Chapter 11
Forest Management Based on Site Suitability: A Case Study of Odai Town, Mie Prefecture, Japan

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Abstract Increase in degraded plantation forests in Japan requires an integrated management system that enhances the multiple-use of forests to achieve sustainable forest management. This paper introduces the steps taken in Odai town in Mie Prefecture, Japan, to establish a forest management regime map by evaluating the site suitability for forestry. Site suitability was evaluated from two aspects: the natural site conditions and the relationship among site conditions, growth, and insect damage by *Anaglyptus subfasciatus* Pic. in *Cryptomeria japonica* D. Don and *Chamaecyparis obtusa* Sieb. et Zucc. forests. By analyzing the relationship among site conditions, growth, and insect damage based on field data obtained in plantation forests, a growth evaluation map and insect damage evaluation map were developed. Based on the natural forest investigation, natural site condition maps for *C. japonica* and *C. obtusa* were established. Furthermore, by integrating these evaluation maps with the forest road maps showing the accessibility to the forest, the forest management regime for whole of the plantation area of Odai town was established. The forest management regime map indicates sites suitable for long-rotation forestry and short-rotation forestry, and potential sites for short-rotation forestry. Sites more suitable for conversion to broadleaved forests are also identified. Based on the forest management regime map, different forest operations have begun to be implemented at each evaluated area. For sites suitable for long rotation, thinning is implemented for inferior trees and will be repeated as the trees approach the age for cutting (more than 100 years). Thinning is also conducted for the sites suitable for short rotation. However, these will be cut down more rapidly as the trees reach the age for cutting (50 years). At sites evaluated as being more suitable for conversion to broadleaved forests, clear-cutting in a small area is conducted and about 20 broadleaved species are planted in an area of

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80–120 m^2 protected by deer fences. As these measures have just begun, their effect on enhancing sustainable forest management is still being monitored. Notably, the people implementing these measures are proud of their task and work actively, which might be the most important driving force to solve the problem of plantation forest abandonment and to enhance sustainable forest management in Japan.

1 Introduction

Increase in degraded plantation forests caused by the abandonment of forest management is anticipated to reduce future timber production and the capacity to conserve soil, water, and biodiversity in Japan. An overall management regime that classifies sites for forestry that should be rehabilitated by encouraging appropriate forest management practices and plantation sites that should be converted to broadleaved forests or conifer-broadleaved mixed forest is required to enhance the multiple functions of forests to achieve sustainable forest management.

The most important consideration for sustainable forest management is to ensure that the tree species are suited to the site conditions (Ray and Broome 2003). Traditionally, forest sites were evaluated by using the site index, which is the mean height of dominant trees at a reference age. It was developed to assess site productivity of mono-cultural even-aged stands (Pokharel and Dech 2011), and it has been used worldwide, including in Japan (Hagglund 1981; Monserud et al. 1990; Mitsuda et al. 2007). However, several drawbacks have been observed with this method, such as the difficulty to determine site indexes in degraded stands and uneven-aged stands (Pokharel and Froese 2009). As an alternative approach, ecological land classification (ELC) began to attract attention. ELC is an approach that stratifies the landscape into ecologically meaningful units (ecosites) based on biotic, climatic, and soil conditions (Pokharel and Dech 2011) and uses this classification as a common base to understand the forest attributes of interest. Applying the predicted ecosite-base productivity derived from the stand-level studies to the ecosite map, which represents a combination of accounted substrate and vegetation types, allows us to understand productivity at the landscape level. In addition, the interaction of ecosites with other forest attributes, such as wildlife habitat, biodiversity, and non-timber forest products, might support decision-making regarding integrated forest management (Pokharel and Dech 2011).

The ELC approach might be useful to establish an overall management regime showing where to continue forestry and where to convert plantations to broadleaved forests in Japan. However, this approach is not without its challenges. This paper introduces these challenges in Odai town in Mie Prefecture of Japan where sites suitable for forestry were classified by applying ELC for forest management.

