

Article

Sustainable Forest Management Evaluation Using Carbon Credits: From Production to Environmental Forests

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Abstract: The biodiversity and carbon dioxide absorption function of forests have received attention due to global warming. However, most of the world's forests are general production forests. Since production forests are maintained by production activities, a decrease in production or abandonment of management leads to a decline in forest functions and increases the risk of disasters such as landslides. Against this background, the retention approach has been proposed as a way to convert general production forests into forests with enhanced environmental functions, but it has rarely been applied due to technical and cost barriers. This study focuses on cost barriers and examines the possibility of introducing a retention approach to converting production forests to environmental forests, using Japan as a case study. About 70% of Japan's land area is covered with forests, 40% of which are production forests. However, due to the sharp decline in demand for timber in recent years and price competition with imported timber, the selling price of timber has fallen below the cost of managing production forests, and the management of many production forests has been abandoned. The dilemma is that the retention approach applied to the wood production process cannot be applied to forests where production activities are stagnant. Therefore, we explored the possibility of recovering the necessary costs with carbon credits that are available in the Japanese market. We calculated the cumulative carbon stocks of carbon dioxide in production forests by age, using intensity, and estimated how many years after planting the combined costs of normal production forests management and the retention approach would balance out. Our calculations show that even if carbon credits were sold at the lowest market price, the balance of payments would be balanced about 30 years after planting, resulting in a net profit from the sale of the wood.

Keywords: forest sustainability; production forests; environment forests; carbon credit; forest management; retention approach



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1. Introduction

Forests play a critical multifunctional role in environmental conservation. Significant and irreplaceable forest functions include ecological aspects such as the preservation of ecosystems and biodiversity, and the carbon-dioxide absorption that mitigates global warming [1,2]. In particular, the absorption of carbon dioxide is essential for controlling the destruction of the ecosystem itself as a result of global warming. Currently, there are only two ways available to reduce atmospheric carbon dioxide: either to reduce or absorb emissions.

Regarding forest functions, forests such as tropical rainforests with special ecological rarity have historically attracted substantial attention [3,4]; however, Lindenmayer et al. [5] highlighted that 11% of the world's forests are protected forests and 4% are intensive wood production forests, while the remaining 85% are neither, nor emphasized the importance of focusing on these. The retention approach has been proposed as a forest management method for improving ecosystem quality in such 'general' production forests [5]. Data from relevant research has led to the retention forest approach being globally recognized in

recent times as an effective means for converting production forests into environmental forests [6–9].

Despite the consensus on the importance of the retention forest approach, only a few countries have adopted it [10] due to the technical issues and cost barriers. From a technical point of view, research is still necessary to assess which logging methods can be beneficial for a variety of ecosystems [10]. In terms of cost, there has been insufficient discussion on how to deal with the additional costs of adopting a retention approach. Above all, as the selling price of timber is being reduced due to intensifying international competition, it is becoming difficult to secure even the normal maintenance cost of production forests when the production forests are located on steep slopes with low productivity, as is the case in Japan.

Long-term forest management planning and careful harvesting operations are essential in implementing the retention approach, which require additional costs covering detailed forest conditions surveys and biodiversity-based surveys ensuring proper logging planning. Barreto et al. [11] estimated that approximately US 72/ha more are required to develop a forest logging management plan, while having no plan is more profitable in the short term. Arnott and Beese [12] showed that harvesting costs increase by approximately 50% when biodiversity-friendly logging is carried out. The total cost required not only for felling but also shipping as timber will increase by at least 10% [10]. However, as mentioned earlier, it is almost impossible to meet these costs in production forests with low productivity. In the case of production forests that have been abandoned, there is no opportunity to adopt such a retention approach. In other words, a social dilemma arises in which the production forests with the greatest need for conversion to environmental forests do not have the opportunity to do so because they cannot bear the cost of conversion.

To cope with the costs of converting to environmental forests, we focused on carbon credits, which are generally used as payments for contributions to the environment. This is because the forestry industry in many countries, including Japan, is already supported by subsidies, and if the dependence on subsidies increases, the forestry industry itself will be weakened. In Japan, even the number of forestry workers who receive subsidies is already decreasing. Therefore, we examined the possibility of using marketable carbon credits as a way to establish sustainable forestry in a market economy. There are already cases where carbon dioxide fixation by forest management is incorporated into the carbon offset mechanism. At present, however, carbon offsetting tends to be biased toward renewable energy, and carbon offsetting for forest management is not widely used. This study uses Japan as its case study, where the steep terrain prevents efficient forestry, and the management of many production forests has been abandoned. Japan has a system of carbon offsetting, but it was only used once in 2015, and since then, carbon offsetting has not been used for forest management [13]. One of the reasons why carbon credits have not been actively used for forest management is that it is difficult to evaluate carbon credits for forest management [14,15].

Malmsheimer et al. [15] highlighted the following three issues regarding carbon credit for forests: first, it is difficult to calculate costs other than for new tree-planting projects; second, the carbon absorption estimation baseline has not yet been clearly established; and third, it is difficult to incorporate carbon credits accumulated in the past. However, we developed a simple model of forest carbon sequestration and forest management costs in order to understand whether production forests that cannot afford management costs can be converted to environmental forests using the retention approach. The reason for this is that we thought that it would be best to examine the possibility here first, and then perform detailed calculations. The model is based on the amount of carbon dioxide absorbed in production forests by different age groups. The amount of carbon dioxide absorbed is valued as carbon credits that can be traded in the market.

We hypothesize that carbon credits can cover the cost of the retention approach and proper management of production forests; this hypothesis we shall henceforth refer to as the ‘market carbon trade hypothesis’. The amount paid to the production forests is determined by the amount of carbon accumulated in it. We aim to elucidate under which basic conditions the hypothesis is valid.

