Effects of artificial gap creation on the stand structure of an abandoned evergreen coppice

Kazuhiro Yamashita1,2 · Satoshi Ito3 • Ryoko Hirata3

Received: 21 January 2022 / Revised: 14 March 2022 / Accepted: 15 March 2022 / Published online: 5 April 2022
© The Author(s) 2022

Abstract

We examined the effects of artificial gap creation on the diversification of simplified stand structures in an abandoned coppice. A study plot was placed in a 49-year-old evergreen coppice, and two canopy gaps of ca. 100 m² were artificially created by logging in December 1992. In 2015–2016 (22–23 years after gap creation), stand structure was resurveyed and compared between a gap-treated plot (PT) and control plot (PC). PT was separated into gap (G), gap edge (GE), and forest interior (FI) parts, and their structures were compared. G and GE, where recruitment of new stems/individuals was expected, had no increase in small stems in 2015 and 2016, showing a mono-modal height distribution pattern in PT similar to PC. Species number also showed no difference between PT and PC, demonstrating a large proportion of species common to PT and PC. No species specific to G and GE was found. In PT, resprouted stems recovered their individual heights during the study period, resulting in a re-simplified local structure and canopy closure. From these results, we concluded that artificial gap creation in the studied stand was insufficient to diversify the stand structure at a mid-term (20 years) scale, and that repeated cutting and/or control of the resprouted stem density is required for diversification of abandoned coppices.

Keywords Structural diversification • Stem density • Height distribution • Canopy closure • Species richness

Introduction

The decline in biodiversity of coppice woodlands has become an important issue worldwide (Buckley 2020), because most coppice woodlands were abandoned after the fuel revolution, resulting in simplified stand structures with low biodiversity (Oliver 1981; Bond and Midgley 2001; Ito et al. 2008). In Japan, the abandonment of coppice woodlands typically occurred in rural satoyama after the 1960s (Kamada and Nakagoshi 1990; Hirayama et al. 2011; Azuma et al. 2014; Hiratsuka et al. 2020) and is associated with biodiversity decline and the deterioration of ecosystem services (Kamada and Nakagoshi 1990; Ito et al. 2008; Nagaike et al. 2010).

To re-diversify abandoned coppices, it is effective to shift the developmental stage from “stem exclusion” to “understory re-initiation” as defined by Oliver (1981). However, recent studies conducted on natural stand development of abandoned evergreen coppices in warm-temperate Japan (Ito et al. 2008; Yamashita et al. 2018; Hirayama et al. 2019) have found that at least 50 or 60 years are required to allow re-colonization of tree seedlings and saplings. Hirayama et al. (2019) suggested from their long-term observation that the formation of large-sized canopy gaps is necessary for old coppices to form a stand structure close to that of old-growth natural forests. Similarly, artificial canopy gap creation is an effective measure for the early diversification of a simplified stand structure of abandoned coppices by shifting the developmental stage from “stem exclusion” to “understory re-initiation”. Furthermore, gap creation can diversify the structure of the part of the stand surrounding the gap through edge effects (Matlack 1994; Murcia 1995; Sakai et al. 2013). However, the effectiveness of gap creation in diversifying abandoned coppices has not been fully examined, and limited information about them is available in warm-temperate Japan.

*Satoshi Ito
s.ito@cc.miyazaki-u.ac.jp

1 Interdisciplinary Graduate School of Agriculture and Engineering, University of Miyazaki, Miyazaki, Japan
2 Present Address: Japan International Forestry Promotion and Cooperation Center (JIFPRO), Tokyo, Japan
3 Faculty of Agriculture, University of Miyazaki, 1-1, Gakuen-kibanadai-nishi, Miyazaki 889-2192, Japan
In the present study, we examined the effects of artificial gap creation on the structural change of an evergreen abandon coppice by comparing its stand structure before and ca. 20 years after gap creation.