2 Study Area

Odai town is located in the central south-western part of Mie Prefecture (34°39′ N, 136°40′ E), central Japan (Fig. 1). More than 90% of the area (36,294 ha) is covered by forests, which are mostly privately owned (27,989 ha), and 59% of the private forests (16,500 ha) comprise plantation forests (Mie Prefectural Government 2011). The area is largely mountainous, mostly covered by steep slopes of more than 30°. The climate is temperate with an annual mean temperature of 15.5 °C and heavy rains with annual precipitation of 3147 mm from the year 1981 to 2010 (Japan Meteorological Agency 2013). Forestry is one of the main industries of the town. However, as with other forestry areas in Japan, it had been influenced by the difficulties currently faced by Japanese forestry (e.g., falling timber prices, increasing operational costs, and aging and declining forestry workforce) which have resulted in an increase in the number of forestry sites that have abandoned forest management practices.

With a view to normalize and enhance forestry in the town, the Odai town government decided to establish a forest management regime based on site suitability by cooperating with the forestry cooperatives who implement forest management practices in Odai town. The objective of the regime was to enhance the multiple functions of forests together with improving the economic efficiency of plantation forests. In concrete, it aimed to determine the site suitability of *Cryptomeria japonica* D. Don and *Chamaecyparis obtusa* Sieb. et Zucc., the main species in the plantation, by using geographic information system (GIS) data and identify suitable sites to continue with forestry for each species and suitable sites for converting plantations to broadleaved forests.

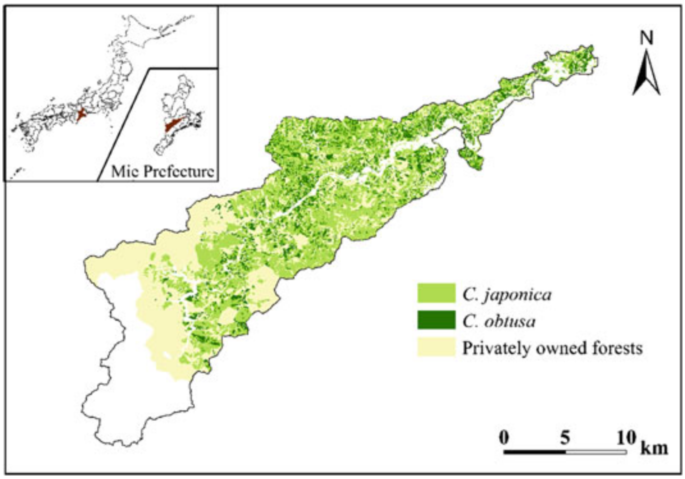

Fig. 1 Location of Odai town and its plantation area of *C. japonica* and *C. obtusa* forest (modified from Nagashima et al. 2017)

3 Evaluation of Site Suitability

3.1 Steps of Site Suitability Evaluation

Site suitability was evaluated mainly from two aspects: the natural distribution in natural forests and growth and insect damage in plantation forests (Fig. 2). The former was aimed at understanding the original or natural site suitability of the two main plantation species (*C. japonica* and *C. obtusa*), which might provide knowledge for long-rotation forestry. The latter aimed to evaluate the site not only for productivity but also for the quality of the timber, which influences the timber price at the plantation forests. By analyzing the relationships among site conditions, growth, and insect damage based on the field data obtained in the plantation forests, a growth evaluation map and an insect damage evaluation map were developed. Based on the natural forest investigation, natural site condition maps for

