Patterns and Determinants of Early-stage Vegetation Development in Abandoned Plantation Clearcut Sites in Kyushu, Japan: Toward Prioritizing Sites for Restoration

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ABSTRACT

The abandonment of plantation sites after clearcutting is increasing in Japan; there is concern that if vegetation fails to recover or develops too slowly after clearcutting, there will be a decline in forest ecosystem services. An appropriate management strategy for rectifying the situation might include predicting vegetation recovery for each abandoned site and prioritizing sites for restoration. Here, we present a regional-scale study that investigated a large number of abandoned plantation clearcut sites distributed across Kyushu Island. The objective was to develop a better general understanding of early-stage vegetation recovery patterns and their determinants, which will be useful in prioritizing sites for restoration. Four vegetation classes - grassland (GL), few pioneer trees (FPT), non-pioneer trees (NPT), and pioneer trees (PT) - were detected by a vegetation survey. Sites that were (1) affected by deer browsing, (2) had relatively young tree stands at the time of clearcutting, and (3) that had been clearcut recently most often recovered to GL or FPT. Under these site conditions, efforts should be directed toward reducing deer grazing to enhance vegetation recovery during the initial stages of regrowth. Restoration effort should be allocated to sites classified as GL even 5 years after clearcutting, which includes a relatively large proportion of the study area. FPT, PT, and NPT sites should be monitored over the long term. This monitoring effort should be used to determine (1) whether tree species recovery is successful in FPT sites and (2) whether PT or NPT sites will convert successfully to evergreen broad-leaved forests (lucidophyllous forests).

Keywords: forest management, restoration priority, simplified vegetation survey, deer browsing, tree species recovery

INTRODUCTION

In Japan, there has been a substantial increase in the number of forest sites abandoned without replanting after clearcutting because of the prevailing unfavorable forestry conditions, such as falling timber prices, increased operational costs, and an aging and declining workforce. Abandonment after clearcutting is spreading through the nation (Sakai, 2003; Sakai et al., 2006; Yamagawa et al., 2006) and is indicative of an impending decline in domestic timber production. There is also concern that if vegetation fails to recover or develops too slowly after clearcutting, there will be a reduction in the capacity of the forests to influence soil, water, and biodiversity conservation (Sakai, 2003; Yoshida, 2003; Yamagawa et al., 2006).

One appropriate management strategy to rectify these circumstances might include (1) predicting vegetation recovery for each abandoned site and (2) prioritizing sites
for restoration based upon the site-specific amount of effort needed to aid recovery. Vegetation stabilizes soil, and waterholding capacity increases through the progressive steps of plant community succession (Fujimori, 2004). Hence, restoration efforts may be preferentially allocated toward (1) sites where tree establishment is difficult, (2) sites where pioneer species become dominant, and (3) sites with non-pioneer/late successional species that are likely to develop into the ideal target vegetation of evergreen broad-leaved forest (lucidophyllous forest). Implementation of such a management strategy will require broad-scale interpretations of vegetation recovery patterns and its determinants.

In a previous study, we investigated the patterns and determinants of early-stage vegetation recovery in abandoned plantation clearcut sites in Oita prefecture (633,900 ha) in northeastern Kyushu (Nagashima et al., 2009). We demonstrated that relatively small abandoned sites that had been clearcut many years prior to the study and were adjacent to evergreen broad-leaved forests were likely to allow invasion by evergreen tree species. Pioneer species tended to become dominant under adverse conditions. The presence of regenerative plant fragments (i.e., tree stumps) capable of sprouting new stems also markedly influenced (from the earliest stages) recovery of non-pioneer/late successional species (both evergreen and deciduous). Several other studies have shown that elevation and slope type can influence regeneration patterns in abandoned clearcut sites (Sakai et al., 2006; Yamagawa et al., 2006), but these factors were not identified in our previous study.