**Methods**

**Study site**

The study was conducted in an abandoned evergreen coppice stand (49 years old in 1992 at the time of the first survey in this study) located in Amakusa Island, western Kyushu, southwestern Japan (130°06’ E, 32°28’ N) (Fig. 1a). The stand was situated in a gentle ridge on a west-facing slope (15°–35°) at 390 m above sea level (asl), which corresponds to the lower part of the warm-temperate region where natural forests consist primarily of evergreen Fagaceae and Lauraceae species (Miyawaki 1981). The annual mean temperature is 16.4 °C, and mean annual precipitation is 2076 mm as measured at the nearest (but 30 m asl.) meteorological station (Amakusa city). The stand was co-dominated by Quercus salicina, Castanopsis sieboldii var. sieboldii, and Machilus thunbergii in the canopy layer when we made the first survey in 1992 (Table 1).

**Field survey**

In December 1992, we established a single plot sized 40 m (slope) × 50 m (contour). We recorded species names, diameter at breast height (DBH; 1.3 m in height), tree position for all living individuals (having stems of DBH ≥ 5 cm) in the plot, and the individual height (the highest stem for multi-stem clumps). Then, we artificially created two small circular gaps (25 m²) (not used for this study; see below) on the upper slope, and two large circular gaps (100 m²) on the lower slope (Fig. 1b). The gaps were created by cutting all the canopy and understory trees/shrubs by chainsaw, and all the felled trees/shrubs were manually removed from the plot.

In January 2015 (22 years after the artificial gap creation), species names and DBH for all living stems (DBH ≥ 5 cm) in the plot were recorded. Among the found individuals in the gaps, those resprouted from the cut stumps were identified on site by comparing their position and stump size with those recorded in 1992. In February 2016, individual heights (the highest stem for multi-stem clumps) were measured.

**Data analyses**

The study plot was divided into 80 grids (5 m × 5 m) and then classified based on their positional relationship to the created gaps (Fig. 1b). First, the half of the plot that included

![Fig. 1](image-url)
Table 1  Stem density (No./ha) of species occurring in the control plot (PC) and treated plot (PT)

