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Case Study of the Effects of the Japanese Verified Emissions Reduction (J-VER) System on Joint Forest Production of Timber and Carbon Sequestration

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1. Introduction

In the context of climate change (including global warming), the net reduction in carbon emissions as a result of forest carbon sinks and sustainable forest management are two critical issues. Recently, the benefits of carbon sequestration by forests have been highlighted and carbon sequestration has been measured throughout the world: in the United States (Sakata 2005; Calish et al 1978; Foley et al 2009; Ehman et al 2002; Im et al 2007), Europe (Backèus et al 2005; Liski et al 2001; Matala et al 2009;Pohjola and Valsta 2007;Sivrikaya et al 2007; Kaipainen et al 2004; Seidl et al 2007), Canada (Hennigar et al 2008; Thompson et al 2009), Oceania (Campbell and Jennings 2004) and Asia (Ravendranath 1995; Han and Youn 2009). Forests not only have economic value through the production of commercial timber, but they also have other values to society including acting as carbon sinks, supporting biodiversity, and providing water protection (Pukkala 2002). Forest management subsidies are required from national budgets (funded by the tax payer) to increase the public benefit of forests by restricting the area that is clear cut and preventing other damaging silvicultural activities from being practiced. On the other hand, in the absence of artificial thinning, intensive self-thinning can occur (Nakajima et al., 2011d), resulting in significant CO_2 emissions. Therefore, both thinning and harvesting are necessary not only for commercial timber production, but also in order to reduce CO_2 emissions and gain carbon credits. In addition, tree growth gradually decreases with age (Nakajima et al., 2010; 2011d; Pienaar and Turnbull 1978), so older stands will eventually cease to increase their carbon stock. It, therefore, makes economic sense to undertake clear felling before such stagnation occurs in older stands and carbon credits are no longer available.
Because Japanese forest management profits have been in decline as a result of lower timber prices (Forestry Agency 2007), almost all Japanese forest owners depend on government

subsidies to maintain their forests (Komaki 2006; Nakajima et al 2007b). Previous studies have shown that the area of silvicultural practice including planting, weeding, pruning, pre-commercial thinning and thinning, is strongly correlated with the amount of national subsidy that is provided (Hiroshima and Nakajima 2006). Therefore, the planted forests of Japan that are funded by national subsidies should be in a condition suitable for the public to benefit from them. Generally, it is not possible to rely on natural regeneration in planted forests in Japan. The silvicultural practices used to ensure regeneration in Japan have been described in previous studies (Nakajima et al., 2011b; Sakura 1999; Ohtsuka, 1993) and are outlined in table 1.

Silvicultural practices	Stand age (year)
Land preparation and planting	0
Weeding	1–10*
Pruning	15
Precommecial thinning	20, 25

* Weeding is undertaken every year in stands aged 1 to 10 years

Table 1. Silvicultural practices undertaken at the study site

In addition, Japanese citizens think that acting as carbon sinks will be one of the most important functions of forests in the future (Forestry Agency 2007). Based on public opinion, it would be an valuable for forest managers to include the carbon benefits in their forestry profit predictions.

In order to include carbon benefits in forest management, a number of previous studies have proposed what is known as the 'social rule' (Im et al 2007; Foley et al 2009; Hennigar et al 2008). Because the rotation period is important for forest management decision making and strongly affected by regional forest resources, some studies have focused on estimating how the optimum rotation period is affected by different carbon offset systems. Carbon offsetting may be advantageous for forest management based on optimizing the rotation period (Raymer et al 2009), but it can be disadvantageous because of the effects of natural disturbance, which can release carbon (Galik and Jackson 2009). However, few studies have investigated the effects of existing carbon offsetting programs (including forest carbon sinks) in the context of global warming policy frameworks.

Under the global policy framework (resulting from the Kyoto Protocol) the size of the carbon sink in a forest is calculated for forests that have experienced afforestation, reforestation and deforestation (ARD forests) since 1990, as described by Article 3.3; and in terms of forests where silvicultural practices have been conducted since 1990 (FM forests) under Article 3.4.

The Kyoto Protocol requires signatories to reduce their CO_2 emissions and other greenhouse gases by their quantified reduction commitments below 1990 levels during the first commitment period (FCP), 2008–2012. Now that the end of the FCP is fast approaching, each country is preparing to report on emissions and the removal of carbon by forests in accordance with the Good Practice Guidance for Land Use, Land-Use Change, and Forestry (GPG-LULUCF) (Amano 2008a; Houghton et al 1997; IPCC 2000; IPCC 2007). In the protocol, Japan is committed to reducing CO_2 equivalent emissions to 6% below its 1990 level (Amano 2008b; Amano and Tsukada 2006). At the same time, the protocol allows net changes in greenhouse gas emissions to be included. For example, removal by sinks resulting from human-induced land-use changes and forestry (LUCF) activities can be added to or subtracted from their reduction commitments as appropriate.

Under the Kyoto mechanism, carbon emission trading can be undertaken. Carbon dioxide (CO_2) credits have already been traded in some markets, such as the carbon market in the United Kingdom since April 2002. The carbon price is expected to affect forestry profits and has the potential to cause considerable changes to harvesting ages. Predicting how changes in the cutting age affect carbon prices encourages the consideration of forestry measures in these terms. In order to quantify carbon storage, previous studies have proposed various methods for estimating carbon credits, including the stock changing, average storing, and ton-year methods (Richards and Stokes 1994; Schroeder 1992; Moura-Costa and Wilson 2000).

To accelerate efforts to combat global warming in accordance with the Kyoto Protocol, based on the stock changing method, Japan's Ministry of the Environment has established a forest carbon credit system. The system, which is based on the Japan Verified Emissions Reduction (J-VER) system, was launched in November 2008 and will help in calculations of forest CO_2 absorption. This is the first system of its kind. The absorption will be calculated in credits, which can then be sold to CO_2-emitting companies already registered in the J-VER system. The Ministry hopes that the credits will be traded on the carbon market in the future and funds reinvested in the expansion of the current area where silviculture is practiced; this can then be counted as CO_2 absorption under the Kyoto protocol.

Carbon accounting is based on accounting systems developed as part of the FCP under the Kyoto Protocol. Three project types are particularly important in the J-VER system: thinning promotion and management; sustainable forest management; and plantation management. Areas thinned after 2007 will be the target of the efforts under the Japanese system. Sustainable forest management activities will focus on areas that were harvested and replanted after 1990. Plantation projects will focus on replanting, and all forests eligible for credits under the credit system need to have a forest management system compliant with current Forest Law.

No previous study has clarified the effect of this new carbon offset accounting system on the actual forest area formally identified in the J-VER system. For medium- to long-term forest management strategies, it is important to clarify the effect of the J-VER system on forestry strategies. Therefore, this study aimed to investigate the effects of the carbon offsetting system on the carbon stock and timber production relative to the carbon price. Because harvesting activities need to be included in long-term forest management, we examined the sustainable forest management project under the J-VER system.

2. Materials and methods

2.1 Study area

This research was conducted in the University of Tokyo Forest, located in the cities of Kamogawa and Kimitsu, Chiba Prefecture, Japan (Fig. 1).

This forest lies 50 to 370 m above sea level and is characterized by undulating terrain with steep slopes and primarily brown forest soils. It is located in a warm temperate zone, with an average annual temperature of 14°C and an average annual precipitation of 2182 mm. The total forest area is 2216 ha; 824 ha (37%) contain sugi (*Cryptomeria japonica*) and hinoki (*Chamaecyparis obtusa*) stands, 949 ha (43%) are natural hardwood forest, and 387 ha (17%) are natural conifer forest. The remaining 57 ha (3%) are occupied by a demonstration forest. Many permanent research plots have been established in sugi stands within the forest since

1916, and tree height, height to crown base, and diameter at breast height (DBH) have been recorded approximately every 5 years since that time. A national subsidy system for the thinning of all planted tree species is commonly applied, but mainly to forest plantations less than 35 years old. The grant rates of the subsidy systems cover approximately 70 % of the cost of thinning. Inventory data relating to the private forests, such as stand age, area, tree species, slope, address of forest owners and site index, were available and were also linked to each stand included in the geographic information system (GIS). Using the inventory data, age distribution at this study site was derived and is shown in Figure 2. The site index map in this study area was also established using the airborne LiDAR measurements (Hirata et al., 2009; Hiroshima and Nakajima 2009). Only sugi (*Cryptomeria japonica*), the best-known planted tree species in Japan, was considered.