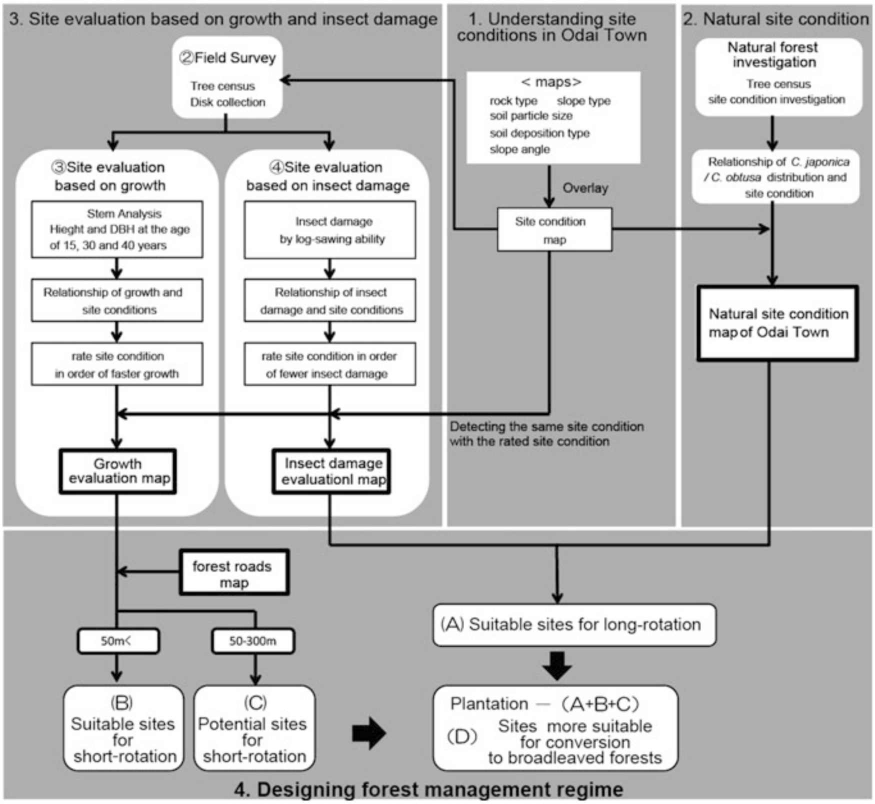

Fig. 2 Steps of site suitability evaluation (modified from Nagashima 2013)

C. japonica and *C. obtusa* were established. By integrating these evaluation maps with the forest road maps showing the accessibility to the forest, the forest management regime was determined for whole of the plantation of Odai town.

3.2 Understanding Site Conditions in Odai Town

The first step of site evaluation was to understand the site conditions of Odai town (Fig. 2). The site condition was interpreted by overlaying the maps of rock type, slope type, soil particle size, soil deposition type, and slope angle by using GIS. The 1/200,000 scaled seamless digital geological map (The National Institute of Advanced Industrial Science and Technology 2010) was used as a rock type map. The slope angle map was obtained by calculating the slope angle based on the 5 m digital elevation model provided by Odai town, which was then divided into three classes: gentle slope (0°–20°), moderately steep (21°–30°), and steep (31° and above). The slope type, soil particle size, and soil deposition type maps were developed by interpretation of topographical maps and confirmation in the field. The obtained site condition map consisted of polygons representing combinations of the attributes, which are recognized as ecosites using the ELC approach.

3.3 Site Evaluation Based on Natural Distribution

3.3.1 Understanding the Natural Site Conditions of *C. obtusa*

For understanding the natural site conditions of *C. obtusa*, Odaigahara in Yoshino-Kumano National Park of Nara Prefecture (Fig. 3), where natural *C. obtusa* forests are distributed, was selected as a study site. Fifty 10×10 m^2 study plots were established in the western Odai area, and tree census (tree species, diameter at breast height (DBH), and height) and site conditions (slope type, slope angle, deposition type, and soil particle size) were investigated. The average DBH of *C. obtusa* was 43.0 cm and the maximum DBH was 104.3 cm. The average height was 17.4 m and the maximum height was 30.7 m. The study plots were divided into vegetation groups based on the proportion of accumulated basal area of each species for each study plot by cluster analysis, and the relationship between vegetation groups and site condition was analyzed using decision tree analysis. A group was thus identified dominated by *C. obtusa* showing a tendency to distribute on the convex site with residual deposits and soil particle size of clay (Tsuchida 2013).

Therefore, by detecting the site combination of convex slope type and residual deposits with clay from the site condition map, the natural site condition map for *C. obtusa* in Odai town was developed as shown in Fig. 4.