| Life form     | Species                     | PC | PT | Total | PC | PT | Forest interior | PC | PT | Gap edge | PC | PT | Gap |
|---------------|-----------------------------|----|----|-------|----|----|----------------|----|----|----------|----|----|------|
|               |                             | 1992| 2015| 1992 | 2015| 1992 | 2015          | 1992| 2015|          | 1992| 2015|      |
| Evergreen tree| *Quercus salicina*          | 2,832|1,792|2,790|1710|2,591|2174|2,143|1,000|7,333|1,467|
|               | *Castanopsis sieboldii var. sieboldii* | 1,264|640|450|330|330|157|743|657|–|133|
|               | *Machilus thunbergii*       | 1,040|672|970|560|748|487|1,114|657|2,000|667|
|               | *Distylium racemosum*       | 304|400|240|290|191|261|343|314|133|400|
|               | *Quercus acuta*             | 256|144|270|210|470|365|457|371|–|–|
|               | *Ilex integra*              | 256|272|590|530|696|661|457|314|400|533|
|               | *Diospyros morrisiana*      | 192|112|290|230|226|174|457|371|–|–|
|               | *Ilex buergeri*             | 96|144|100|160|122|104|29|200|267|400|
|               | *Cinnamomum japonicum*      | 80|80|40|30|70|52|–|–|–|–|
|               | *Elaeocarpus japonicus*     | 80|64|–|–|–|–|–|–|–|–|
|               | *Camellia japonica*         | 80|64|70|140|52|139|114|171|–|–|
|               | *Ilex rotunda*              | 48|32|–|–|–|–|–|–|–|–|
|               | *Dendropanax trifidus*      | 48|16|–|10|–|17|–|–|–|–|
|               | *Pinus densiflora*          | 32|–|10|–|17|–|–|–|–|–|
|               | *Quercus glauca*            | 16|16|–|–|–|–|–|–|–|–|
|               | *Meliosma rigida*           | 16|16|10|10|17|17|–|–|–|–|
|               | *Morella rubra*             | –|–|40|30|70|52|–|–|–|–|
|               | *Litsea coreana*            | –|–|10|–|17|–|–|–|–|–|
|               | *Symplocos lucida*          | –|–|10|10|17|17|–|–|–|–|
| Evergreen shrub| *Pieris japonica*           | 112|48|70|50|–|35|–|86|–|–|
|               | *Ligustrum japonicum*       | 32|48|–|–|–|–|–|–|–|–|
|               | *Eurya japonica*            | 48|32|20|60|17|35|29|114|–|–|
|               | *Camellia sasanqua*         | –|16|–|–|52|–|114|–|–|–|
|               | *Vaccinium bracteatum*      | –|–|190|20|122|–|343|57|–|–|
| Deciduous tree| *Quercus serrata*           | 16|–|90|60|87|–|114|171|–|–|
|               | *Clethra barbinervis*       | –|–|50|20|87|35|–|–|–|–|
|               | **Total**                   | 6,848|4,608|6,310|4,460|5,990|4,773|5,994|4,111|10,133|3,598|
the large gaps (100 m²) was defined as the ‘treated’ plot (PT). PT was subdivided into the following three subcategories: (1) gap (G): three grids (75 m² in total) that had mostly been included in the created gaps in 1992; (2) gap edge (GE): 14 grids (350 m²) that included the original gap boundaries; and (3) forest interior (FI): the other 23 grids (575 m²). The other half of the plot including the two small gaps (25 m²) was defined as the ‘control’ plot (PC), because the small gaps were closed within 4 or 5 years after the gap creation by the expansion of canopies of the gap edge trees. However, considering the possible effect of the created gaps on the gap edge trees, we excluded the 15 grids (375 m²) that had been occupied more than 30% by the original gaps or that were adjacent to the original gaps. Consequently, PC consisted of 25 grids (625 m²) subjected to the analyses.

Stem density and basal area (BA) in 1992 and 2015 were calculated and compared for PC and PT (for total, G, GE, and FI). To examine the difference in population structure with and without artificial gap creation, the DBH-class distribution of the stem and height-class distribution of individuals were compared between PC and PT. We counted the species number of evergreen trees (including Pinus densiflora, an evergreen conifer), evergreen shrubs, and deciduous trees to compare the species richness between PC and PT, and among the parts of PT (G, GE, and FI) in 1992 and 2015, respectively. The number of species common/specific to PC and PT, as well as to G, GE, and FI, was also counted to analyze the similarity of species occurrence.

Results

Stem density and basal area

During the observation period, stem density in both PC (control) and PT (treated) areas decreased by ca. 30% from 6848 (ha) and 6310 in 1992 to 4,608 and 4,460 in 2015, respectively (Fig. 2a; Table 1). The decrease in stem density of the forest interior (FI) and the gap edge (GE) in PT was similar to that observed in the total PT. However, in the gap (G), stem density decreased by 64% (from 10,133 to 3,598), which is attributed to a large decrease of stems in several multi-stem individuals of Q. salicina that had large numbers of stems within clumps in 1992.

In contrast to stem density, the basal area (BA) increased during the observation period in all parts except for G (Fig. 2b). The BA as the total of PT increased by 36% from 35.6 (m²/ha) in 1992 to 48.3 in 2015, but the increase was smaller than that in PC (57%, from 40.7 in 1992 to 63.8 in 2015). BA in G decreased by 38% from 56.6 in 1992 to 35.2 in 2015 due to the loss of large multi-stem individuals of Q. salicina.

DBH- and height-class distribution

The DBH-class distribution of stems in 1992 showed similar inverse-J shaped patterns for PC and PT (Fig. 3). In 2015, the range of DBH expanded to more than 30 cm both in PC and PT. The stems in G consisted of stems of
DBH less than 10 cm in 2015, while the maximum DBH reached 23 cm.