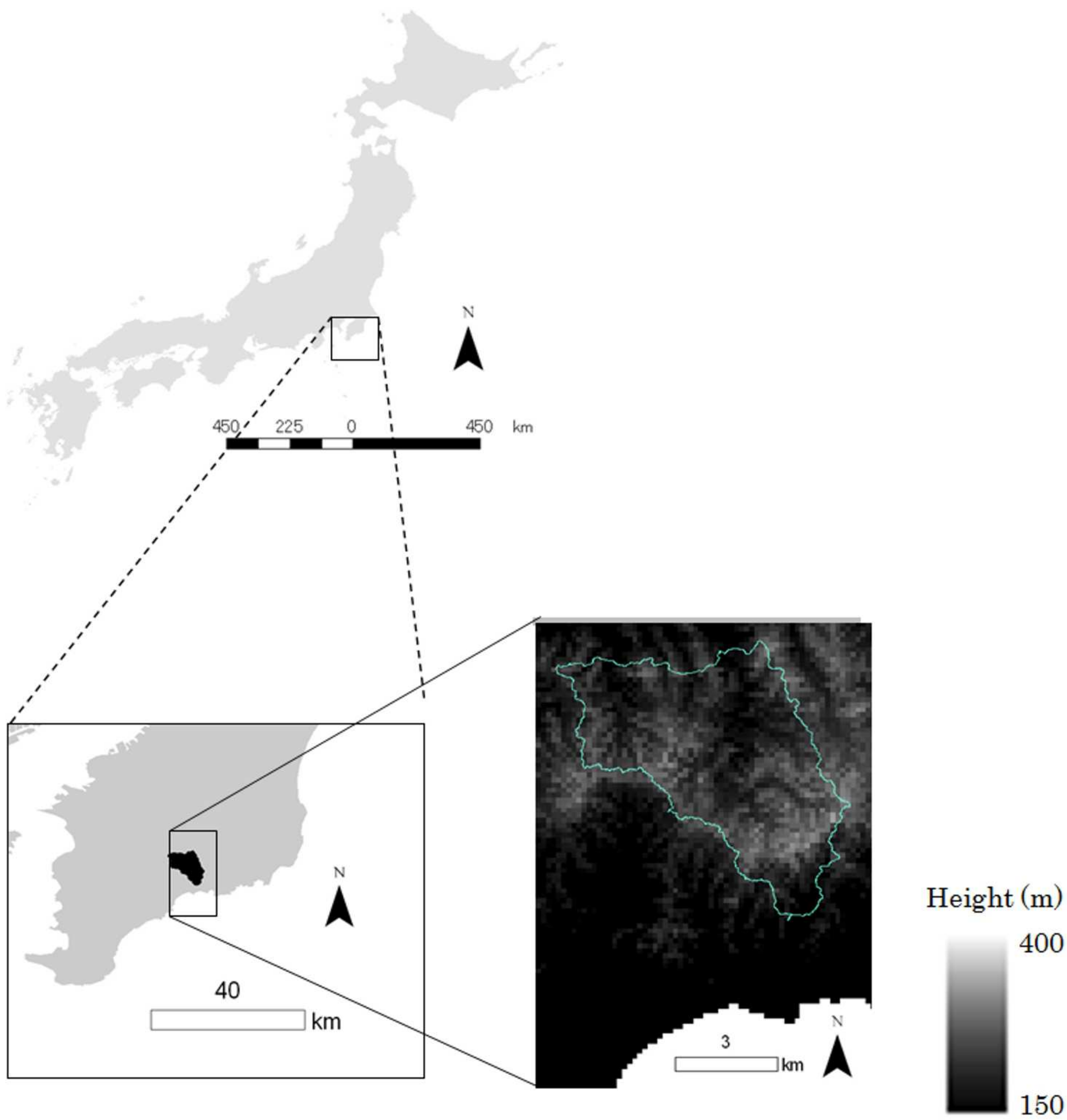

Fig. 1. Location of the University Forest in Chiba, showing an elevation of the study site. The blue line shows the forest boundary line of the University Forest in Chiba.

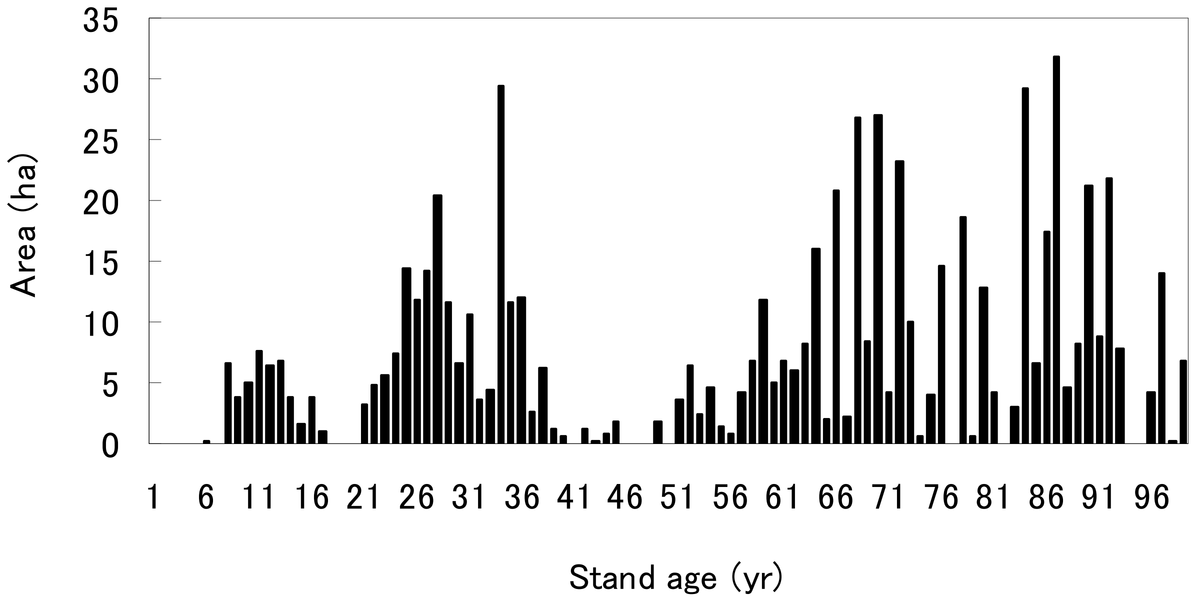

Fig. 2. The age distribution of forested areas in the study site

Approximately 58 % of planted forests in Japan are privately owned (Forestry Agency, 2007), and the forest policy subsidy system is known to have a great influence on the management practiced within them (Hiroshima and Nakajima, 2006). Furthermore, due to the socio-economic situation in Japan, there has been little financial incentive to practice sound forest management and profits have been very low as a result of decreasing timber prices. This has resulted in increased areas of unmanaged and unthinned forests, many of which have been left untended for more than 10 years (Nakajima et al., 2007).

Hence, there is an urgent need to improve the profitability of Japanese forestry. Due to the general lack of thinning, self-thinning has been increasing, accompanied by reductions in the carbon stock and adverse effects on forest ecosystem functioning. These developments are in direct conflict with a need to increase thinned areas of forest, relative to 1990 levels (Japanese Forestry Agency, 2007), under Kyoto Protocol commitments (Houghton et al., 1997; UNFCC, 1998; Robert et al., 2000; UNFCC, 2002; IPCC, 2003; Jansen and Di, 2003). Thus, there is an urgent need to expand the areas that are subject to planned thinning, and to reduce the cost of such operations by increasing their scale through forest owner cooperation. Therefore, silvicultural practices are now supported by a subsidy system (Nakajima et al., 2007), under which forest owners are required to report the conditions of their stands and the silvicultural treatments they have applied. The central government and local Prefectural government subsidize the thinning of planted forests containing trees younger than 35 years of any species, meeting approximately 70 % of the thinning cost. The subsidies for thinning are available in forests that have been subsidized in the preceding five years.

This area was one of the forest projects formally identified in Japan's Verified Emission Reduction system (J-VER), which is a Japanese carbon offset system. It is important, therefore, to establish a sustainable forest management system that takes into consideration timber production and the amount of carbon stock held in the area.