We selected Japan as the target location for this “market carbon trading hypothesis”. There are two reasons for this. First, the demand for timber in Japan has plummeted over the past 50 years, leaving production forests unmanaged and unattended. The government has intervened many times with subsidies to the forestry industry, but without significant effect. Timber is exposed to international competition, and in Japan, where production forests are located in steep mountains, the selling price of timber is less than the cost of managing the production forests. Although 70% of the country’s land area is covered with forests, and about 40% of these are production forests, the production forests are left unattended, which poses a challenge to the conservation of ecosystems and risks inducing disasters. There is a need to examine whether carbon credits can overcome the dilemma that the more production forests that need to be converted to environmental forests, the more difficult it is to introduce a retention approach.

Second, carbon credits are traded in the Japanese market; therefore, it is possible to evaluate the current carbon price. For the payment of the environmental conservation function of forests, some countries and regions have already adopted mandatory or voluntary emissions-reduction mechanisms [16,17]. Preece et al. [18] showed that the advanced carbon farming system established in Australia in 2011 plays a key role in sustainable forest management. It is important to examine the possibilities in countries other than those already studied, and the results obtained from the study can provide useful suggestions internationally.

To examine the above hypothesis, we adopt the following three procedures: First, we estimate the carbon absorption from production forests using data of the Japanese forest research institutes (Forestry and Forest Products Research Institute, Japan; FFPRI), thereby revealing the carbon baseline setting, which is important when introducing the carbon credit system to forests. Second, we calculate the cost of proper forest management. We use the management cost calculated using the forestry association data on the proper management cost of production forests. We assume that the retention approach will be adopted during logging and forest management. The cost of adopting the retention approach is based on earlier research, which assumes that the cost of logging will increase by 10% [10]. The cost of planning and investigating the retention approach was excluded from this calculation because it can be formulated separately from forest management activities. Third, we simulate the price of accumulated carbon in production forests by using multiple carbon-credit prices traded on the market. Based on this simulation, we judge the price and period for which carbon credits balance management costs. We infer that if the valuation of carbon credits exceeds the cost required for proper management of production forests and adaption of the retention approach, it is possible to apply the retention approach. We propose to solve the dilemma of degraded production forests by converting production forests into environmental forests through the introduction of carbon credits in forests where productivity cannot be increased. Finally, we present the policy implications of this study.

2. Materials and Methods

2.1. Literature Review

We reviewed production forests on a global scale and addressed the retention approach, a proposed new management method for production forests. We elaborate on the evaluation of the function and amount of carbon absorption in forests and discuss the contribution of carbon credits related to environmental issues.

We provide an overview of the current state of forests globally, and then focus on production forests. The total forest area globally is 4.60 billion hectares (ha), accounting for about 31% of the world's land-surface area [19,20]. The global forest area has been generally in decline; however, it has recently slightly increased due to continuous efforts to maintain and preserve the diverse functions of forests. Nevertheless, Butchart et al. [21] revealed that biodiversity loss remains severe, despite efforts to establish sustainable forest management in some areas. Researchers highlight that future global climate change could affect forest ecosystems [22,23]. In this regard, the 2015 United Nations Sustainable Development Summit set 17 Sustainable Development Goals (SDGs). The fifteenth SDG states: "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" [24].

Particularly, critical functions that forests have for the environment are ecological aspects such as the preservation of ecosystems and biodiversity, and the carbon-dioxide absorption function that mitigates global warming [25]. Lindenmayer et al. [5] found that most forests globally are neither formally protected nor dedicated to intensive wood production. The retention approach has been proposed as a forest management method for improving the quality of ecosystems in such general production forests [5]. Groot et al. [26] showed that transforming Canadian traditional forests into retention forests is the most practical management method of present forestry. It has been shown that long-term forest planning is required to achieve retention forestry. Gustafsson et al. [6] evaluated the retention approach as a scientifically validated approach that can resolve conflicting goals regarding timber production and biodiversity conservation and preserve a degree of species richness equivalent to that of primary forests. Currently, the retention forestry approach is recognized globally as a conservation tool in production forests [9]; however, its implementation is limited to some countries and regions due to technical and cost barriers [8]. Additionally, research on logging methods that contribute to diverse biodiversity are ongoing [10].

We elaborate on the evaluation methods of the function and amount of carbon absorption in forests. Relevant studies can be grouped into three types: estimates based on remote sensing, estimates based on actual measurements, and calculation of carbon content using equations and models. Research with estimates based on remote sensing aims mainly to assess a meta-level carbon storage over wide forested areas. Such research is usually conducted on tropical rainforests, where the impact of area reduction on the environment is significant [27,28]. Saatchi et al. [4] mapped the total carbon stock of living biomass above and below ground, using a combination of data from in situ inventory plots and satellite light detection and ranging (Lidar) samples of forest structure to estimate carbon storage. They created a benchmark map of the forest carbon stock in the early 2000s. Baccini et al. [3] used multi-sensor satellite data to estimate aboveground carbon density of living woody vegetation in pan-tropical ecosystems and its spatial distribution. They highlighted that one of the reasons for adopting this method was to reduce the cost of assessing the carbon stock in forests [4]. Actual measurements of carbon accumulation in forests capture the changes in carbon content due to logging. Rainforests are often selected for investigations [29]. Keith et al. [30] studied the Australian temperate moist eucalyptus forests and some other types of forest carbon stocks. Such studies provide important basic data for carbon calculations; however, the areas of application are limited since logging is a requirement. In addition, since the amount of accumulated carbon in a forest varies greatly depending on the tree species, it is difficult to evaluate the entire amount without investigating the tree species [31].

The calculation of carbon content by equations and models is used to obtain a rough amount of the carbon storage of the entire forest. Diverse international and national researchers and research institutes began examining the carbon-absorption function of forests and assessing carbon dioxide reductions based on the 1997 Kyoto Protocol by the United Nations Framework Convention on Climate Change (UNFCCC). Chave et al. [32] developed a regression model involving only wood density and stem diameter to estimate the amount of tropical biomass and the contributions of the tropical forest biome and deforestation to the global carbon cycle. Jenkins et al. [33] compiled diameter-based allometric regression equations for estimating the total aboveground and component biomass, defined in dry-weight terms, for trees in the United States. These earlier studies are mainly used to create reference values and obtain a rough idea of changes in carbon content. Since the purpose of this study is also to test the hypothesis, we decided to use the basic unit calculated by the Forestry and Forest Products Research Institute, Japan [34].