The effects of deer browsing can be crucial for vegetation recovery. As in many areas of the world, deer populations in Japan have increased dramatically over recent decades and have hindered tree regeneration in many forests (Takatsuki and Gorai, 1994; Nomiya et al., 2003; Ito and Hino, 2005). Sika deer (Cervus nippon) browsing decreases the number of seedlings and saplings in vegetation (Takatsuki and Gorai, 1994; Tsuneno and Yumoto, 2004), retarding woodland successional development (Gill and Beardall, 2001). Few studies have evaluated the effects of deer browsing on abandoned plantation clearcut sites, and the extent to which deer browsing affects vegetation recovery are not well understood. Deer grazing was not considered in our previous study (Nagashima et al., 2009) because there were few overt signs of browsing-related damage. Nevertheless, sika deer are widely distributed in the southern part of Kyushu Island (Tsuneta, 1998), where there are large numbers of abandoned plantation clearcut sites (Yamamoto, 2003). It is therefore possible that vegetation recovery patterns are now different from those during our previous study conducted in Oita prefecture. It is now obvious that a regional-scale approach is required to discern the generalities of vegetation recovery patterns in abandoned clearcut sites in warm-temperate regions.

Accordingly, we investigated a large number of abandoned clearcut sites distributed across Kyushu Island to analyze the relationship between recovered vegetation types and the putative determinants of variation among vegetation types. Our objective is to use this information in directing restoration efforts based on our previously mentioned priority ranking. To this end, we also applied a simplified vegetation survey exploring the coverage of pioneer or non-pioneer trees in a plot, instead of conducting a precise vegetation survey (i.e., tree census); this simplified method might be useful to determine the vegetation development status of extensively distributed abandoned plantation clearcut sites. Therefore, the validity of interpreting recovered vegetation based on this simplified vegetation survey is also discussed.

**MATERIALS AND METHODS**

**Study Area**

Kyushu, the third largest island in the Japanese archipelago, is located in the southeastern part of the country (Fig. 1). The island has a total area of approximately 4,217,810 ha. Sixty-three percent of the area (2,674,023 ha) is covered by forest (Forestry Agency of Japan, 2009); the natural vegetation in most of the region is warm-temperate evergreen broad-leaved forest. However, above 1000 m elevation, the vegetation gradually changes to cool-temperate deciduous broad-leaved forest (Miyawaki, 1982). The island is one of the best-known active forestry regions in the country. Plantations occupy >50% of forested area (1,500,995 ha), mostly in the southern sectors of the island (Miyazaki, Kumamoto, and Kagoshima prefectures). This region is strongly impacted by difficulties currently facing the Japanese forestry industry. Plantations abandoned after clearcutting first appeared in the 1990s (Okamori, 2003) and have since expanded progressively year after year. A 1996 survey (Okamori, 2003) showed that

![Fig. 1 Study area and distribution map of 671 abandoned clearcut sites of plantation](image-url)

**Table 1 Number of abandoned clearcut sites and investigated sites by prefecture**

<table>
<thead>
<tr>
<th>Prefectures</th>
<th>Abandoned sites</th>
<th>Investigated sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fukuoka</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>Saga</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Nagasaki</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Kumamoto</td>
<td>273</td>
<td>16</td>
</tr>
<tr>
<td>Oita</td>
<td>58</td>
<td>51</td>
</tr>
<tr>
<td>Miyazaki</td>
<td>287</td>
<td>81</td>
</tr>
<tr>
<td>Kagoshima</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>671</td>
<td>187</td>
</tr>
</tbody>
</table>
Miyazaki (143 sites, 375 ha) and Kumamoto prefectures (105 sites, 278 ha) had the second- and third-largest number of abandoned clearcut sites after Hokkaido (295 sites, 865 ha). There are many of these sites in Oita prefecture (NAGASHIMA et al., 2009), and this number is increasing (OKAMORI, 2003).

