distribution pattern of bulk density in beech stems examined using SDA, and Table 1 shows the size of each tree and the range of bulk densities in individual trees. The results show that the range of bulk density greatly varied with the individual.

As shown in Fig. 1, even in the same individual and in the same annual ring, bulk density varied with the height, and even at the same height, bulk density of each annual ring varied with the year of the ring formation. Thus, the distribution of bulk density was diverse. As a whole, the bulk density of the wider annual rings near the center of stem had higher bulk density than the narrower annual rings near the bark. This pattern was similar to that reported for sugi (*Cryptomeria japonica*) by FUKAZAWA (1976), but was quite different from that in Japanese larch (*Larix leptolepsis*) (NOBORI 1988). Fig. 1 also shows that the distribution of bulk

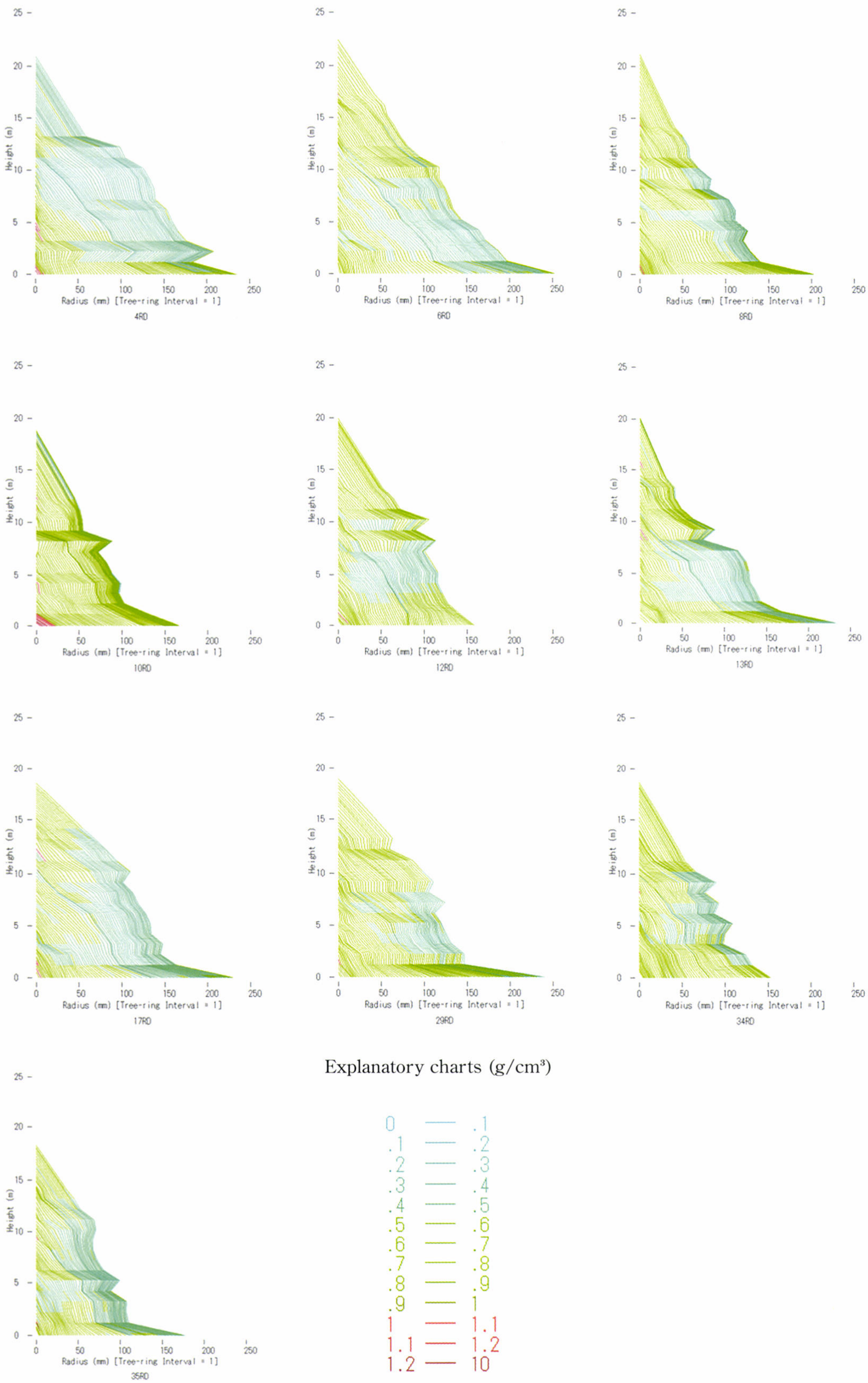

Fig. 1 Distribution pattern of bulk density in beech stems

Table 1 Sample size and range of bulk density

Sample (No.)	DBH (cm)	Tree height (m)	Branch length (m)	Tree ring number at 0.2m height	Range of bulk density (g/cm³)
4	32.6	20.9	11.2	82	0.278～1.401
6	41.0	22.4	11.3	81	0.301～1.147
8	26.6	21.1	8.4	80	0.286～1.096
10	20.8	18.8	8.9	87	0.264～1.345
12	26.2	19.9	9.1	81	0.348～1.204
13	27.6	20.1	8.7	78	0.327～1.349
17	29.4	18.5	8.8	82	0.292～1.727
29	24.8	18.9	11.6	82	0.314～1.025
34	20.6	18.6	9.7	81	0.287～1.050
35	19.4	18.2	14.3	81	0.259～1.057

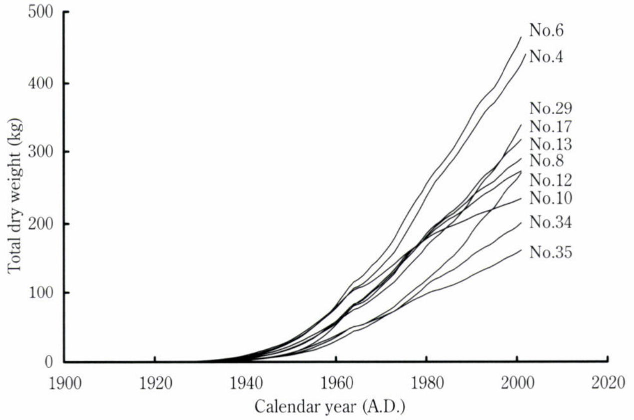

Fig. 2 Total increase in stem dry weight

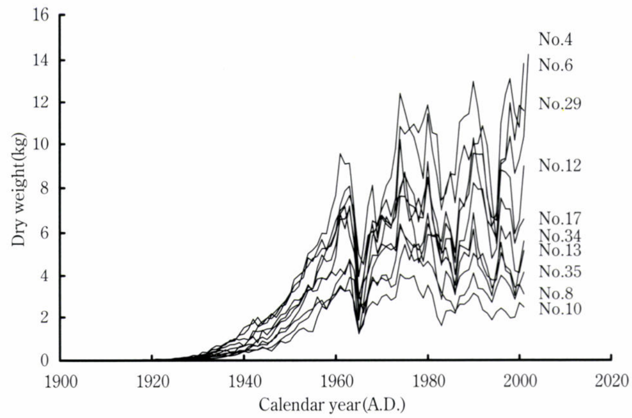

Fig. 3 Total increase in stem dry weight

density in each tree varied with the individual even under the same environmental conditions. FUKAZAWA *et al.* (1990) presented that in the ring porous wood of broad-leaved trees, the wider the annual-ring width, the higher the bulk density, but in the scattering porous wood, the relationship between annual-ring width and bulk density was obscure. However, they also reported that beech wood had a bulk-density distribution similar to that in ring porous wood. The wood of beech seems to have the bulk density characteristic similar to that in the ring porous wood.

Increase in Dry Weight of Stem and Carbon Weight

By the stem analysis with SDA, not only yearly increase and total increase in stem volume, but also yearly increase and total increase in stem dry weight can be calculated using the information on bulk density. The volume of annual ring is fixed after the formation, but the weight of annual ring is not fixed due to chemical changes after annual ring formation. In this study, however, we assumed that both weight and volume of each annual ring are fixed after the annual ring formation for convenience. Under these conditions, the total increase in stem dry weight was calculated, and Fig. 2 shows the result. After 1960, dry weight of stem increased linearly in each tree, except for sample No. 10.

Fig. 3 shows the yearly increase in stem dry weight. The dry weight increased along the quadratic curve until 1960, but the yearly growth fluctuated thereafter, and the year of minimum increase in each tree tended to be synchronized. Even in the annual rings formed in the same year, annual weight growth greatly varied with the individual in the rage of 2 – 14kg. The synchronous change in yearly growth of each tree might be correlated with the fruiting as indicated by OGATA (1994). HARA (1996) reported that beech trees require 40 – 50years for flowering and 60 – 80years for fruiting. In the year of 1965, when the minimum dry weight increase was observed in all trees synchronously, the tree age was 51 – 61years, which suggested that the beech trees examined in this study were near maturity. Synchronous growth decrease is not discussed here, because it is not the subject of this study.

Stem Volume, Dry Weight and Bulk Density of Individual Trees

Table 2 shows the stem volume and stem dry weight of individual trees calculated using SDA, and the bulk density and carbon weight calculated from these values. The stem volume of individual trees was in the range of 0.344 – 1.013m³, dry weight was in the range of 162.5 – 441kg, and carbon weight was in the range of 81.3 – 22.0kg. The carbon weight of the stem of individual trees highly correlated with DBH as shown in Fig. 4. The average bulk density of each stem greatly varied between 0.44 and 0.70 g/cm³ (Table 2), although the variance was smaller than that of each part of stem shown in Fig. 1. In spite of such large variance in bulk density, a very high correlation was observed between the stem volume and carbon weight (Fig. 5). This suggests that carbon weight can be measured by the above-described method even in beech trees of different sizes.

Method of Conversion of Stem Volume to Carbon Weight

Figs. 6 and 7 show the number and volume of the stems in each DBH class, respectively. Since carbon weight was significantly correlated with either DBH or stem volume as shown in Figs. 4 and 5, respectively, we calculated carbon weight based on the DBH (eq. 1) and volume (eq. 2) of each tree.

$y = 42.308\, e^{0.0452x}$ $R^2=0.8048$ ($p<0.001$) (eq. 1)

$y = 194.75\, x + 32.31$ $R^2=0.9336$ ($p<0.001$) (eq. 2)

Where, y is carbon weight, x is DBH in eq. 1 and stem volume in eq. 2.