Fig. 3 Natural *C. obtusa* forest in Odaigahara, Yoshino-Kumano National Park of Nara Prefecture

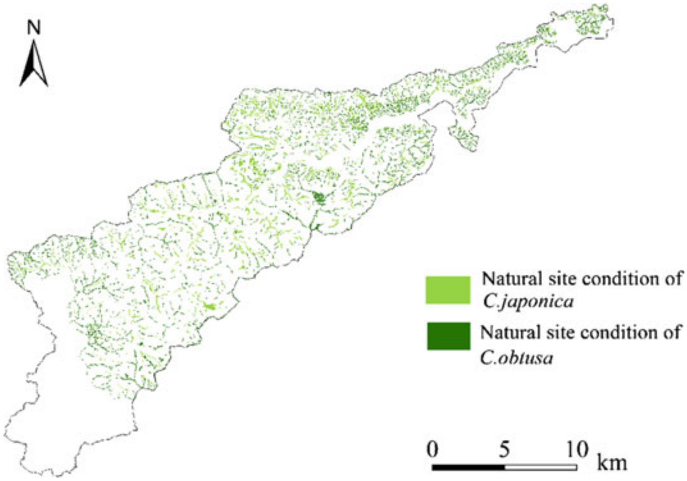

Fig. 4 Natural site condition map for *C. japonica* and *C. obtusa*

3.3.2 Understanding the Natural Site Condition of *C. japonica*

It is known that *C. japonica* could be divided into two groups genetically: the group mainly distributed along the Sea of Japan and that distributed along the Pacific Ocean (Kimura et al. 2014; Shiraishi et al. 2016). The natural forests of the Pacific Ocean of the type *C. japonica*, which is the same type as that planted in Odai town, are rarely found. Therefore, we investigated a 190-year-old *C. japonica* stand at Omata national forest in Mie Prefecture (Fig. 5), which consists of large *C. japonica* stands similar to those in the natural forests and might provide insight for site suitability assessments.

Fig. 5 190-year-old *C. japonica* stand at Omata national forest, Mie Prefecture

Three 30 × 30 m^2 study plots and one 30 × 10 m^2 study plot were established in the 190-year-old *C. japonica* stand, and DBH, tree height, and site conditions (slope type, slope angle, deposition type, and soil particle size) were investigated. The average DBH of the stand was 89.5 cm with a maximum of 140.7 cm. The mean height was 39.8 m with a maximum of 50.8 m. The site was covered by silt with colluvial deposits, which was considered to have high potential for growing large *C. japonica* trees. In other words, the site was considered to be suitable for long-rotation forestry (Tsuchida 2013).

Therefore, the site combination of silt with colluvial deposits was identified using the site condition map, and the natural site condition map for *C. japonica* in Odai town was developed as shown in Fig. 4.

3.4 Site Evaluation Based on Growth and Insect Damage

3.4.1 Field Survey

In order to understand the relationship among site conditions, growth, and insect damage, 11 plantation sites with main site conditions in Odai town were detected. In total, 153 study plots with dimensions of 10 × 10 m^2 were set up in a *C. japonica* forest stand and 142 plots in a *C. obtusa* forest stand at the 11 detected plantation sites. Tree census (DBH, height) was conducted, and, based on the tree census data, three trees (dominant, intermediate, and inferior) were selected and cut down for disk collection. Disks were collected at heights of 0, 0.2, and 1.2 m, and at 2-m intervals afterward to the top of the tree; these were used for both stem analysis and insect damage investigation.

3.4.2 Site Evaluation Based on Growth

By measuring the tree ring width of the disks collected during the field survey, the DBH and height of trees aged 15, 30, and 40 years were calculated for each tree. Then, the average DBH and height at the age of 15, 30, and 40 years were calculated for each plot. As site condition information based on the GIS data was already available for each plot, the data with the same site conditions were pooled to calculate the average DBH and height at the age of 15, 30, and 40 years for each site condition. Cluster analysis was then performed to divide site conditions into groups with the same tendency of growth of DBH and height.

Four groups of site conditions with the same tendency of growth of DBH and height were identified by cluster analysis, for *C. japonica* and five groups for *C. obtusa* forests. The clusters were ranked by the rate of growth, mainly considering the growth rate of DBH (Fig. 6), and the site conditions classified into each rated group were confirmed. As for *C. japonica,* concave sites with colluvial deposits tended to grow more quickly while convex sites with residual deposits tended to grow more slowly, as has been reported in previous studies (Makihara 1987). The higher proportion of sites with colluvial deposits in the faster growth cluster and higher proportion of sites with residual deposits in the slower growth clusters were also observed for *C. obtusa.* In addition, *C. obtusa* tended to grow slower at sites with clay soil.