2.2 Analysis tool

The data source and analysis tool used in this study for estimating carbon absorbed by the forest were developed in accordance with the J-VER guidelines (Environmental Ministry

2009), which are based on the carbon accounting system developed for the Kyoto Protocol. J-VER guidelines suggest the use of the Local Yield Table Construction System (Nakajima et al. 2009a; Nakajima et al. 2010), which is a timber growth and carbon stock simulator. This growth model is applicable to the main tree species, including sugi (*Cryptomeria japonica*), hinoki (*Chamaecyparis obtusa*), karamatsu (*Larix leptolepis*) and todomatsu (*Abies sachalinensis*), which are planted throughout Japan. By combining LYCS with a wood conversion algorithm and a harvesting cost model (Nakajima et al. 2009a; 2009c), we can predict not only carbon stock but also harvested timber volume and forestry income. The stand age and tree species included in the forest inventory data can be used as input data for the LYCS. The harvest and silvicultural practice records of the study site, including details of incomes, costs, and labor, were used to estimate forestry profits for harvesting and silviculture. The unit price of subsidies depends on the standard silviculture system and historical records of the amount of labor required to carry out various silvicultural practices including silviculture treatments (planting, weeding, pruning, pre-commercial thinning) and harvesting (thinning, clear-cutting) were also available from the University forest in Chiba.

2.3 Data analysis

In the present study, we investigate through simulation modeling the effects of the J-VER system on timber production, carbon stock holdings. Two carbon price scenarios were assumed: Scenario 1 was no J-VER system applied to stands; Scenario 2 was the J-VER system fixing the carbon price to 1000 yen/ton-CO_2 considering previous research (Nakajima et al. 2011c), applied to stands. The international pledge made under the Kyoto Protocol commitments (Houghton et al., 1997; UNFCC, 1998; UNFCC, 2002), requires a 6 % reduction of CO_2 emissions from the 1990 level, of which 3.8 % may be attributed to carbon absorption by means of 'forest management' (Hiroshima 2004; Forestry Agency 2007). Increasing the area of 'forest management' as described under article 3.4 in the Kyoto Protocol, requires pre-commercial or commercial thinning (Nakajima et al., 2007a). Therefore, to fulfill Japan's international pledge under the Kyoto Protocol in a global context (Hiroshima and Nakajima et al., 2006), it has been proposed that a new J-VER system (i.e. Scenario 2) can be applied. This will promote thinning and restrict large-scale clear cutting by supporting long-rotation silviculture (Forest Agency 2007).

Based on the assumptions of the two scenarios, the harvesting area, amount of harvested timber, subsidy, forestry profits, carbon stock and quantity of labor were calculated by using an existing stand growth model (Nakajima et al. 2010), a wood conversion algorithm (Nakajima et al. 2009c) and a forestry cost model (Nakajima et al. 2009a). With data describing the stand condition (stand age, site index and tree species), the thinning plan (thinning ratios, number of thinnings and the thinning age) and the timber price as model inputs, the future stand volume, timber volume and forestry profits can be generated as model output (Nakajima et al., 2009a, 2009c, 2010).

The accuracy of the basic model for predicting future stands has been exhaustively checked by comparing estimated tree growth with observed tree growth data in permanent plots (Ohmura et al. 2004) gathered over more than 30 years (Shiraishi 1986; Nakajima et al. 2010). By inputting the stand condition into these models, the future forestry profits could be estimated as a function of the harvesting plan strategies and the carbon price. However, because it is not easy to predict inflation and timber price fluctuations precisely, we assume in the model that the socio-economic situation driving these variables is constant. We therefore assume that timber price remains constant throughout the prediction period and is as described by a previous study (Nakajima et al. 2009a). We believe this assumption is justified since a survey by the forest association, and government reports (Forestry Agency 2007) indicate that the current annual average timber price has been stable over recent years. The final age at cutting was chosen to maximize the present net value of forestry profits, estimated from those valid at the most recent final cutting. Although the thinning plan is included in the input data as mentioned above, it can be changed according to a particular stand density control strategy. The optimum thinning plan was decided upon by selecting the one which maximized the net present value. We varied the thinning ratios by 5 % increments from 20 % to 40 % in line with the existing standard silviculture systems (Forestry Agency 2007). We also varied the number of thinnings between zero and three, and the thinning age by increments of 5 years between the initial stand age and the final age at cutting. By inputting these various thinning plans into the LYCS, we simulated forestry profits under all harvesting strategies. We then selected the cutting plan that maximized the present net value of forestry profits.

The forestry profits could then be estimated from the forestry income and the carbon credit. Sakata (2005) examined the effects of the carbon market on forestry profits in the USA. At the study site selected by Sakata (2005), both saw logs and pulp wood were considered to contribute to any profits. On the other hand, production of pulp wood at the current study site is not commercially viable because the cost of harvesting is so high. Therefore, the study described herein examined the effects of the carbon market on forestry profits when producing saw logs alone and not pulp wood.

The carbon stocks were also estimated by substituting stand volumes derived from LYCS into the following formula (Environmental Ministry 2009):

$$C = V \cdot D \cdot BEF \cdot (1 + R) \cdot CF \tag{1}$$

where C is the carbon stock (t-C), V is the stand volume (m^3), D is the wood density (t-dm/m^3), BEF is the biomass expansion factor, R is the ratio of below ground biomass to above ground biomass and CF is the carbon content (t-C/t-dm).

The biomass expansion factor for trees younger than 20 years was 1.57; the biomass expansion factor for trees older than 20 years was 1.23; the ratio of below ground biomass to above ground biomass was 0.25; the wood density (tonnes/m^3) was 0.314; and the carbon content (t-C/t-dm) was 0.5 (Environmental Ministry 2009; Fukuda et al. 2003). By multiplying 3.67(44/12=molecule of CO_2/molecule of C) by the amount of the carbon stock present, the amount of CO_2 can be calculated. The carbon credit can be calculated by multiplying the CO_2 increase per year by the carbon price (yen/ton).

Many previous studies (van Kooten et al. 1995; Nakajima et al., 2011c) used increases in timber volume as a base from which to calculate carbon credits. The gain in carbon credits has been calculated on the basis of timber growth, and the release of carbon credits occurred when timber was harvested. In the J-VER system, however, the accounting is based on the total volume of the tree stock (we refer to this method as J-VER accounting). Therefore, when estimating carbon credits under the J-VER system, there is no need to undertake lifecycle assessments. We conducted a sensitivity analysis, in order to clarify the effects on the net present value (NPV) of changes in various parameters, including the initial stand age (0, 20 or 40 years), the site index and the carbon price (CP) and discount rate within the J-VER system.

The traditional final cutting age in order to maintain the maximum mean growth rate in Japanese planted forests is approximately 50 years (The Tokyo University Forests, 2006). Using this age as a reference, we set the initial stand ages in our models to be 0, 20 and 40 years. The discount rate was then estimated relative to a value considered to be reasonable to society; in this case 3.0 % was considered reasonable as this represents the average long-term yield of Japanese government bonds (Tokyo Stock Exchange 2007). Using the discount rate (3.0 %) as a reference, we set the discount rate to 0, 20 and 40 % in our models. Using the yield table presented by Nakajima et al. (2010) as a reference, we set the site indexes 1, 2 and 3 to represent good, intermediate and poor site quality, respectively. We examined various combinations of the different parameters to estimate the NPV of timber production, carbon credits and total NPV. In addition, wind hazard probability is an important parameter; wind it the main natural disturbance in Japanese mountain forests and it increases with increasing stand age and height (Nakajima et al., 2009b; Tsuyuki et al., 2011). The probability of wind disturbance, thus, also increases with time. However, tremendous wind disturbance records were not observed in the study site, so we did not include this parameter when calculating NPV for the forest area studied.

Based on the methodologies for calculating NPV mentioned above, the predictions at the forest level could then be estimated by summarizing the predicted values at the stand level. Because the period of validation over which these previous studies were conducted was longer than the prediction period of 25 years adopted in the present study, estimates of future timber production and forestry profits (Nakajima et al. 2009a; 2009c) could be calculated based on predictions of future tree growth at the level of stands. If the predicted values derived from existing models at the stand level are accurate, it follows that the predicted value at the forest level, which is the sum of values at the stand level, would be also accurate. For descriptive purposes, the prediction period was set to 25 years, which is the period specified for natural resource predictions by the Japanese Ministry of Education, Culture, Sports, Science and Technology (Science Council 2008).