The carbon weight calculated by eqs. 1 and 2 was 159.551 and 120.884 ton/ha, respectively. We can calculate estimation error of carbon weight from these equation and R^2. The error was larger in eq. 1 than in eq. 2.

Carbon stock calculated using the formula proposed by IPCC (1996) is as follows.

Table 2 Stem volume, dry weight and carbon weight

Sample (No.)	Stem volume (m³)	Dry weight (kg)	Average bulk density (g/cm³)	Carbon weight (kg)
4	1.013	441.6	0.44	220.8
6	0.961	465.7	0.48	232.8
8	0.501	272.0	0.54	136.0
10	0.334	234.1	0.70	117.1
12	0.517	269.5	0.52	134.7
13	0.598	289.5	0.48	144.8
17	0.721	316.6	0.44	158.3
29	0.646	338.0	0.52	169.0
34	0.384	201.1	0.52	100.6
35	0.344	162.5	0.47	81.3
mean	0.602	299.1	0.51	149.53
S.D.	0.240	96.6	0.08	48.32

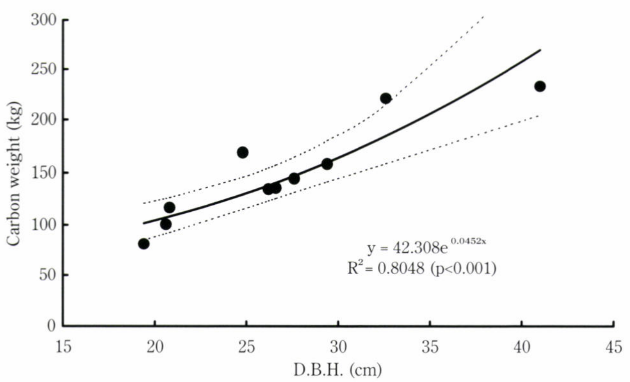

Fig. 4 Relationship between DBH and carbon weight
Note: Dotted lines are minimum and maximum estimation errors of 95% reliability.

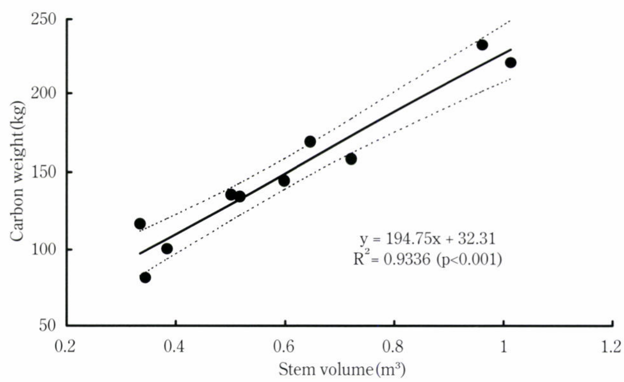

Fig. 5 Relationship between stem volume and carbon weight
Note: Dotted lines are minimum and maximum estimation errors of 95% reliability.

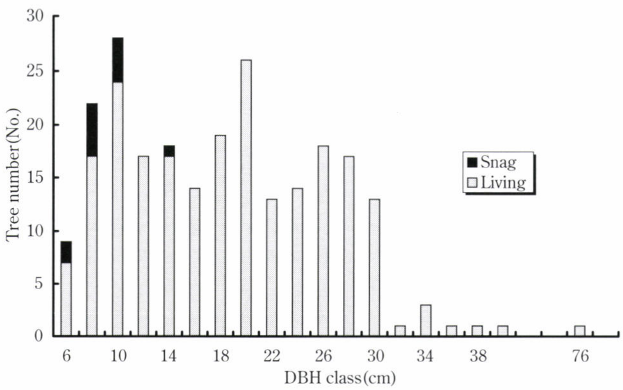

Fig. 6 Number of trees in each DBH class in study area

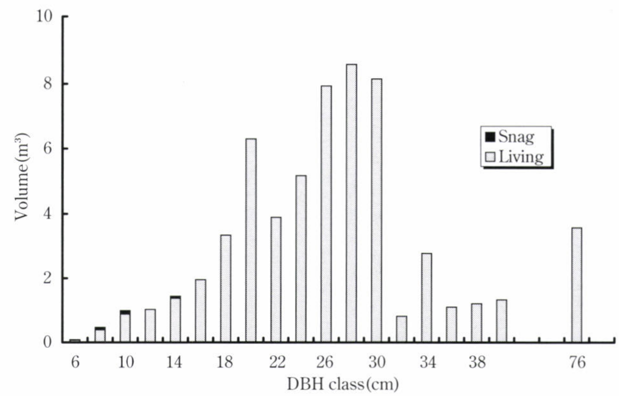

Fig. 7 Stem volume of trees in each DBH class in sampling area

Table 3 Carbon weight estimated by various methods

Estimation methods	Estimated Carbon weight (ton/ha)	Error range (ton/ha)	Ratio
Originate from DBH	159.551	115.729～228.418	1.66
Originate from stem volume	120.884	84.291～157.477	1.26
Originate from IPCC guideline	95.880	No data	1.00

Note: Error ranges are calculated from 95% reliability limits on each formula.

Carbon stock = stand volume × expansion coefficient × bulk density × carbon content

In this formula, expansion coefficient is the ratio of tree volume including branches, leaves and roots to stem volume, bulk density is 0.49 ton/m^3 for broad-leaved trees and carbon content is 0.5. Here, stand volume was regarded as 376.0m^3/ha, which is the total stem volume at the sampling time, bulk density as 0.51, which is the average value of the trees used in this study, carbon content as 0.5, and expansion coefficient was excluded, because in this study we examined only the stem volume. As a result, carbon stock was calculated as 95.88 ton/ha. Table 3 shows the carbon weight obtained by eq. 1 (based on DBH) and eq. 2 (based on stem volume) relative to that obtained by the formula proposed by IPCC. The carbon weight calculated by eqs. 1 and 2 using DBH and stem volume, respectively, were 66 and 26% heavier, respectively, than the carbon weight calculated by the method proposed by IPCC. Such a difference may be attributed to the following factors. In the present study, the dry weight was calculated from the volume and bulk density of each part of stem, and the carbon weight was obtained using the correlation with the stem size. The most important reason may be the greater bulk density of the stem in the center of the stem, the slightly higher average bulk density in the stem with a small DBH than that with a large DBH, and the larger number of stems with a small DBH than that of the stem with a large DBH. In addition, in our method, carbon weight is calculated as a function of DBH or stem volume, and we can show the error of estimation. This is important because the need to take into account "uncertainties" and "transparency in reporting" is prescribed in the Kyoto Protocol. The present study showed that taking bulk density and stand structure into consideration is very important for the calculation of carbon stock in the forest.

CONCLUSION

In this study, we discussed the carbon weight of the stems in the secondary stand of beech, but we did not take the age of the stand into consideration. It is known that the volume of each annual ring is fixed after formation, but whether or not the weight of each annual ring is fixed is uncertain. Therefore, we have to examine the distribution of bulk density in the stems at various ages.

If it is confirmed that the weight increase of annual rings after the ring formation is fixed, we can easily calculate the carbon weight as follows. First, count the number of trees in each DBH class for each tree species, no matter whether it is in the compartment of a stand or a planned regional stand. Second, analyze the stem structure for each DBH class, obtain the data of bulk density in the stem and calculate dry weight and carbon weight using SDA. Third, obtain the relational equation between the stem size and carbon weight. If only DBH is available as the size information, the accuracy of the estimation will be low, but if the data of stem volume is available the accuracy will be increased. Finally, multiply the carbon weight of the stem in each DBH class by the number of trees with each DBH, to calculate carbon weight in the investigation area.

If the weight increase of annual ring after the ring formation is not fixed, the above calculation should be made for the trees of each age class. Although the method of calculation of carbon absorption by the forest may be improved further, the above method using SDA is considered to be valuable for the present. Of course, We must increase the investigation sample number.

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(Received 7 January 2005)
(Accepted 10 April 2005)

Article

A System to Predict Diameter Distribution in Pure Even-aged Hinoki (*Chamaecyparis obtusa* SIEB.) Plantations (II) Application to Sugi (*Cryptomeria japonica* D. DON) Plantations

Takao Hayashi[*1] and Kazukiyo Yamamoto[*1*2]

ABSTRACT

A diameter-distribution prediction system (DDPS) was previously developed for pure even-aged hinoki (*Chamaecyparis obtusa* Sieb.) plantation. In this study, we examined the applicability of this DDPS to sugi (*Cryptomeria japonica* D. Don) plantation. We estimated the parameters for the DDPS mainly using a data set obtained from permanent sample plots in western Japan and validated the parameters using a data set obtained from permanent sample plots in the Kanto and Kinki regions. We also compared predicted and observed diameter distributions. We found that when the length of the prediction period was shorter than 16 years and initial stand age was larger than or equal to 31 yr, the predicted and observed density and basal area were not significantly different. The difference between predicted and observed distributions were minor and the goodness of fit appeared sufficient to allow this method to be used for prediction of sugi stand variables and diameter distributions for stands aged over 30 years. Considering the independency of the two data sets used for parameter prediction and validation, it is concluded that the DDPS would accurately predict stand growth in other regions.

Keywords: diameter distribution succession, pure even-aged sugi (*Cryptomeria japonica* D. DON) plantation, applicability

INTRODUCTION

In a previous study (HAYASHI *et al*., 2002) we presented a new diameter-distribution prediction system that could predict stand growth at each year without tree height data for pure even-aged hinoki (*Chamaecyparis obtusa* SIEB.) plantations; we also validated the system using measurement data that were independent of the data used for model development. The results of the validation indicated that this system could predict density, basal area, mean DBH, and diameter distribution without tree height data. The applicability of the system to other tree species was not tested in the previous study.