The height-class distribution of individuals was a mono-modal pattern with a peak at 8–10 m in 1992 for both of PC and PT (Fig. 4). The distribution in 2016 for both PC and PT showed patterns that could be regarded as a mono-modal distribution, though the peaks became unclear with the expanded height ranges. The individuals in G also showed a wide height range and included the highest individual exceeding 14 m in height.

**Number of species**

The total number of species in PC and PT was 20 in 1992 (Fig. 5), including almost equivalent numbers of evergreen broadleaved tree species (15 and 14 species in PC and PT, respectively). Of the total species in 1992, 15 species, including 11 evergreen broadleaved tree species, were common to PC and PT (Fig. 6a). Although there was a slight increase or decrease in the number of species in 2015, the number of species common and specific to PC and PT showed almost the same tendency as in 1992 (Fig. 6a).
Among FI, GE, and G in PT, FI had the largest species number in 1992 (20 species including 14 evergreen broad-leaved tree species) (Figs. 5, 6b). Of these 20 species, five evergreen broad-leaved tree species were common to GE and G (Fig. 6b). Seven species including three evergreen broad-leaved tree species were common to FI and GE. No species specific to GE or G was observed. No species common to FI and G and GE and G were found. A similar tendency as in 1992 was observed in 2015; 7 species out of all 17 species that occurred in PT were specific to FI, and six and four species were common to FI–G and GE–G, respectively. No species specific to GE or G was found, the same as in 1992.

**Recovery of felled individuals**

The stem number per clump (multi-stem individual) in G in 2015 was positively correlated with that in 1992 ($r = 0.69, p < 0.01$) and decreased in most individuals (Fig. 7a). Basal area also showed a positive correlation between 1992 and 2015; however, in contrast to the stem number, they increased in 2015 up to 1.5 or 2 times that of 1992 (Fig. 7b).

**Discussion**

Our case analysis of stand structure before and 22–23 years after artificial gap creation indicated that the creation of canopy gaps of an area less than 100 m² did not largely diversify the structure of an abandoned evergreen coppice. Stem density decreased in both PC (control plot) and PT (treated plot) similarly along the progress of forest succession during the observation period (Fig. 2a). Furthermore, the created gaps (G), where the recruitment of new stems or individuals had been expected, had rather lower stem density compared to forest interior (FI) and gap edge (GE), as well as to PC, in 2015. DBH and height-class distribution...
also did not differ between PC and PT in either 1992 or 2015/2016 (Figs. 3, 4), indicating low effectiveness of the artificial gap creation in facilitating structural diversification. In the studied stand, the establishment of a large number of seedlings was observed 1–2 years after the gap creation (personal observation). However, the height distribution of PT in 2016 almost maintained a mono-modal pattern (Fig. 4), which is typically observed in coppices where coppice stems simultaneously emerge from cut stumps (Ito et al. 2008). This result suggested that most seedlings established immediately after the gap creation disappeared and did not contribute to the diversification of the stand structure 23 years after gap creation.

From the viewpoint of tree species composition, an increase in species number via the recruitment of additional species was expected in PT, especially in GE and G. However, species number and composition were almost the same in PC and PT both before and 22 years after gap creation (Figs. 5, 6). This result, together with there being no species specific to GE and G (Fig. 6), suggested that the artificial gap creation was not effective in increasing the species richness of the stand.

Most individuals in G felled by gap creation recovered by resprouting, resulting in a lower stem number and more basal area in 2015 than in 1991 (Fig. 7). This indicated that the resprouted stems grew vigorously, and severe competition among stems and/or individuals occurred during the observation period. That is, even though gaps of 100 m² had been created, the population of resprouted stems reached the ‘stem exclusion stage’ (Oliver 1981) and simplified the structure within the gaps. In fact, we could find no seedlings beneath the dense canopy of the resprouted stumps.

