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NATURAL REGENERATION AND ARTIFICIAL THINNING FOR EARLY FOREST RESTORATION ON A PERMANENTLY CLOSED SKI SLOPE

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ABSTRACT: In recent decades, numerous ski resorts in Japan have had to close due to financial difficulties. Forest restoration on these abandoned ski slopes is necessary for landscape management and to prevent avalanches and landslides. However, forest restoration activities are hindered by the scarcity of nutrients due to topsoil removal at the time of ski slope construction. In this study, the effect of thinning on alleviating competition for soil nutrients was examined. The study site was located on Mt. Tateshina in central Japan. The study site's ski slope was closed permanently in 1997, and the first natural regeneration of larch occurred in 1998. Chubu Regional Forest Office performed artificial thinning in 2003. Two thinned, nine un-thinned quadrat plots in 2016 were established and measured the total height and diameter at all living and dead trees' breast height. Tree-ring analysis of nine sample trees in each of the un-thinned and thinned plots at 1 m height intervals was performed to clarify tree growth. The un-thinned field had a high tree density, small tree size, and numerous dead trees, suggesting the existence of severe competition. Conversely, the thinned plot was characterized by a lower tree density, large tree size, and fewer dead trees. According to the tree-ring analysis, artificial thinning improved the survival rate and smaller trees' growth rate. It was concluded that the artificial thinning of natural forests on ski slopes is useful for accelerating tree growth and early forest development.

Keywords: Abandoned ski slope, Decreasing competition, Forest restoration, Topsoil removal

1. INTRODUCTION

In temperate regions of the world, ski resorts are often developed in mountainous areas. Unlike the ski slopes in the European Alps, usually located in pastureland and heathland areas, ski slopes in Japan are typically constructed in forested areas [1]. The construction of ski slopes in Japan is associated with extensive civil engineering works, which dramatically change the landscape and separate the forest ecosystems from adjacent grass and dwarf-shrub ecosystems [1,2].

In developing ski slopes, the civil engineering works harvest all of the trees on a slope and remove their root systems. Furthermore, large amounts of topsoil and rocks are removed to smooth the ski slope [2-4]. In many cases, exotic or indigenous meadow species are introduced and maintained. Previous studies in Japan have shown that ski slope vegetation typically has the following characteristics: introduced exotic grasses, development of unvegetated patches, and restriction of woody plant establishment [1,2]. These vegetation characteristics are the result of the civil engineering works and the maintenance of the ski slopes.

In recent years, numerous Japanese ski resorts have had to close due to financial difficulties [5]. The ski slopes are left derelict because these ski resort companies lack the capital required to remediate the environment. These abandoned ski slopes fragment the forest ecosystem and deteriorate landscape quality. Besides, they increase the risk of avalanches, topsoil erosion, and landslides [2,4].

Within the context of conserving quantity and quality of ecosystem services, early forest restoration on the abandoned ski slopes is necessary. The root system of vegetation has the function of stabilizing slopes and preventing landslides [6]. Therefore, there are many studies on vegetation restoration in landslide sites [7-10]. However, artificial reforestation on an abandoned ski slope is impractical due to the expenses involved. Although natural regeneration is possible, the effectiveness of such efforts is characterized by uncertainty [11]. For example, seed supply is directly affected by masting events in the surrounding forests. In some cases, patches of large herbaceous perennial plant or shrub species inhibit tree species' regeneration and development [4,12,13]. Besides, the removal of topsoil limits the availability of nutrients and, consequently, trees' regrowth and forest restoration [3,4,14].

In this study, the effects of artificial thinning on ski slopes that have been subjected to extensive topsoil removal were evaluated. Specifically, a site at which Japanese larch's natural regeneration was successful was examined [4]. Since the number of samplings at the study site was considered too much for regeneration, trees avoided competition under nutrient-poor conditions. Therefore, the hypothesis that artificial thinning would alleviate competition among trees and accelerate their growth was tested.