Hinoki and sugi (*Cryptomeria japonica* D. DON) are major plantation tree species in Japan. Hinoki plantations cover 2.6 million hectares, or 24.9% of the total plantation area (THE PLANNING DIVISION OF FORESTRY AGENCY OF JAPAN, 2002), and provide about 17% of the timber produced annually within Japan (STATISTICS DEPARTMENT OF THE MINISTRY OF AGRICULTURE, FORESTRY AND FISHERIES OF JAPAN, 2002). Sugi plantations cover 4.5 million hectares, or 43.8% of the total plantation area (THE PLANNING DIVISION OF FORESTRY AGENCY OF JAPAN, 2002), and provide more than 55% of the timber produced annually within Japan (STATISTICS DEPARTMENT OF THE MINISTRY OF AGRICULTURE, FORESTRY AND FISHERIES OF JAPAN, 2002). Thus, forest growth and yield models that can apply to both sugi and hinoki plantations would be of great utility to Japanese forest managers.

Due to the difference in shade tolerance (NAKAMURA, 1956; TSUTSUMI, 1994; MURATA, 2004), growth pattern is different between Sugi and Hinoki. For example, growth ratio of unthinned even-aged hinoki plantation is larger than that of unthinned even-aged sugi plantations (YAMAMOTO *et al*., 1987). In fact, in the most existing growth models, parameters that relate to the growth pattern take species-specific values (e.g. ITO and OSUMI, 1984, 1986; YAMAMOTO, 1992). To apply the diameter-distribution prediction system, it is neccessary to

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estimate the parameters for sugi plantations and validate them.

The objective of this paper was to test how well the HAYASHI *et al.* (2002) diameter-distribution prediction system applied to pure even-aged sugi plantations. To test the applicability of the system to sugi plantations, we re-estimated the parameters of the system and predicted stand growth using the estimated parameters. We then compared the predicted and observed values and examined the effects of initial stand age and length of the prediction period on prediction accuracy.

METHODS

Model Equation and Parameter Estimation

The diameter-distribution prediction system (DDPS) consists of three component models: basal area prediction model, maximum density estimation model, and diameter distribution succession model. In this study, we estimated the parameters for the basal area prediction model and maximum density estimation model using the same method as HAYASHI *et al.* (2002). The equations for these models are as follows:

(a) Basal area prediction model:

$$G(t+1)=G(t)\cdot \exp\left[a_1\left(\frac{1}{t+1}-\frac{1}{t}\right)\right]\cdot\left(\frac{t+1}{t}\right)^{a_2}\cdot\left(\frac{\rho(t+1)}{\rho(t)}\right)^{a_3} \quad [1]$$

(b) Maximum density estimation model:

$$\ln\rho_{\max}(t)=\ln b_0+\frac{1}{b_2}\ln\left[\left(\frac{G(t)}{b_3}\right)^{b_1 b_2}+\left(\frac{b_0}{\rho_0}\right)^{b_2}\right] \quad [2]$$

where $G(t)$ means basal area at stand age t (m^2/ha), $\rho(t)$ means density at stand age t (trees/ha), $\rho_{max}(t)$ means maximum density at stand age t (trees/ha), ρ_0 means initial density (trees/ha), a_j and b_j are the parameters ($j = 0-3$) to be estimated.

The parameters of both models were estimated by the same methods as the previous study (HAYASHI *et al.*, 2002). The parameters a_1, a_2, and a_3 were simultaneously estimated by multivariate analysis on the data for development. The parameters b_0, b_2, and b_3 were estimated by use of nonlinear regression for the data of an unthinned plot after the estimation of parameter b_1 as the slope of the maximum density line.

Data

In this study, we used measurement data from permanent sample plots established in sugi plantations (Fig. 1). The data were divided into two data sets, one for parameter estimation and one for validation. Basic information on the permanent sample plots and the thinning regime applied in each area are presented in Table 1.

The data used for parameter estimation were collected from total 27 permanent sample plots in western Japan. Among these plots, 23 were located in permanent sample plots established by the Kyushu and Kansai branches of the Government Forest Experiment Station (currently, Forestry and Forest Products Research Institute) of Japan (e.g. KONDO, 1997; HOSODA, 2000a), three were located in private forest in Owase City, Mie Prefecture in the Kinki region (34° 03' N, 136°

Table 1 Basic statistics of data sets.

Variables	Data for parameter estimation (n = 27)				Data for validation (n = 31)			
	mean	min	max	S.D.	mean	min	max	S.D.
Plot area (ha)	0.1321	0.02	0.261	0.088	0.1322	0.034	0.54	0.114
Measurement Time (times)	4.8	2	11	3.2	7.4	3	13	2.5
Inventory Period (years)	21.9	4	65	20.8	37.9	14	68	13.9
Initial Condition								
Stand Age (yr)	32.4	6	66	18.6	31.7	11	168	27.2
Density (trees/ha)	2059.0	481	6050	1252.6	2021.7	297	3852	969.2
mean DBH (cm)	19.4	5.2	42.0	9.8	20.2	7.0	53.7	9.2
Basal Area (m^2/ha)	46.6	13.70	81.09	19.93	53.5	14.59	86.10	16.62
Thinning regime								
Stand age at thinning (yr)	42.2	15	82	18.53	39.7	16	84	17.52
Thinning Intensity								
Tree Number	0.15	0.00	0.36	0.11	0.32	0.01	0.68	0.16
Basal area	0.10	0.01	0.28	0.07	0.23	0.01	0.63	0.14
Data source	HONDA *et al.*, 1975, 1976, 1977, 1978, 1979, 1980; HOSODA, 1997, 1998, 2000a, 2000b; HOSODA *et al.*, 2001; KONDO, 1997; MORITA, 1989; MORITA *et al.*, 1983, 1984, 1985; UENO and HASEGAWA, 1975				NAITOH, 1982; NAITO, 1987, 1994; NAITO *et al.*, 1996; OOMURA *et al.*, 2004; OOTOMO *et al.*, 2002; TAKEUCHI and HASEGAWA, 1975; YAMAMOTO *et al.*, 1988			

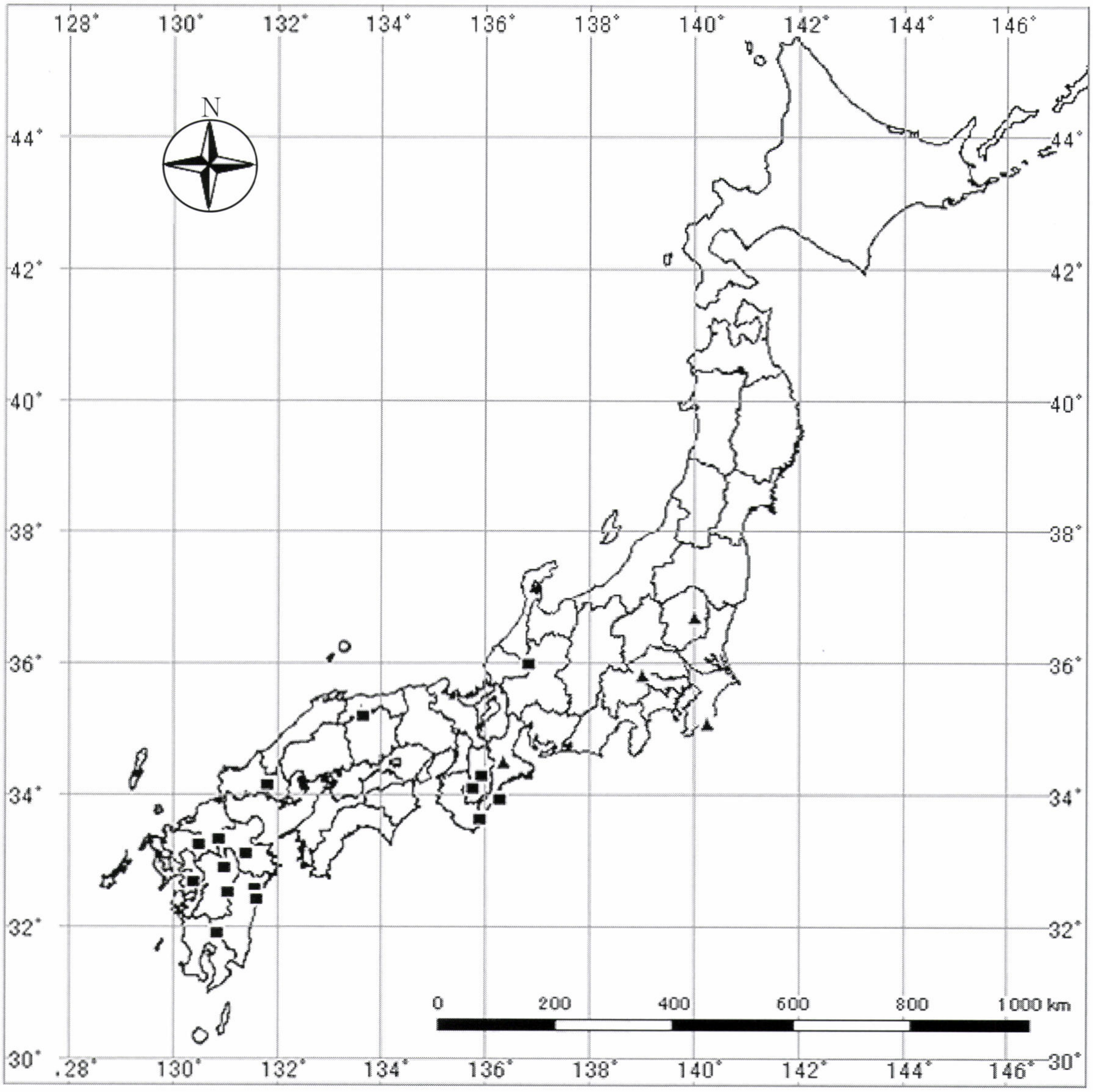

Fig. 1 The distribution of permanent sample plots. Squares represent permanent sample plots used for parameter estimation and triangles represent permanent sample plots used for model validation.

10' E), and one plot was located in the Tokyo University Forest in Chichibu (YAMAMOTO *et al.*, 1988; OOMURA *et al.*, 2004).

The 23 permanent sample plots was established by the Kyushu and Kansai branches of the Government Forest Experiment Station of Japan in the Hokuriku, Kinki, Chugoku, and Kyushu regions (e.g. KONDO, 1997; HOSODA, 2000a). Site indexes and planting densities of these plots were unknown and plot area differed among plots. Available data (e.g. KONDO, 1997; HOSODA, 2000a) consisted of density, mean DBH, mean tree height, basal area, and stand age for each recorder. In this study, we used stand age, density and basal area.