Based on site conditions of each rated group, the site condition map was color-coded and growth evaluation maps were obtained for *C. japonica* and *C. obtusa* (Fig. 7).

3.4.3 Site Evaluation Based on Insect Damage

Here, insect damage refers to damage by *Anaglyptus subfasciatus* Pic. Damage by *A. subfasciatus* was considered because it was the main disturbance that occurred in plantations of Odai town, turning the timber brownish and therefore directly influencing the timber price. If a certain site has high productivity but also has a

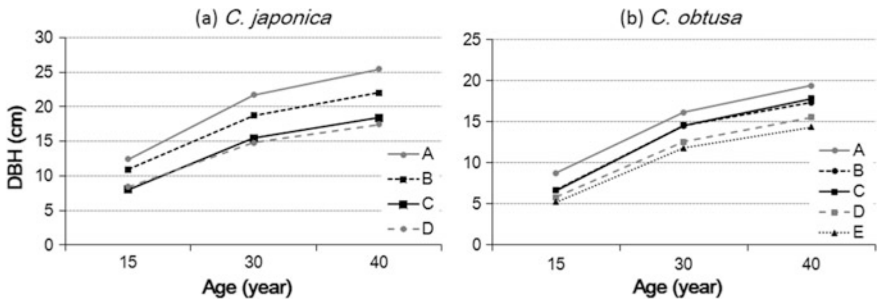

Fig. 6 Growth of DBH by ranked classes

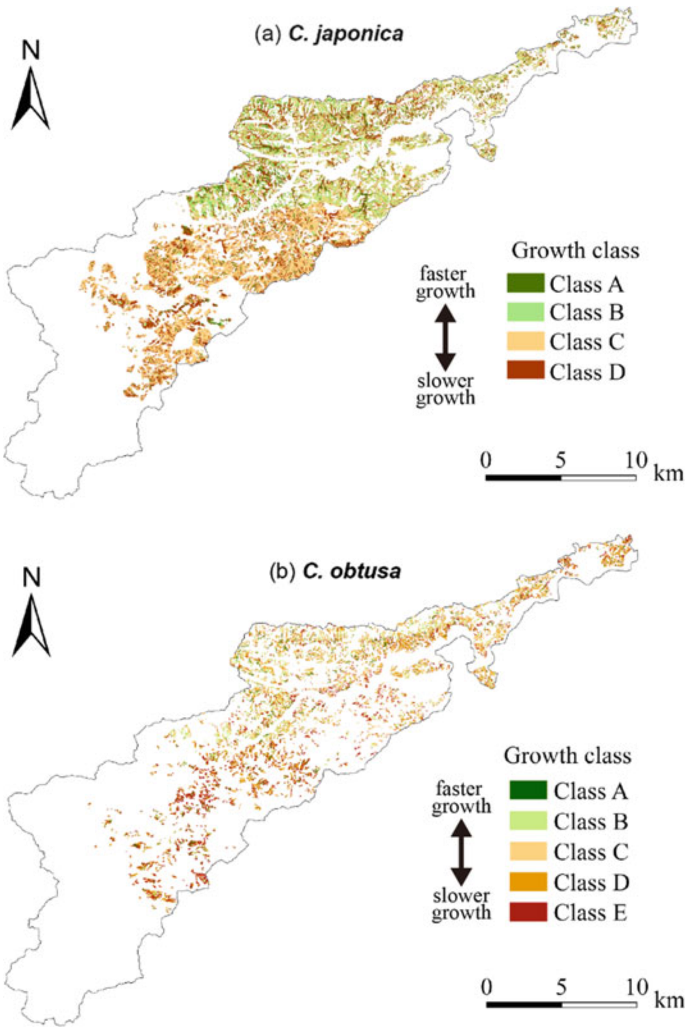

Fig. 7 Growth evaluation maps for *C. japonica* and *C. obtusa*

tendency for considerable damage by *A. subfasciatus,* the site might be difficult to evaluate as a suitable site for long-rotation forestry because the obtained timber might attract a lower price even if trees grew for a long time, increasing the cost of production. On the other hand, if a site with low productivity is not susceptible to damage, it could be considered a suitable site for long-rotation forestry, especially for *C. obtusa*, because it might provide large trees with thick tree rings, which attract high prices in the market. Thus, the quality of the log was one of the crucial points for evaluating site suitability for forestry in this study.