2. STUDY SITE AND METHODS

2.1 Study Site

The study site was located on a north-facing slope (36.1216 N, 138.3405 E, alt. 1,800 m) on Mt. Tateshina in Nagano Prefecture, central Japan (Fig. 1). The shuttered Tateshina Associates Ski Resort previously leased this area from the Chubu Regional Forest Office until 1997.

The ski slope was surrounded by artificial forests comprising Japanese larch (*Larix kaempferi*). The ski slope was elevated by a height of 1 to 4 m from the surrounding larch forests, indicating that extensive civil engineering work was required to construct it.

Immediately after the closure of the ski resort, the first natural regeneration of larch occurred in 1998. In 2002, the density of larch was 70,000 trees/ha, and that of broad-leaved pioneer tree species (*e.g.*, *Betula platyphylla*, *Alnus filma*, *Alnus matsumurae*, and *Salix sachalinensis*) was 20,000 trees/ha (Dr. Y. Koyama, pers. comm.). In 2003, when the trees were 5-year-old, the Chubu Regional Forest Office thinned these stands of trees to 3,000 trees/ha as they considered that severe competition among trees would stunt regrowth.

Small patches of un-thinned larch trees on the slope, comprising 6, 11, and 18-year-old individuals, respectively was discovered in 2016. The 18-year-old patch was located in the middle of the slope. This rectangular patch measured 10 m x 15 m and was surrounded by thinned larch and a broad-

Fig. 1 The studied abandoned ski slope covered by larch trees.

leaved trees' stand. Another 18-year-old un-thinned patch near a road at the lower part of the ski slope was found. In this latest patch, the density of larch was lower due to the coverage of dwarf bamboo (*Sasa senanensis*). The 11-year-old patches were located near the top of the ski slope. To construct the starting terraces, the topsoil in this area was removed to a depth of approximately 3 m. The 6-year-old patches were established adjacent to an area that was used as a parking lot for construction vehicles, and the surface of this area was highly compacted.

2.1 Quadrat Plot

To assess the tree developmental stage using the chronosequence method, eleven quadrat plots in the patches containing the different tree cohorts (Table 1) was established. The size of the quadrat plots was determined based on the patch size and the stand density.

Two 18-year-old thinned (T18-1 and T18-2) and

Table 1 Outline of quadrat plots

Plot	Treatment	Regeneration	Age	Size [m^2]	Location on slope	Vegetation of ground surface	Dead tree	Thinned stump
T18-1 T18-2	Thinned	1998	18	10 x 10	Middle	Meadow	-	Many
C18-1 C18-2	Un-thinned	1998	18	5 x 5	Middle	-	Many	-
S18-1	Un-thinned	1998	18	10 x 10	Bottom	Dwarf bamboo	Few	-
C11-1 C11-2 C11-3	Un-thinned	2005	11	2 x 3	Top	-	Many	-
C6-1 C6-2 C6-3	Un-thinned	2010	6	1 x 1	Bottom	Herbaceous plants	-	-

two un-thinned plots (C18-1 and C18-2) on the ski slope were established along with an un-thinned plot near a road (S18-1). Besides, three un-thinned 11-year-old (C11-1, C11-2, and C11-3) and three un-thinned 6-year-old (C6-1, C6-2, and C6-3) plots, measuring 2 m x 1 m, were also established. There was no vegetation cover in the 11-year-old plots, but herbaceous plants covered the 6-year-old plots.

2.3 Measurement

The total height and diameter at breast height (DBH) for every alive and dead tree for each plot was measured, and identified the species. The tree height and DBH were measured using a height meter (Measurement Pole, SK Co., Japan or Vertex IV, Haglov Co., Sweden) and steel tape.

The stem rings to reconstruct tree growth were analyzed. The stem disk samples at 1-m intervals from nine trees in thinned plots (T18-1) and nine trees in un-thinned plots (C18-1) were collected. These sample trees were selected based on the tree-size classification in each plot. At first, the rank of tree size was identified in each plot. Second, the rank was classified into three rank-classes (*i.e.*, top-, intermediate- and bottom-third). At last, three sample trees were selected from each rank-class. The annual ring width in four radial directions was measured, and reconstructed the height and DBH growth process.