The sample plots in private forest in Owase City, Mie Prefecture in the Kinki region were established in 1962 and had an area of these plots is 0.02 ha. The planted density, stand age and site index of these plots also varied between plots. The DBH of all live trees in all three plots were measured from 1962 to 1966 at 2-year intervals. We calculated density and basal area using these measurement data.

The Chichibu experimental forests are located in Chichibu City, Saitama Prefecture (35° 56' N, 138° 51' E). There are 44 experimentally thinned plots (including 7 unthinned plots) in the forests, 23 of which were located in sugi stand. These 23 plots were established between 1956 and 1967. Planted density, plot size, site index and treatment regimes of these plots varied. The DBH of all live trees was measured. One unthinned plot named "005B" (YAMAMOTO *et* *al*., 1988; OOMURA *et al*., 2004) was used to estimate parameter b_0, b_2, and b_3 in equation [2] by using nonlinear regression. Plot 005B was established in 1956 and has an area of 0.0502 ha. Since the year of its establishment, eight measurements have been conducted at ages ranging from 26 yr to 72 yr (YAMAMOTO *et al*., 1988; OOMURA *et al*., 2004).

The data used for validation were collected from 31 permanent sample plots in the Kanto and Kinki regions. Among these plots, six plots were located in the Tokyo University Forest in Chiba (TAKEUCHI and HASEGAWA, 1975), 22 in the Tokyo University Forest in Chichibu (YAMAMOTO *et al*., 1988; OOMURA *et al*., 2004), two in the Utsunomiya University Forest in Funyu (NAITOH, 1982; NAITO, 1987, 1994; NAITO *et al*., 1996), and one in the Mie University Forest in Hirakura (OOTOMO *et al*., 2002). The DBHs of all living trees in these plots were re-measured. We summarized the data into diameter distribution and calculated the density and basal area. The interval for the diameter distribution was 2cm.

The experimental forests of the Tokyo University Forest at Chiba are located in Amatsu Town in Chiba Prefecture (35° 09' N, 140° 10' E). Of the eight experimentally thinned plots in the forest, six are located in sugi stands. These six plots were established in 1916 and 1940. Planted density, plot size, site index and treatment regimes of these plots were different. Measurements of these plots were taken eight to 13 times at varying intervals of approximately five years (TAKEUCHI and HASEGAWA, 1975).

The experimental forests of the Utsunomiya University Forest at Funyu are located in Shioya-gun, Tochigi Prefecture (36° 47' N, 139° 51' E). NAITOH (1982) established eight plots in these forests, two of which are located in sugi stands, These two plots were established in 1980. Planted density, plot size, site index and treatment regimes of these plots varied, and measurements have been conducted three times at five, nine, and 14 years after plot establishment (NAITO, 1987, 1994; NAITO *et al*., 1996).

The permanent sample plot of the Mie University Forests at Hirakura is located in Misugi village, Mie Prefecture (34° 28' N, 136° 13' E). This plot was established in 1977 at an age of 168 yr. Measurements have been conducted three at plot establishment and again at 12 and 22 years after establishment (OOTOMO *et al*., 2002).

Evaluation of Model Applicability

We evaluated the prediction accuracy of the parameterized DDPS for pure even-aged sugi plantations by applying it to the validation data set and comparing the predicted and observed values of density, basal area, mean DBH (hereafter referred to as "stand variables"), and diameter distribution. In the prediction process, thinning was treated as the subtraction of the number of thinned tree from that of predicted live tree for each DBH class. In this study, the number of thinned tree for each DBH class were determined as follows:

$$nt_{pred}(j) = \min(nt_{obs}(j),\ n_{pred}(j)) \qquad [3]$$

where $nt_{pred}(j)$ means the number of thinned tree in the j-th DBH class determined in the prediction process, $nt_{obs}(j)$ means the number of observed thinned tree in the j-th DBH class, and $n_{pred}(j)$ means the number of predicted live tree in the j-th DBH class. If the number of predicted tree in j-th class was larger than the number of observed thinned tree in j-th class, the number of predicted thinned tree was decided to be equal to observed thinned tree. Otherwise, the number of predicted thinned tree was reduced to the number of predicted tree of j-th DBH class. In the latter case, the number of predicted thinned tree per plot was smaller than observed one. This loss of thinned tree in some DBH class was not compensated by reduction of tree number from other DBH class.

To examine the effect of the initial stand age and the length of the prediction period on prediction accuracy, we repeated the growth prediction for each plot by varying the initial stand age and classifying the predictions into several groups according to initial stand age (t_0) and length of prediction period (Δt). Growth predictions were performed using each measurement except the last as values for t_0. In the classification process, we ensured that all predictions in each group originated from different plots. If more than one prediction originating from the same plot was contained in a group, we selected the one with the longest prediction period and largest initial stand age.

The categories of initial stand age were as follows: (1) $11 \leqq t_0 < 21$, (2) $21 \leqq t_0 < 31$, (3) $31 \leqq t_0 < 41$, (4) $41 \leqq t_0 < 51$, (5) $51 \leqq t_0 < 61$, (6) $61 \leqq t_0 < 71$, and (7) $t_0 \geqq 71$ yr. There were 11 categories for prediction period: (a) $\Delta t < 6$, (b) $6 \leqq \Delta t < 11$, (c) $11 \leqq \Delta t < 16$, (d) $16 \leqq \Delta t < 21$, (e) $21 \leqq \Delta t < 26$, (f) $26 \leqq \Delta t < 31$, (g) $31 \leqq \Delta t < 36$, (h) $36 \leqq \Delta t < 41$, (i) $41 \leqq \Delta t < 46$, (j) $46 \leqq \Delta t < 51$, and (k) $\Delta t \geqq 51$ years. Of the 77 combinations of these categories, actual representatives existed for 55 of them. A description of these groups is shown in Table 2.

To evaluate the prediction accuracy of the stand variables, we calculated the root mean squared error (RMSE) and mean error (ME) expressed as follows:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{j=1}^{n} (x_{pred}(j) - x_{obs}(j))^2}{n}} \qquad [4]$$

$$\mathrm{ME} = \frac{1}{n}\left(\sum_{j=1}^{n} x_{pred}(j) - x_{obs}(j)\right) \qquad [5]$$

where $x_{pred}(j)$ and $x_{obs}(j)$ represent the predicted and observed stand variables of the j-th plot and n represents the number of plots. Paired t-test was also used to compare the predicted and observed stand variables for all category combinations where there were more than two values.

RESULTS

The parameterized equations for the stand basal area prediction model and the maximum density estimation model

Table 2 Means of initial stand age (t_0), prediction period (Δt), and number of predictions (n) for groups of predictions formed from all possible combinations of prediction period and initial stand age for the validation data.

		t_0=11-20	t_0=21-30	t_0=31-40	t_0=41-50	t_0=51-60	t_0=61-70	t_0=71-180
		mean ± S.D.	mean ± S.D.	mean ± S.D.	mean ± S.D.	mean ± S.D.	mean ± S.D.	mean ± S.D.
Δt=1-5	t_0	16.0 ± 3.24	27.8 ± 1.63	36.4 ± 1.71	47.1 ± 2.82	58.0 ± 1.66	67.2 ± 1.74	79.3 ± 5.88
	Δt	5.0 ± 0.00	4.2 ± 1.01	4.5 ± 0.63	4.1 ± 1.21	4.9 ± 0.44	5.0 ± 0.00	5.0 ± 0.00
	n	5	13	16	14	21	16	7
Δt=6-10	t_0	19.0 ± 0.71	26.6 ± 2.95	36.8 ± 3.05	46.4 ± 2.20	56.6 ± 2.52	65.3 ± 2.62	98.4 ± 45.62
	Δt	9.2 ± 0.45	9.1 ± 1.23	8.9 ± 1.27	9.0 ± 1.50	9.5 ± 0.89	9.1 ± 1.69	6.8 ± 1.79
	n	5	14	20	22	20	17	5
Δt=11-15	t_0	19.0 ± 0.71	27.2 ± 2.04	37.7 ± 3.12	46.4 ± 2.48	55.5 ± 2.58	63.0 ± 0.00	96.0 ± 40.25
	Δt	14.2 ± 0.45	13.3 ± 1.75	14.2 ± 0.99	14.3 ± 1.53	14.6 ± 0.67	15.0 ± 0.00	11.2 ± 0.45
	n	5	15	18	18	21	3	5
Δt=16-20	t_0	18.2 ± 1.30	27.8 ± 1.86	38.3 ± 2.14	45.6 ± 2.84	53.9 ± 2.34	68.0 ± 0.00	73.0 ± 0.00
	Δt	19.4 ± 0.55	19.6 ± 0.51	18.7 ± 1.32	18.6 ± 1.72	18.6 ± 1.91	16.0 ± 0.00	16.0 ± 0.00
	n	5	12	18	21	14	4	4
Δt=21-25	t_0	16.0 ± 3.24	26.6 ± 3.32	37.6 ± 2.75	45.9 ± 2.81	52.8 ± 0.46	68.0 ± 0.00	168.0
	Δt	24.6 ± 0.55	24.8 ± 0.39	23.8 ± 1.23	22.9 ± 1.68	23.0 ± 2.14	21.0 ± 0.00	22.0
	n	5	12	19	20	8	4	1
Δt=26-30	t_0	18.0 ± 1.41	27.3 ± 2.87	37.8 ± 2.36	45.2 ± 3.03			
	Δt	29.0 ± 0.00	29.8 ± 0.58	28.7 ± 1.15	28.9 ± 1.51			
	n	4	12	19	11			
Δt=31-35	t_0	16.0 ± 3.24	27.8 ± 2.33	36.8 ± 1.87	45.7 ± 3.16	53.0 ± 0.00		
	Δt	34.0 ± 0.71	34.8 ± 0.87	32.9 ± 1.29	34.1 ± 1.76	31.0 ± 0.00		
	n	5	12	16	9	4		
Δt=36-40	t_0	19.0 ± 0.82	26.9 ± 2.87	33.0 ± 1.89	49.0 ± 0.00	53.0 ± 0.00		
	Δt	39.3 ± 0.50	39.8 ± 0.58	37.2 ± 1.26	40.0 ± 0.00	36.0 ± 0.00		
	n	4	12	15	4	4		
Δt=41-45	t_0	19.0 ± 0.71	27.5 ± 1.31	32.5 ± 1.91	45.3 ± 0.50			
	Δt	44.2 ± 0.45	42.8 ± 1.67	42.8 ± 1.71	43.8 ± 0.50			
	n	5	8	4	4			
Δt=46-50	t_0	18.2 ± 1.30	24.4 ± 3.21					
	Δt	49.6 ± 0.55	47.0 ± 1.41					
	n	5	5					
Δt=51-70	t_0	14.2 ± 2.95	21.5 ± 0.71					
	Δt	54.6 ± 0.55	59.5 ± 12.02					
	n	5	2					

were obtained as follows:

$$G(t+1)=G(t)\cdot\exp\left[-8.765\left(\frac{1}{t+1}-\frac{1}{t}\right)\right]\cdot\left(\frac{t+1}{t}\right)^{0.908}\cdot\left(\frac{\rho(t+1)}{\rho(t)}\right)^{0.709} \quad [6]$$

$$\ln\rho_{\max}(t)=\ln 2582.2-\frac{1}{2.92}\ln\left[\left(\frac{G(t)}{85.15}\right)^{2.92\cdot 10.82}+\left(\frac{2582.2}{\rho_0}\right)^{2.92}\right] \quad [7]$$