By inputting the stand condition derived from forest inventory data into our models, future forestry profits could be estimated as a function of the harvesting plan strategies and the carbon price. As mentioned above, the discount rate was then estimated relative to a value considered to be reasonable to society; in this case 3.0 % was considered reasonable as this represents the average long-term yield of Japanese government bonds (Tokyo Stock Exchange 2007). The total harvesting area and the quantity of harvested timber were calculated by summarizing their respective values based on the harvesting plans calculated for each of the two scenarios under the carbon price of 0 and 1000 yen/CO_2-ton. The subsidies were estimated by summarizing the silviculture and thinning subsidies derived from government subsidy unit prices. In this study, the term "thinning subsidies" refers to subsidies associated with commercial thinning. In other words, the harvesting is not conducted as part of the silvicultural practices that include pre-commercial thinning. The total forestry profits could then be estimated from the forestry income and the subsidy. The carbon stocks were also estimated by substituting stand volumes derived from LYCS into the following formula (1):

In addition, labor requirements were calculated by multiplying the amount of labor required per hectare for each silvicultural practice, by the area over which that silviculture would be practiced, based on the estimated harvesting plans and the age distribution of trees in the study site.

3. Results and discussion

Results of the sensitivity analysis, based on the initial stand age (0, 20 or 40 years), and taking into account carbon price (CP), discount rate and site index within the J-VER system, are presented in Figure 3.

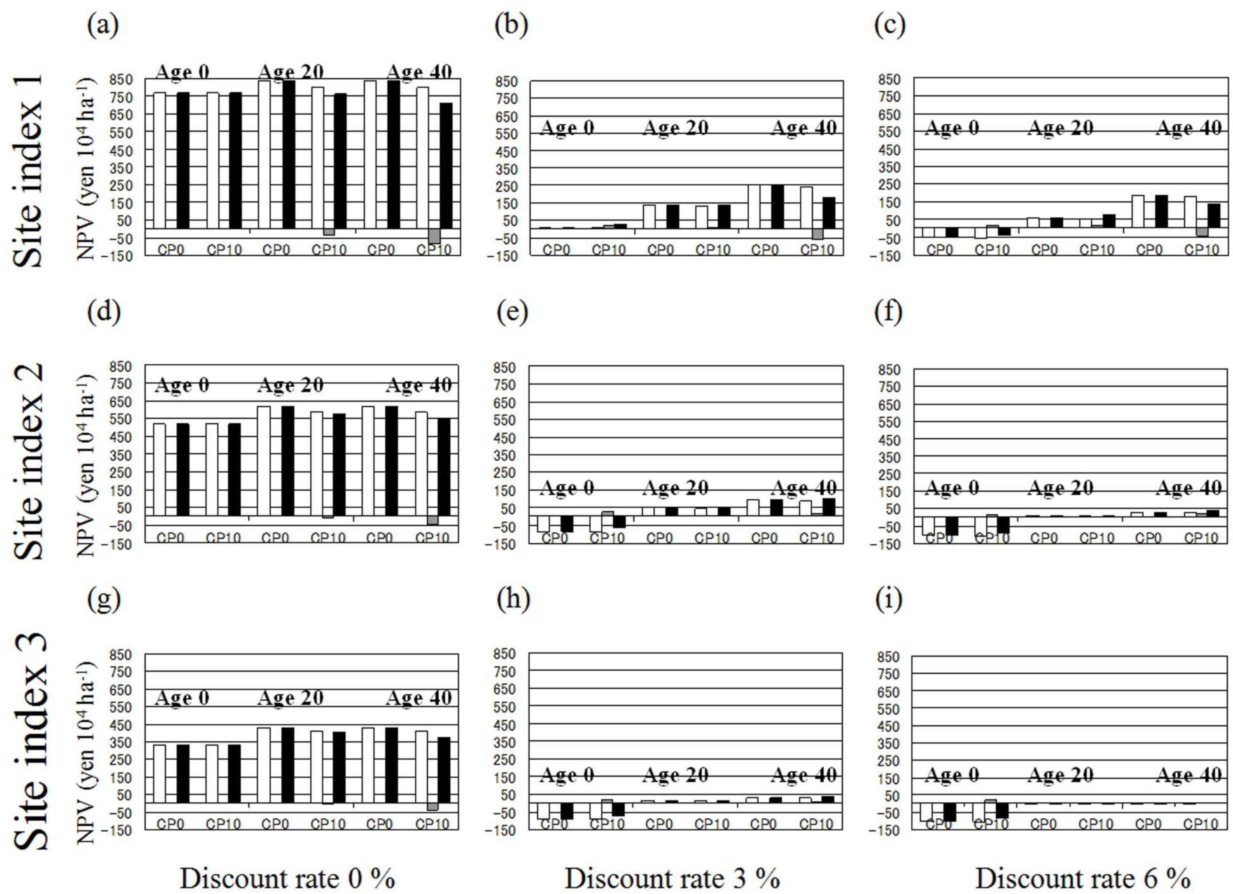

Fig. 3. Sensitivity analysis separated on the basis of initial stand age (0, 20 and 40 years), taking into account the site index, carbon price (CP) and discount rate within the J-VER system.

The white, grey and black bars show, respectively, the NPV of timber production, the carbon credit and the total NPV.

The profits change depending on the site quality, initial stand age, the carbon credit and the discount rate. As shown in figure 3, the higher the initial stand age, the lower the effect of carbon credit on the total profit. In addition, the higher the discount rate, the lower the profit. It is particularly noteworthy that the profit when the initial stand age is 20 years under the J-VER system shown in figure 3b is almost 0. This means that the carbon credit of 1000 yen for a stand with a site index of 1 and an initial stand age of 20 years could be sufficient to compensate landowners and make carbon storage economically attractive.

Several previous studies that have examined the effect of carbon price and taxes on forest management have accounted for carbon stock and release on the basis of timber volume (we call this method 'timber-based accounting' Nakajima et al., 2011c; van Kooten et al. 1995). The J-VER system had a greater impact on forestry profits than the timber-based accounting system (Nakajima et al., 2011c). Generally, the economic effect on the NPV calculated by the

J-VER accounting system was more sensitive than that calculated in previous studies using timber-based accounting (Nakajima et al., 2011c). We consider that the main reason for this result is that the estimated number of carbon credits under the J-VER accounting system is greater than estimates using the timber-based method (Nakajima et al., 2011c; van Kooten et al. 1995). This difference affected the profits derived from different forests depending on the age distribution under the carbon offsetting system. Figure 3 shows the positive or negative effect of stand age and carbon price in the targeted forest area on forestry profits. A strong positive effect was found for younger stands and a negative effect was found for older stands under the J-VER system. For example, in figure 3, the total effect of a carbon price of 1000 yen on the forestry profits for a stand with an initial age of 0 years (e.g. Fig. 3b, e, h) was positive, but with an initial stand age of 40 years (e.g. Fig. 3a, b, c, d, g) the owner would make a loss. Therefore it might be more important to consider stand age distribution, allocation of the harvesting area and carbon price fluctuation when planning forest management under the J-VER accounting system. Under the J-VER system, the total carbon storage included leaves, branches and roots, which were all counted as carbon sinks. Therefore, the lost of carbon credit by emission derived from clear cutting was greater than that calculated using the timber-based accounting system. In general, the age of existing Japanese planted forest stands is increasing (Forestry Agency 2007). Therefore, we suggest that the J-VER system may have a negative effect on forest profitability throughout Japan.

In particular, such negative impacts are likely to be greater in stands with high site quality. Therefore, harvesting, and particularly clear cutting, of stands on high quality sites will decline (Fig.3a-c). At the forest level, for the whole area examined in this study, the harvested area was calculated by summing the stand level harvesting area. Thus, the harvested area at the forest level also decreased under the J-VER system (Fig. 4).