Field Survey
Among 671 abandoned clearcut sites found in Kyushu Island (Fig. 1; see MURAKAMI et al., 2006 and 2007 for procedures to detect abandoned clearcut sites), 187 were selected for vegetation surveys. In prefectures that had a relatively small number of abandoned sites, nearly all were investigated, except those that were inaccessible (Table 1). In Miyazaki prefecture, we randomly selected 81 abandoned sites among >250. In Kumamoto prefecture, we selected 16 sites that were common to our survey and a 2005 survey conducted by the prefecture. The selected sites were distributed across varying elevations (50-1,050 m above sea level; median height, 500 m), had a wide range of clearcut areas (0.5-66.5 ha; median 3.35 ha), and had undergone clearcutting at different times before our study (from 1-12 years prior; median, 6 years).

We obtained field measurements in the period between 2005 and 2008. At each study site, 1 or 2 study plots measuring 10 × 10 m were set up; in some sites, 2-5 plots measuring 4 × 4 m were established. The total number of study plots was 218. The locations of study plots were chosen carefully to include vegetation typical of each site. We selected slopes rather than ridges or valleys; forest edges were avoided to exclude edge effects. We used both areas and abundances of typical vegetation types present to determine the number of plots established at each site. Specifically, 4 × 4 m study plots were established in clearcut plantations that were either large in area or had several typical vegetation types; in addition, these sites had recovered vegetation up to 4 m tall. We adopted different plot sizes to better understand characteristics of recovered vegetation in abandoned clearcut sites that are extensively distributed throughout Kyushu Island. We also hypothesized that since vegetation height is a parameter used to determine appropriate quadrant sizes (SUZUKI, 1954), the ratio of vegetation cover should be equivalent when plot sizes are determined by vegetation height.

For conducting the simplified vegetation survey, a list of tree species categorized by their successional trends (pioneer/non-pioneer) was prepared using descriptions in illustrated guidebooks (KITAMURA and MURATA, 1979; OKUDA, 1997; MOGI et al., 2000) and informed recommendations made by researchers with broad experience in vegetation survey in Kyushu Island (Appendix). Based on this list, we recorded coverage of pioneer and non-pioneer tree species at canopy and shrub layers in each plot; we also measured coverage in the herb layer. The dominant species in the canopy layer were also recorded. Vegetation was divided into shrub and canopy layers when 2-layered stratification was clearly observable at 1.5-2 m and >5 m above ground level. When there was (1) no clear differentiation between shrub and canopy layers and (2) trees covering the site to a height of 2-4 m, the tree layer was designated as the canopy layer. When there were few trees of <2 m high scattered throughout the site, the trees were included in the shrub layer, and the canopy layer coverage was recorded as zero. Herb layer coverage was described by the cover of herbaceous plants. We also recorded (1) physiographic features (including slope angle, slope aspect (N, NE, E, SE, S, SW, W, and NW), and slope form (convex, flat, and concave)), (2) extent of deer browsing (none, slight, moderate, and serious), and (3) presence-absence of adjacent natural broad-leaved forests. The extent of deer browsing was categorized as follows: none (no damage among any of the trees in the plot), slight ($<25\%$ of trees damaged), moderate (26-75\% of trees damaged), and serious (>75\% of trees damaged).

Data Analysis
Recovered vegetation was classified by cluster analysis (squared Euclidian distance, Ward method), based on the coverage of pioneer and non-pioneer tree species in the canopy and shrub layers of each plot, using SPSS version 17.0 (SPSS, 2008). Using PC-ORD version 4 for Windows (McCUNE and MEFFORD, 1999), nonmetric multidimensional scaling ordination (NMS) was also carried out, based on the same data set used for cluster analysis. With these multivariate procedures, we explored our data to determine the vegetation classification best suited for accomplishing the objectives of this study. NMS was implemented using (1) squared Euclidian distance as the distance measure and (2) the “slow and thorough” autopilot mode (step length = 0.2, stability criterion = 0.00001, iterations = maximum of 400) to generate solutions; the lowest stress solution was adopted.