3. RESULTS

3.1 Stand Structure

The stand density for each plot is shown in Fig. 2. The stand density for T18 (triangles), S18 (solid circle), and C18 (open circles) were approximately 3,000, 6,000, and 12,000 tree/ha, respectively. On the other hand, the stand densities for C6 and C11 (open circles) ranged from 30,000 to 80,000 and from 27,000 to 60,000 tree/ha, respectively.

The canopy height for each plot is shown in Fig. 3. The dashed line represents a height growth curve for the lowest-grade site index (In Japan, the site index is graded into five classes associated with canopy height growth. The fifth grade is the lowest grade). This curve by referring to the growth curve for a fifth-grade site in Nagano Prefecture [15] was calculated. The canopy height for the un-thinned plots (C6, C11, and C18, open circles) was lower than that for the fifth-grade site index. On the other hand, the canopy height for the S18 plot (solid circle) and T18 plots (triangles) were close to those fifth-grade site index. The average DBH was large in the T18 plots (triangles) and S18 plots (solid circles) and small in the C18 plots (open circles).

The relationship between the average D^2H and the stand density is shown in Fig. 4. The power

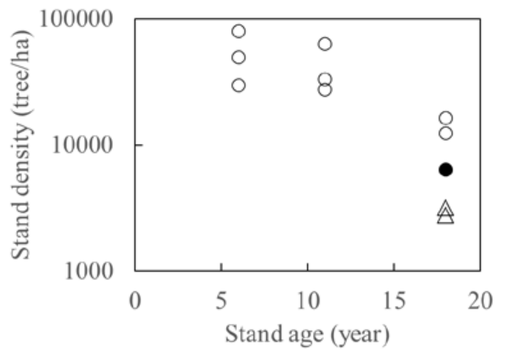

Fig. 2 Stand density of each quadrat plot.

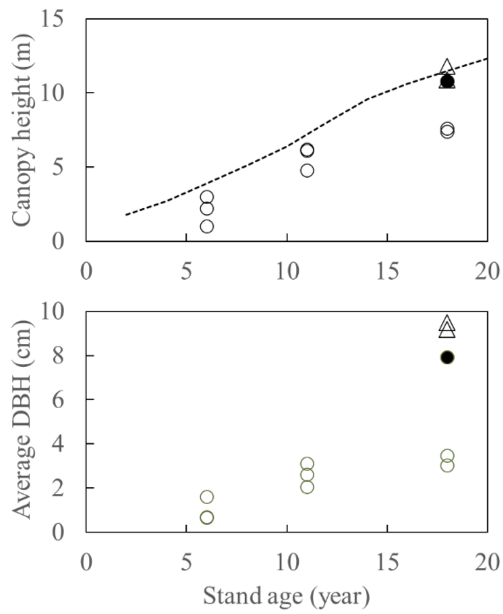

Fig. 3 Canopy height and average DBH of each quadrat plot.

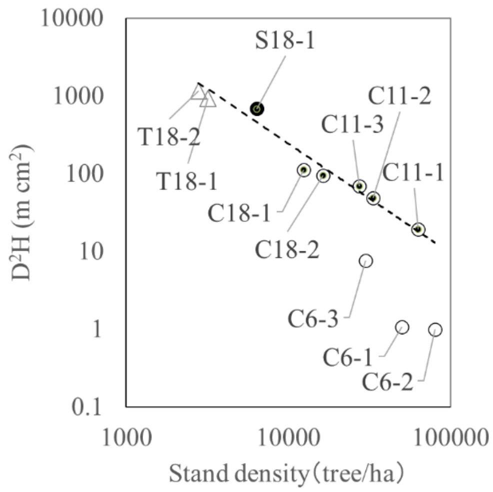

Fig. 4 Relationship between average D^2H and stand density.

function was determined using the data from the C11, C18, and S18 and was approximately -1.5 (ln [D^2H] = 18.49-1.411 ln [Stand density], $r^2 = 0.931$). The stand density values obtained for the C6 are less than this power function, whereas the values for the T18 are closed to the curve.