The RMSE and ME of the predicted stand variables and the results of paired *t*-test are presented in Table 3. The RMSE and ME tended to decrease as the length of the prediction period became shorter or the initial stand age became larger, especially for mean DBH. When the length of the prediction period was shorter than 16 years and the initial stand age was larger than or equal to 21 yr, both absolute ME and RMSE of mean DBH were less than 2 cm (the size of DBH classes) in most cases. When the length of the prediction period was shorter than 16 years and the initial stand age was larger than or equal to 31 yr, ME of both density and basal area were less than ±50 trees/ha and ±3.00 m²/ha, respectively. The results of paired *t*-test indicate that when the length of prediction period was shorter than 21 years and initial stand age was larger than or equal to 31 yr, predicted density and basal area were not significantly different (p > 0.05) from the observed values (Table 3). The ME and paired *t*-test indicate that the prediction of stand variables was accurate when the initial stand age was larger than or equal to 31 yr and the length of the prediction period was shorter than 16 years.

Scatter plots of the predicted and observed values of stand variables are presented in Fig. 2. In this figure, A_1, B_1 and C_1 represent the short-term prediction (prediction period less than 16 years) for stands with an initial stand age larger than or equal to 31 yr. This figure shows that when initial stand age was larger than or equal to 31 yr and the length of the prediction period was shorter than 16 years, the difference between predicted and observed stand variables was small, especially for mean DBH.

Fig. 3 shows a selection of predicted and observed diameter distributions along with the initial diameter distribution for a selection of plots. Fig. 3 shows that when initial stand age was larger than or equal to 31 yr, the difference between predicted and observed distributions were small at each measurement time, and the goodness of fit may be sufficient to allow this method to be used for prediction. On the other hand, when the initial stand age was smaller than 31

Table 3 Root mean squared error (RMSE) and mean error (ME) of predicted stand variables for groups of predictions formed from all possible combinations of prediction period and initial stand age. Asterisks denote a significant difference between predicted and observed values for the group based on a paired *t*-test.

		t_0=11-20		t_0=21-30		t_0=31-40		t_0=41-50		t_0=51-60		t_0=61-70		t_0=71-180	
		RMSE	ME	RMSE	ME	RMSE	ME	RMSE	ME	RMSE	ME	RMSE	ME	RMSE	ME
Δt=1-5	*N*	27	-12	53	-26	77	-15	86	8	68	29	43	10	14	-3
	D	1.5	-1.4**	0.4	-0.2	0.5	-0.1	0.7	-0.3	0.6	-0.4**	0.7	-0.3	0.9	0.4
	G	11.1	-10.5**	3.5	-2.5**	3.0	-0.7	4.4	-0.2	3.5	1.2	2.9	0.3	2.5	1.0
Δt=6-10	*N*	86	45	283	-100	217	20	119	29	91	26	53	-12	12	-7
	D	2.1	-2.0**	1.4	-0.8	1.6	-0.8*	1.2	-0.8**	1.3	-0.5	0.5	-0.2	0.9	0.8*
	G	11.8	-11.3**	9.3	-7.9**	6.4	-2.2	5.2	-0.9	5.2	0.0	5.1	-1.2	1.3	1.1
Δt=11-15	*N*	43	5	154	-5	236	26	185	42	112	37	48	31	15	-13*
	D	2.9	-2.8*	1.8	-1.0*	2.0	-1.2*	2.3	-1.2*	1.5	-1.2**	1.8	-1.8**	2.0	2.0**
	G	-17.4	-16.8**	8.7	-5.3*	9.7	-2.7	8.3	-1.3	7.7	-0.9	5.9	-2.7	2.7	2.4*
Δt=16-20	*N*	207	7	216	37	252	76	175	89*	149	84*	49	-36	55	-45
	D	3.9	-3.6**	2.8	-1.8**	2.9	-1.9**	2.9	-1.8**	2.2	-1.8**	1.7	1.6*	2.8	2.6*
	G	22.3	-21.8**	10.0	-6.4**	9.5	-1.0	8.6	-0.5	7.9	0.6	4.2	-0.5	3.0	-1.0
Δt=21-25	*N*	429	153	377	89	272	155**	156	63	169	73	49	-42		
	D	6.1	-5.6**	4.4	-2.9*	4.0	-3.0**	3.1	-2.1**	2.3	-1.8**	3.2	3.1**		
	G	27.2	-26.7**	13.8	-6.5	9.9	1.1	7.9	-2.8	10.3	-0.3	4.0	0.6		
Δt=26-30	*N*	392	84	361	94	280	134*	187	114*						
	D	5.4	-4.8*	5.2	-3.6**	4.4	-3.1**	4.1	-3.7**						
	G	25.2	-24.4**	12.5	-5.0	10.4	-0.5	10.8	-3.3						
Δt=31-35	*N*	571	283	365	117	282	178**	119	38	67	-61*				
	D	8.2	-7.5*	5.7	-4.0**	5.1	-3.8**	3.9	-2.9*	0.7	0.6				
	G	27.3	-26.3**	13.0	-2.5	12.5	1.0	10.3	-8.7**	8.5	-8.0*				
Δt=36-40	*N*	227	48	336	138	309	142	62	-58*	65	-62*				
	D	7.6	-3.6	6.4	-5.3**	5.8	-4.4**	0.5	0.4	1.9	1.7*				
	G	23.5	-9.2	16.2	-5.8	12.5	-3.0	10.7	-9.9*	7.3	-6.8*				
Δt=41-45	*N*	215	49	357	151	368	349*	112	-82						
	D	8.3	-4.7	6.9	-5.1*	8.3	-7.7*	8.8	3.9						
	G	21.6	-9.1	12.9	-1.6	15.6	4.9	9.3	-4.9						
Δt=46-50	*N*	257	92	171	-38										
	D	9.6	-5.6	3.6	-3.3*										
	G	21.1	-6.6	18.1	-14.3										
Δt=51-70	*N*	360	279												
	D	15.4	-13.6												
	G	23.0	-21.1												

NOTE. Δ*t*: the length of prediction period (yrs), t_0: initial stand age (yr), *N*: density, *D*: mean DBH, *G*: basal area,
**: p<0.01, *: p<0.05

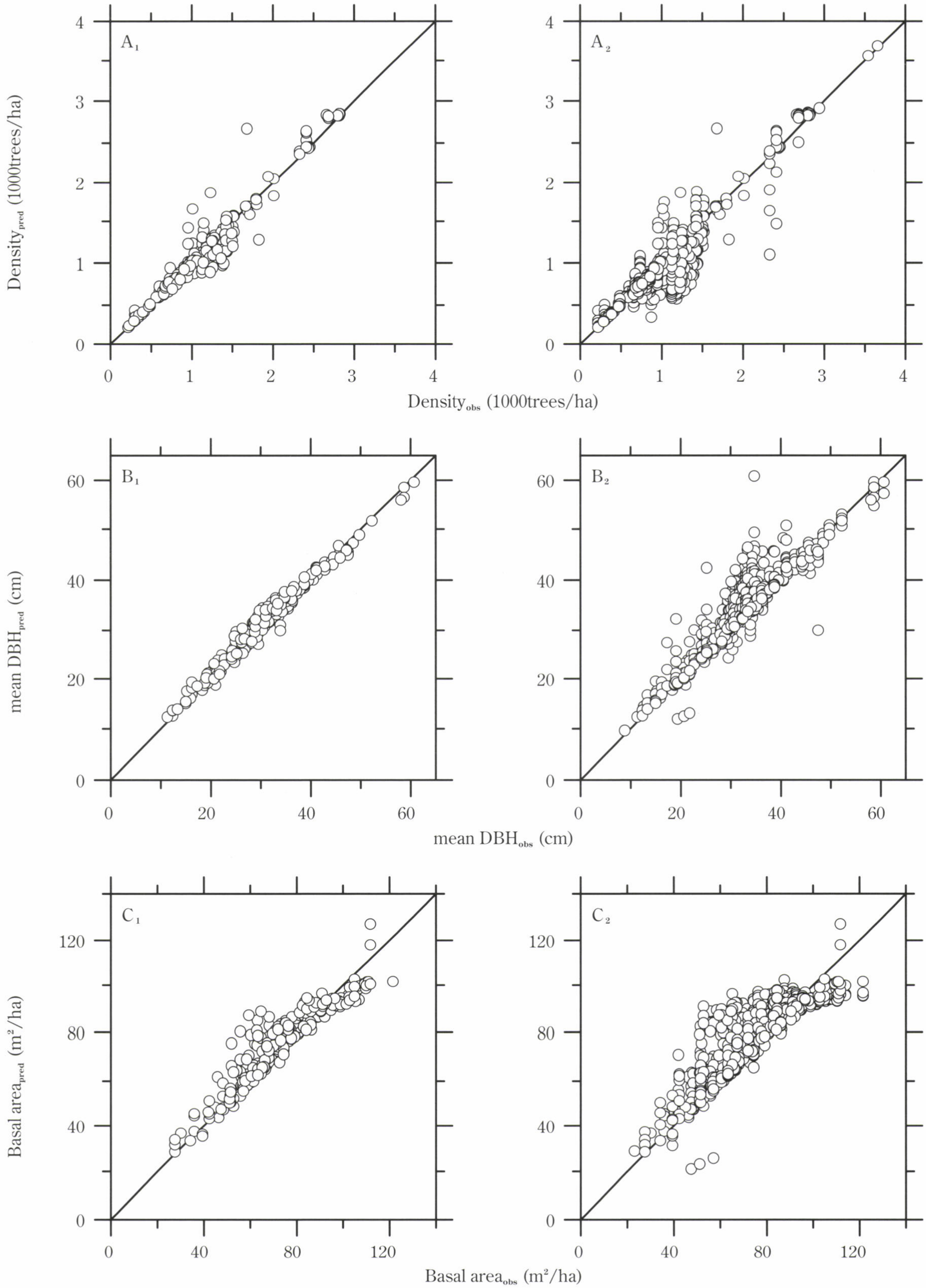

Fig. 2 Scatter plots of observed and predicted stand variables in the short-term prediction period (less than 16 years) for stands with initial stand ages larger than or equal to 31yr (A_1, B_1 and C_1) and the other (A_2, B_2 and C_2) with a respect to density (A_1 and A_2), mean DBH (B_1 and B_2), and basal area (C_1 and C_2).