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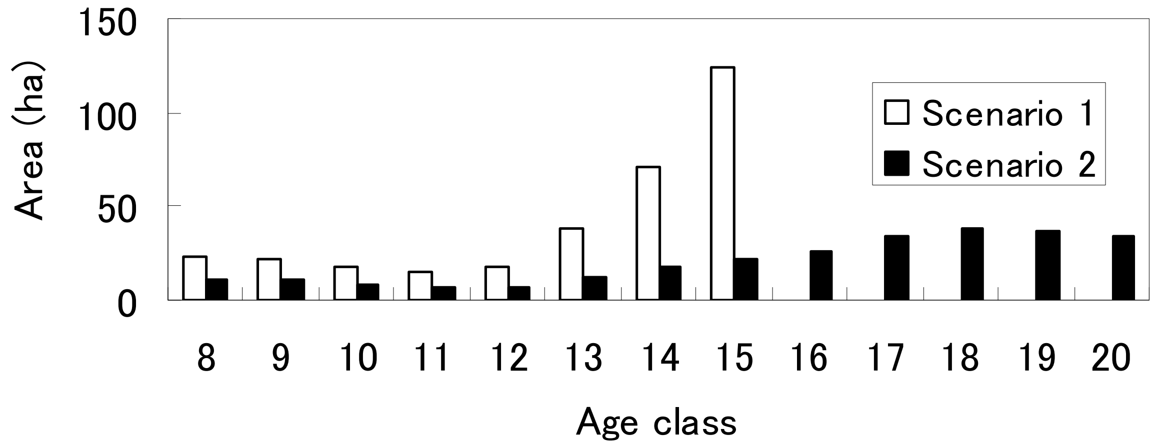
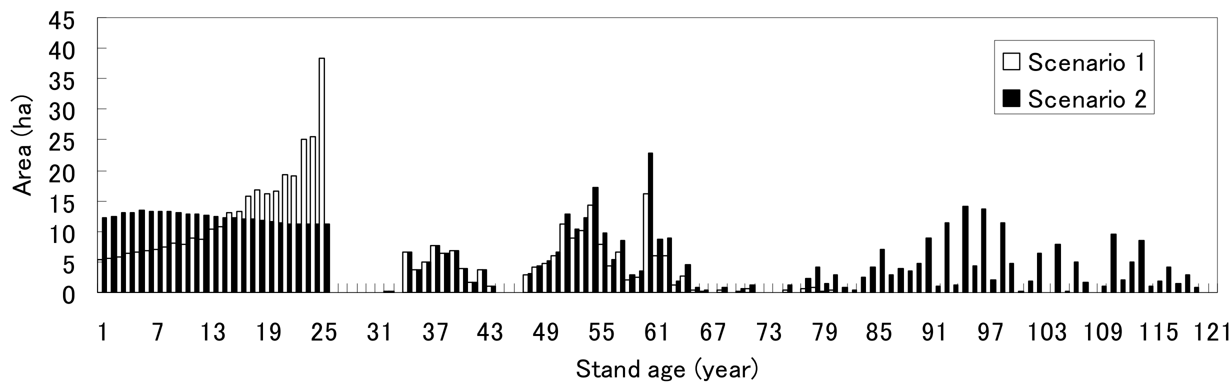
Figure 4 shows: (a) the age distribution of the final cutting area under different scenarios and (b) age class graphs for the scenarios at the end of the 25-year simulations. The former shows that the average stand age, under Scenarios 1 and 2, at the time of clear-cutting was 65 years and 80 years, respectively. The age classes at clear-cutting ranged from 8–15 years under Scenario 1, and from 8–20 years under Scenario 2. Because the target tree species was the most commonly planted species for timber production in Japan (Forestry Agency, 2007), this tendency for a reduction in the harvested area at the forest level studied could be applied to the regional level.

The increase in the potential harvesting area is derived from the increasing area of mature forest as the age distribution of stands in the study site changes over time (Fig. 5).

Under Scenario 1, profits from stands in an age class greater than 4 (36 years old) could be derived from harvest income alone, while under Scenario 2 profits could be derived from harvesting income and carbon sequestration. A comparison of the two scenarios clearly reveals a larger clear-cutting area under Scenario 1 than under Scenario 2 in the initial stage under the prediction period, the difference ranging between 1 ha and 27 ha. In 2021, the magnitude of the difference in clear-cutting areas decreased by up to 5.3 % of its maximum value. In contrast, the thinning area under Scenario 2 is clearly larger than under Scenario 1, with the difference ranging between 10 and 17 ha. These results show that the harvesting practices under the scenarios 1 and 2 were mainly clear cutting and thinning, respectively.

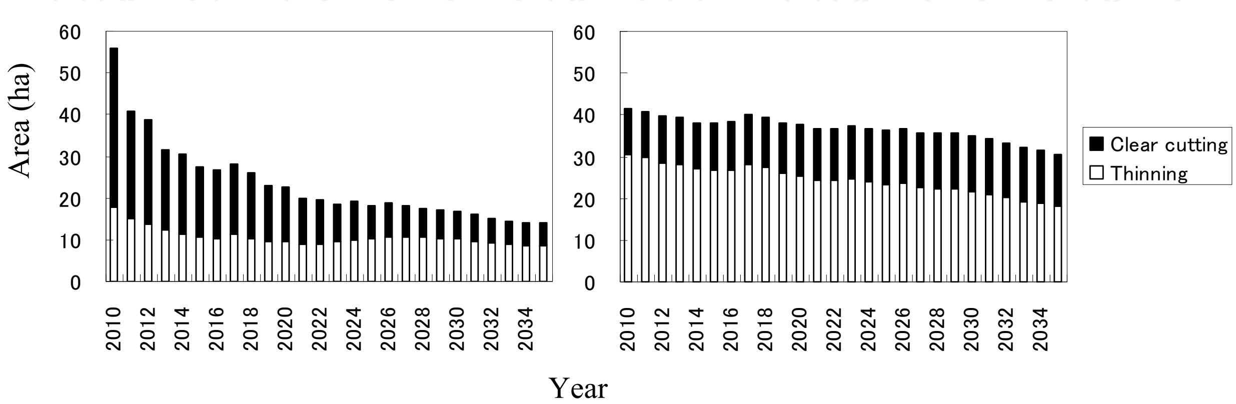


(a)



(b)

Fig. 4. (a) The age distribution of final cutting area under different scenarios and (b) age class graphs of scenarios at the end of the 25-year simulations. White and black blocks show the final cutting area under Scenarios 1 and 2, respectively.



(a) (b)

Fig. 5. The clear-cutting and thinning harvesting areas under (a) Scenario 1 and (b) Scenario 2.

White and black blocks show the thinning and clear-cutting harvesting areas, respectively.

3.1 Timber production

Figure 6 shows the differences in volumes of harvested timber under the two scenarios. Under Scenario 1, the harvest of clear-cut timber at the initial stage of the prediction period was larger than that of thinned timber, with a percentage clear-cut to thinned timber ranging from 87 % and 13 % in 2010 to 64% and 36 % in 2033.

After 2011, the volume of harvested timber decreased by up to 15.5 % of its maximum value due to a decrease of harvesting area (Fig. 5a) for clear-cutting.

Under Scenario 2 the clear–cut timber harvest was little larger than that of thinned timber with the percentages of the clear-cut to thinned timber ranging between 47% and 53 % in 2010 to 29% and 71 % in 2035.

The harvested timber volume decreased by up to 91.2 % of its maximum value between 2010 and 2035 due to a reduction in the harvested area (Fig. 5b). Although the total volume of harvested timber under Scenario 1 was larger than that under Scenario 2 up to 2014, in 2015 the pattern was reversed.

A comparison of the two scenarios clearly shows that the harvested volume of clear-cut timber in the initial stage of the prediction period was larger under Scenario 1 than Scenario 2, with differences ranging between 7.7 and 0.3 × 10^3 m^3. After 2010, the difference between volumes of clear-cut timber decreased by up to 2.5 % of its maximum value. In contrast, the volume of thinned timber harvested under Scenario 2 was clearly larger than under Scenario 1, with differences ranging between 1.2 and 1.6 × 10^3 m^3. These results show that production was predominantly of clear-cut timber especially under Scenario 1. Comparing Figs 5 and 6 shows that the ratio of clear-cut timber to total harvested timber is higher than the ratios of their respective harvested areas indicating that the volume of harvested timber per unit of harvested area was larger for clear-cut timber than thinned timber. Under the J-VER system (scenario 2), the amount of timber derived from clear cutting, which generally yields timber of larger dimensions than that derived from thinning, would be less than that under the non J-VER system (see figure 6). In particular, in the short-term, the total timber yield would be reduced under the J-VER system.