The height frequency distributions for a living (open bars) and dead (solid bars) trees in each plot are shown in Fig. 5. In the C6, a concentrated or unimodal distribution pattern is observed. In the C11 plots, the height frequency distribution shows a bimodal distribution, and the small trees died. In the C18 plots, a bimodal distribution is also observed, but the height frequency distribution is positively skewed, and the small trees died. In the S18 and T18 plots, the height frequency distribution has a unimodal distribution, and negative skewness is observed, but few dead trees.

3.2 Reconstruction of Stem Growth

Based on the tree ring analysis, height growth was reconstructed (Fig. 6). In both plots, bimodal size distribution is observed before thinning. However, smaller trees experienced fast growth in the thinned plot. Finally, the height range of smaller trees increased in the thinned plot (T18-1).

4. DISCUSSIONS

4.1 Natural Regeneration and Self-Thinning

Natural regeneration of larch occurred at the study site in 1998, 2005, and 2010 (Table 1), which implies that Japanese larch's masting-seeding cycle ranges from five to eight years. This long interval also suggests that the occurrence of masting-seeding presents a valuable opportunity for larch forest establishment.

A high stand density characterized the un-thinned plot. The initial stand density was estimated to range from 60,000 to 80,000 trees/ha, based on the first and third regeneration event (Fig. 2, C6 plots). These values are considered to be sufficient for the natural establishment of forests. However, a previous study reported that, under natural regeneration conditions, the stand density of 4- to 7-year-old Japanese larch ranged from 60,000 to 280,000 tree/ha [11], considerably higher than that observed in this study.

The numerous, small, living trees, and dead trees with a high stand density in the control plots suggest that intense competition occurred among trees (Fig. 4). In particular, there were many dead trees in the C11 and C18 plots. The power function between density and tree size in these plots suggests that self-thinning due to competition [16] occurred (Fig. 5). Conversely, there were few dead trees in the C6 plots, and their size distribution was

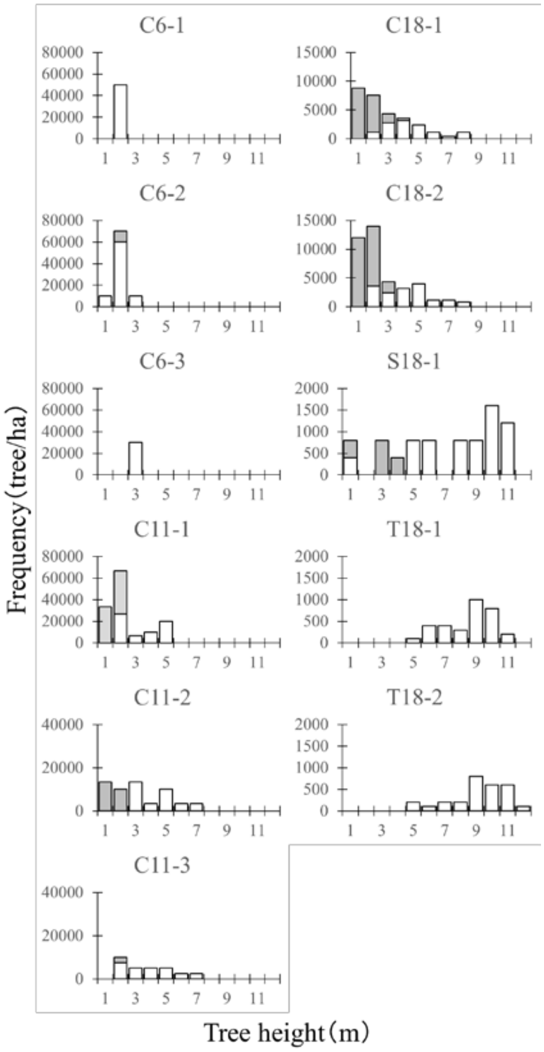

Fig. 5 Size structure of each quadrat plot.