To understand the relationship between site condition and damage by *A. subfasciatus*, the obtained disks of each tree were divided into height levels (low: 0.2–3.2 m, medium: 5.2–9.2 m, and high: above 11.2 m) based on the height to crosscut the stem to produce bottom and the second logs. Then, the presence and absence (scored as 1 or 0, respectively) of insect damage by *A. subfasciatus* was investigated. Thereafter, the average score at each site condition was calculated and rated into three ranks in increasing order of insect damage based on log sawing ability. Damage class A indicated that both the bottom and the second logs could be sawed; class B indicated that only the bottom log could be sawed; class C indicated that only the second log could be sawed; and class D indicated heavy damage, with low probability that the bottom and second logs could be sawed.

Prior to applying the result of site evaluation, the relationship with the site condition and the damage by *A. subfasciatus* was investigated. We confirmed that concave sites with colluvial deposits, the site conditions with faster growth groups, tended to show slight damage in *C. japonica* forests. In *C. obtusa* stands, less damage was observed at clay sites where slower growth tendency was observed. Sites with colluvial deposits that showed tendency for faster growth tended to be vulnerable to damage (Nagashima et al. 2014). These sites that were not susceptible to insect damage by *A. subfasciatus* showed the same conditions as those obtained by the natural forest investigation and have historically been considered suitable sites (Saito 1959; Sakaguchi 1983). This indicates that damage by *A. subfasciatus* might decrease if *C. japonica* and *C. obtusa* are planted at suitable sites identified in this study.

By color-coding the obtained site conditions of each rated group to the site condition map, an insect damage evaluation map for both *C. japonica* and *C. obtusa* was obtained (Fig. 8).

3.5 Designing the Forest Management Regime of Odai Town

Comparing the natural site condition, growth evaluation, and insect damage evaluation maps generated in the present study might help forest managers to interpret potential site suitability for forestry. The natural site, for both *C. japonica* and *C. obtusa,* where less insect damage was observed might be suitable for long-rotation forestry because it has a high potential to grow large trees with good quality and thus high profitability. Sites that showed fast growth but were not natural distribution sites and had some insect damage were also observed. These might have potential for short-rotation forestry. However, these sites should be easy to access to reduce costs associated with short-rotation forestry. The remaining sites might have low potential for forestry and might be more suited for conversion to broadleaved forests. The process for assessing each site is explained in detail in the following sections.