We also focused on empirical studies on forest management costs and carbon credit contributions to the environment. Canadell and Raupach [35] claimed that forests absorb billions of tons of CO₂ globally every year; an economic subsidy of hundreds of billions of dollars would be necessary in order to create an equivalent sink. In some countries and regions, the payment for the environmental conservation function of forests have already adopted mandatory or voluntary emissions-reduction mechanisms [16,36]. Preece et al. [18] highlighted that Australia's 2011 Carbon Farming Initiative incorporates carbon credits, supports reforestation, and has been beneficial for sustainable forest management. Kurz et al. [37] proposed a carbon-dynamics model for forestry and land use change for Canada. Morse et al. [38] analyzed the effectiveness of forestry legislation in Costa Rica, which introduced payments for environmental services in 1996. Results showed that the payment of environmental services increased forestry retention, and the carbon stocks of secondary forests approached the levels of primary forests after 25–30 years. Kayo et al. [39] evaluated the possibility of converting production to environmental forests in Japan, similar to this study; however, carbon credits had not been introduced at that point, and the validity of the study was not assessed. Ellison et al. [40] claimed that current approaches of resource-based carbon accounting consider only a fraction of the forest's potential. Currently, Japan is trading in the carbon credit market, and it is possible to explore its potential.

We acknowledge these studies and will consider the possibility of utilizing carbon credits for the transition from production to environmental forests. Evaluating the distribution of credits instead of mandatory taxes could enable private initiatives to contribute to environmental conservation without increasing the burden on citizens. If attempts to revitalize forestry with subsidies are not very effective, as in the case with Japan, it becomes necessary to introduce alternative mechanisms as well. Carbon credits through the market can stimulate proper forest management. Furthermore, the introduction of the retention approach can enhance multifaceted forest functions, such as biodiversity, thereby creating value beyond carbon and increasing the interest in forest management. Most Japanese production forests in the case-study area have only cedar tree species [41], so it is possible to estimate the amount of carbon reserves more accurately. The 'market carbon trade hypothesis' promotes the reduction of the burden related to the conversion of production to environmental forests by appropriately evaluating their carbon absorption function. Conversion of production to environmental forests might occur in many regions in the future; our findings provide meaningful insight into the sustainable management and ecological-value increase of production forests. Our results will be useful to stakeholders of production forests with decreasing demand and of the global environment.

2.2. Framework for the Research Design

The analysis consists of two parts. The first part analyzes the changes in the environment surrounding production forests in Japan, the target area of the case study.

As previously mentioned, 70% of Japan's land area is covered by forests, 40% of which are production forests. However, the utilization rate of forests is less than 1%, which is the lowest in the OECD. Neglected production forests need to be converted to environmental forests in order to prevent landslides and restore ecosystems. However, the dilemma is that the retention approach is difficult to implement in planted forests that need to be converted to environmental forests because the retention approach for conversion from production forests to environmental forests assumes production activities. In this study, we propose a method of converting production forests, which are difficult to implement the retention approach through production activities, into environmental forests. In Japan's production forests, this analysis has shown that recent lifestyle changes have directly affected the forest environment. This situation of lifestyle influencing forests may not be limited to Japan. Therefore, we considered a system that would support not only the people of a particular region, but society as a whole to take responsibility for the sustainable management of forests.

The second part of the study examines the potential for carbon credits to cover the costs of managing and transitioning from production forests to environmental forests using the retention approach, mostly through simulation. The amount of carbon stored in a properly managed plantation forest by age class is simulated and evaluated with several carbon credit prices available in the market. We will identify the market price and time period required to adopt a retention approach over and above the management costs of production forests.

2.3. Simulation Framework for Evaluating the Carbon Absorption Function of Production Forests

2.3.1. Basic Unit of Carbon Absorption

We employed the definition of the carbon dioxide absorption model of the FFPRI in Japan [34]. In accordance with the Kyoto Protocol, FFPRI conducted an analysis of the carbon-absorption function in typical Japanese forests. Our simulation targets Japanese cedar, which is a typical Japanese production forest tree species. Japanese cedar, cypress, and broad-leaved trees are typical tree species in Japanese production forests, and among them, Japanese Cedar has the highest proportion.

Figure 1 shows the basic numerical value of carbon absorption per hectare of a general Japanese cedar production forest. The cumulative carbon absorption (t-C/ha) is based on the FFPRI model. Figure 1 shows the cumulative carbon absorption of cedar by age and the carbon absorption period. From about the age of ten years, the growth rate of cedar gradually increases, and the absorption of carbon dioxide also increases sharply. The reason why the carbon absorption per period seems to decrease significantly in the 25th year is because thinning takes place during this period, reducing the number of trees present per hectare. Beyond the age of 50 years (which corresponds to the main logging season), the growth rate slows and the rate of increase in carbon dioxide absorption also slows; however, the cumulative carbon absorption of cedar production forests continues to increase. Figure 1 shows the weight of carbon, and in order to convert this to the weight of carbon dioxide, we multiply it by 44/12. The molecular weight of CO₂ is 44 (the atomic weight of C is 12 and the atomic weight of O is 16, so $12 + 16 \times 2 = 44$). Since the atomic weight of C is 12, we can multiply the carbon equivalent weight by 44/12 to get the carbon dioxide equivalent. So 44t-CO₂ is equal to 12t-C.