In order to interpret the factors underlying variation in vegetation types, we examined relationships between axes derived by NMS and site features by calculating Pearson’s correlation coefficients for numerical attributes and Kendall’s rank correlation coefficients for categorical attributes. In order to minimize the influence of outlier site areas, which greatly influenced the median, we excluded data for abandoned sites >25 ha when calculating correlation coefficients. Site features included slope aspect, slope angle, slope form, elevation, area, time passed since clearcutting, stand age at clearcutting, presence of adjacent natural broad-leaved forests, extent of deer browsing, and land use before plantation establishment. Data on slope aspect, slope angle, slope form, presence of adjacent natural broad-leaved forests, and extent of deer browsing were obtained by field surveys. Areas of abandoned sites were obtained from the forest register or were calculated from Geographic Information System (GIS)-based forest maps possessed by each prefecture. Time since clearcutting and the stand age at the time of clearcutting were obtained from the forest register or through interviews. We obtained elevation data by overlaying distribution maps of abandoned clearcut sites over a 1:25,000 scale topographical map and recording contour elevations of study plots at a resolution of 50 m. Land use before plantation establishment was determined from aerial images captured in the late 1940s by the US Army. Land uses were categorized as “nonforest,” “plantation,” “broad-leaved tree scattering,” and “broad-leaved forest.” In addition to the ordination analysis, the relationships between vegetation types and factors were examined by Kruskal-Wallis tests and adjusted Bonferroni multiple comparisons using Mann-Whitney U tests. Categorical attributes (slope
Classification of Vegetation Types

Seven vegetation types were identified through cluster analysis (Fig. 2). Group A had little tree coverage at the canopy and shrub layers but high cover at the herb layer (Table 2); this group was designated “grassland (g)”. Canopy layer coverage in group B was 30% and comprised mainly of pioneer species such as Mallotus japonicus, indicating that a few pioneer trees had recovered; this group was designated “a few pioneer trees (fpt)”. Group C had very high coverage of non-pioneer trees in the canopy layer (60%) and was designated “canopy non-pioneer trees (cnp)”. Group D had high coverage of non-pioneer trees in the canopy layer (60%) and was designated “canopy non-pioneer trees (cnp)”. Group E had 20% coverage of non-pioneer tree species in both canopy and shrub layers; this group was designated “non-pioneer trees (np)”. Group F, 30% of both canopy and shrub layers comprised pioneer species; this group was designated “pioneer trees (p)”. Group G had high mean pioneer species coverage (60%) at the canopy layer and was designated “canopy pioneer trees (cp)”. NMS ordination yielded a 2-dimensional depiction that explained 86.0% of variation in the data (Axis 1 = 57.8%, Axis 2 = 28.2%; final stress = 18.90; final instability = 0.02803). Axis 1 of the ordination (Fig. 3) had high scores for vegetation types dominated by pioneer species (p and cp) and lower scores for non-pioneer species (snp, cnp, and np). Axis 2 had low scores for vegetation types g and fpt, and high scores for remaining vegetation types dominated by tree species. Consequently, NMS ordination successfully separated plots designated “g”.


\[
\begin{array}{|c|c|c|c|c|c|c|}
\hline
\text{Group} & \text{Vegetation type} & \text{Canopy layer} & \text{Shrub layer} & \text{Herb layer} \\
\hline
\text{A} & g & 1.62 & 11.42 & 13.04 & 1.76 & 2.88 & 4.64 & 58.20 \\
\text{C} & snp & 12.33 & 24.83 & 37.17 & 13.47 & 73.00 & 86.47 & 48.33 \\
\text{D} & cnp & 10.82 & 60.64 & 71.45 & 5.00 & 8.18 & 13.18 & 60.00 \\
\text{E} & np & 7.70 & 27.46 & 35.16 & 5.78 & 23.54 & 29.33 & 40.88 \\
\text{F} & p & 28.21 & 17.89 & 46.11 & 37.26 & 12.63 & 49.89 & 72.63 \\
\text{G} & cp & 59.42 & 10.17 & 69.58 & 14.30 & 19.96 & 34.26 & 52.42 \\
\hline
\end{array}
\]

\* g: grassland; fpt: a few pioneer trees; snp: shrub non-pioneer trees; cnp: canopy non-pioneer trees; np: non-pioneer trees; p: pioneer trees; cp: canopy pioneer trees.