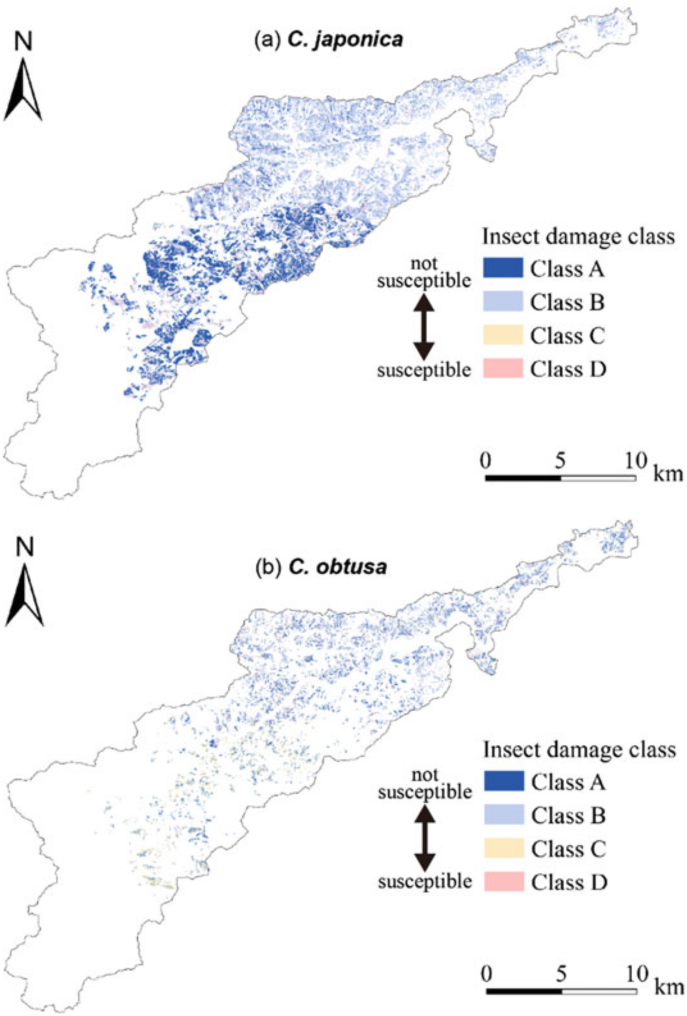

Fig. 8 Insect damage evaluation maps for *C. japonica* and *C. obtusa*

3.5.1 Suitable Sites for Long-Rotation Forestry

The natural site conditions showed high potential to provide large trees in the long term. Managing the forest over a long time is associated with higher costs for tree growth. Therefore, the site should not be susceptible to insect damage by *A. subfasciatus*, which reduces the timber price considerably, in order to be profitable. To ensure that the site least susceptible to *A. subfasciatus* damage within the natural site condition was identified, we detected the least susceptible site (rank A) using the insect damage evaluation map and overlaid it with the natural site condition map to determine suitable sites for long-rotation forestry (Fig. 9), although the natural

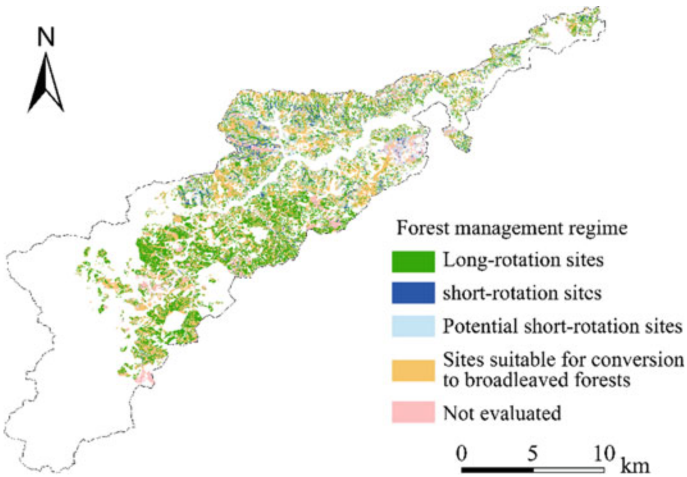

Fig. 9 Forest management regime map of Odai town

site condition itself was less vulnerable to damage by *A. subfasciatus* (Nagashima et al. 2014).

3.5.2 Suitable Sites and Potential Sites for Short-Rotation Forestry

Sites showing relatively rapid growth might have the potential for short-rotation forestry because they provide a certain size of logs in the short term. Our recent investigation indicated that the log size with the highest demand in the market is 22–24 cm in diameter for *C. japonica* and 16–18 cm for *C. obtusa* (Yamamoto et al. 2017). Although the price will decrease by approximately 1000 yen/m^3 if insect damage is observed (Yamamoto et al. 2017), the influence of insect damage on price is considered to be lower if the log size is smaller. Moreover, sites might be considered profitable if they are easy to access.

Therefore, to determine suitable sites for short-rotation forestry, we first identified sites showing relatively rapid growth (rated as ranks A and B on the growth evaluation map for *C. japonica* and *C. obtusa*). Accessibility was evaluated by drawing buffers from the current road system at a distance of 50 and 300 m outward from the polygon representing the road system by using GIS. Fifty meters is considered a suitable distance for harvest using a harvester, and 300 m is considered the harvestable distance when using the tower yarder (Umezawa et al. 2013). By overlaying the rapid growth site map, which indicates the ranks A and B of the growth evaluation map, and the accessibility map, rapid growth sites within 50 m of the current road system were identified and defined as "suitable sites for short rotation." In addition, rapid growth sites 51–300 m from the current road system were identified and defined as "potential sites for short rotation" (Fig. 9). The suitable sites for short rotation are the sites at which harvesting can be done using the operation system currently utilized by the forest cooperative. The potential sites for short rotation are sites that can become harvestable if the forest cooperative commences the use of the tower yarder system.