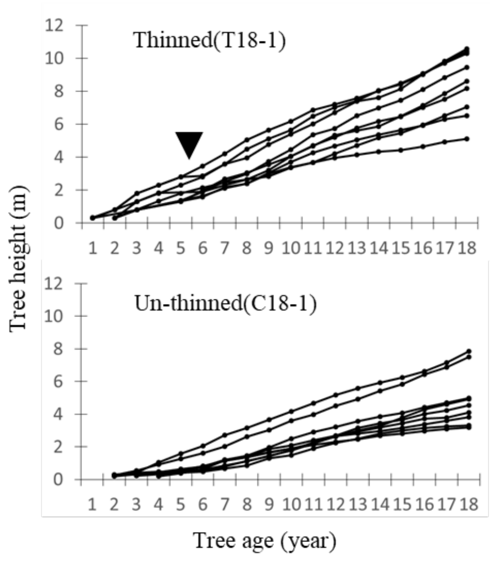

Fig. 6 Reconstructed height growth of nine trees in thinned and un-thinned plot.

unimodal (Fig. 4). Besides, their size was significantly smaller than that predicted by the maximum size-stand density relationship (Fig. 5). These characteristics of the C6 plots show that the competition among trees was not severe.

Additionally, the trees in the un-thinned plots were characterized by a low growth rate in height and diameter. Compared to the lowest growth curve obtained for larch trees in Nagano Prefecture [15], the trees in the un-thinned plots were smaller. Since topsoil removal typically inhibits tree growth [3,4,14], more intense competition might not only have occurred for light but also nutrients. The intense competition for soil nutrients due to topsoil removal is likely to be one reason why an increase in height was limited.

4.2 Effects of Artificial Thinning

Thinning has been shown to decrease competition for light and nutrients among trees; trees in thinned plots were taller than those in un-thinned plots (Figs.2 and 3). The same effects in the S plots where dwarf bamboos presence had decreased the density of larch trees was found. The low tree density reduced competition in the S plots, resulting in accelerated tree growth until reaching the lowest height-growth curve [15].

Further, thinning also affects the size structure of a stand (Fig. 5). The skewness of the height distribution from positive to negative indicates that the proportion of large trees increased in the population. There were upper and lower layers in the un-thinned and thinned plots at the thinning time (*i.e.*, when trees were 5-year-old). This stratification was maintained in un-thinned plots until the trees were 18-year-old. Conversely, thinning improved the lower-layer trees' survival and growth rates and broadened the height frequency distribution.

Artificial thinning also contributed to decreasing mortality and increasing initial growth in a dense natural regenerated stand in this study. This effect may be enhanced under poor soil conditions, such as those on constructed ski slopes. However, it is necessary to pay attention to the limitation of this effect. From the perspective of controlling competition, thinning should be undertaken before the intense competition stage; at this study site, thinning should have been performed before the trees were 11-year-old.

Besides, the effect is finite under severer soil conditions. The presence of sufficient resources is a prerequisite for easing competition; if there are no or limited resources, then the benefits associated with thinning are likely to be limited. Under such conditions, it may be necessary to fertilize or to plant trees together with nitrogen-fixing plants may be required.

5. CONCLUSION

The civil engineering activities employed to develop ski slopes can have long-lasting adverse effects on the vegetation in an area. Such activities remove soil nutrients, increase competition for resources, suppress tree growth, and make reforestation difficult. While natural regeneration at high seedling densities may enhance these adverse effects, sometimes artificial stand density control methods are necessary. Artificial thinning can be used to increase the survival and growth rates of smaller trees and enhance reforestation.

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7. REFERENCES

[1] Titus H.J. and Tsuyuzaki S. Ski Slope Vegetation at Snoqualmie Pass, Washington State, USA, and a Comparison with Ski Slope Vegetation in Temperate Coniferous Forest Zones. Ecol. Res. Vol.13, 1998, pp.97-104.