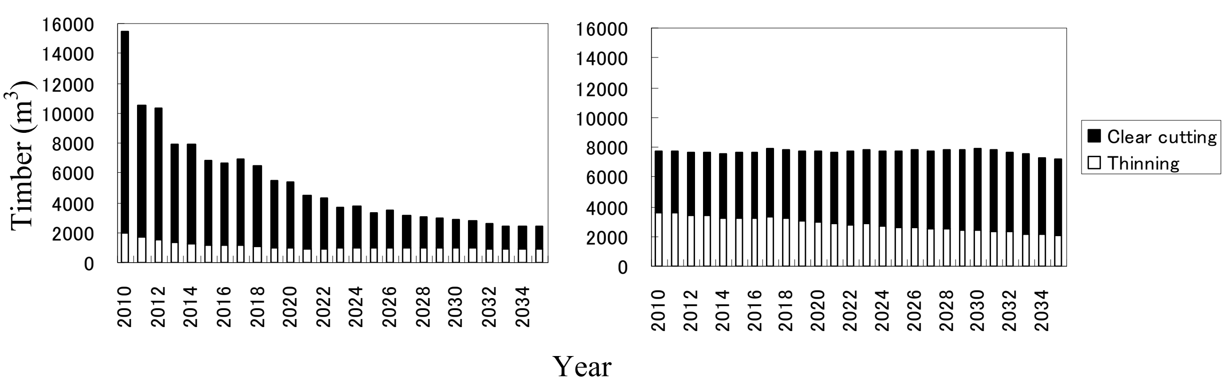


Fig. 6. The clear-cutting and thinning harvested timber volume under (a) Scenario 1, and (b) Scenario 2.

White and black blocks show the thinning and clear-cutting harvested timber volume, respectively.

3.2 Carbon stock

Figure 7 shows the response of the carbon stock to the different scenarios. Under Scenario 1 the maximum and minimum carbon stocks were 49948 tonnes in 2010 and 27639 in 2023. The carbon stock decreased by up to 55.3 % of its maximum due to the reduction in area harvested by clear-cutting (Fig. 5a).

Under Scenario 2 the maximum and minimum carbon stocks were 78037 tonnes in 2010 and 48342 in 2035. Between 2010 and 2035 carbon stock increased by up to 61.9 % of its minimum due to forest growth (Fig. 7b). The total carbon stock was smaller under Scenario 1 than under Scenario 2 throughout the prediction period.

Generally, the carbon stock under Scenario 2 was relatively more stable than that under Scenario 1. A comparison of the two scenarios clearly shows the carbon stock under Scenario 1 to be smaller than under Scenario 2 with differences ranging between 0 and 658.3 Kt suggesting that differences in carbon stock between the two scenarios were mainly due to clear-cutting. According to the carbon accounting system under the Kyoto Protocol, all carbon stock held as standing timber is counted as being released into the atmosphere by clear-cutting (Hiroshima and Nakajima 2006). Therefore, the larger clear-cutting area (Fig. 5) under Scenario 1 decreased the carbon stock dramatically.

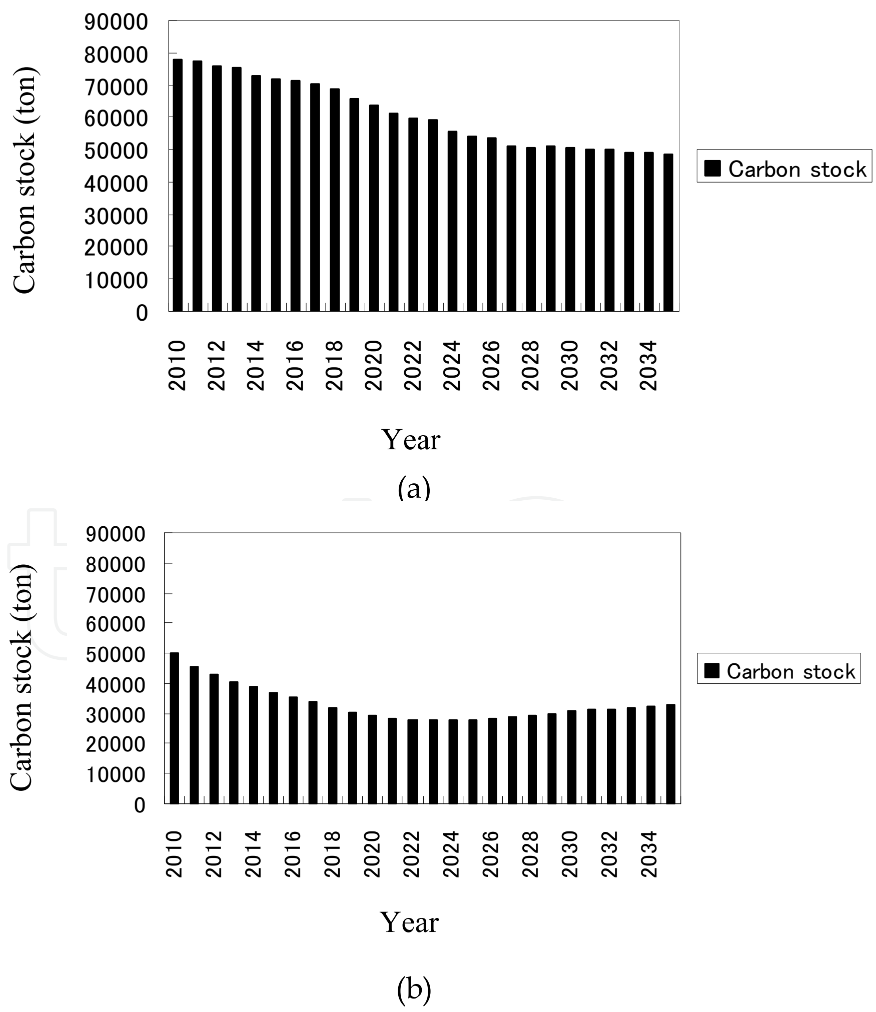


Fig. 7. The carbon stock under (a) Scenario 1, and (b) Scenario 2.

3.3 Subsidy

Figure 8 shows how subsidies vary depending on the scenario. Under Scenario 1, the maximum and minimum subsidies were 32.9 million yen (M¥) in 2017 and 6.8 M¥ in2010; the maximum and minimum silviculture subsidies were 30.0 M¥ in 2017 and 2.4 M¥ in 2010; and the maximum and minimum thinning subsidies were 4.4 M¥ in 2010 and 2.1 M¥ in 2035. Under Scenario 1 the silviculture subsidy was generally larger than the thinning subsidy, with the percentages ranging from 35 % and 65 % in 2010 to 92 % and 8 % in 2016.

After 2017, the subsidies decreased by up to 38.2 % of their maximum value due to a decrease in the harvesting area (Fig. 5a) for clear-cutting. The subsidy in 2035 was 184.6 % of the subsidy in 2010. Under Scenario 2 the maximum and minimum subsidies were 24.9 M¥ in 2017 and 1.0 M¥ in 2010; the maximum and minimum silviculture subsidies were 19.1 M¥ in 2034 and 2.4 M¥ in 2010; and the maximum and minimum thinning subsidies were 7.6 M¥ in 2010 and 4.6 M¥ in 2035. Under Scenario 2 the thinning subsidy in the initial stage of the prediction period was larger than the silviculture subsidy with percentages of silviculture and thinning subsidies ranging from 24 % and 76 % in 2010 to 80 % and 20 % in 2035.

Subsidies increased by up to 248.9 % of their minimum value over the period of simulated predictions due to an increase in the total harvesting area (Fig. 5b). The total subsidy under Scenario 1 is larger than that under Scenario 2 between 2012 and 2021.

A comparison of the two scenarios shows the silviculture subsidy in Scenario 1 of the initial stage under the prediction period to be clearly larger than that of Scenario 2, with differences ranging between 0 and 14.9 M¥. After 2012, the difference of silviculture subsidy decreased by up to 0.2 % of the maximum difference, while the thinning subsidy was clearly larger under Scenario 2 than Scenario 1, with differences ranging between 2.5 and 4.2 M¥.

3.4 Forestry profits

Figure 9 shows the forestry profits under the two scenarios. Under Scenario 1 the maximum and minimum forestry profits were 44.2 M¥ in 2010 and 1.8 M¥ in 2029. After 2011, the forestry profits decreased by up to 4.0 % of their maximum values due to a decrease of harvesting area (Fig. 5a) for clear-cutting.

Under Scenario 2 the maximum and minimum forestry profits were 19.6M¥ in 2011 and 12.2 M¥ in 2035. Between 2010 and 2035 forestry profits decreased by up to 62.4 % of their minimum values due to the increased harvesting area (Fig. 5b). Although the total forestry profits under Scenario 1 are larger than under Scenario 2 up to 2012, the pattern was reversed in 2013.

A comparison of the two scenarios shows the forestry profits under Scenario 1 before 2013 to be larger than under Scenario 2, with differences ranging between 3.4 M¥ and 24.9 M¥.