The parenthetic numbers correspond to the number of plots under each group.

Fig. 2 Cluster analysis dendrogram of 218 plots

Fig. 3 Result of NMS ordination of 218 plots

Table 3 Main component species of each vegetation class*

<table>
<thead>
<tr>
<th>Vegetation class</th>
<th>Main component species</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPT</td>
<td><em>Quercus glauca</em> Thunb. Ex Murray</td>
</tr>
<tr>
<td></td>
<td><em>Machilus thunbergii</em> Sieb. et Zucc.</td>
</tr>
<tr>
<td></td>
<td><em>Neolitsea sericea</em> (Bl.) Koidz.</td>
</tr>
<tr>
<td></td>
<td><em>Daphniphyllum macropodum</em> Miq.</td>
</tr>
<tr>
<td></td>
<td><em>Swida macrophylla</em> (Wall.) Soj.</td>
</tr>
<tr>
<td></td>
<td><em>Lindera erythrocarpa</em> Makino</td>
</tr>
<tr>
<td></td>
<td><em>Zanthoxylum ailanthoides</em> Sieb. et Zucc.</td>
</tr>
<tr>
<td></td>
<td><em>Clerodendrum trichotomum</em> Thunb.</td>
</tr>
<tr>
<td></td>
<td><em>Aralia elata</em> (Miq.) Seemann</td>
</tr>
</tbody>
</table>

* The component species of vegetation class GL were excluded because the dominant species of the herb layer were not investigated.

and “fp”. It also clearly divided the vegetation types dominated by pioneer species (including p and cp) and non-pioneer species (including snp, cnp, and np). We therefore concluded that the most appropriate vegetation classes for recognition in our study region were grassland (GL), few pioneer trees (FPT), non-pioneer species (NPT, including groups snp, cnp, and np identified by cluster analysis), and pioneer species (PT, including p and cp). Among the 218 abandoned clearcut sites, 74 were classified as GL, 41 as FPT, 43 as PT, and 60 as NPT. The major component species in each vegetation class are presented in Table 3.

Factors Affecting Early-stage Vegetation Recovery

A comparison of the site conditions among vegetation classes by Kruskal-Wallis and Mann-Whitney U tests revealed significant differences in elevation ($p = 0.026$), time since clearcutting ($p = 0.035$), slope form ($p = 0.018$), and extent of deer browsing ($p < 0.001$). Elevations increased in the following rank order of vegetation categories: NPT < PT < GL < FPT, which occurred mainly in the elevation range of 300-700 m (Fig. 4b). GL tended to establish on abandoned sites with a shorter time since clearcutting (Fig. 4d). FPT and PT had a tendency to establish on concave sites (Fig. 5b). The extent of deer browsing was greater in GL than in other vegetation classes (Fig. 5d). Vegetation categories were not related to slope aspect ($p = 0.083$), slope angle ($p = 0.936$), abandoned area ($p = 0.391$), stand age at time of clearcutting ($p = 0.685$), occurrence of adjacent natural broad-leaved forest ($p = 0.672$), and land use before plantation establishment ($p = 0.123$).

Analysis of the relationship between the derived NMS axes and site conditions demonstrated that Axis 1 was negatively correlated with slope angle ($r = -0.175$, $p = 0.011$),
slope form \( r = -0.128, p = 0.016 \), and extent of deer browsing \( r = -0.127, p = 0.016 \). Axis 2 was negatively correlated with extent of deer browsing \( r = -0.261, p < 0.001 \) and positively correlated with stand age at time of clearcutting \( r = 0.153, p = 0.033 \) and time since clearcutting \( r = 0.139, p = 0.048 \).