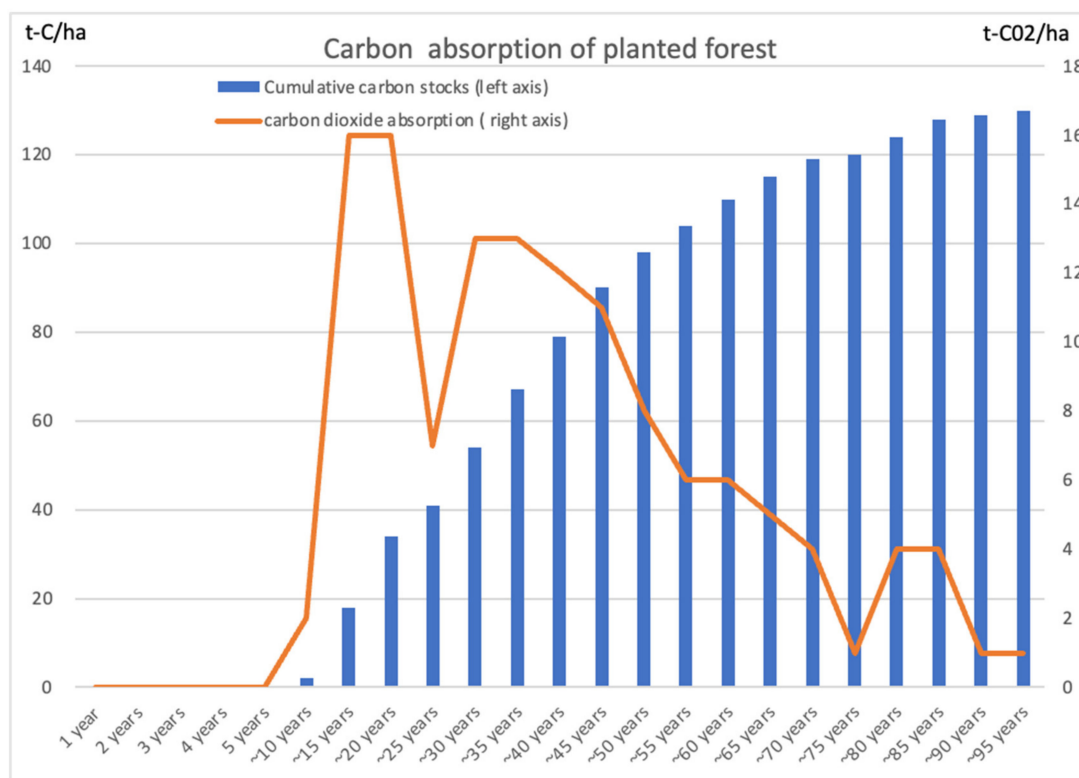


Figure 1. Cumulative carbon absorption and carbon-absorption period in a general Japanese cedar production forest. Source: [34].

2.3.2. Management Costs of Production Forests

For the annual management costs of production forests, we used the values published by the Ministry of Agriculture, Forestry, and Fisheries [42]. The name of the data is “Forestry Management Statistics Survey”, and is published as official statistical data of the government. Since the annual management costs after the 51st year, which is the main harvesting period, were not provided, we assumed they were equivalent to the management costs required in years 46 to 50.

The retention approach requires selective logging. Although previous studies have shown that the additional cost of adopting a retention approach is required at the time of harvesting and does not add to normal management costs, leaving dead trees in the forest will increase the amount of management effort. There are various estimates of the cost of the retention approach, and it is currently not fully determined. Then, this study assumed a 10% increase in logging costs when adopting a retention approach based on previous studies. In addition, we have added 10% to the cost required for management. These transactions are conducted in Japanese Yen; however, we have converted them to US dollars for the sake of the readers’ understanding. The conversion rate from Japanese yen to US dollar used is JPY 110, i.e., the average of the Telegraphic Transfer Selling Rate (TTS) in 2019. These figures are shown in Table 1.

Table 1. Maintenance costs of production forests in Japan (Unit: ha). Source: [42].

Period	Years	Type of Maintenance Activity	Normal Costs (Yen/ha)	Normal Costs (USD/ha)	Cost with Retention Approach (USD/ha)
Forestation period	1	Afforestation	418,679	3806	-
	2	Cutting underbrush	232,502	2114	-
	3		119,760	1089	-
	4		163,112	1482	-
	5		9282	844	-
Growth period	6–10	Thinning	47,738	434	477
	11–15		21,079	192	211
	16–20		17,195	156	172
	21–25		38,195	347	382
	26–30		21,364	194	214
	31–35		12,466	113	125
	36–40		9734	88	97
	41–45		6468	59	65
	46–50		9862	90	99
	Maturity period		51–	Maintenance	9862

One of the costs of implementing the retention approach is the cost of research and planning, but since the retention approach is still in the experimental stage, the cost has not been presented in previous studies. We assumed that the cost of such planning would be borne by the national and local governments, not the forestry community. This is because the scale of Japan's forestry industry is not large, and the work involved in forestry itself is already supported by subsidies. For this reason, this study does not take into account the research and planning costs that would be required to introduce a retention approach. The purpose of this study is to focus on the costs of forest management if a retention approach is introduced, and to examine the possibility that this could be covered by the market.

2.3.3. Setting Carbon Credit Prices in the Simulation

Under the United Nations Framework Convention on Climate Change (UNFCCC), each country has declared carbon reductions, and Japan has set a high target of 26% reduction by 2030 compared to 2013 [43]. A key for achieving this goal is reducing emissions, especially in large cities with high carbon footprints. Tokyo is the largest city in Japan, where companies are concentrated, and the Tokyo Metropolitan Assembly passed a revision of the Ordinance on the Environment to Ensure the Health and Safety of Citizens in 2008, mandating the reduction of greenhouse gas emissions from large-scale business establishments (i.e., those that used annually more than 1500 kL of crude oil equivalent in terms of fuel, heat, and electricity). Based on this, the Tokyo Metropolitan Government introduced a cap-and-trade system to reduce carbon dioxide emissions from 2010 onward. This is the first urban-area cap-and-trade system in the world that covers office buildings, and the Tokyo Metropolitan Government has set its own reduction targets: by 8% between 2010 and 2014, and by 17% between 2015 and 2019. As a means of achieving this goal, the Tokyo Metropolitan Government has set up a carbon credit trading system [44,45].