3.5 Labor requirements

Figure 10 shows the labor requirements under the different scenarios. Under Scenario 1 the maximum and minimum labor requirements were 4647 workers in 2012 and 1830 workers in 2011; the maximum and minimum number of required silviculture workers were 2977 in 2011 and 87 in 2011; the maximum and minimum number of workers for stand thinning were 799 in 2010 and 342 in 2035; and the maximum and minimum number of forest workers for clear-cutting were 1627 in 2010 and 186 in 2034. Under Scenario 1 the labor requirements for clear-cutting and silviculture were generally larger than those for thinning, with the ratio of the proportion of total labor required for clear–cutting to the proportion of the total labor required for thinning ranging from 58 % and 37 % in 2011 to 18 % and 13 % in 2019.

After 2012, the labor requirements decreased by up to 30.5 % of their maximum value. The overall decrease was due to a decrease in the harvesting area (Fig. 5a) for clear-cutting.

Under Scenario 2 the maximum and minimum labor requirements were 3272 personnel in 2030 and 2014 in 2011; the maximum and minimum numbers of workers required in silviculture were 1663 in 2032 and 87 in 2011; the maximum and minimum numbers of people involved in thinning were 1450 in 2010 and 829 in 2035; and the maximum and minimum numbers of clear-cutting forest workers were 661 in 2031 and 498 in 2010. Under Scenario 2 the labor required for clear-cutting and silviculture was generally larger than was required for thinning, with percentages of clear-cutting labor to thinning labor ranging from 25 % and 71 % in 2011 to 20 % and 27 % in 2034. Labor requirements increased by up to 162.5 % of the minimum value between 2011 and 2030, the increase being due to the increase in harvesting area (Fig. 5b).

Labor requirements increased by up to 162.5 % of the minimum value between 2011 and 2030, the increase being due to the increase in harvesting area (Fig. 5b).

A comparison of the two scenarios clearly shows that silviculture requires more workers under Scenario 1 than under Scenario 2 in the initial stage of the prediction period with differences ranging between 0 and 2039 personnel. After 2013, the difference in labor requirements for silviculture decreased by up to 1.0 % of the maximum value. In contrast, the labor required for thinning was greater under Scenario 2 than under Scenario 1, with differences ranging between 486 and 857 personnel. These results suggest that the differences in labor requirements under Scenarios 1 and 2 were mainly associated with silviculture practices and thinning, respectively.

Because the estimated subsidies, forestry profits, carbon stocks, and labor requirements are affected by fluctuations in the stand age distribution and the stand condition over time, the observed pattern of increase was not monotonic.

Our approach enables the effects of different carbon price scenarios on forestry to be calculated. Although timber production is the basic function of forests, their role in storing carbon stock also holds a high position in the public mind, especially during the first commitment period of the Kyoto Protocol. Figures 6 and 9 enable us to consider the influence of forest management under different carbon price on both of these factors. In addition, the simulation results for subsidies and labor requirements can be considered as important practical issues for forest management. Subsidies (Fig. 8) and labor requirements (Fig. 10) under the two scenarios were thus mainly allocated to clear-cutting and thinning (Fig. 5) under Scenarios 1 and 2, respectively. These results suggest that if the clear-cutting area were to decrease (Fig. 5a), the required subsidy (Fig. 8a) and labor (Fig. 10a) would not decrease immediately, because weeding continues to be required for 5 years after planting in the clear-cutting area.

Previous studies have analyzed useful variables and estimated parameters for several econometric models including the probit model (Dennis 1990; Pattanayak et al. 2003) and the logistic regression model (Royer 1987; Zhang and Pearse 1997), which can be used to predict the effects of forestry policies and subsidy systems. Other previous studies (e.g. Lewis and Plantinga 2007; Kurttila et al. 2006; Bolkesjø and Baardsen, 2002) have created models to estimate the effects of different amounts of subsidy. The models used herein mainly made use of established statistical techniques.

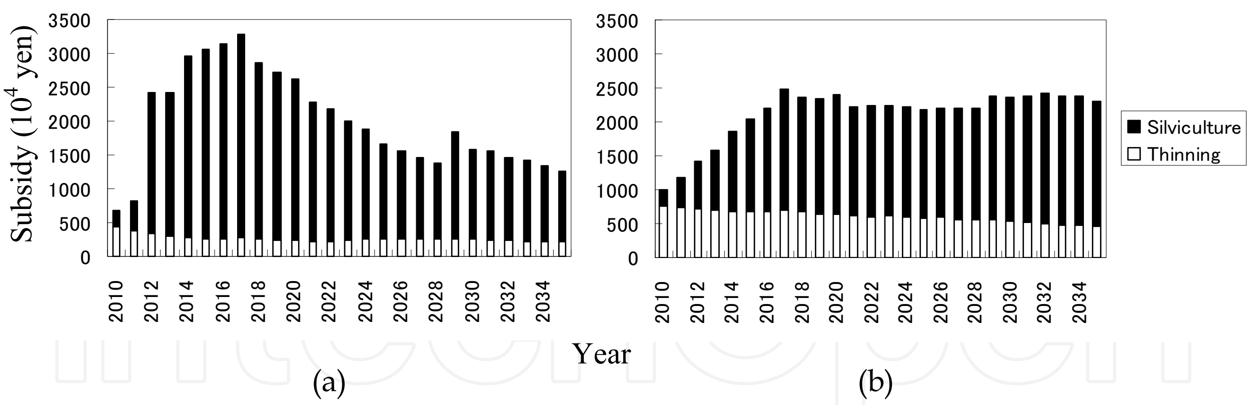
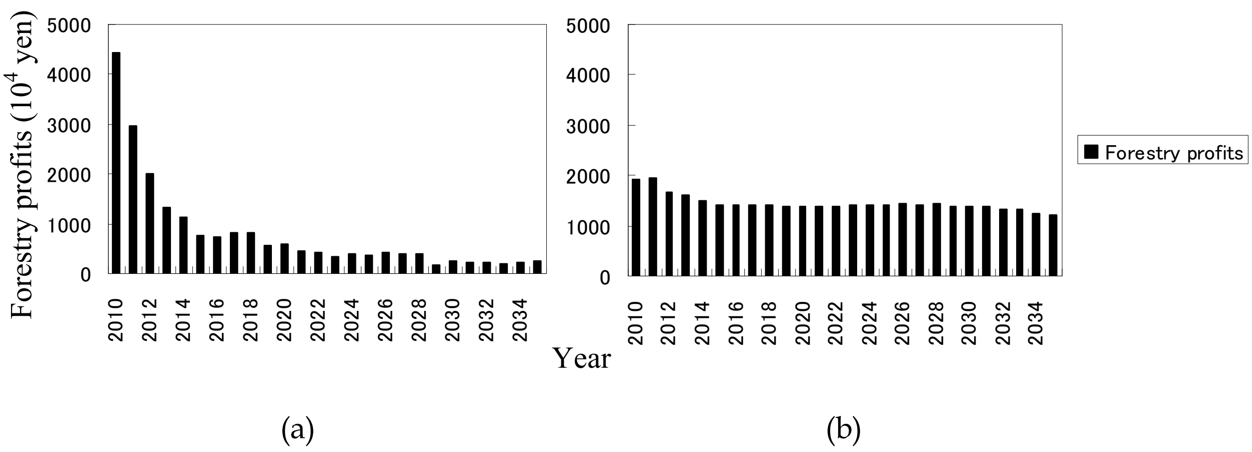


Fig. 8. The silviculture and thinning subsidy under (a) Scenario 1, and (b) Scenario 2. White and black blocks show the thinning and silviculture subsidy, respectively.