**DISCUSSION**

Vegetation Classification Using the Data of Simplified Vegetation Surveys

Previous studies (SAKAI et al., 2006; YAMAGAWA et al., 2006; NAGASHIMA et al., 2009) have described the different recovery patterns of pioneer tree species and non-pioneer tree species at abandoned plantation clearcut sites: the former are likely to recover from the existing soil seed bank, while the latter can recover by resprouting. Therefore, valid methods of classifying vegetation should consider the prevalence of pioneer versus non-pioneer species in a given site. In addition, animal grazing can have a large impact upon vegetative regrowth (TAKATSUKI and GORAI, 1994; GILL and BEARDALL, 2001; TSUJINO and YUMOTO, 2004), and as such, these effects must be considered in any valid description of regrowth. Our analysis, based on the data of simplified vegetation surveys that recorded the coverage of pioneer and non-pioneer species, classified vegetation into four categories (GL, FPT, PT, and NPT); in this way, both the impact of animal (deer) grazing and the prevalence of pioneer vs. non-pioneer colonization were accounted for. As discussed below, this classification system also allows us to recommend the allocation of restoration efforts to sites based upon the following order of priorities: (1) sites in which tree establishment is difficult, (2) sites in which pioneer species tend to become dominant, and (3) sites comprised largely of non-pioneer/late-successional species. In summary, our simplified method of vegetation surveys can describe both the regrowth of pioneer/non-pioneer species and the effects of animal grazing at the canopy or shrub layer. The method is useful for evaluating the likelihood of vegetation recovery and therefore the urgency/necessity of human intervention into site recovery, as well as a measure of the potential efficacy of human intervention. The method should therefore be employed when determining the best management strategy for recovering clearcut sites.

Factors Influencing Tree Species Recovery

GL and FPT differentiated from PT and NPT on Axis 2 of the ordination diagram. Hence, this axis represents factors that influence tree species recovery. The extent of deer browsing was negatively correlated with Axis 2, while stand age at the time of clearcutting and time since clearcutting were positively correlated with this axis. Specifically, tree species recoveries became more difficult when (1) deer browsing pressure was elevated, (2) when stands were young at the time
of clearcutting, and (3) when clearcutting was recent. Under these circumstances, GL or FPT were often established. When conditions were adverse, tree species recovered steadily and NPT or PT became established. The Kruskal-Wallis and Mann-Whitney U tests also indicated that GL tended to establish itself on sites with serious deer browsing and shorter time since clearcutting. High densities of sika deer may result in loss of seedlings and saplings (Takatsuki and Goria, 1994; Tsujino and Yumoto, 2004), preventing forest recovery (Gill and Beardall, 2001). Accordingly, abandoned clearcut sites classified as GL occurred in island sectors with large deer populations, particularly in the southern part of Kyushu Island (Tsuneta, 1998). At the same time, it is quite natural that the recovery of few tree species was observed at sites where only a few years had passed since clearcutting. Our previous study (Nagashima et al., 2009) indicated that tree species recovered vigorously 5 years after clearcutting when deer browsing was negligible. Therefore, it might be important to pay attention to sites where tree species do not recover even 5 years after clearcutting, as the absence of trees could signal the presence of ongoing damage.

Abandoned clearcut sites that had high scores on Axis 2 had relatively old stands (age >45 years) at the time of clearcutting; thus, stand age at clearcutting influenced tree species recovery, even though there were no significant differences in stand age at clearcutting among vegetation classes. The stand age at clearcutting can reflect the quantity of regeneration sources such as regenerative plant fragments (i.e., tree stumps) and soil seed banks. Yamagawa et al. (2006) demonstrated better evergreen broad-leaved tree recovery after clearcutting of older plantations than after cutting younger stands. This age effect might relate to the richer understory tree flora in older plantations (Ito et al., 2003). After felling, these trees leave stumps and other fragments, which are good sources of regenerating sprouts; these stumps are less frequent after cutting a young stand (Yamagawa et al., 2006). Soil seed banks develop in plantations by frugivorous seed dispersal (Sato and Sakai, 2003). The older the stand age of a plantation became, the greater the amount of seeds that accumulate in the soil seed bank, which indicates a higher possibility of tree species recovery after clearcutting. In the same way, a protracted time after clearcutting may provide long-term opportunities for seed dispersal and propagation in felled areas, with consequently improved tree species recovery.