There are five kinds of credits for emissions trading. The first is excess reduction credit, the second is small and medium-sized enterprise credit, the third is large enterprise credit outside Tokyo, the fourth is neighboring prefecture credit of Tokyo, and the fifth is renewable energy credit. Only two types of valuation-price surveys are being conducted: renewable energy and excess reduction credits. Since excess abatement credits are specific to transactions between individual companies, this study refers to the prices of renewable energy credits that are established as independent credits. The Tokyo Metropolitan Government has published the 10-year price fluctuations of renewable energy credits from 2011

to 2020. The highest price is JPY 12,500, the lowest price is JPY 5500, the average price over 10 years is JPY 8335, and the most recent price is JPY 5600 (March 2020) [46]. We converted these to dollars using the TTS prices mentioned above. These figures are shown in Table 2. We decided to run our simulations using these four values.

Table 2. Trading price for carbon credits ¹ (unit: USD/t-CO₂; based on [46]).

Type	Lowest Price	Highest Price	Average Price	Most Recent Price (March 2020)
Renewable energy credit	JPY 5500 USD 50	JPY 12,500 USD 114	JPY 8335 USD 76	JPY 5600 USD 51

¹ The conversion rate from Japanese Yen to US dollars used is JPY 110, by TTS in 2019.

3. Results

3.1. Challenges in Sustainable Management of Japanese Forests

3.1.1. Changes in the Forestry and Lumber Industries in Japan

Japan is known as the “Land of Forests” in the world. Forests are deeply involved in the lives and culture of the Japanese people, and the term “satoyama” (sato; human habitation, yama; mountain) was born in Japan [47]. Japan’s forests underwent major changes after World War II in 1945. As the population grew after the war, demand for lumber surged in Japan, where wooden houses were the standard form of housing. The lumber-producing regions could not keep up with production and began to rely partially on imports. On the other hand, forest owners, attracted by the high price of lumber, enthusiastically engaged in afforestation activities, focusing on cedar, which is used for building materials. As a result, as of 2012, 41% of Japan’s total forest area is production forests, of which 44% is made up of cedar [48].

In Japan, it takes about 50 years from planting to harvesting. However, during the past 50 years, Japanese lifestyles and economic conditions have changed dramatically. In urban areas, reinforced concrete housing complexes instead of wooden houses have become the main way of living [49]. As a result, the demand for wood for housing has decreased. In addition, Japan’s mountain forests have many steep slopes, and the cost of producing lumber is relatively high, making domestic lumber more expensive than imported lumber and making it uncompetitive. Currently, the cost of managing production forests exceeds the selling price of timber, and there are many production forests that are poorly managed and production activities have stagnated. Figure 2 shows the ratio of timber production to forest accumulation in the OECD (Organization for Economic Cooperation and Development) countries [50]. Japan has the lowest ratio of wood production to forest accumulation among the OECD countries, at only 0.47% in 2015. This is about one-tenth of Scandinavia, which has the highest amount of wood production relative to forest accumulation and is the lowest. Table 3 shows this in figures. Japan’s wood production to forest accumulation was only 39.17% in 2015 compared to the average of OECD countries.

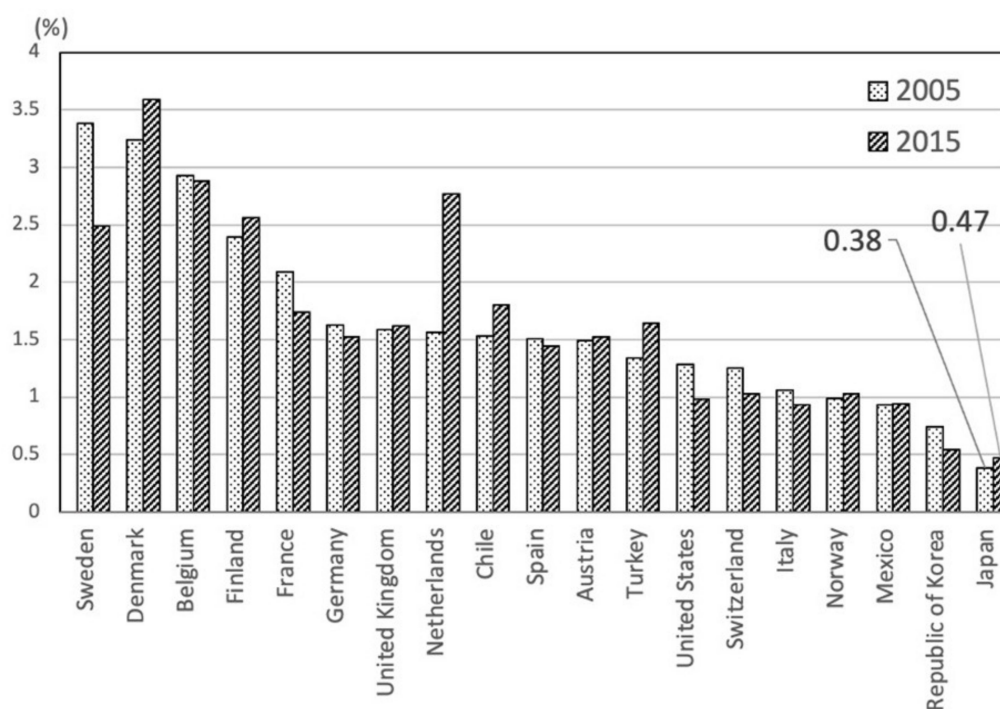


Figure 2. Ratio of timber to forest production of some OECD countries, based on [50].

Table 3. Timber to forest production ratio, based on [50].