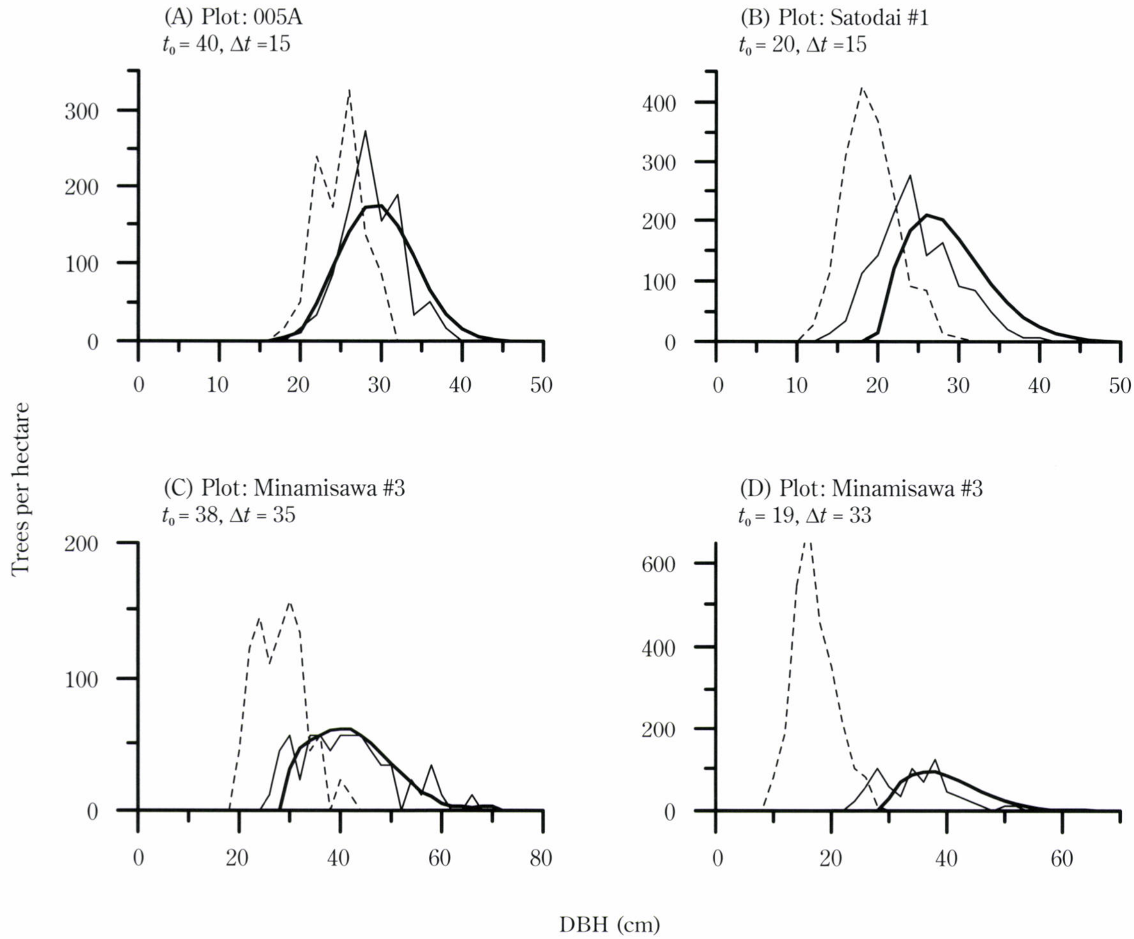

Fig. 3 Comparisons of individual diameter distribution predictions for a selection of plots (dashed line is the initial distribution; thin line is the observed distribution; bold line is the predicted distribution): (A) Initial stand age (t_0) is larger than or equal to 31 years and prediction period (Δt) is shorter than 16 years; (B) t_0 is less than 31 years and Δt is less than 16 years; (C) t_0 is greater than or equal to 31 years and Δt is greater than 16 years; (D) t_0 is less than 31 years and Δt is greater than 16 years.

yr, this model tended to predict a diameter distribution skewed towards larger values.

DISCUSSION

In this study, we re-estimated the parameters of DDPS and validated them. The validation showed that prediction accuracy was varied according to the initial stand age and the length of the prediction period; when the length of the prediction period was shorter than 16 years and the initial stand age was larger than or equal to 31 yr, the prediction accuracy was relatively high (Table 3, Fig. 2, 3). In the previous study for hinoki (HAYASHI *et al*., 2002), the predicted and observed stand variables were not significantly different. However, in the hinoki study the initial stand ages of all plots except one in the validation data set were larger than or equal to 31 yr. It is suggested that the DDPS can be used to accurately predict the growth of pure even-aged sugi and hinoki plantations for stands aged above 30 yr.

In both the present study and the earlier HAYASHI *et al.* (2002) study, the spatial distribution of the plots in the data sets used for parameter estimation and model development were very wide (Fig. 1). Because of this wide distribution of plots, the DDPS is expected to represent the average growth pattern of the various regions. In addition, it was assumed that the validation data were independent of the data used for parameter estimation and model development since the plots in the two data sets were selected independently of each other. The validation in both studies indicated that the DDPS could predict growth in plots that were independent of the plots used for parameter estimation without adjusting the parameter values. It is suggested that the DDPS is applicable to pure even-aged sugi and hinoki plantations in the various regions.

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*: The titles are tentative translations from original Japanese translated by the authors of this paper.

+: These literature were used as a data source and are not otherwise cited in the body of the paper.

(Received 2 March 2005)
(Accepted 12 September 2005)

Article

Effects of Canopy Tree Characteristics and Forest Floor Vegetation on Defication Site Selection of a Japanese Serow (*Capricornis crispus*) Population in Lowland Managed Forests in Northern Japan

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ABSTRACT

The objective of this study was to elucidate the relationships between canopy tree and forest floor vegetation characteristics, and the fecal pellet-group distribution of a Japanese serow population, in lowland managed forests of Iwate Prefecture in northern Japan. The study area was classified into five forest types: Japanese red pine (JRP), Japanese cedar (JC), other conifers (OC), a mixture of conifer and broad-leaved trees (MCB), and deciduous broad-leaved trees (DBL). Fecal pellet-groups throughout the study area were counted during November/December 2002. Between June and September 2002, the forest vegetation was surveyed using plot inventory in the largest forest block of the study area. One hundred and thirty-eight 100-m² circular plots were established in the forest at the same time. The observed numbers of pellet-groups in the JRP and DBL forests were significantly lower than the left-tail threshold of the expected random distributions generated by a Monte Carlo simulation. In contrast, the observed numbers of pellet-groups in the JC and OC forests were significantly higher than the right-tail threshold of the expected random distributions. These results indicate that the serow used the JC forests frequently for defecation sites, and that the DBL and JRP forests were not used in proportion to their areas. We propose that serows make selective use of JC stands because of reduced forest floor vegetation in these plantations. Coverage by the major component of the forest floor vegetation, dwarf bamboo, is likely reduced in the JC forests by the removal of ground cover vegetation before thinning and by the shady conditions beneath the canopy, which result from canopy tree characteristics.

Keywords: canopy tree, dwarf bamboo, fecal pellet-group, habitat use, Japanese serow

INTRODUCTION

Conservation of biodiversity has become one of the most important guiding principles in sustainable forestry (HUNTER, 1999). Management from an ecological perspective is important for conserving populations of large mammals that inhabit forest areas (FUJIMORI *et al.*, 1999), especially since the home ranges of these animals are proportional to their body mass (TAKATSUKI, 1998). Understanding the habitat use of large mammals is an essential component of conservation-oriented forest management (HIGUCHI, 1996).

The Japanese serow (*Capricornis crispus*) is an endemic ungulate that has been given "Special Natural Monument" status in Japan. The serow is a forest dweller (MIURA, 1999) that is found mainly in the broad-leaved forest zone throughout Honshu, Shikoku, and Kyushu islands (FUJIMORI *et al.*, 1999). Habitat use by the serow has been studied in relation to its food habits (OCHIAI, 1999; SONE *et al.*, 1999; NOSE and AOI, 2003; OKI, 2004), but few reports on their habitat use have been based on other attributes, such as defecation patterns (OMACHI ALPINE MUSEUM, 1991).

The Japanese serow is a solitary species with a resource-defended territory (KISHIMOTO and KAWAMICHI, 1996). Defecation occurs within a limited area of this territory (OMACHI ALPINE MUSEUM, 1991); serows defecate about 300 fecal pellets at a time (TAKATSUKI *et al.*, 1981). The distribution of these pellet-groups is a useful index for studying defecation site selection, and habitat use by deer populations has been well-documented using pellet-group distributions (COLLINS and URNESS, 1981; SAKURAGI *et al.*, 1999; van der WAL *et al.*, 2001;

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HEMAMI *et al*., 2004; AKASHI and TERAZAWA, 2005). However, there have been no comparable studies of the Japanese serow.

The objective of this study was to elucidate the effects of the properties of forest canopy trees and of forest floor vegetation on the fecal pellet-group distribution of a Japanese serow population in lowland managed forests in northern Japan by examining the relationships between forest types and pellet-group density, comparing the characteristics of canopy-forming trees and forest floor vegetation among forest types, and analyzing the effects of these variables on pellet-group distribution.