We expected elevation to influence tree species recovery because GL and FPT tended to occur at higher elevation sites according to the Mann-Whitney U test. However, this was not apparent from correlations on Axis 2 of the ordination. Because GL tends to occur at high-elevation sites with strong impacts of deer browsing, elevation can be considered as a factor influencing the occurrence of deer browsing (Sakai et al., 2006; Tanaka et al., 2008) but not affecting the recovery of tree species. These multivariate relationships should be investigated in future studies.

Factors Influencing Dominant Tree Species

PT and NPT were arrayed separately on Axis 1 of the ordination, which appears to express factors that influence the dominant tree species. Slope angle, slope form, and extent of deer browsing were negatively correlated with Axis 1. Thus, sites with steeper slopes, convex slopes, and elevated deer browsing effects tended to recover to NPT, and sites with adverse conditions tended to recover to PT; the same tendencies were also detected for the latter two factors by the Mann-Whitney U test. The effect of deer browsing was more closely related to Axis 2 than Axis 1, which indicates that browsing has less influence on selection of the dominant tree species than on tree species recovery. Deer browsing may be correlated with Axis 1 because NPT is established more easily than other vegetation classes (even under heavy deer browsing) due to rapid growth of sprouting shoots, which allows non-pioneer trees to grow to size categories that are less susceptible to browsing pressure (Shimoda et al., 1994; Koda et al., 2008). Distribution trends for late-successional species on ridges or steeper slopes and for pioneer species within valleys or lower slopes have been observed in several studies on the understoreys of sugi plantations and evergreen broad-leaved forests (Sakai and Ohsawa, 1994; Nakagawa et al., 1998). Since a high proportion of non-pioneer trees recover by sprouting at plantation clearcut sites from the earliest stages of abandonment (Yamagawa and Ito, 2006; Nagashima et al., 2009), the composition of recovered vegetation may be a reflection of the understorey tree distribution prior to clearcutting. Therefore, topographic variation in understorey tree species may influence the composition of recovered vegetation, as suggested by Yamagawa et al. (2006).

Implications for Abandoned Clearcut Site Management

According to our rank order of restoration priority, first efforts should be directed toward GL, a vegetation class mostly covered by herbs. The second priority should be toward FPT, a vegetation class in which a few tree species have recovered. Sites (1) impacted by deer browsing, (2) with young stands at the time of clearcutting, and (3) that were cut recently tend to recover to GL or FPT; hence, measures to eliminate deer browsing are likely key to enhancing vegetation recovery at such sites, particularly during the initial stages of recovery. In addition, special attention should be paid to sites classified as GL or FPT even 5 years after clearcutting, because within 5 years, tree species usually show steady recovery in the absence of deer browsing. The proportion of total plots classified as GL >5 years after clearcutting was relatively high (28%), indicating that restoration of this vegetation class will require considerable resources. Decisions regarding restoration of GL sites <5 years after clearcutting and FPT should be contingent on long-term recovery of tree species after clearcutting. This may require protracted monitoring of vegetation change. Although the vegetation classes PT and NPT have low priorities for immediate restoration, they will also require long-term monitoring to determine whether they will progress to the target lucidophyllous forest state. The climax stage of lucidophyllous forests contains Q. acuta, Q. salicina, Q. glauca, and Distylium racemosum (Nagamatsu et al., 2002); this is the ideal target of vegetation recovery toward which we are striving. However, the main component species of NPT was Q. glauca, a tree that dominates the early stages of vegetation development (Tanouchi, 1990). Moreover, NPT
vegetation can easily regenerate by sprouting from stumps and other late-stage remnants after clearcutting (Yamagawa and Ito, 2006; Yamagawa et al., 2008; Nagashima et al., 2009). Vegetative sprouting promotes successful early recovery of component species in lucidophyllous forests, but this reproductive process may simplify the species composition, slowing the progress toward climactic vegetative diversity (Bond and Midgley, 2001; Ito et al., 2008; Yamagawa et al., 2008). In order to promote the succession to the climax stage of lucidophyllous forests, it might be necessary to allocate labor for manual manipulations that remove such impediments to natural succession, in the future.