Classification	Value of All OECD Member Countries			Value for Japan	
	Amount of Wood Production (million m ³)	Amount of Forest Accumulation (million m ³)	Wood Production/Accumulation (%)	Wood Production/Accumulation (%)	Comparison with OECD Average (%)
2005	1046	76,529	1.37	0.38	27.74
2015	1022	85,180	1.20	0.47	39.17

In light of this situation, it must be said that it is currently difficult to convert production forests into environmental forests through use. In order to properly manage abandoned production forests and convert them into environmental forests, a new added value that complements the use-value of wood is necessary. This study explores the possibility of evaluating the carbon sequestration function of production forests as carbon credits to see if it is possible to cover the costs of managing production forests and renewing them into environmental forests.

3.1.2. Forest Age Structure

In Japanese forestry (practice), forests are classified into age classes that have 5 years width. The highest possible age class is 20 with a final age of 100 years. Figure 3 shows the age classes of Japan's production forests in 2017. The area occupied by the 10th–12th age classes is the largest among the production forests, indicating that afforestation was actively carried out in the late 1960s and 1970s. Today, 50 to 60 years have passed since the time of planting, and most of the trees are in a condition suitable for logging.

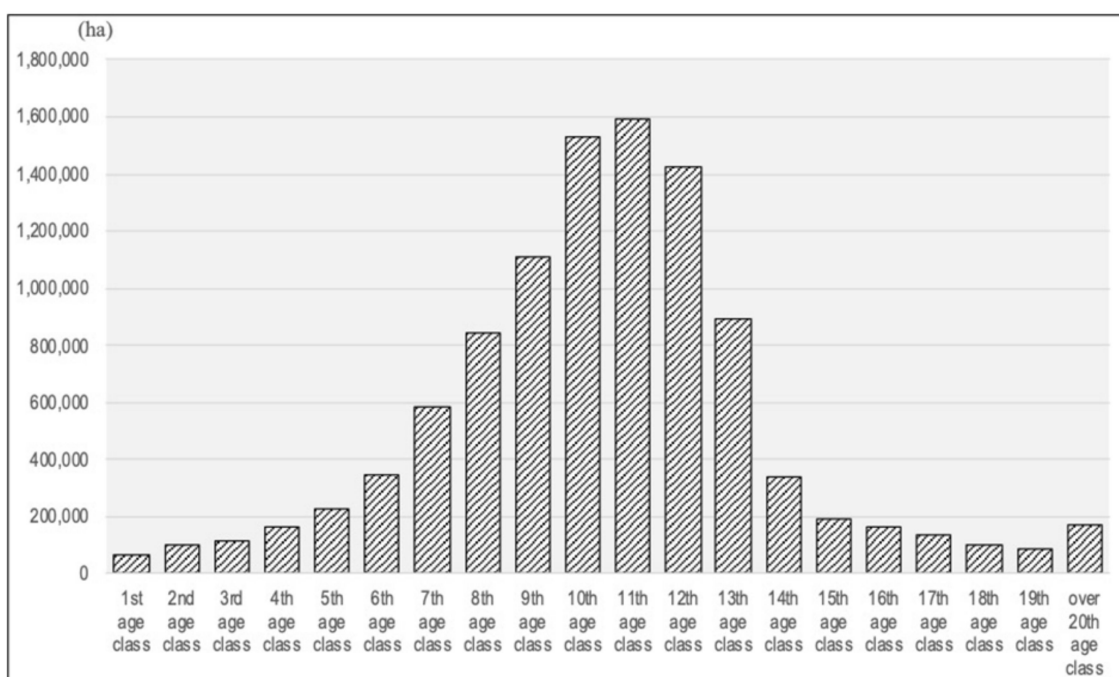


Figure 3. Total area of production forests in Japan presented by age classes in 2017, based on [51].

In the 1960s, when vigorous afforestation was carried out, Japan was in a period of rapid economic growth, with a rapidly growing population and increasing demand for housing. However, due to the subsequent spread of reinforced concrete housing complexes and price competition with imported lumber, the domestic demand for lumber rapidly declined. As a result, the area of forestation has also been decreasing since its peak around 50 years ago. In addition, even when the timber has reached the optimum age for harvesting, the cost of managing production forests is higher than the profits from timber sales, so production forests are left unmanaged.

3.1.3. Forest Management

The main activities in Japan's production forests can be classified into four processes: logging, thinning, underbrush clearing, and afforestation. After planting, weeding is carried out for 20 years, and from the 20th year to the 50th year, thinning is performed to allow the tree trunks to grow. About 50 years after planting, the trees in the production forests grow to a size suitable for harvesting. In Japan, there are about 10 million hectares of production forests [52], of which 980,000 hectares, or about 10%, are outsourced to forest cooperatives or private companies for management [53]. Table 4 shows the area and ratio of logging, thinning, underbrush cutting, and afforestation by contracted forestry companies on these 980,000 ha. Figure 3 shows that although it is clear that most of Japan's production forests have reached the appropriate age for logging, only 4.47% of the contracted area is logged, and only 22.01% of the area is thinned. Furthermore, it is a fact that the area entrusted for the project is 10% of the production forests. This data shows that it is impossible to change the forest structure through forestry.

Table 4. Ratio of management work to planted forest area in 2015, based on [52]. (Unit: ha)

Logging	Thinning	Cutting Underbrush	Afforestation
43,825	215,771	148,833	24,401
4.47%	22.01%	15.19%	2.49%

The data in Table 4 also shows another problem: in 2015, only about half of the production forests area that was cut down was planted. If this trend continues, tens of

thousands of hectares of forest area will be lost every year. Due to this situation, the law was amended in 2017 to require afforestation after logging. However, since afforestation is costly, the dilemma arises that making afforestation mandatory will further hinder the progress of logging. In order to turn neglected production forests into environmental forests, we need an engine to overcome this dilemma.