9. The forestry profits under (a) Scenario 1, and (b) Scenario 2.

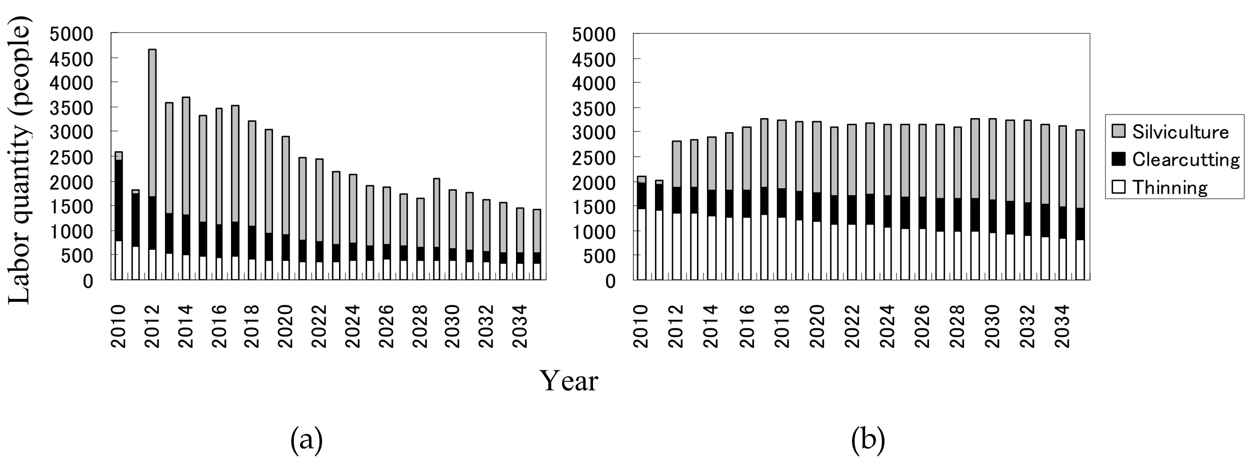


Fig. 10. The labor requirements for silviculture, clear-cutting and thinning under (a) Scenario 1, and (b) Scenario 2.

White, black and gray blocks show the thinning, clear-cutting and silviculture labor requirements, respectively.

If policy makers wish to apply these models to other geographical areas, different values for the statistical parameters may be required. We made use of a number of simulations developed and applied to Japan at the national level (Nakajima et al., 2010), so the current models are applicable throughout Japan without the need for new estimates of the parameters. Compared with other studies using similar statistical modeling approaches (Dennis 1990; Pattanayak et al. 2003; Royer 1987; Zhang and Pearse 1997; Lewis and Plantinga 2007; Kurttila et al. 2006; Bolkesjø and Baardsen, 2002), our work appears to be more broadly applicable. Although there may be dramatic changes in carbon and timber prices in the future, our approach should enable us to predict the effect of carbon price scenarios on forest resources and timber production in Japanese forest plantations.

For instance, in the present study, under Scenario 1 it is feasible to increase timber production during the early period of our predicted output (Fig. 6). However, Scenario 2 is a better option if the forests' function of holding carbon stock is the more pressing and stronger requirement (Fig. 9). The most suitable scenario could be selected by considering practical issues based on labor requirements and subsidies (Figs 8 and 10).

As explained in the introduction, Scenario 2 focuses on expanding the thinning area and restricting the clear-cutting area and so supports long-rotation silviculture as a means of increasing the carbon stock as required under the Kyoto Protocol. A comparison of the simulation results of Scenarios 1 and 2 shows that maintaining the carbon stock is more feasible under Scenario 2 (Fig. 7). Because a larger amount of subsidy is available for silviculture (Fig. 8a) following regenerations in the larger clear-cutting area (Fig. 5a). However, if the production of a large amount of timber is not an immediate requirement, Scenario 2 can be the better alternative with a lower subsidy budget. Notwithstanding this, in terms of the efficient use of the timber resource, such a choice might be irrational under some circumstances because of the possibility that some profitable stands might then be forced to avoid clear-cutting in order to produce larger timber.

These simulations can help policy makers and forestry practitioners propose policy changes that would not only enhance timber production, but also fulfill carbon stock obligations pledged under the Kyoto Protocol. Because there was no real and practical system for trading carbon credits at that time, Calish *et al*. (1978) did not consider the accumulation of carbon credits to be a management objective. The current study clarifies the effect of the Japanese carbon credit trading system on future forest resources. Sakata (2005), similarly, examined the effects of the carbon market on forestry profits in the USA. At the study site selected by Sakata (2005), unlike our site, pulp wood was a second commercially viable product, along with timber. Therefore, the current study shows the effect of the carbon market on forestry profits associated with timber but not pulp wood production.

Planted forests in the present study was conducted are highly productive of timber, especially from the main tree species (*Cryptomeria japonica*). Because this species is very broadly distributed (Fukuda et al. 2003), the simulations described here, which are based on real data, could also be applied to planted forests in other regions. In other words, *Cryptomeria japonica*, which is the target tree species in this study, is the most common tree species in Japanese planted forests (Forestry agency, 2007), so the work is applicable to other parts of Japan. In addition, the growth prediction system used in this study has been applied to the main tree species that grow throughout Japan (Nakajima et al., 2010; 2011a), so this methodology could also be applied to other areas of Japan. Sakata (2005) estimated the effect of the carbon market on the forestry profits based on standard silvicultural practices and costs over a large area including the southeastern United States. Although we considered a standard silvicultural system and costs (Nakajima *et al*., 2011a) in the present study, we made use of real age distribution and site index data for the study site, which is representative of much of the Japanese planted forest area (The Tokyo University Forests, 2006). We, thus, consider our results to be generally applicable across Japan.

Basically, the cycle for forest management depends on the management objective. Although in the present study, we assumed certain values in order to predict the effect of the real Japanese carbon trading system on timber production and carbon stock, certain socio-economic conditions that are represented by model parameters, could change. However, because the discount rate is the interest rate used to determine the present value of future cash flows (Eatwell et al. 1987; Winton JR. 1951), it is defined relative to a value that society considers to be reasonable. Although a previous study (van Kooten et al. 1995) has stated that, in general, the higher the discount rate, the shorter the rotation period, it is difficult to predict accurately not only the future timber price but also the discount rate as it might be affected by changing socio-economic conditions. Thus, it would be better to improve forest management plans by inputting into the simulation model parameter values that reflect the current socio-economic conditions, and changes in those socio-economic conditions, including discount rates and timber prices that might prevail in the future. Forest management plans could then be simulated by considering, not only socio-economic conditions, but also forest resource productivity and the age distribution of stands derived from forest inventory data.

In the present paper we have described an approach that is designed to increase information concerning objective economic and environmental outcomes of forest management such as timber volume (Fig. 6), forestry profits (Fig. 9) and carbon stock (Fig.7), budgets, operability and subsidies (Fig. 8), labor requirements (Fig. 10). Thus, policy makers could use the information from the simulations designed to understand the influence of different carbon price scenarios on local forestry, to select appropriate plans that would meet their management goals. Other simulation results could be used to decide what information should be taken into consideration when deciding whether or not the benefits of a particular management action would justify the costs of its implementation.

Although there are always uncertainties concerning the future state of socio-economic conditions, the present simulation results can at least provide information about any future tendency of estimated values to change over the prediction period in response to the carbon price scenario currently being implemented under the present socio-economic conditions. However, because estimates are prone to errors derived from a dramatic change in the socio-economic conditions that pertain to forestry, such as timber price, carbon price and discount rate, it is important that the actual forest area continues to be monitored in order to check the accuracy of simulations designed to predict future state of forestry. Although our assumptions concerning socio-economic conditions and forest resources were necessarily relatively simple for the preliminary simulation conducted for the present study, as were the patterns of the different subsidy system scenarios, any uncertainty derived from the future changes in socio-economic conditions should be monitored during the management of regional forest resources.

The next challenge is to test the uncertainty of the simulation by monitoring the study area, and to apply the simulation to other forest regions. Depending on the degree of uncertainty and the wider applicability of the simulation, it may be possible to analyze the feasibility of different management strategies and the efficiencies of different subsidy systems according to different regional forest resources, variations in local socio–economic conditions, and diverse forest management goals.

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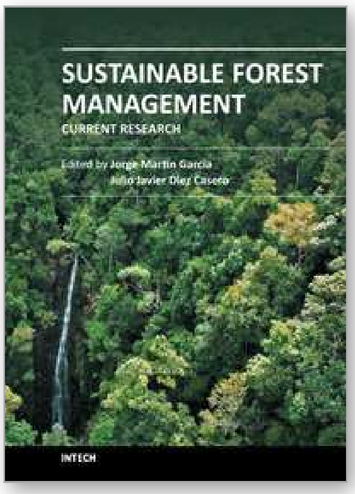

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Sustainable forest management (SFM) is not a new concept. However, its popularity has increased in the last few decades because of public concern about the dramatic decrease in forest resources. The implementation of SFM is generally achieved using criteria and indicators (C&I) and several countries have established their own sets of C&I. This book summarises some of the recent research carried out to test the current indicators, to search for new indicators and to develop new decision-making tools. The book collects original research studies on carbon and forest resources, forest health, biodiversity and productive, protective and socioeconomic functions. These studies should shed light on the current research carried out to provide forest managers with useful tools for choosing between different management strategies or improving indicators of SFM.

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