Finally, it is important to mention that the management strategy and the rank order of restoration priority discussed in this paper is one useful approach for managing abandoned clearcut sites. The proposed management strategy takes into consideration the current unfavorable economic conditions, which make it difficult to reestablish plantation on abandoned clearcut sites. The objective is to avoid a reduction in the soil and water holding capacity of the forest, which might occur when the vegetation fails to recover or develops too Slowly. Therefore, we give greater priority to sites where the vegetation recovers slowly. In order to enhance biodiversity, we selected evergreen broad-leaved forest as the target vegetation. However, we did not proceed to cover the all sites with evergreen broad-leaved forest as soon as possible; instead, we took a long-term view for biodiversity recovery, and gave sites with non-pioneer/late successional species a low priority in our rank order. If reestablishing plantation on certain sites is economically viable, then an alternative is to first prioritize sites well suited to plantation based on their site productivity and then apply our strategy to sites not favorable for plantation establishment. If biodiversity conservation is of greater priority, then the alternative is to suitably change the rank order and allocate labor to NFT. It is important to note that the decision regarding which strategy must be applied depends on the management objective and the target vegetation.

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Appendix: Tree species identified as pioneer species

**Trees**

Albizia julibrissin Durazz.
Alnus firma Sieb. et Zucc.
Alnus hirsuta Turcz.
Alnus hirsuta Turcz. var. sibirica (Fischer) C.K. Schn.
Alnus sieboldiana Matsumura
Celtis jessoensis Koidz.
Eudesia melifolia (Hance) Benth.
Firmiana simplex (L.) W. F. Wight
Idesia polyarpa Maxim.
Mallotus japonicus (Thunb. ex Murray) Muell. Arg.
Pinus densiflora Sieb. et Zucc.
Platycarya strobilacea Sieb. et Zucc.
Rhus succedanea L.
Robinia pseudoacacia L.
Zanthoxylum ailanthoides Sieb. et Zucc.

**Shrubs**

Aralia elata (Miq.) Seemann
Boehmeria spicata Thunb.
Broussonetia kazinoki Sieb.
Caesalpinia decapetala (Roth) Alst. var. japonica (Sieb. et Zucc.) Ohhashi
Clerodendrum trichotomum Thunb.
Deutzia crenata Sieb et Zucc.
Deutzia scabra Thunb.
Diplomorpha ganpi (Sieb. et Zucc.) Nakai
Diplomorpha trichotoma (Thunb.) Nakai
Hydrangea paniculata Sieb. et Zucc.
Lespedeza bicolor Turcz.
Liltea citriodora (Sieb. et Zucc.) Hatusima
Oreocnide fruticosa (Gaoudich.) Hand-Mazz.
Rhus japonica L. var. roxburghii (DC.) Rehd. et Wils.
Rhus sylvistris Sieb. et Zucc.
Rhus trichocarpa Miq.
Rosa multiflora Thunb.
Rosa onoei Makino
Rosa wichuraiana Crépin
Rubus cuneifolius Bunge
Rubus hirsutus Thunb.
Rubus palmatus Thunb. var. palmatus
Rubus parvifolius L.
Rubus sieboldii Bl.
Rubus sumatr anus Miq.
Sambucus racemosa L. subsp. sieboldiana (Miq.) Hara
Stachyurus praecox Sieb. Et Zucc.
Weigela decola (Nakai) Nakai
Weigela japonica Thunb.
Zanthoxylum schinifolium Sieb. et Zucc.

Note: The appendix only shows the pioneer tree species. Other tree species observed in the abandoned plantation clearcut sites are recognized as non-pioneer species.