In this study, we initially expected the recruitment of seedlings and enhanced growth of advance regeneration in the gap edge (GE) due to the penetration of light from the created gaps. However, we could not detect an edge effect; stem density, basal area, and the species number in GE in 2015 did not differ from those in FI. This was probably due to the far faster height growth of the coppice stems compared to seedlings (Ito 1996). In the studied stand where the canopy height was relatively low (12–16 m), the coppice stems that emerged from the felled stumps might be able to reach the lower crown of the canopy trees surrounding the gaps and close the gaps early from the forest floor. This might be the reason that edge effects did not occur or had disappeared during the observation period.

We concluded from these results that artificial gap creation in the studied stand was insufficient to diversify the stand structure at a mid-term, 20-year scale, and that repeated cutting and/or control of the resprouted stem density is required for diversification of abandoned coppices.

Acknowledgements We thank Dr. Junji Miyajima, Kumamoto Prefecture Office, for his assistance in arranging the study site and field survey. The present study was supported in part by JSPS KAKENHI Grant Nos 25252029 19H02997, and 21K18226.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not
References

Azuma W, Iwasaki A, Ohsugi Y, Ishii H (2014) Stand structure of an abandoned deciduous broadleaf secondary forest adjacent to lucidophyllous forest and agricultural fields. J Jpn Soc 96:75–82 (in Japanese with English abstract)

Bond WJ, Midgley JJ (2001) Ecology of sprouting in woody plants: the persistence niche. Trends Ecol Evol 16:45–51

Buckley P (2020) Coppice restoration and conservation: a European perspective. J for Res 25:125–133

Hiratsuka M, Hatakeyama K, Ohukubo T, Takeuchi D (2020) Dynamics of secondary forest and its perspective under the Satoyama system in Saitama prefecture, Japan. J for Res 25:51–57

Hirayama K, Yamada K, Nishimura T, Kawamura S, Takahara H (2011) Changes in species composition and diversity with respect to the successional stage of urban forests in Kyoto City, western Japan. J Jpn Soc 93:21–28 (in Japanese with English abstract)

Hirayama T, Ito S, Yamagawa H, Hirata R, Mitsuda Y (2019) Dynamics of an old evergreen coppice in southwestern Japan with special focus on a typical coppice species (Castanopsis cuspidata) and a climax species (Distylium racemosum). Landsc Ecol Eng 15:205–214

Ito S (1996) Studies on the forest dynamics control on the basis of the physiological functions of sprouts. Bull Miyazaki Univ Forests 13:1–22 (in Japanese with English abstract)

Ito H, Ito S, Tsukamoto M, Nakao T (2008) Dynamics of multi-stem clump structure of canopy trees affect the change in stand structure of secondary lucidophyllous forests. J Jpn for Soc 90:46–54 (in Japanese with English abstract)

Kamada M, Nakagoshi N (1990) Patterns and processes of secondary vegetation at a farm village in southwestern Japan after the 1960s. Jpn J Ecol 40:137–150 (in Japanese with English abstract)

Matlack GR (1994) Vegetation dynamics of the forest edge -trends in space and successional time. J Ecol 82:113–123

Miyawaki A (1981) Vegetation of Japan Kyushu. Shibundo, Tokyo (in Japanese)

Murcia C (1995) Edge effects in fragmented forests: implications for conservation. Trends Ecol Evol 10:58–62

Nagaike T, Hayashi A, Kubo M (2010) Diversity of naturally regenerating tree species in the overstory layer of Larix Kaempleri plantations and abandoned broadleaf coppice stands in central Japan. Forestry 83:285–291

Oliver CD (1981) Forest development in north America following major disturbance. For Ecol Manag 3:153–168

Sakai A, Yamagawa H, Seiwa K (2013) How far does edge effect reach in forest landscapes in Japan? Jpn J Ecol 63:261–268 (in Japanese)

Yamashita K, Ito S, Hirata R, Mitsuda Y, Yamagishi K (2018) Thirty-year stand dynamics of an old evergreen coppice forest in Southern Kyushu, Southwestern Japan. J for Res 23:304–308