STUDY SITE

The study was conducted in the Takizawa Experimental Forest of Iwate University (TEF), Iwate Prefecture, northern Japan (280.5 ha; 39°47'N, 141°10'E; Fig. 1). We selected the TEF because nine serows had been seen there (MIYAZAWA and AOI, unpublished data), and because silvicultural practices were uniform for each forest type. The altitude of the study area ranged from 170 to 274m. According to meteorological data collected at the TEF between 1983 and 2003, the mean annual precipitation and temperature at 210m elevation were 1219mm and 9.2°C, respectively. The annual maximum snow depth was about 40cm. The TEF is within a cool-temperate

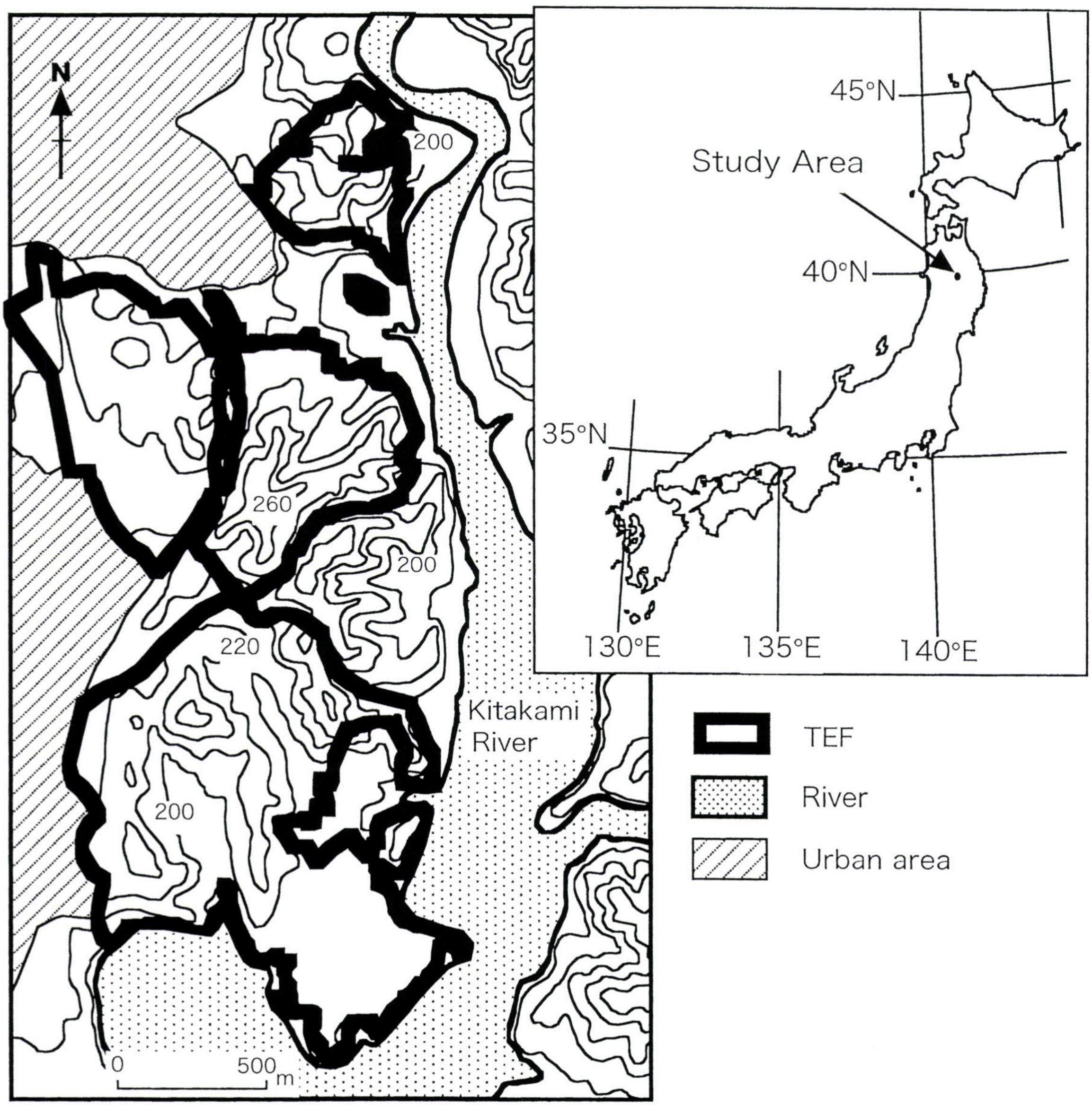

Fig. 1 Location of the Takizawa Experimental Forest of Iwate University (TEF)

lowland deciduous forest zone that is comprised mostly of natural forests dominated by Japanese red pine (*Pinus densiflora*), *Quercus serrata, Prunus leveilleana*, and artificial plantations of Japanese cedar (*Cryptomeria japonica*).

Based on species composition or growth forms in the canopies, the TEF was classified into five forest types: Japanese red pine (JRP), Japanese cedar (JC), other conifers (OC), a mixture of conifer and broad-leaved trees (MCB), and deciduous broad-leaved trees (DBL).

METHODS

Fecal Pellet-Group Counts

Fecal pellet-groups were surveyed throughout the entire TEF during November /December 2002. In each stand, five or six surveyors walked slowly through the area and recorded the positions of pellet-groups using a GPS receiver (eTrex Regend, Garmin Intl., Shijr, Taiwan) and 1:5,000 topographic maps published by Iwate University Forests. A pellet-group was defined as ten or more pellets.

We assumed that the fecal pellet groups counted in this study had accumulated from late September to December. Older pellets disappear through consumption by dung beetles and natural decay (IKEDA *et al.*, 2002). IKEDA *et al.* (*op. cit.*) reported that the disappearance rate of sika deer pellets in Japan was positively correlated with the mean monthly temperature. Assuming that the disappearance rate of pellets per month is the same for Japanese serow and sika deer, we estimated the ages of serow pellets during November/December. We assumed that 10% of the pellets defecated in August were still present at the end of the year, while the figures for pellets defecated in September, October, and November/December were 20, 70, and 100%, respectively. In addition, we confirmed empirically that almost all pellet groups defecated in September persisted for 2months or more in a sample area within the TEF (KUNISAKI *et al.*, personal observation).

Vegetation Surveys

During June-September 2002, forest vegetation was surveyed by using plot inventory in the largest forest block (138.8ha) in the south of the TEF (Fig. 2). The inventory was conducted as a line-transect survey, in which the survey lines crossed the entire block in NS-WE directions. The distance between consecutive lines was 75m. The starting point for sampling was at the westernmost point on each survey line. Thereafter, plots were established at 150-m intervals along the survey lines. One hundred and thirty-eight 100-m² circular

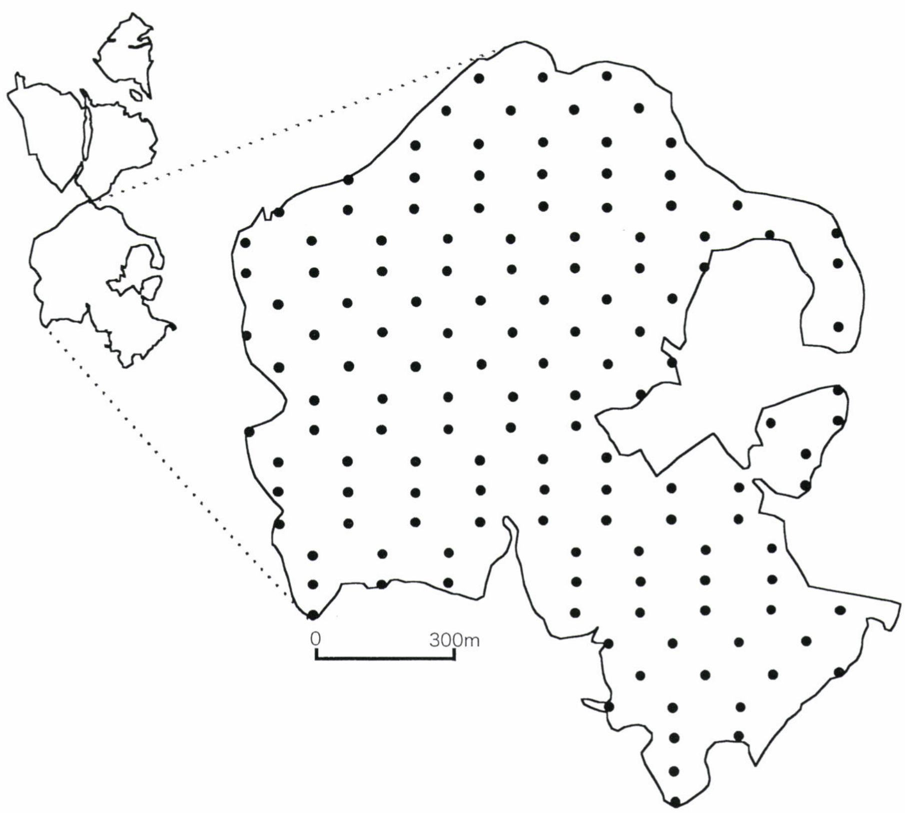

Fig. 2 Locations of sample plots in the largest forest block in the south of the TEF
Closed circles represent sample plots.

plots were set up in the forest block.

For each tree larger than 3-cm diameter at breast height (DBH) in each plot, we recorded the species, DBH, and height. The number of shrub trees >1 m tall and < 3 cm DBH in each plot was recorded. One 1 × 1-m quadrat was established in the center of each plot, and the species and culm heights of dwarf bamboo (*Sasa senanensis*, *S. borealis*, *Sasaella ramoa*, and *Pleioblastus chino*) were recorded.

Topographic Surveys

To quantify slope steepness in each plot, slope inclination was measured using a clinometer.

Estimating Light Conditions under the Canopy

At the center point of each plot, a hemispherical photograph was taken under cloudy conditions using a digital camera (Coolpix 950, Nikon, Tokyo, Japan) with a quasi-fish-eye lens (fish-eye converter FC-F8, Nikon). The camera was set on a monopod 1.3m above ground level, or above the dwarf bamboo cover, and aimed vertically at the canopy. The aperture and shutter speed were set on automatic function. In accordance with Inoue *et al.* (2002), image quality and size were selected for basic and VGA resolutions, respectively.