[2] Tsuyuzaki S., Environmental Deterioration Resulting from Ski-Resort Construction in Japan. Environmental Conservation, Vol.21, 1994, pp.121-125.

[3] Nakamura T., Human Impacts on Vegetation and Soil of Skiing Area: I. A Case Study in Teine Skiing Area, Hokkaido, Japan. J. Japan. Grassl. Sci., 29, 1984, pp.331-340. (In Japanese with English Summary)

[4] Koyama Y., and Koyama K., Vegetation Change for 20-Year Period at Abandoned Ski Slopes in Northern Nagano Prefecture, Central Japan. Bull. Inst. Natur. Edu. Shiga Heights, Shinshu Univ. Vol.39, 2002, pp.1-6. (In Japanese with English Summary)

[5] Kureha, M., Changing ski tourism in Japan: From mass tourism to ecotourism? Global Environmental Research, Vol.12, 2008, pp.137-144.

[6] Hytiris N., Fraser M., and Mickovski S. B., Enhancing Slope Stability with Vegetation, Int. J. of GEOMATE, Vol.9, 2015, pp. 1477-1482

[7] Arase T. and Okano T., Influence of Fertilization of Native Plants and Exotic Pasture Grasses on the Fascined Landslide Slopes in Mikura-jima Island, Japan, Int. J. of

GEOMATE, Vol.8, 2015, pp. 1316-1322
[8] Okano T. and Arase T., Vegetation Recovery Process on Landslide Steep Slope after Alnus sieboldiana and Miscanthus condensatus Planting with Simple Terracing Work in Mikura-jima Island, Japan., Int. J. of GEOMATE, Vol.10, 2016, pp. 1884-1890
[9] Kondo K., Uchida T., Hayasaka D., Tanaka J., Sato A., and Arase T., Vegetation Succession of Cut Slopes Covered with Exotic Grassed for Erosion Control, Mt. Sakurajima, Int. J. of GEOMATE, Vol.11, 2016, pp. 2136-2142
[10] Arase T., Okano T., Shirota T., Hino M., and Uchida T., Characterization of Temperature Environment on Mikura-jima Island, Japan Considering Vegetation Recovery, Int. J. of GEOMATE, Vol.18, 2020, pp. 37-43
[11] Igarashi T., Yajima T., Matsuda K., Natsume S., and S., Natural Regeneration in the Japanese Larch Plantation, Bull. Exp. For. Hokkaido Univ., Vol.44, 1987, pp.1019-1040. (In Japanese with English Summary)
[12] Saito I.T., Miscanthus sinensis Community as an Indicator for Forecasting Tree Regeneration on Abandoned Skislope in the Lowland of Hokkaido, Northern Japan. Vege. Sci. Vol.29, 2012, 41-48.
[13] Iwasaki C., Shirota T., Okano T., and Oya S., A Difficulty of Ski Slope Reforestation with the Tall Glass Community. Bull. Shinshu Univ. AFC. Vol.17, 2019, pp.26-36. (In Japanese with English Summary)
[14] Nakagawa M., Hasui H., Ishihara N., Takiya M., Ohno Y., and Yasama M., Effects of Topsoil Removal for Natural Regeneration on Growth of Japanese Larch - A Case Study in Higashi-kagura Town-. Boreal Forest Research Vol.60, 2012, pp.117-119. (In Japanese)
[15] Katakura M., Yamauchi M., and Furukawa H., A Study on Long- Harvesting- Cycled Management of Japanese Cypress and Japanese Larch. Bulletin of Nagano Prefecture Forest Research Center, Vol. 19, 2005, pp.1-16. (In Japanese)
[16] Yoda, K., Kira, T., Ogawa, H. and Hozumi, K., Self-thinning in Overcrowded Pure Stands under Cultivated and Natural Conditions: Intraspecific Competition among Higher Plants XI. J. Biol. Osaka City Univ. Vol.14, 1963, pp.107-129.