3.2. Verification of the Market Carbon Trade Hypothesis

3.2.1. Calculation of Carbon Absorption and Management Cost by Age

We performed a carbon credit assessment of the carbon dioxide absorption of forests. Table 5 shows the amount of carbon absorbed and the management cost by age. In Japan, trees in planted forests are divided into the following three periods according to the degree of their growth: until the 5th year after planting is the “forestation period”; from the 6th to 50th year after planting is the “growth period”; and from the 51st to 95th year after planting is the “maturity period”. The amount of carbon absorbed in each period was calculated based on the criteria in Section 3.2.1. The carbon absorption during the forestation period was zero. At the end of the forestation and the beginning of the growing period, the trees grew large, and the amount of carbon absorbed increased rapidly. In Japan, the cumulative amount of carbon absorbed in forests is published in five-year groups; hence, Table 5 shows the amount of carbon absorbed in each period.

Table 5. Calculation of carbon absorption and management cost by age.

Period	Managing Activities	Years	Accumulated Carbon Amount		Carbon Dioxide Absorption during the Period (t-CO ₂ ha ⁻¹)	Management Cost (USD)	Including Retention Approach Cost (USD)
			Cumulative Carbon Content (t-C ha ⁻¹)	Periodic Carbon Accumulation (t-C ha ⁻¹)			
Forestation period	Afforestation	1	0	0	0.00	3806	3806
	Cutting underbrush	2	0	0	0.00	2114	2114
		3	0	0	0.00	1089	1089
		4	0	0	0.00	1483	1483
		5	0	0	0.00	844	844
Growth period	Thinning	6–10	2	2	7.34	434	477
		11–15	18	16	58.72	192	211
		16–20	34	16	58.72	156	172
		21–25	41	7	25.69	347	382
		26–30	54	13	47.71	194	213
		31–35	67	13	47.71	113	124
		36–40	79	12	44.04	88	97
	Maintenance	41–45	90	11	40.37	59	65
		46–50	98	8	29.36	90	99
	Maturity period	Maintenance	51–55	104	6	22.02	90
56–60			110	6	22.02	90	99
61–65			115	5	18.35	90	99
66–70			119	4	14.68	90	99
71–75			120	1	3.67	90	99
76–80			124	4	14.68	90	99
81–85			128	4	14.68	90	99
86–90			129	1	3.67	90	99
	91–95	130	1	3.67	90	99	

We then calculated the management costs required for each period. This was based on Section 3.2.2 and Table 1 and was calculated assuming that the retention approach was implemented; since the retention approach involves logging operations, the cost was

added after the sixth year, when thinning begins. The calculation assumes a 10% increase in management costs from previous studies.

3.2.2. Evaluation of Pay Ability by Carbon Credit

Finally, we assessed carbon credits against the carbon sequestration of our production forests. Table 6 shows the carbon sequestration and management costs of production forests by forest age, and the price at which carbon credits would be balanced against this. The prices of carbon credits were estimated as shown in Table 2, with the lowest price of USD 50, the highest price of USD 114, the average price of USD 76, and the latest price of USD 51. In the first five years of the planting period, carbon sequestration is counted as zero. Only administrative costs are incurred, and the balance is always negative. However, from the sixth year, the carbon sink of the production forests rises rapidly, and even if the carbon credit is the lowest at USD 50, the price of the carbon credit balances the price needed to cover the cost after 30 years. After 50 years, when the trees are ready to be harvested, the carbon sink will slow down, but even if we adopt the retention approach, we will still be able to make a positive balance until the end.

Table 6. Simulation of cedar production-forests management costs per ha and renewable credit pricing (US dollars) ¹.

Period	Years	(a) ²	(b) ³	Valuation Price of Carbon Credits				Balance of Payments			
				50 USD ⁴	51 USD ⁵	76 USD ⁶	114 USD ⁷	50 USD ⁴	51 USD ⁵	76 USD ⁶	114 USD ⁷
Forestation period	1	0.00	3806	0	0	0	0	-3806	-3806	-3806	-3806
	2	0.00	2114	0	0	0	0	-5920	-5920	-5920	-5920
	3	0.00	1089	0	0	0	0	-7009	-7009	-7009	-7009
	4	0.00	1482	0	0	0	0	-8491	-8491	-8491	-8491
	5	0.00	844	0	0	0	0	-9335	-9335	-9335	-9335
Growth period	6–10	7.33	477	367	374	557	836	-9446	-9439	-9255	-8977
	11–15	58.67	211	2933	2992	4459	6688	-6723	-6657	-5007	-2499
	16–20	58.67	172	2933	2992	4459	6688	-3962	-3837	-721	4017
	21–25	25.67	382	1283	1309	1951	2926	-3061	-2910	848	6561
	26–30	47.67	213	2383	2431	3623	5434	-891	-693	4258	11,781
	31–35	47.67	124	2383	2431	3623	5434	1368	1613	7755	17,090
	36–40	44.00	97	2200	2244	3344	5016	3470	3760	11,002	22,009
	41–45	40.33	65	2017	2057	3065	4598	5422	5752	14,002	26,542
	46–50	29.33	90	1467	1496	2229	3344	6799	7158	16,142	29,796
Maturity period	51–55	22.00	99	1100	1122	1672	2508	7800	8182	17,715	32,206
	56–60	22.00	99	1100	1122	1672	2508	8802	9205	19,288	34,615
	61–65	18.33	99	917	935	1393	2090	9620	10,042	20,583	36,607
	66–70	14.67	99	733	748	1115	1672	10,255	10,691	21,599	38,180
	71–75	3.67	99	183	187	279	418	10,339	10,779	21,779	38,499
	76–80	14.67	99	733	748	1115	1672	10,974	11,429	22,795	40,073
	81–85	14.67	99	733	748	1115	1672	11,609	12,078	23,811	41,646
	86–90	3.67	99	183	187	279	418	11,693	12,166	23,991	41,965
	91–95	3.67	99	183	187	279	418	11,778	12,255	24,171	42,285

¹ Numbers marked with ‘-’ indicate deficits. ² Carbon dioxide absorption during the period (t-CO₂ ha⁻¹). ³ Management costs of implementing the retention approach (including planting, cutting underbrush, thinning, and maintenance). ⁴ The case of the lowest price of renewable energy credits. ⁵ The case of the most recent price of renewable energy credits. ⁶ The case of the average price of renewable energy credits. ⁷ The case of the highest price of renewable energy credits.