Weighted openness was estimated from the image files using the image analysis software LIA32 (Yamamoto, 1998). Weighted openness is an index of light conditions under the canopy and is correlated with relative illuminance (Inoue *et al.*, 1996, 2002) and relative photon flux density (Kunisaki, 2002).

Statistical Analysis

A Monte Carlo simulation was performed to test the null hypothesis that the number of pellet-groups per forest type is proportional to the forest type area. In this simulation, we constructed an artificial random distribution of pellet-groups using the accumulated count data (N = 119 pellet-groups), and then calculated the number of pellet-groups for each forest type. The Monte Carlo model was run 10,000 times to generate a frequency distribution of expected values (concordant with the null hypothesis) for each forest type. Then, the observed value (number of pellet-groups) for a certain forest type was compared with the expected distribution. If the observed value was situated within the left- or right-hand tails (two-tailed test at P = 0.05) of the expected distribution generated by the Monte Carlo simulation, it was considered significantly different from a random distribution (Manly, 1997).

The plot data from 33 JRP natural stands, 34 JC artificial plantations, and 33 DBL natural stands were used in the statistical analysis. The Kruskal-Wallis test was performed to test for significant differences in slope inclination, canopy height, tree density, total basal area, shrub tree density, accumulated culm height of the dwarf bamboos, and weighted openness among the three forest types. When there were significant differences among the three forest types, multiple comparisons were performed using the Mann-Whitney *U*-test with Bonferroni correction of the overall significance level.

RESULTS

A total of 119 fecal pellet-groups was found during November/December in the entire TEF (Table 1). The proportions of forest area for the four largest types were 34, 26, 23, and 9% for the JRP, DBL, JC, and OC, respectively. The observed numbers of pellet-groups in the JRP and DBL forests were significantly lower than the left-tail threshold of the expected distributions generated by the Monte Carlo simulation (red pine, $P < 0.05$; broad-leaved, $P < 0.01$; Fig. 3).

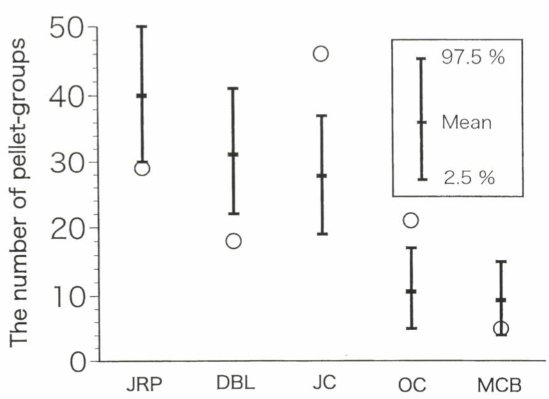

Fig. 3 The observed and expected distributions of the numbers of pellet-groups for each forest type
Open circles represent observed values, and vertical bars represent the expected range of values generated by a Monte Carlo simulation.

Table 1 Forest area and the number of fecal pellet-groups for each forest type

Forest type		JRP	DBL	JC	OC	MCB	Total
Area	(ha)	87.74	68.15	60.68	23.21	20.47	260.25
Area	(%)	33.7	26.2	23.3	8.9	7.9	100
The number of pellet-groups		29	18	46	21	5	119

JRP, Japanese red pine; DBL, deciduous broad-leaved trees; JC, Japanese cedar;
OC, other conifers; MCB, a mixture of conifer and broad-leaved trees.

Table 2 Mean ± standard error of slope inclination, canopy height, tree density, total basal area, shrub tree density, weighted openness, and accumulated culm height of the dwarf bamboos

Forest type	JC	JRP	DBL
Slope inclination (degree)	13.9 ± 1.71[a]	11.4 ± 1.63[a]	9.1 ± 1.50[a]
Canopy height (m)	22.4 ± 0.93[ab]	23.7 ± 0.49[a]	20.3 ± 0.74[b]
Tree density (no./ha)	1147 ± 88.0[a]	1145 ± 91.2[a]	1255 ± 96.1[a]
Total basal area (m^2/ha)	48.0 ± 3.91[a]	50.6 ± 3.63[a]	29.2 ± 2.98[b]
Shrub density (no./ha)	3382 ± 661.8[a]	2367 ± 425.4[a]	1841 ± 250.2[a]
Weighted openness (%)	24.2 ± 0.58[b]	24.8 ± 0.59[b]	26.6 ± 0.60[a]
Accumulated culm height of dwarf bamboos (m/m^2)	3.4 ± 1.37[c]	7.5 ± 2.12[b]	18.2 ± 4.02[a]

Forest types that share a common superscript occurred within the same homogenous subset (Mann-Whitney *U*-test with Bonferroni correction, $P < 0.05$).

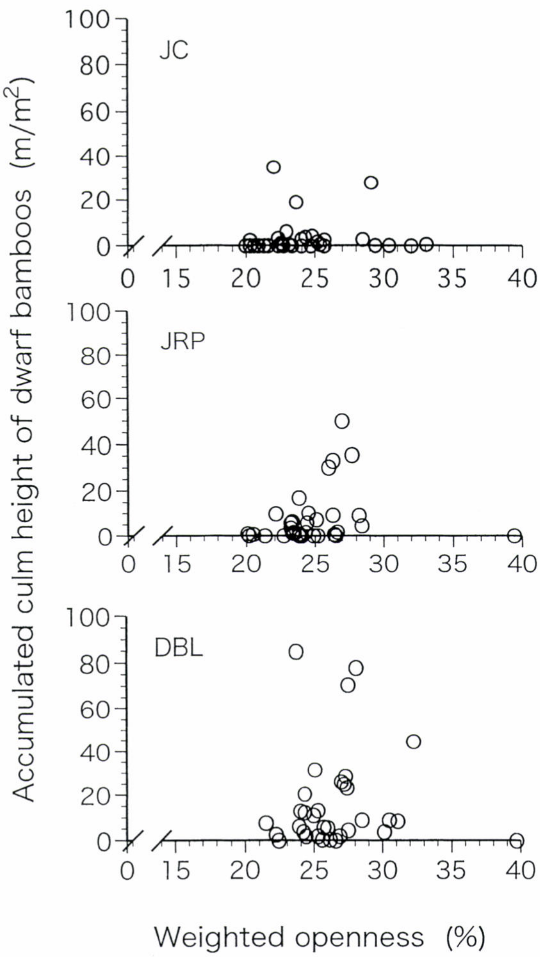

Fig. 4 Relationship between weighted openness and the accumulated culm height of dwarf bamboos for three forest types

In contrast, the numbers of pellet-groups in the JC and OC forests were significantly higher than the right-tail threshold of the expected distributions ($P < 0.01$; Fig. 3).

Slope inclination was not significantly different among the JRP stands, DBL stands, and JC plantations ($P = 0.13$; Table 2).

The total basal area of the DBL stands was significantly lower than that of the JRP stands and JC plantations ($P < 0.05$; Table 2). In contrast, the weighted openness of the DBL stands was significantly higher than that of the JRP stands and JC plantations ($P < 0.05$; Table 2). The accumulated culm heights of dwarf bamboo were highest and lowest, respectively, in the DBL stands and JC plantations ($P < 0.05$; Table 2; Fig. 4).

DISCUSSION

The results suggest that the Japanese serow used the JC stands in the TEF frequently as defecation sites, while the DBL and JRP stands were not used in proportion to their areas. We propose that the animals selectively use sites with reduced dwarf bamboo cover beneath the tree canopy, *i.e.*, the JC stands where ground cover vegetation is removed before the thinning of trees. Furthermore, the JC stands had the most shade according to our light measurements, and the aboveground biomass of dwarf bamboo on a forest floor is positively correlated with incident light intensity (OHSHIMA, 1962; KAWAHARA, 1987; SUZAKI *et al.*, 2005). The DBL stands had the highest sub-canopy light levels (especially during winter when broad leaves are shed), and the highest accumulated culm heights of dwarf bamboo. The JC stands had the lowest accumulated culm heights. Accumulated culm height is an index of the aboveground biomass of dwarf bamboo (KUNISAKI, 2004).

Corroborating evidence for our theory includes YAMAYA (1981), who reported that the Japanese serow was restricted in *Sasa kurilensis* communities on Shimokita Peninsula in northern Japan, and OKUMURA (1991), who reported that Japanese serows were absent in *Sasa nipponica* communities of the Ashio National Forest, Tochigi Prefecture, central Japan.

Furthermore, the Japanese serow is generally believed to defecate within forest sites that have good visual penetration (OMACHI ALPINE MUSEUM, 1991).

In general, closed artificial plantations of evergreen conifer are not believed to support diverse wildlife communities because of the shady conditions under the canopy and lower food availability as compared to broad-leaved natural forests (HIGUCHI, 1996). In addition, other studies have indicated that Japanese serow frequently select broad-leaved natural forests as defecation sites (OMACHI ALPINE MUSEUM, 1991). Our findings, however, suggest that defecation site selection by the Japanese serow is primarily affected not by the dominant canopy tree species but by the density of vegetation on the forest floor.

CONCLUSIONS

In this study, the effects of forest canopy and forest floor vegetation on defecation site selection by the Japanese serow were examined using fecal pellet-group counts and vegetation surveys. The observed numbers of pellet-groups in Japanese red pine and deciduous broad-leaved forests were significantly lower than the left-tail threshold of the expected random distributions generated by a Monte Carlo simulation. In contrast, the observed numbers of pellet-groups in Japanese cedar forests was significantly higher than the right-tail threshold of the expected random distributions. Slope inclination was not significantly different among the three forest types. The structural differences among the three forest types were expressed in the accumulated culm height of the dwarf bamboo community on the forest floor. This index was lowest within the Japanese cedar plantations. In conclusion, defecation site selection by the serow was negatively correlated with the dwarf bamboo accumulated culm height.

ACKNOWLEDGEMENT

We thank the staff of the Takizawa Experimental Forest of Iwate University for permitting this survey. We are also grateful to Drs. K. MATSUBARA, A. HIYANE and S. YAMAMOTO at Faculty of Agriculture, Iwate University for their kind advice during this study. This study was supported by a Grant for Environmental Research Projects (No. 013030) from the Sumitomo Foundation, and by a Grant-in-Aid for Scientific Research (No. 13460062) from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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(Received 25 July 2005)
(Accepted 25 January 2006)

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