3.5.3 Sites More Suitable for Conversion to Broadleaved Forests

Suitable sites for long and short rotations and potential sites for short rotation are sites suitable for forestry in the area currently covered by plantations in Odai town. Plantation sites, except the areas identified as suitable sites for forestry, are the areas more suitable for conversion to broadleaved forests. Therefore, the sites more suitable for conversion to broadleaved forests were identified by eliminating suitable sites for long and short rotations and the potential suitable sites for short rotation from the map showing the current *C. japonica* and *C. obtusa* plantation area (Fig. 9).

3.5.4 The Forest Management Regime Map of Odai Town

Combining the maps showing sites for long rotation, short rotation, potential short rotation, and sites more suitable for conversion to broadleaved forests of *C. japonica* and *C. obtusa*, forest management regime map was developed. Consequently, 34.9% (3,649.9 ha) of the current *C. japonica* forest area (10,448.6 ha) was identified as suitable for long-rotation sites, while short-rotation sites and potential short-rotation sites occupied 3.2% (335 ha) and 13.0% (1,358.2 ha) of the forest area, respectively (Table 1). Sites more suitable for conversion to broadleaved forests accounted for 36.9% (3,855.5 ha) of the *C. japonica* forests, which occupied 1/3 of the area, similar to the long-rotation sites. The same tendency was observed for the *C. obtusa* forests: 35.0% (1,329.3 ha) and 33.0% (1,253.6 ha) of the *C. obtusa* forests area (3,800.4 ha), respectively. The relatively small area covered by short-rotation sites (3.6%) and potential short-rotation sites (15.7%) was also observed in the *C. obtusa* forests. The remaining area, 1,250 ha of *C. japonica* and 482 ha of *C. obtusa* forests (Table 1), had site conditions different from our investigated conditions and therefore could not be evaluated. These conditions need to be further investigated to complete the evaluation of the whole plantation area of Odai town.

4 Continuous Measures to Enhance Sustainable Forest Management

Based on the forest management regime map, the forest cooperative has begun to apply different forest operations at each evaluated area. For sites suitable for long rotation, thinning is implemented for inferior trees and will be repeated as the trees approach the age for cutting (more than 100 years). Thinning is also conducted for the sites suitable for short rotation. However, trees will be cut down soon as they reach the age for cutting (50 years). At sites evaluated as more suited for conversion to broadleaved forests, clear-cutting in a small area is conducted (Photograph 1), and about 20 broadleaved species (shrubs and trees) are planted in an area of 80–120 m^2 protected by Sika deer fences (Photograph 2). This measure is implemented to restore broadleaved forests despite browsing pressure from deer (*Cervus nippon*). On the other hand, it also ensures the use of broadleaved trees in the future, not only for wood production but also for non-wood products, which might enhance the multiple-use value of forests.

Table 1 Area of sites evaluated to each forest management regime by species

Management regime	*C. japonica*		*C. obtusa*	
	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
Long rotations	3649.9	34.9	1329.3	35.0
Short-rotation sites	335.0	3.2	137.5	3.6
Potential short-rotation sites	1358.2	13.0	597.6	15.7
Sites more suitable for conversion to broadleaved forests	3855.5	36.9	1253.6	33.0
Not evaluated	1250.0	12.0	482.5	12.7
Total	10448.6	100.0	3800.4	100.0

Photograph 1 Clear-cutting conducted at sites more suitable for conversion to broadleaved forests

Photograph 2 Planted broadleaved trees in an area protected by a Sika deer fence

These measures have just begun to be implemented, and their effects on enhancing sustainable forest management should be monitored. Based on the monitoring results, the relationships among site conditions, growth, and insect damage and the site suitability should be confirmed, which requires the forest management regime map to be updated. Such continuous measures for adaptive management might be the key to accomplish the objective of forest management in Odai town: To enhance the multiple functions of forests together with improving the economic efficiency of plantation forests. As such, the forest cooperative in Odai town has taken up the task as the main driver to monitor forest management, re-evaluate site suitability, and update the management regime map along with the Odai town government. It is notable that people in the forest cooperative and Odai town government are proud of their measures and are working actively, which might be the most important driving force to enhance sustainable forest management.

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