4. Discussion

In this study, we calculated the amount of carbon dioxide absorbed per hectare of Japanese cedar, a common production forests species in Japan. Utilizing the results of this calculation, we examined the possibility of appropriate management of production forests using the carbon credit method, which was introduced by the Tokyo Metropolitan Government. As a result, even with the lowest published carbon credit price of USD 50, the accumulated income and expenditure will be positive 30 years after planting. Beyond that point, the balance of carbon credits and management costs will remain positive, so it can be expected that proper management of production forests will provide a sustainable carbon dioxide absorption function. In Japan, felling occurs 50 years after planting. At that point, the balance is positive, so it is possible to consider a carbon credit system that requires the introduction of a retention approach.

Carbon credits do not subsidize the use of timber or forest management, nor do they build new biomass power plants; they merely change the flow of funds as a system. Therefore, there is almost no new production of carbon dioxide, and this approach is also applicable in countries other than Japan. Appropriate land use and adequate management are some of the infrastructure systems for global environmental conservation [54].

Proper forest management also leads to forest monitoring by which managers can quickly notice small changes in forest conditions. There are many functions that can be activated in a properly managed production forest, such as the establishment of habitats for animals and insects, the preservation of earth water by the soil, and the creation of beautiful landscapes. In degraded forests, proper thinning is not performed, and trees cannot root firmly into the ground, which may cause further damage if disasters happen. In fact, in Japan, the abandonment of production-forests management led to the devastation of forests and increased the likelihood of damage from disasters. In Japan, in 2019, damage from fallen trees during a major typhoon caused power outages for up to 934,900 homes and up to two weeks in areas that included urban areas [55]. In addition, owing to insufficient funds for production-forests management, even when thinning is performed, the thinned wood may remain in the forest, which could also trigger a disaster. Proper production-forests management is important not only for environmental protection but also from a natural risk management perspective.

The use of carbon credits for the carbon dioxide absorption function of planted forest management not only reduces carbon dioxide emissions, but also reduces disaster risk, maintains a beautiful landscape, and provides economic and recreational opportunities. In addition, proper production-forests management ensures the production of quality wood, in case wood demand increases in the future. Thus, this paper shows that carbon credits can be applied to the management of Japanese production forests.

However, even if carbon credits are paid for by the production-forests management, it is necessary to monitor whether appropriate management is performed. Communities located near forests are likely to be suitable for this auditing. Without the construction of these appropriate systems, the carbon credit system may not function effectively.

5. Conclusions

We investigated the possibility of sustainable management and conversion to environmental forests by introducing carbon credits for production forests where the framework of forest management through the use of timber has reached its limit. We found that the management cost of the production forests is compensated by the balance of carbon credits within a maximum of 30 years since planting. The introduction of carbon credits does not introduce new subsidies, nor does it build new facilities such as biomass power plants; it only changes the mechanism. Construction of a biomass power plant is costly, and the transportation of timber also emits carbon dioxide [56,57]. Conversely, the carbon credit method is not only a burden on forest owners and small producers, but there is also almost no burden on the new environment. Moreover, the payment of carbon credits for the

carbon-absorption function of forests is limited, but it already exists as a mechanism at this time. By developing the current system, it can be introduced nationwide.

As a policy implication, there are two major advantages of introducing carbon credits to production forests in areas where timber demand is declining sharply: one advantage is that sustainable management can be achieved without depending on subsidies. Mitigating global warming is an urgent task, and the carbon credit system is an indispensable mechanism for reducing greenhouse gases. Utilizing the carbon credit system available in the market, rather than government subsidies, can pave the way for international forest conservation. If independent forest management becomes possible, it will be possible to improve the biased forest structure. The second advantage is emphasizing the value of forests. Production forests were valuable in the past because the trees were used as timber; however, when timber is not used, it becomes difficult to evaluate the value of the forest, and as a result, it tends to lead to abandonment and poor management. Abandonment is likely to induce disasters and lead to the deterioration of the forest function. Millar and Stephenson [58] point out that proper management of forests in temperate climate regions such as Japan can help respond to global warming and minimize the loss of ecosystem services. By introducing carbon credits, the value of forests can be emphasized, thereby motivating forest management. In Japan and other Asian countries where the risk of torrential rains and typhoons is increasing due to climate change, this method can be evaluated as being more effective because the degradation of production forests is likely to amplify natural disaster risks.

Porter-Bolland et al. [59] found that community-managed forests presented lower and less variable annual deforestation rates than protected forests. Based on these results, we believe that carbon credit payments for forest management could be directed not only to landowners but also to local communities. Agrawal and Gibson [60] also noted that effective institutionalization of community-based forest conservation activities requires the availability of sufficient funds for implementing the rules created by local groups. According to our estimation, the introduction of carbon credits resulted in a positive balance when there was sufficient time before logging, making it possible for local communities to evaluate a variety of possibilities, such as the introduction of retention approaches. Scheffer et al. [61] point out that maintaining resilience is important in responding to ecosystem changes caused by global warming and urbanization. From that point of view, the cooperation between the retention approach and carbon credit is important.

Finally, the limitations of this study are as follows: the first is the limitation of data, which is essential for such a study. The exact cost of applying the retention approach to Japanese production forests was unknown. We also lacked the data necessary to make accurate comparisons between production forests and environmental forests. We hope that our research will contribute to the development of a retention approach in Japan in the future. Second, it is possible that the production forests will change to an intensive production forest again; however, it is possible to adopt a retention approach for forests, even if the timber is produced more intensely than before. Third, if the carbon absorption supply increases, the unit price will decrease, and the hypothesis may not hold. However, global warming is advancing, and the demand for carbon credits is expected to increase.

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